RENEWABLE INDOOR RADIANT COOLING AND EARTH TUBE HEAT EXCHANGER HYBRID FOR THERMAL COMFORT IMPROVEMENT

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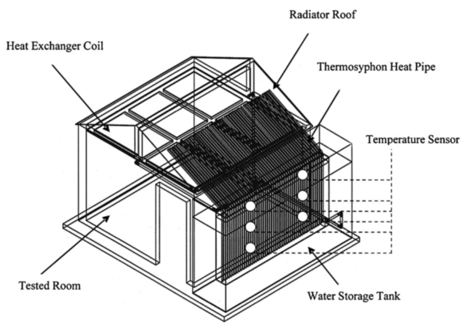
Abstract
This study investigates the applicability of hydronic radiant cooling system charged with night cooled water to cool down building in Sarawak particularly for low income building to a thermally acceptable level. The system uses night sky as well as the ground as a heat sink source to passively cool the building while operating at a low energy level. Results from building energy simulation program or Energy Plus shows that for a stand-alone hydronic radiant system only 77% of the time the thermal condition could meet ASHRAE acceptable PMV thermal condition between -0.5 and + 0.5. Another simulation of the radiant and earth tube system hybrid further improved the indoor thermal condition significantly by 100% to meet the same PMV level. The hybrid system was able to improve the baseline uncomfortable operative temperature of 37ºC to 28.5ºC while meeting the average comfort zone upper limit for Malaysia of 30.1 ºC. Simulation on energy spent shows that as much as 94% energy could be saved by using the hybrid system. This level of saving is not impossible as renewable night cooled water was used to charge the indoor hydronic radiant cooling system.

Key words: Earth tube system, Energy Plus program, hybrid system, low energy, radiant cooling.

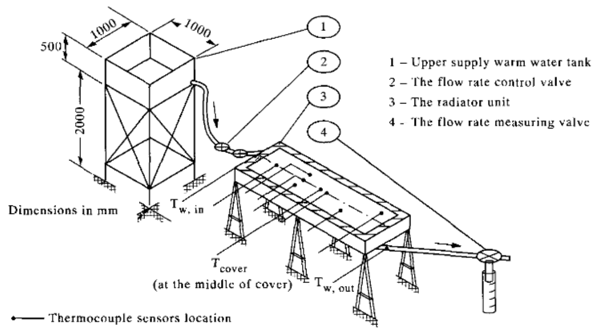
INTRODUCTION

Building sector in Malaysia accounts for 40% of the total energy consumption and most of the energy is used to maintain an adequate thermal indoor climatic condition by heating, cooling and ventilation (Nielsen, 2012). Typically 60% of energy is used for building indoor air cooling in hot and humid regions (Vangtook & Chirarattananon, 2007). High saving potential is possible with the current technology that optimizes the building envelope as well as the HVAC system. Radiant system integrated in building is able to provide such saving where 12% to 18% energy reduction is a minimum expectation for a radiant system in comparison to a convective system providing equivalent comfort (Watson & Chapman, 2002). Energy conservation of building using a radiant cooling system are on the order of 17% - 53% below the upper limit set by ASHRAE Standard 90.1-2010 (Uponor Inc, 2013). This is due to the efficient operating modes by allowing chiller to operate at a higher temperature and thus lower overall energy use. Temperature between 12.7°C to 17.2°C is the typical temperature for a radiant cooling system and this allows the mechanical chillers to operate in efficient ranges. However some researcher have restricted the temperature between 20°C to 25°C due to dew point and condensation restriction in hot and humid climate and that lower temperature is advisable with the use of a desiccant dehumidification as a means to improve the performance of radiant cooling panel in hot and humid climate (Binghooth & Zainal, 2012). Ideal water temperature to be used in this region is in the range of 21°C to 25°C and in Malaysian climate the yearly minimum temperature could provide such cooling source. Due to the higher temperature operation range, there is potential alternative source for chilled water which may include fluid coolers, geothermal heat pumps or lake water (Uponor Inc, 2013). Combining radiant cooling system with a free cooling source can reduce energy consumption by 80-90% since traditional chillers can be eliminated and only electricity for circulation pumps is needed (Nielsen, 2012).

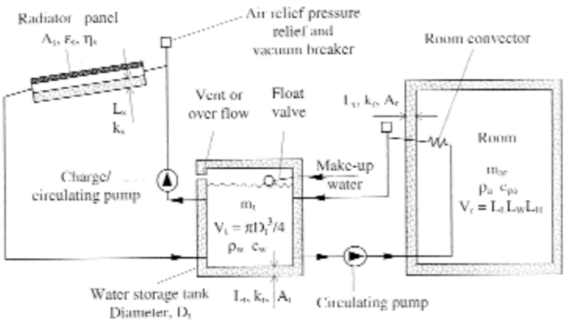
A high potential cool water source in this hot and humid region is the cooling of water via long wave radiation to the night sky. There are several ways or devices that could be used to cool the water under the night sky to take advantage of the night radiation including evaporation and conduction heat loss effect. Literature survey have found studies done by others such as water flowing under flat plate collector (Hamza, Taha, & Ismail, 1995), open tank experiment (Ali, 2007), water flowing openly over solar collector (Dan & Chinnappa, 1989), thermosyphon heat pipe radiator cooling (Chotivisarut, Nuntaphan, & Kiatsiriroat, 2012), roof pond experiment (Runsheng, Etzion, & Erell, 2003) and (E Erell & Etzion, 1999), converted flat plate solar collectors (Evyatar Erell & Etzion, 2000), thermal absorber with water pipes numerical analysis (Sima et al. 2014), hybrid nocturnal radiative cooling and direct evaporative cooling test (Heidarinejad, Farmahini, & Delfani, 2010), piped nocturnal radiator with phase change material (PCM) (Zhang & Niu, 2012), solar water heater absorber test (Dobson, 2005) and others. Study by Azhaili et al. (2011) have shown that water temperature in the morning after a night cooling process by trickling water over roof could reach lower than 25°C in Malaysian region. The process only requires minimum pumping energy therefore greatly reduce the energy consumption in comparison to a mechanical chiller. This night cooled water supply could be used as cooling medium for indoor radiant cooling system for building cooling. Figure 1 demonstrates a few of the mentioned water cooling devices which utilize the night sky.



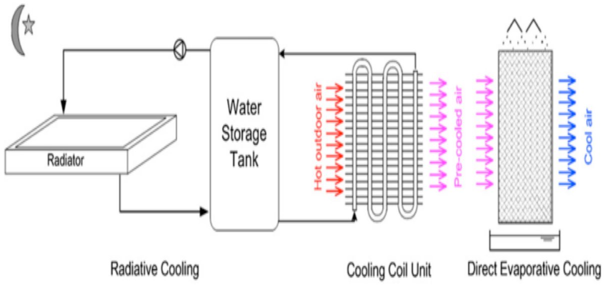
(a) Heat pipe radiator for nocturnal cooling cooling (Chotivisarut et al. 2012)



(b) Schematic drawing of open loop night sky radiation cooling unit (Hamza et al., 1995)



(c) Thermal model of night sky radiation cooling system (Dobson, 2005).



(d) Schematic diagram of hybrid nocturnal radiative cooling and direct evaporative cooling (Heidarinejad et al. 2010),

Figure 1: Example of a few prototypes which uses night cooling in its operation

Another method of building cooling that is rare in this region is the use of ground as a heat sink source. 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 technologies 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 of building cooling have been shown to be a promising method outside of Malaysia as explained by Woodson et al. (2012), Ascione et al. (2011), Florides & Kalogirou (2007), Leong et al. (1998), Man et al. (2011), Sharan & Jadhav (2003), Yu et al. (2014), Yusof et al. (2013) well as Zimmermann & Andersson, (1998).

This technology was first tested by Reimann et al. (2007) and Sanusi et al. (2013) at the Peninsular region of Malaysia. Reimann et al. 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. 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 focuses only on the pipe outlet air temperature after travelling through earth tube in the ground, impact of earth tube application towards indoor thermal comfort of a full scale building was not demonstrated. Both studies was 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. 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. (2013) in the peninsular so far.

Both radiant cooling and earth tube system is designed to improve the indoor mean radiant temperature (MRT) as well as the mean air dry bulb temperature (DB). Both MRT and air DB temperature have the same influence on a thermal comfort of a person (Tang & Chin, 2013) therefore operative temperature (OT) which describe the average of MRT and air DB is normally used as an indicator of thermal comfort in a room. The room temperature in which occupants exchange heat by radiation and convection is expressed as the operative temperature (ANSI/ASHRAE, 2013). There are six factors that determine an acceptable thermal environment which are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity. These factors are used as parameters to calculate the Predicted Mean Vote (PMV) which is another way to determine thermal comfort. PMV is an index that predicts the mean value of the votes of a large group of persons on the 7 point thermal sensation scale (ISO, 2005). The thermal sensation scale which spread between +3 and -3 indicates a person thermal sensation of hot (+3), warm (+2), slightly warm (+1) , neutral (0) , slightly cool (-1), cool (-2) or cold (-3). MRT and DB are the conditions of the thermal environment that is being addressed in this study to bring the room condition to certain comfort criteria preferably not higher than +1 on the thermal sensation scale.

Building developers nowadays construct residential homes with little regards to indoor thermal comfort and make assumption that the future owner of the 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 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 (HDC Sarawak, 2015). An example of a constructed low cost house in Sarawak and its measured indoor air temperature is shown in Figure 2. Measurement was taken in an occupied unit during clear weather to show the internal climatic condition of the low cost house.

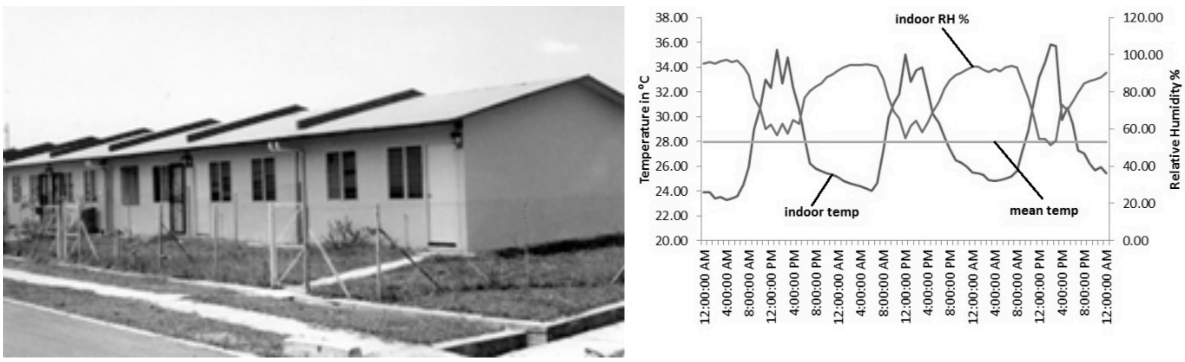


Figure 2: Typical low cost housing indoor climate in Kuching Sarawak. Left: Typical low cost house for low income earners in Sarawak (HDC Sarawak, 2015). Right: Typical low income house indoor climate measure from 30/10/2014 to 1/11/2014

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 climatic condition as shown by Cândido et al. (2010). It has also failed to meet the limits set by ASHRAE Standard 55 (ANSI/ASHRAE, 2013) and ISO 7730 (ISO, 2005). Investigation by other local researcher such as Ibrahim & Tinker (2005), Rajeh (1994),(Nugroho (2011), Kamar et al. (2012) as well as Normah et al. (2012) have showed that typical Malaysian residential house including low income house failed to provide the minimum thermal comfort target. Study by Djamila et al. (2013) in a similar regional condition located in Sabah have shown from a survey that the thermal comfort temperature was at 30.2 ºC. Another study by Hussein et al. (2009) has given an upper limit of 30.7 ºC for an unconditioned building in Malaysia. Similarly study by Nguyen et al. (2012) 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.

The aim of this study is to give some insight on the applicability to utilise radiant cooling system charged with night cooled water combined with the ground as a heat sink source to cool down building in Sarawak particularly for low income building to a thermally acceptable level.

METHODOLOGY

Hydronic Radiant Panel and Earth Tube in Building Simulation using Energy Plus 8.1

The objective of this study is to find out the thermal comfort and energy savings performance of building model fitted with hydronic radiator panel charged with renewable night cooled water in combination with Earth Tube Heat Exchanger (ETHE). The application of this hybrid system for housing has never been tested in Malaysian climatic condition. The system utilises the night sky and cool ground as heat sink source to cool a residential building. Component such as hydronic indoor radiant panel or heat absorber and earth tube is used as heat exchanger in two different ways to link the building to the natural heat sink source. The hydronic radiant panel uses chill water as its cooling medium to cool the building indoor surfaces. The radiant surface will cool the surrounding surfaces and the occupants through radiant heat exchange. The chill water is obtained from a night cooling process where the water is cooled down by radiation and evaporation to the cool night sky. The process utilises the building roof as another readily available heat exchanger to cool the water at night. The cooled water is stored in water tank and will be used during the day time to charge the indoor hydronic radiant panel. The ETHE function is to precool the ventilation air by forcing the warm outdoor ventilation air through underground pipe before delivering the precooled air to the building. The study will focus on using the night sky cooled water and the ground as a bioclimatic approach in cooling down a low income building in Malaysia. Figure 3 shows the hybrid system concept model that is to be evaluated for its impact on the indoor thermal comfort as well as annual energy demand.

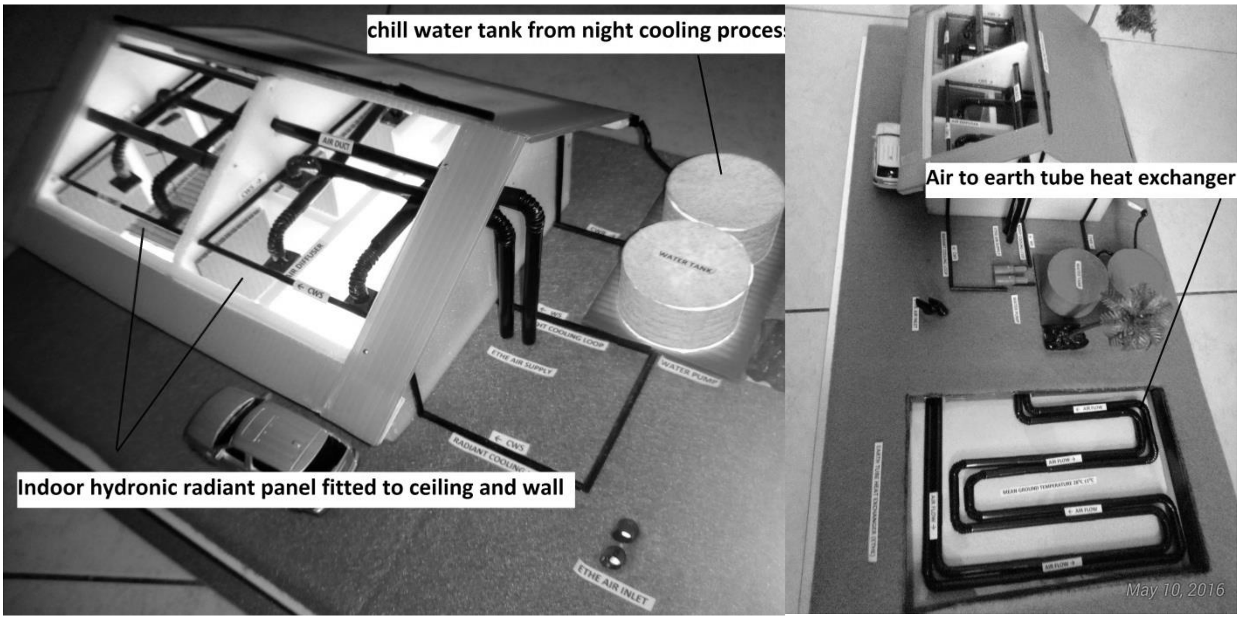
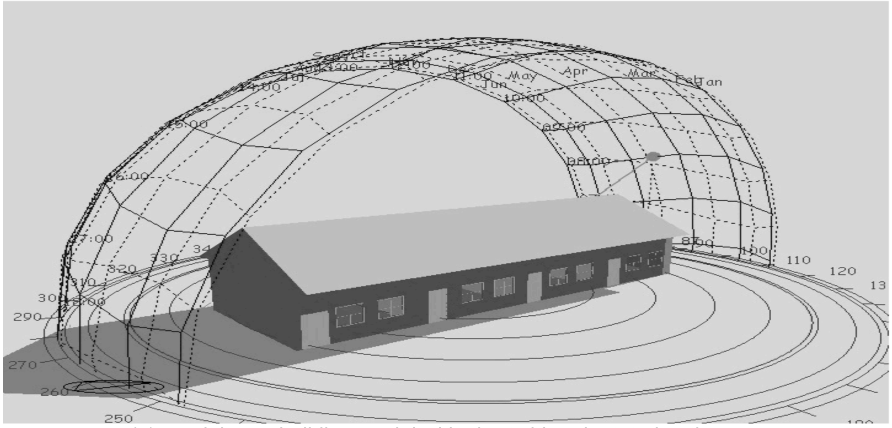
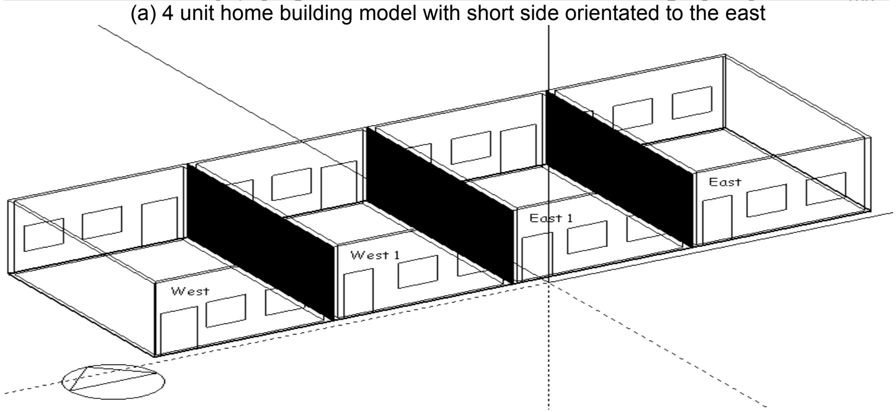


Figure 3: Concept model of the hybrid system which uses night sky and cool ground as heat sink to cool the building

Computer aided building simulation program or Energy Plus 8.1 was used in this study to evaluate the use of radiant surface cooling and earth tube system hybrid installed in a low income building model with 4 unit of houses as shown in Figure 4 (a). The shorter side of the building 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 Figure 4 (b) with an area of 41.25m^2 for every home unit.



(a) 4 unit home building model with short side orientated to the east



(b) 4 units home building with separate thermal zone for each unit

Figure 4: Low income building model and its corresponding thermal zone

For the purpose of this simulation the building thermal properties was set to a minimum requirement as per building energy standard of Malaysia (Standard Malaysia, 2007) as shown in Table 1 and was set as the base case model. The technical data for the radiant system and earth tube installation are shown in Table 2 and Table 3 respectively. The initial tank temperature was set to 24ºC corresponding to the typical final water temperature from the night cooling process as described in the introduction.

Table 1: Building thermal properties minimum requirement

a. Building envelope component	Minimum Value
I. Wall	3.21 (W/m^2 K)
II. Roof	0.27 (W/m^2 K)
III. Window	5.89 (W/m^2 K)
IV. Door	3.13 (W/m^2 K)
V. Floor	1.58 (W/m^2 K)
b. Model Overall Thermal Transfer Value (OTTV),	30 (W/m^2)
c. MS1525 recommended OTTV	50 (W/m^2)

Table 2. Technical data for radiant system in building model

Design Parameter		Input
I.	System Type	Type A (as per ISO 11855-2)
II.	Number of Thermal Zone	4
III.	Surface Name or Radiant Surface Group Name	Ceiling and wall
IV.	Hydronic Tubing Inside Diameter (m)	0.012
V.	Hydronic Tubing Spacing (m)	0.154
VI.	Temperature Control Type	Operative temperature
VII.	Chill water tank volume per unit home (m^3)	6.25

Table 3: Detail of earth tube installation in each unit of the building model

Design Parameter	Units	Input
Earth tube type	-	Exhaust
Pipe Material	-	Clay/ concrete pipe
Pipe Radius	m	0.04
Pipe Thickness	m	0.003
Pipe Length	m	150
Pipe Thermal Conductivity	W/m.K	1.8
Pipe Depth Under Ground Surface	m	1.5
Design Flowrate	m^3/s	0.4
Avg Soil SurfaceTemperature	°C	28

Before the simulation was ran, the earth tube system was calibrated 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. (2013). The ground interface temperature was set to 28°C based on the findings of the same study. Calibration result is shown in Table 4.

Table 4: Calibration of simulation model with an actual earth tube experiment by others

	Simulation Model	Study from (Sanusi et al., 2013)	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].

The first step in the simulation was to determine the indoor thermal comfort condition of the base case building. The simulation was then repeated to find out the thermal comfort condition of the same building fitted with radiant cooling surfaces as well as the earth tube system. The result is presented in terms of indoor operative temperature as well as PMV index for both design day and annual simulation run. The energy consumption of the base case building as predicted by the software was also compared to the retrofitted building to find out the energy savings provided by the hybrid systems.

Computer Programme: Validation against field data set

Discussion from energy modelling community Q&A website shows that field data to validate Energy Plus model is currently not abundant (https://unmethours.com/question/10449/does-energyplus-need-to-be-validated-against-doe-22/) According to Hong et al., (2013) empirical test for Energy Plus is still a growing area. However through DOE funding the Lawrence Berkeley National Laboratory (LBNL) is currently working to build flexible testbed facilities or Facility for Low Energy Experiments in Buildings (FLEXLAB). The Flexlab is primarily used to extract useful field performance data of wide range of building component such as lighting, controls, windows, façade and other building systems such as HVAC. Data collection from FLEXLAB may also be used to validate result predicted by Energy Plus while complying with Annex 58 quality procedures for dynamic full scale testing. Annex 58 is an ongoing project run by IEA under Energy in Building and Community programme that develops the necessary tools, knowledge and networks to achieve a high quality in situ dynamic testing and data analysis method. As validation of Energy Plus with FLEXLAB and Annex 58 is still in early stage and yet to have any software validation report, it is therefore proposed in this study to carry out a validation exercise of Energy Plus for increased confidence. Annex 58 have yet to publish any guideline of publication on the quality procedure involving full scale testing however reference will be made to other independent validation work of Energy Plus by other researchers addressing a few crucial thing such as accuracy of sensors, test environment etc.

The following describes the independent validation process of Energy Plus V8.1. Here a single storey semidetached house located in Kuching Sarawak was selected to be modelled in Energy Plus. The objective here is to compare the results provided by the Energy Plus with site measured data where in this case the result to be predicted and measured on site is the operative temperature of the building. The construction of the building uses typical material for construction such as brick wall, metal roofing with light insulation, concrete slab, glass window and timber door. Details of the building geometry, construction type with its thermos physical properties and building thermal load was surveyed and measured manually and included in the appendix. The building geometry was first created in a 3D building modelling software or Sketch Up, as an open studio model and will be saved as an .osm file extension. Figure 5 shows the completed building geometry while Figure 6 shows the numbered internal spaces or thermal zones from TZ1 to TZ14.

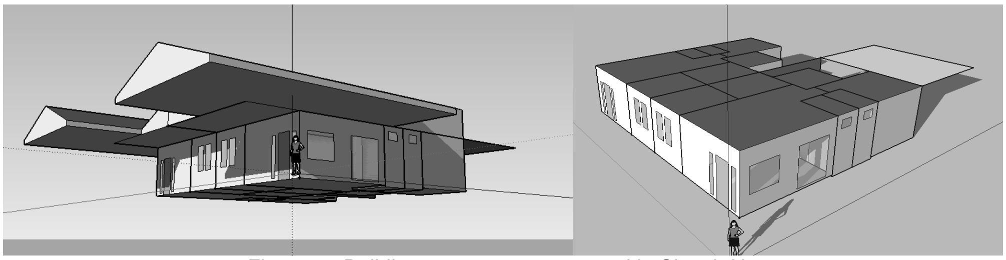


Figure 5: Building geometry constructed in Sketch Up

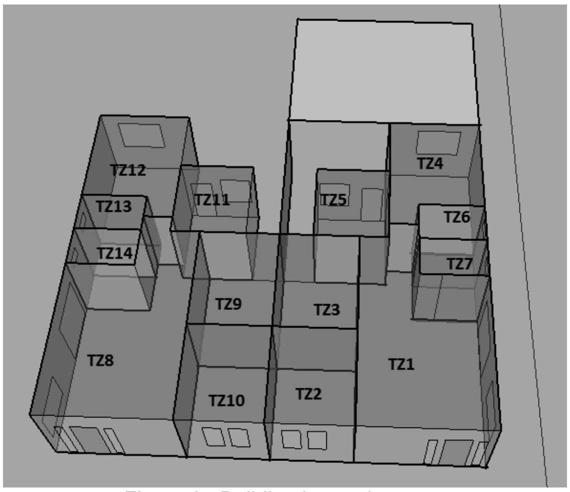


Figure 6: Building internal spaces

The model was then loaded to Open Studio Application Suite a free interface to run Energy Plus, where amendments were made to the construction material thermos physical properties, thermal loads including its schedules where necessary according to the required detail. Prior to running the simulation, the correct weather data or epw. extension file (Energy Plus weather format) was chosen so that simulation is run under the selected climatic region. Therefore the climatic information such as site wind speed, wind direction, site diffused and direct solar radiation rate, relative humidity and dry bulb temperature have to be corrected to reflect the actual climatic condition during which the site measurement is conducted. To complete the validation exercise, on site measurement was conducted between 11th and 13th October 2015. Thermal zone 6 was selected as subject of onsite measurement where hourly internal surface temperature of all 6 surfaces was recorded with a temperature data logger including the room air temperature and humidity level. At the same time measurement were also taken for the climatic condition of the site such as the mean air temperature, relative humidity, solar radiation rate as well as the site wind speed. Other climatic info where needed could also be obtained from the local airport weather station. After completing the onsite measurement, the collected data was then analysed together with output from Energy Plus simulation. Given the uncertainty in the thermos physical properties of building construction material, several simulations were done using different set of input each time that was within the minimum and maximum value of the thermo physical properties of the building. A mean predicted value for room operative temperature (OT) was then established from this multi simulation run. Figure 7 shows that the in situ measurement closely compares to the mean predicted value by Energy Plus with a maximum error of 3.2% or ± 0.3ºC.

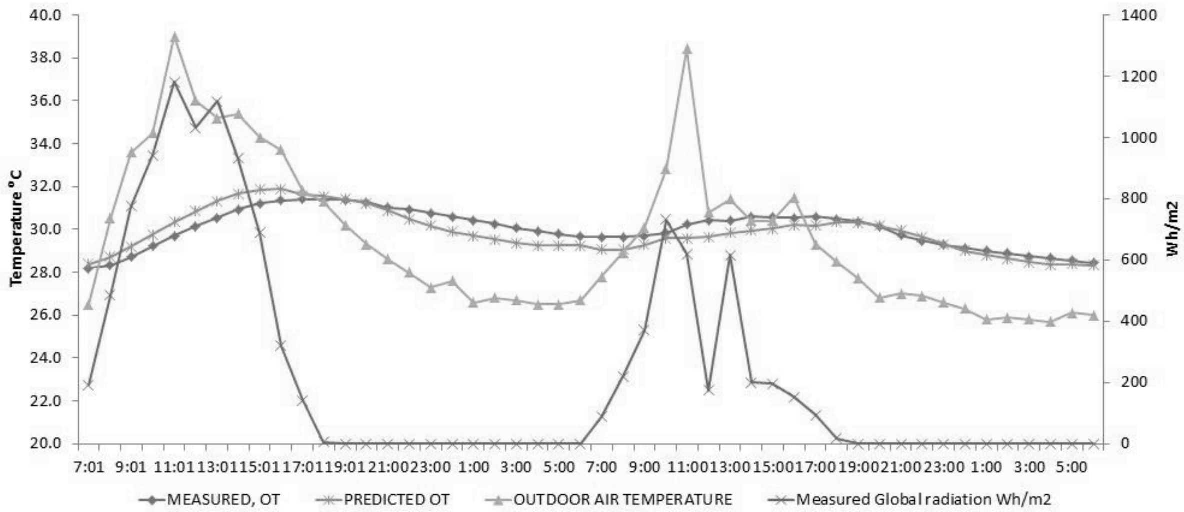


Figure 7: Comparison of predicted operative temperature of thermal zone 6 by Energy Plus and measured on site

RESULT

Annual simulation was conducted for building with radiant system only installed and the result of the simulation is shown in Figure 8. The annual operative temperature for the east facing home unit has been improved to 28ºC most of the time and is within the acceptable range of 21ºC to 28ºC for condition spaces as specified by ASHRAE (ANSI/ASHRAE, 2013) with an air velocity of up to 0.2m/s. ASHRAE has specified that the upper limit could be increased to 31ºC if the occupant control air velocity was elevated to 1.2 m/s. The average comfort zone upper limit in Malaysia is found to be 30.1 ºC as shown by Sanusi et al. (Sanusi, Shao, & Ibrahim, 2012). The radiant system therefore was capable of meeting both ASHRAE and Malaysian comfort zone upper limit. In terms of heat balance, the radiant system which was charged with night cooled water of 24 ºC have resulted in lower indoor ceiling and wall surface temperature. Radiation heat exchange takes place between the cool surfaces and short wave radiation of lights, transmitted solar as well as long wave radiation with other internal surfaces. Apart from the radiation heat exchange, convention heat exchange also take place between the cool surface and the zone indoor air. The low zone surface temperature as well as air temperature resulted in lower and acceptable operative temperature of 28 ºC.

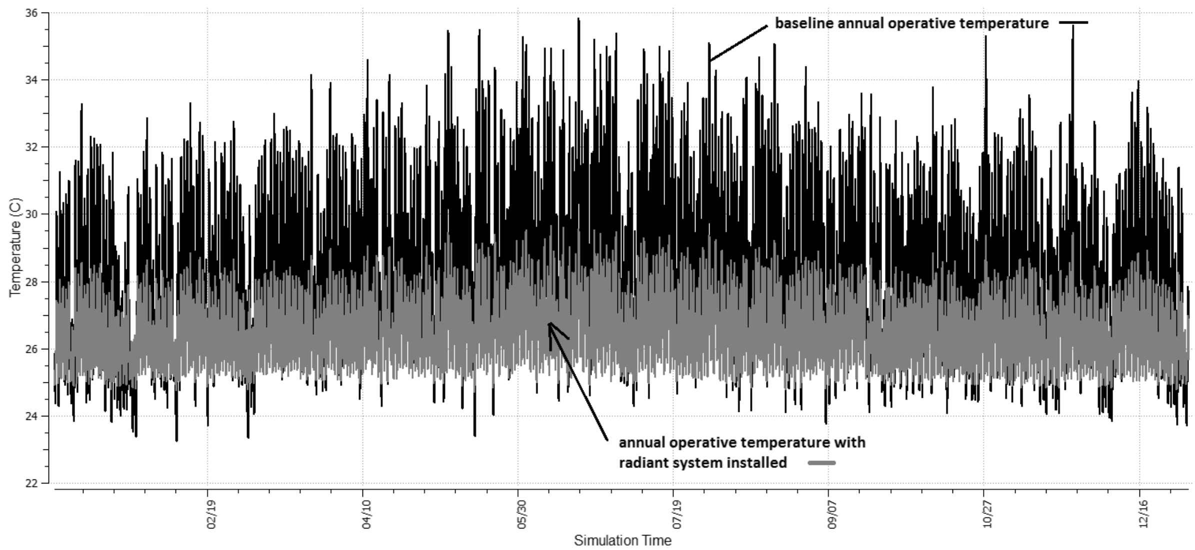


Figure 8: Annual operative temperature comparison of baseline model with radiant cooling system only

On the other hand, Figure 9 presents the annual operative temperature for the same home unit with earth tube system only present to provide indoor cooling. The earth tube system was designed to precool ventilation air before entering the zone thus providing a cooler air temperature.

However the precool air was not sufficient to cool the zone surface through convective cooling. Air has a lower heat transfer capacity compared to water used in radiant system cooling. Radiant system using water circulator in place of a fan to move air use less energy and still give the same amount of heat transfer as well (Uponor Inc, 2013). The operative temperature was improved slightly however not able to meet the comfort zone upper limit as the mean radiant temperature was not addressed.

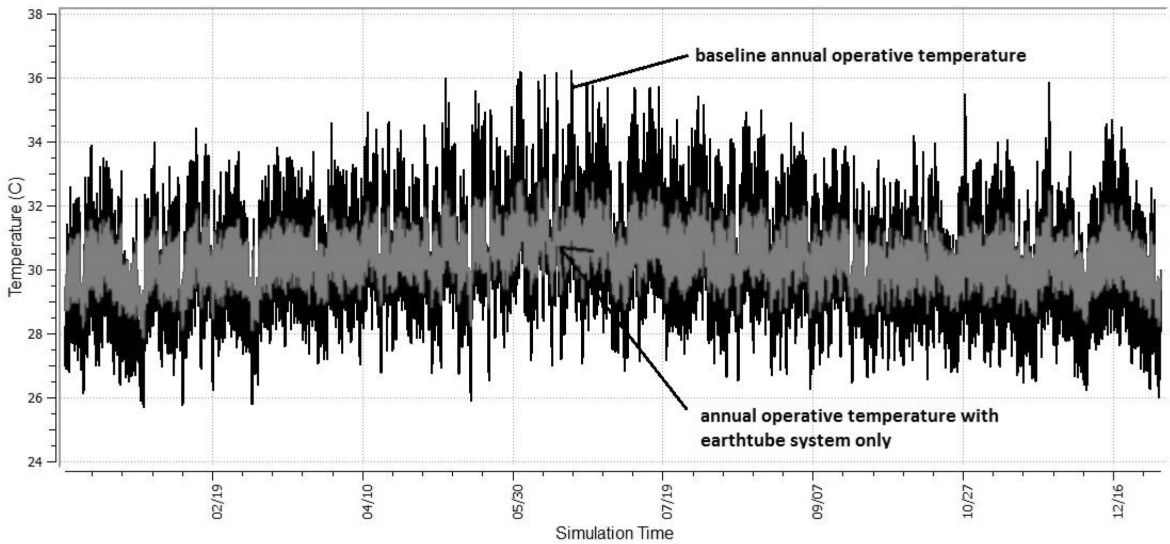


Figure 9: Annual operative temperature comparison of baseline model with earth tube cooling system only

Figure 10 presents the annual operative temperature provided by the hybrid system which consist of both radiant system and earth tube system present in the building model. The presence of earth tube system in treating the ventilation air before entering the zone improves the operative temperature to about 1 ºC lower. The hybrid system fitted in the building models provides significant cooling where building occupants could expect an indoor temperature of not more than 28 ºC nearly 100% of the time all year. The hybrid system in this case was designed to improve both indoor surface temperature and mean air temperature therefore overall operative temperature.

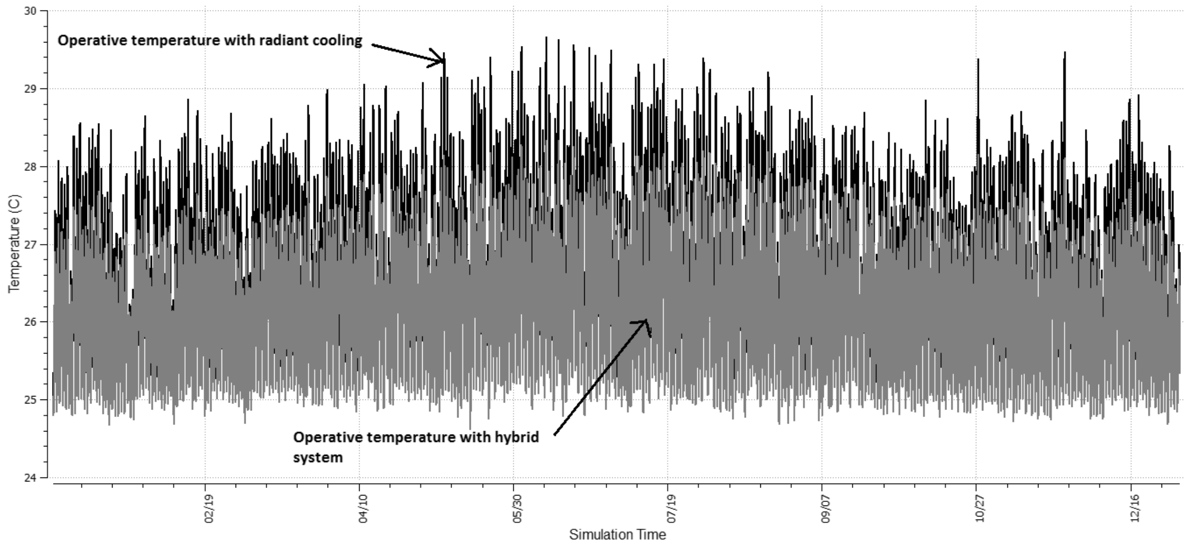


Figure 10: Annual operative temperature comparison for radiant system only model and hybrid system

For the same range of acceptable operative temperature, ASHRAE have specified the corresponding thermal comfort criteria expressed as Predicted Mean Vote (PMV) index of between -0.5 and + 0.5 on the thermal sensation scale. Figure 11 shows the improved PMV after integrating radiant system into the building where about 77% of the time the PMV is within ASHRAE acceptable thermal condition. The calculated PMV was based on preset clothing insulation value of 0.7 clo, room air velocity of 0.2 m/s, work efficiency of 0.3 as well as variable air humidity, air temperature and mean radiant temperature as calculated by Energy Plus using Kuching Sarawak weather data file.

ISO 7730 allows for extended acceptable environments such as category C PMV between -0.7 and + 0.7 that could be set as a criteria in design (ISO, 2005). Therefore about 99% of the time the low income house thermal comfort would have been met. ISO 7730 also specifies that the PMV can be allowed to be outside the selected range for certain time when considering the economic aspect of the cooling system operation. In order to save more on energy bills, it is up to the occupant to compromise on the thermal comfort by running the cooling system at shorter operation time.

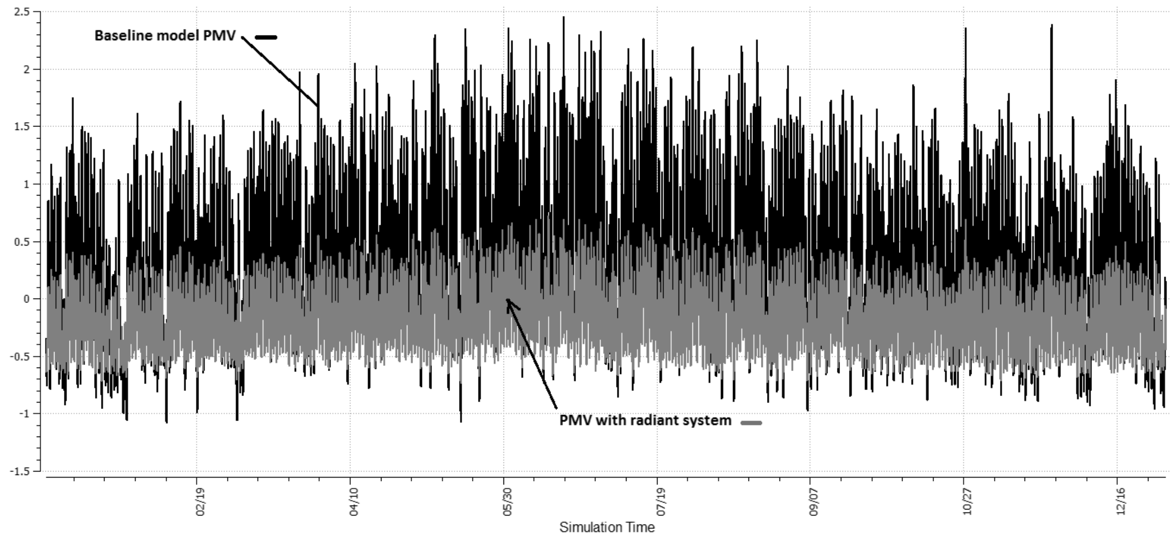


Figure 11: PMV comparison of baseline model and the radiant system model.

As for the hybrid system, the peak PMV was reduced significantly 100% of the time well below ASHRAE upper range of acceptable thermal condition of + 0.5 as shown in Figure 12. The cooler PMV value which takes place at night is not an issue as building occupant could adjust with higher clothing insulation value such as combination of underwear with outer garmet such as long sleeve and legs with sweater and jacket which is equivalent to 1.3 clo (ISO, 2005). The operation time of the hybrid system could also be regulated by the occupant by early system shut off in the late afternoon to prevent overcooling.

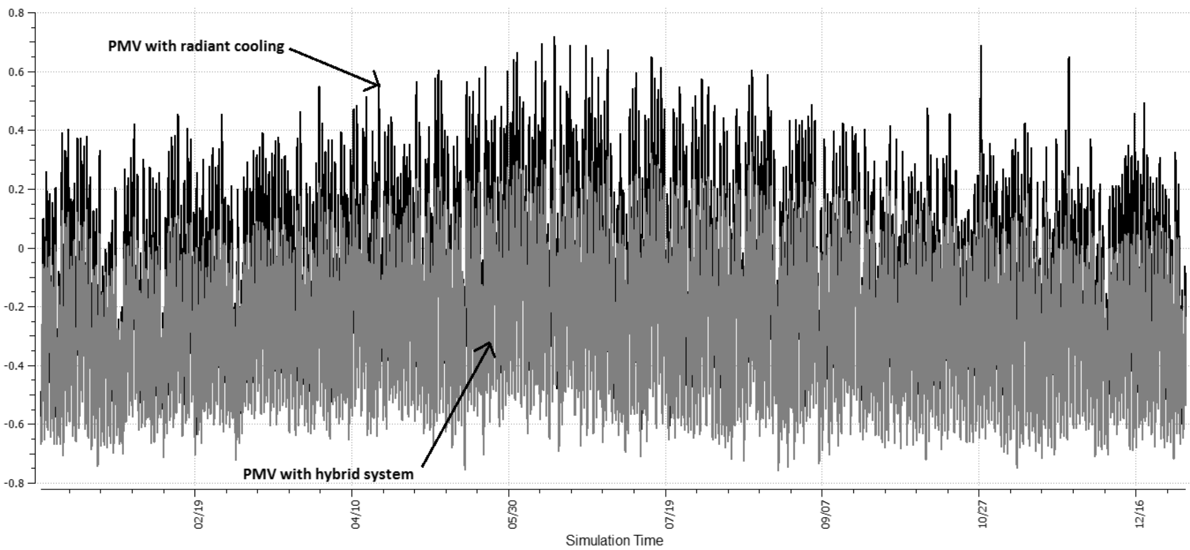


Figure 12: PMV comparison of radiant system only model and hybrid system

The simulation was also conducted for a design day with a maximum dry bulb of 34 ºC which correspond to 0.4% annual percentile of the design cooling condition for Kuching Sarawak as specified by ASHRAE (ASHRAE, 2014). In other words, for a 8760 hour in a year, on average 35 hours. per year the maximum dry bulb of 34 ºC is exceeded. Figure 13 shows the improvement in the operative temperature for east unit of the low income house where the extreme hottest peak operative temperature was reduced to about 30 ºC or about 7 º C drops. This was possible with the usage of radiant system in place of a conventional air conditioning system. The radiant cooling system was integrated with a renewable source such as night cooling water which was kept in a 25m^3 tank at a 24ºC initial temperature. The water temperature in the tank had increased to about 26ºC and by 7 pm the zone operative temperature begins to drop. It is also by this time the supply from the tank to the radiant system was cut off and recharging of the tank begins by night cooling process until early in the morning.

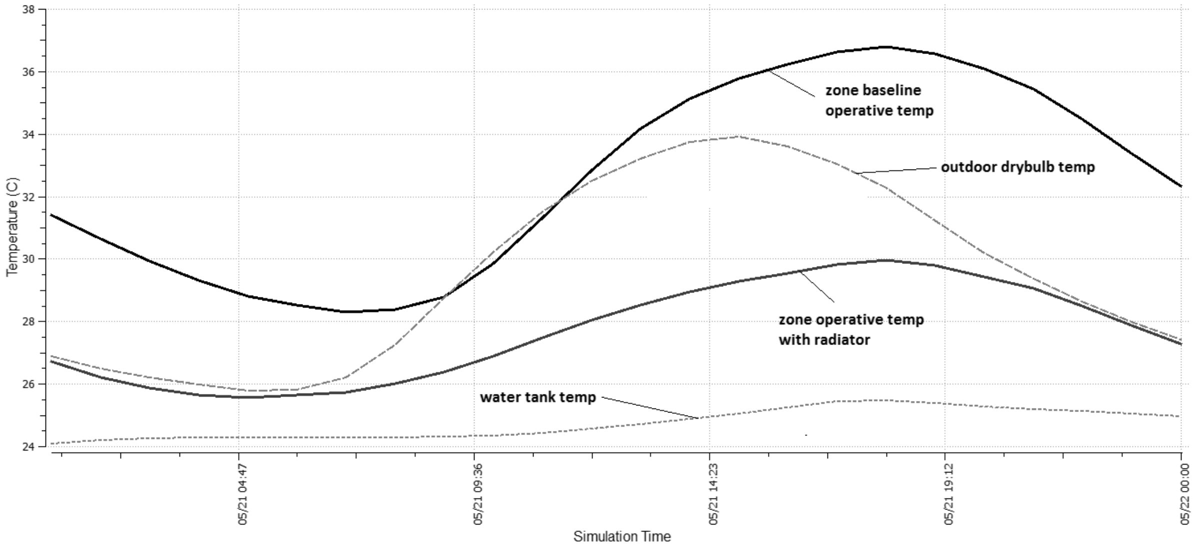


Figure 13: Baseline east unit zone operative temperature reduction by radiant cooling system with renewable water source

With the introduction of earth tube system in combination with the radiant cooling system, almost 2 ºC additional drop was provided as shown in Figure 14. This additional cooling was contributed by the earth tube system where the outdoor air was forced through the ground pipe first to be precooled before it was circulated through the room or space. The earth tube was operated when the outdoor ambient temperature was above 30 ºC.

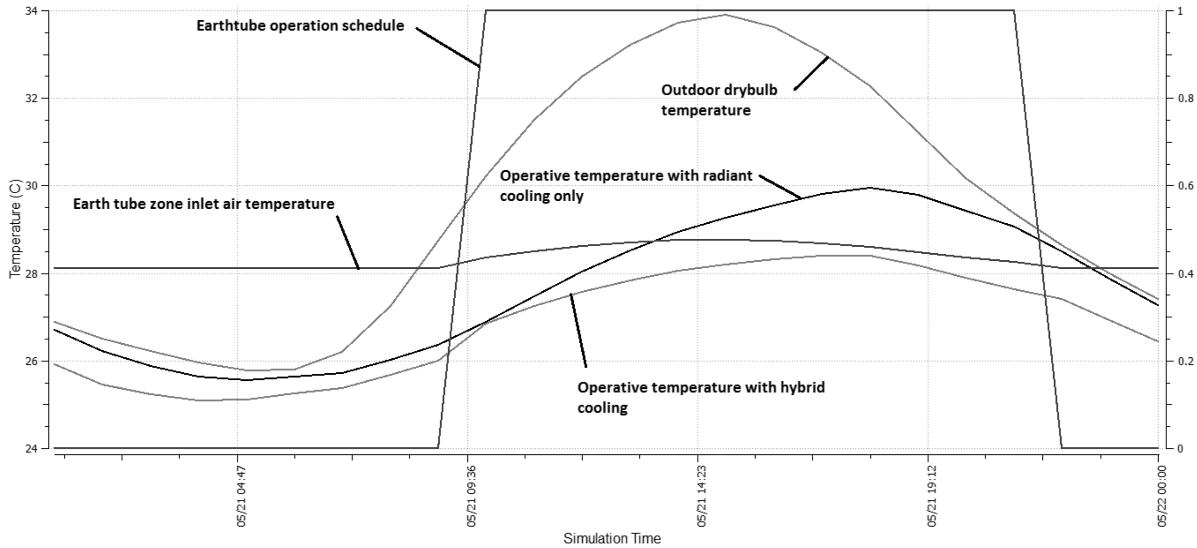


Figure 14: East unit zone operative temperature further reduction by hybrid system

Figure 15 presents the application and effect towards zone operative temperature of earth tube system, radiant system and hybrid system respectively. Application of each system independently or as hybrid both deliver improvement to the zone baseline condition. However to meet the comfort zone upper limit as set out by ASHRAE or ISO 7730 as well as Malaysian local comfort zone, application of radiant system independently or hybrid with earth tube system is required particularly for this low income home unit.

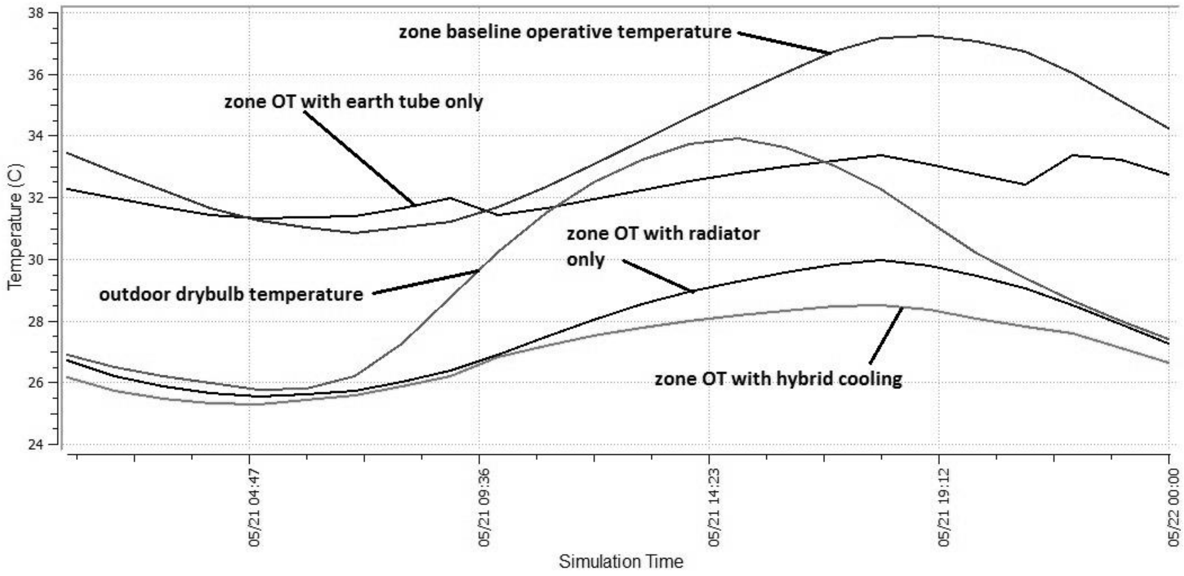


Figure 15: East unit zone operative temperature with the application of earth tube system, radiator system and hybrid system respectively

For this radiant system which has been integrated with a renewable energy source, energy was only required to run 2 units of pump for the demand loop and the supply loop of the radiant system. Additional power was also required to run the blowers associated with the earth tube system.

The energy performance for the base case building and the hybrid building was also evaluated. Energy Plus was able to calculate and predict the energy consumption of model given the design parameter and the site climatic condition provided as input in the simulation runs. Simulations were run for 4 different types of cooling system separately. Energy Plus was able to predict the annual site energy for the 4 different types of cooling systems in term of kWh as shown in Table 5. For the base case building, the building cooling system used was a conventional air conditioning system or split unit and was simulated to provide indoor cooling for 24 hours a day. As for the radiant system, three separate simulations were conducted to represents three different type of possible operating condition. Similarly the radiant system was simulated to provide indoor cooling for 24 hours a day. Table 5 shows the saving in energy and money term that can be achieved by radiant cooling and earth tube hybrid in comparison to the conventional air conditioning system for every low income home unit. The simulation on the amount of energy spent shows that as much as 95% energy could be saved by using radiant system with night cooled water as cooling medium source. This particular system makes use of free chill water that was supplied from renewable night cooling system which only requires minimal pumping power. This level of saving is not impossible as mentioned by radiant cooling industries expert (Nielsen, 2012) as Malaysian climatic condition still allows for night cooling of water to give final water temperature as low as 24 ºC.

Table 5: Calculated energy savings for radiant system with free cooling source relative to conventional air cooling system

Cooling system	Site energy GJ per annum	kWh	Yearly operation cost (RM)	Monthly operation cost (RM)	% of conventional air conditioning operating cost	Remark
Conventional air conditioning	52.85	14681	4551	379	100	24 hrs. air conditioning (mean air temperature set point of 24°C)
Radiant cooling with purchased district cooling supply or chiller	25.11	6976	2162	180	48%	24hrs operation
Radiant cooling with free night cooled water supply	2.60	723	224	19	5%	
Radiant and earth tube hybrid	3.32	923	286	24	6%	As above plus 9am to 9pm daily operation time for earth tube system

CONCLUSION

The focus of this study is on single storey low income house as this type of house is more widely constructed and made available by the government in a huge land reserve of Sarawak. The indoor thermal condition is beyond the thermal comfort range that was set by related standards. Local researchers also have showed that typical Malaysian residential house including low income house failed to provide the minimum thermal comfort target. An annual simulation using Energy Plus program have showed that radiant and earth tube system hybrid improves the indoor thermal condition of the low income house significantly 100% of the time well below ASHRAE upper range of acceptable thermal condition as well as meeting the average comfort zone upper limit for Malaysia of 30.1 ºC. Night cooled water has a great potential to be used as cooling medium for indoor hydronic radiant panel to provide thermal comfort. The amount of the energy spent to operate the hybrid system is at a small fraction of the conventional air system operating cost.

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APPENDIX

Building geometry

Parameter	Value
Total floor area (double unit home)	164.00 m^2
Floor to ceiling height	3.20m
Glazing sill height (bottom of window to floor)	0.90m
Glazing head height (top of window to ceiling)	0.85m

Indoor thermal loads

Occupancy density	0.028	Person/m^2
Lighting (LPD)	10.65	W/m^2
Appliances	3.88	W/m^2

Building all surfaces construction type

Envelope	Construction type	Uncertainty in thermo physical properties			
		Property	Min	Max	Source
Exterior wall /Interior wall	Cement mortar;	λ	0.9	1.2	(Roy & Roger, 2008)
		ρ	1700	1800	
		c	840	1000	(Lomas & Eppel, 1992)
		d	0.01	0.014	
	Brick;	λ	0.75	0.96	(Farzaneh-Gord, Rasekh, Nabati, & Saadat, 2010)
		ρ	1700	2000	
		c	650	840	
		d	0.105	0.115	
	Paint	λ	0.05	0.2	
		R	0.6	0.8	
Roof	Concrete Tiles;	λ	1.25	1.75	(Lomas & Eppel, 1992)
		ρ	2000	2300	
		c	950	1100	
		d	0.01	0.014	
	Fibre plaster ceiling;	λ	0.14	0.22	(Santamouris, Synnefa, & Karlessi, 2011)
		ρ	760	1300	
		c	800	1140	
		d	0.007	0.009	
	Reflective Foil Laminate;	R value	0.15	0.65	(NZS, 2006)
	Air space;	R value	0.15	0.21	generic R value
	Paint	λ	0.05	0.2	
		R	0.4	0.6	
Suspended Slab	Concrete slab reinforced;	λ	1.3	2.5	(ISO, 2007)
		ρ	2300	2400	(Lomas & Eppel, 1992)
		c	800	1000	
		d	0.10	0.15	
	Ceramic tiles;	λ	1.2	1.4	
		ρ	2200	2400	
		c	900	1100	
	Hardcore;	d	0.004	0.006	

	Ground temp	λ ρ c d °C	1.79 1800 612 0.04 26	1.87 2600 812 0.06 29	
Fenestration	Hardwood door; Green Tinted glass;	λ ρ c d λ ST SR	0.17 650 2400 0.03 0.75 0.5 0.05	0.19 750 2600 0.04 1.2 0.7 0.2	(Roy & Roger, 2008) Manufacturer specification