A PASSIVE MALAYSIAN RESIDENTIAL BUILDING WITH A HYDRONIC RADIATOR

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ABSTRACT

This paper presents a study to find a 'green' alternative to the conventional air conditioner seen on the walls of many residential buildings in Malaysia. EnergyPlus®, the official building simulation software of the US Department of Energy, is used to model a row of four units of modern low cost terrace housing, end walls facing East and West to minimize exposure to the sun's ray. The high altitude of the tropical sun heats the metallic roofs to above 60°C during the day and the attic is naturally cooled by outdoor air infiltration through effective leakage area of 2342m^2 per unit. Insulation of R-value 2.5 (m^2.K)/W is added above the ceilings. Simulations are run with outdoor dry bulb temperatures that are exceeded, on average, by 0.4% (35 hours) in a year, for Kuching, in East Malaysia. Typical meteorological year data shows that the maximum nightly temperatures in Kuching are about 25°C and in West Malaysian cities with World Meteorological Organisation stations are about 26°C. When radiative heat loss to the dark night sky is included, water can be cooled to 25°C. Preliminary simulations verify that beam solar radiation enters through the windows, and external window shades lower the maximum indoor temperature in the hottest West end unit, unoccupied, by 0.6°C to 30.5°C. Night cooled water circulated to a hydronic radiator, then lowers the maximum 'well-mixed' operative temperature of the unit, occupied, to below 30.2°C. The indoor air is stratified to a hotter upper and a lower cooler layer, and the occupant's environment is comfortable with air speeds of 0.8m/s.

Keywords: *modern Malaysian low cost housing, night cooled water, hydronic radiator*

1. INTRODUCTION

Malaysia has set the year 2020 to reach developed country status. Many of its residents presently living in rural areas will move to towns and cities and will require affordable and comfortable accommodation. At present, window air conditioners or the condensers of split-type air conditioners are commonly seen on the outside walls of many residential buildings. Most these residential units are newly built, indicating that, after considering orientation, use of materials for the building envelope, and roof designs, the indoor air temperature is still too hot for comfort.

Figure 1 shows the Western Malaysian peninsular and East Malaysia in the north of the Borneo Island. The World Meteorological Organisation (WMO) has stations in Georgetown, Kuala Lumpur, Kota Baharu and Kuching.

Figure 1. Georgetown, Kuala Lumpur and Kota Baharu in West Malaysia and Kuching in East Malaysia.

2. MALAYSIAN CLIMATE AND DAYTIME HEAT GAINS INTO MALAYSIAN HOUSING.

The outdoor temperature in Malaysia is usually between 27 and 32°C during the day and between 22 and 27°C during the night. There is very little variation throughout the year. Situated within the tropics, the maximum daytime solar altitude is more than 67 degrees for the whole year. The global solar radiation reaches 1 KWh/m^2, and the roof temperature can reach above 60°C during daytime. Therefore, the model in this study includes natural infiltration into the attic and added insulation above the ceiling.

Window glass lets the short wave radiation into the building and prevents the long wave radiation from escaping. During daytime, solar radiation would cause the window heat gain achieving about 90% of the total heat gains by the building. The windows should thus be shaded from solar radiation and in this study, external shades are used. The heat gains into modern low Income housing in Malaysia was studied by Ibrahim (2004).

Though there is a monsoon period, there is rain throughout the year. Moisture in the soil lowers its diffusivity and during the day, heat easily penetrates into the ground. The ground temperatures measured in Kuching is between 25 to 27°C. Together with the low coefficient of convective heat transfer for downward flow of heat of about one quarter that of upward flow, it is therefore difficult for the indoor air heat to be transferred to the ground.

3. MODELLING

Figure 2 shows an X-ray view from the North, of the row of four units of single story 5.5 meter wide, 7.5 meter depth, with 2.6 meter high ceilings, with the smaller end walls facing East and West. There are two 1.44m^2 windows with 3mm grey glass on each of the 14.3 m^2 North and South walls of every unit. The walls are constructed with 102mm thick 0.73 W/(m-K) bricks covered with cement plaster on both inside and outside faces.

The pitch of the roof is set to 30 degree, the optimum in Ibrahim's (2004) study. The roofs overhang the North and South walls/windows by 1 meter and wood is used for the soffits. The area of the gaps between the corrugated metallic sheet roof and its straight supports is 2342cm^2 for each unit. This leakage area and 0.000145 $(L/s)^2/(cm^4.K)$ stack coefficient and 0.0001 $(L/s)^2/(cm^4.(m/s)^2)$ wind coefficient are used for infiltration.

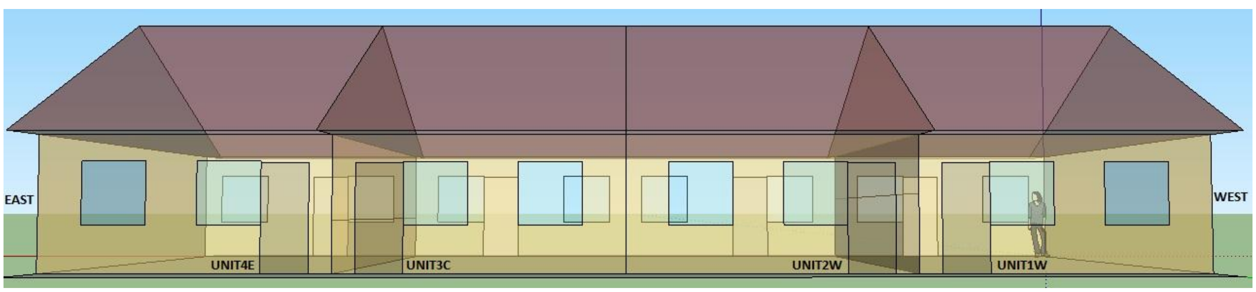

Figure 2. North (front) X-ray view of the 4 residential units modelled for the study. UNIT1W is the end unit at the right.

Insulating material R-Value of 2.5 $(m^2$-K)/W is added above the ceiling to reduce its heat gains from the roof. This value is similar to the U-value of 0.4 $W/(m^2.K)$ for Light Roof weight recommended in Malaysian Standard MS1525 for the roof of a conditioned space.

3.1. Air speeds And Thermal Comfort Temperature.

A.Cengel, (2003) wrote that the skin temperature of a clothed or unclothed person at thermal comfort is 33°C ± 1.5°C and the emissivity of the skin is 0.95.

Watanabe S et al., (2009) placed fans underneath chairs to give individual comfort control with different air speeds at different parts of the body, under various indoor temperatures in a climate chamber in summer. They found that at 28°C indoor temperature, the whole-body thermal sensations were almost thermally neutral, regardless of the type of chair, at 30°C, occupants can make themselves comfortable with these chairs and at 32°C, the chairs, and fans were not able to provide thermal comfort.

Candido et al., (2011) who conducted two field experiments that combined thermal acceptability and air movement assessments in Brazil, another tropical country with humid climate, show that people wanted 'more air velocity' in the ASHRAE adaptive thermal comfort standard. They concluded that for 90% acceptability, from 24 to 27°C the the minimum air velocity for thermal and air movement acceptability is 0.4 meters per second, from 27 to 29°C, the air velocity is 0.41 to 0.8 m/s and from 29 to 31°C, the air velocity is above 0.81 m/s.

Baharun et al., (2009) reported that a neutral temperature of 26.5°C is used for Darwin, the northernmost town in Australia, without air movement. Based on the formula by Aynsley and Szokolay, (1998) an air speed of 1 m/s would cause a cooling sensation equivalent to a temperature drop of 3.8°C. Thus, this research uses an operative temperature of 30.3°C by summing 26.5°C with the neutral temperature with the 3.8°C cooling sensation by air speed of 1 m/s.

4 . SIMULATIONS WITH (1) EXTERNAL WINDOW SHADES FOR AN UNOCCUPIED UNITW, (2) WINDOW SHADES AND HYDRONIC RADIATOR FOR AN OCCUPIED UNIT1W.

Preliminary simulations were done to confirm that, when the solar altitude angle is low, beam solar does enter through the windows from 0.9 to 2.1 meter high on the south and north walls.

Figure 3 shows that, for June and December 21 when the maximum solar altitude is 67 degrees during the day, solar radiation is absorbed by the floor and the inside face of the west wall in the morning, and, by the inside face of the east wall in the evening. The power (watts) absorbed depend on the solar absorptance of the material on the inside face and the magnitude of the direct beam solar. A solar absorptance of 0.95 is used for the vinyl tiles of the floor.

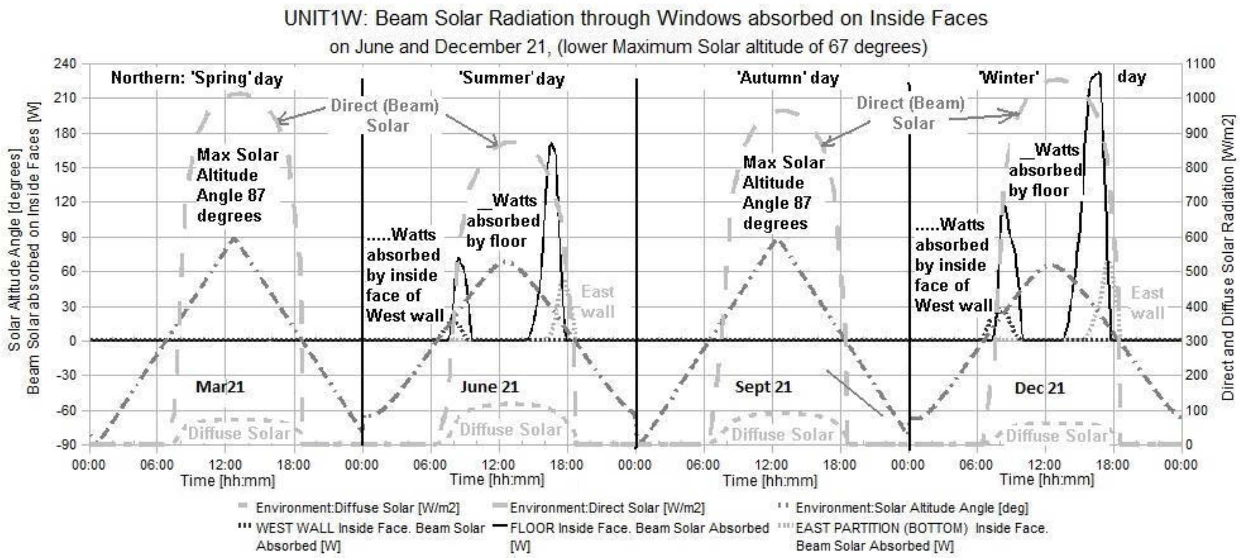

Figure 3. Radiation on floor, inside face of east and west walls from beam solar through windows on June & Dec 21.

When the maximum solar altitude is 87 degrees on March and September 21, the 1 meter roof overhangs at 2.6 meter high shades the windows and there is no solar radiation absorbed by the inside faces. This verifies that EnergyPlus considers beam solar through the windows, and the effect of shading is used in the next subsection.

4.1. External Window Shades Reduce Window Heat Gain And Indoor Air Temperatures

Grey glass, specifications shown in Table 1, is used for the windows. EnergyPlus has several types of controls for blinds, shades or screens. External shades are readily made from cloth and bamboo strips and can be rolled down by ropes from inside the building by the occupant. The control used here is that the external shades, at the edge of the 1 meter overhangs/soffits are rolled down when there is solar radiation. The sides and bottom are open and the specifications for the shades are also shown in Table 1.

Table 1 Properties of Window Glass and External Shades (values are in fractions, unless indicated within [ ]).

Grey Glass		**External Roll Down Shades**	
Solar Transmittance at Normal Incidence	0.626	Solar Transmittance	0.05
Front & Back Side Solar Reflectance at Normal Incidence	0.061	Solar Reflectance	0.3
Visible Transmittance at Normal Incidence	0.611	Visible Transmittance	0.05
Front & Back Side Visible Reflectance at Normal Incidence	0.061	Visible Reflectance	0.3
Infrared Transmittance at Normal Incidence	0	Thermal Hemispherical Emissivity	0.9
Front and Back Side Infrared Hemispherical Emissivity	0.84	Thermal Transmittance	0.007
Conductivity [W/(m-K)]	0.9	Conductivity [W/m-K]	0.1
Thickness [m]	0.003	Thickness [m]	0.007
		Air Flow Permeability	0.25

The broken lines in Figure 4 show the indoor air temperature and window heat gain without external shades for the unoccupied UNIT1W. The continuous lines show these results with external shades. The dotted lines at the bottom show the minimal (less than $20W/m^2$) direct (beam) and diffuse solar radiation that enter the window/s because of the 1 meter side and bottom gaps between the wall and the shades.

The external window shades reduce the maximum indoor air temperature at around 6pm from 31.16 to 30.52°C.

The window heat gain without window shades is up to $700W/^2$, and with window shades is less than $200W/m^2$.

EnergyPlus documentation gives the window heat gain as the sum of

(1) the solar radiation transmitted through the windows, plus
(2) the net infra-red heat flow to the zone from zone side of the glazing, plus
(3) the convective heat flow to the zone from the zone side of the glazing, minus
(4) the short-wave radiation from lights and interior solar radiation transmitted back out the window.

From about 10 am to 2 pm, when the sun is overhead the roof and its overhangs, the window heat gain, without and with shades are depressed.

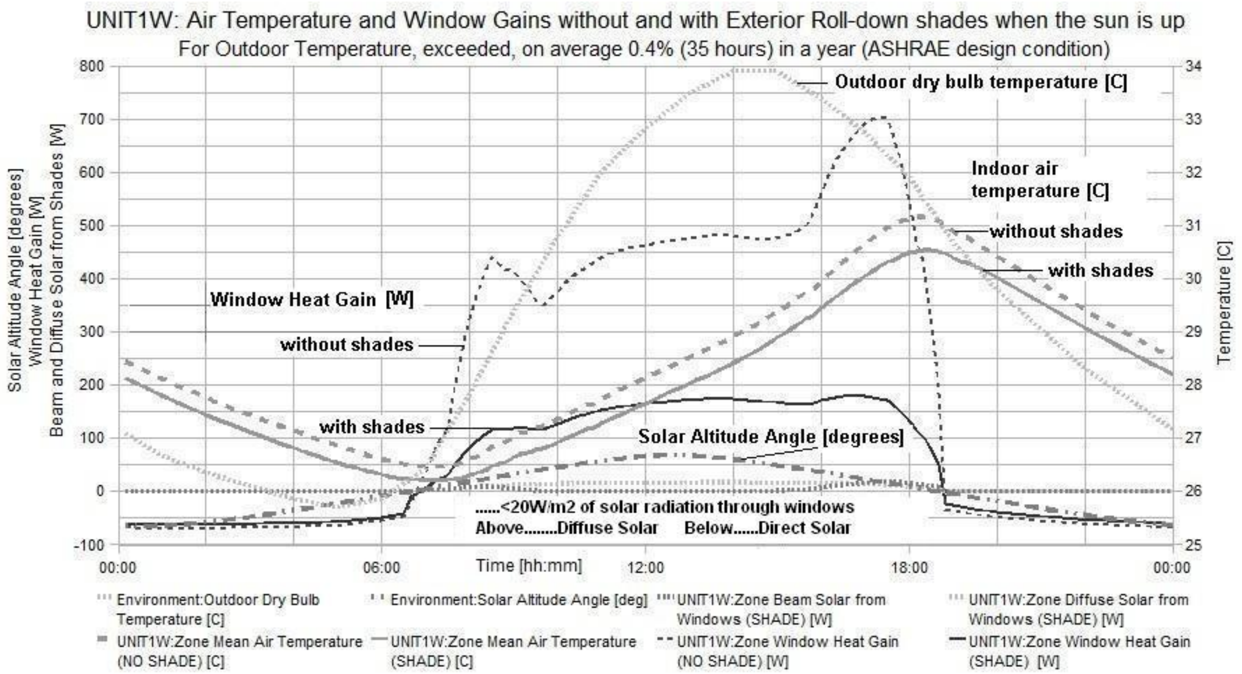

Figure 4. External Shades reduce the maximum indoor air temperature at 6pm from 31.16 to 30.52°C.

4.2. Night Time Outdoor Temperatures, Cooling Power and Water Temperature by Morning.

Hourly data for a typical meteorological year (TMY) are provided by the International Weather for Energy Calculation (IWEC) for four World Meteorological Organisation (WMO) stations, Georgetown, Kuala Lumpur, Kota Baharu and Kuching. These are analysed to decide on the temperature of night cooled water by morning.
Kuching (WMO station # 964130) is in East Malaysia, on the Borneo Island and has the highest rainfall among all Malaysian cities. TMY data provided by IWEC shows that the minimum outdoor temperature at night is above 25°C for only 15 nights a year. The sky is mostly cloudy and cooling power (from long wave radiative heat loss to the dark night sky) may be retarded. This is discussed further in subsection 4.2.1. It is noted that the maximum outdoor temperature on the day following these 15 nights is low, with 4 days over 32.3°C and a maximum of 33.07°C.
In the Western peninsular, TMY data for the three cities show that the maximum outdoor temperatures at night are about 1 degree C higher than those in Kuching. However, there is much less rainfall recorded in these three Western cities, the skies are less cloudy and more opportunities to consider the cooling power from the radiative heat loss to the dark night sky. Subsection 4.2.2 shows the temperatures of night cooled water by morning for Kuala Lumpur (WMO station # 486470) is below 25°C. Similar results are obtained for Penang and Kota Baharu.

25°C is thus used as the temperature of night cooled water for the hydronic radiator.

4.2.1. Night time temperature and water temperature without radiative heat loss to night sky, Kuching

Khedari et al., (2000) investigated the depressions (difference between surface and outdoor air temperatures) of four types of roof materials with clear, cloudy and rainy sky conditions in Thailand, another country with tropical climate. Under rainy skies, the the temperature of different surfaces of roof radiators and ambient air are fairly close. Under clear and cloudy skies the depression is between 1-6°C.

Similar night time depressions of about 1 degree C is shown in the August 2007 measurments at the Universiti Malaysia Sarawak campus at the bottom of Figure 5. Thus, in Kuching, it is possible to cool water to 25°C water during the night, without considering cooling power from radiative heat loss to the dark night sky.

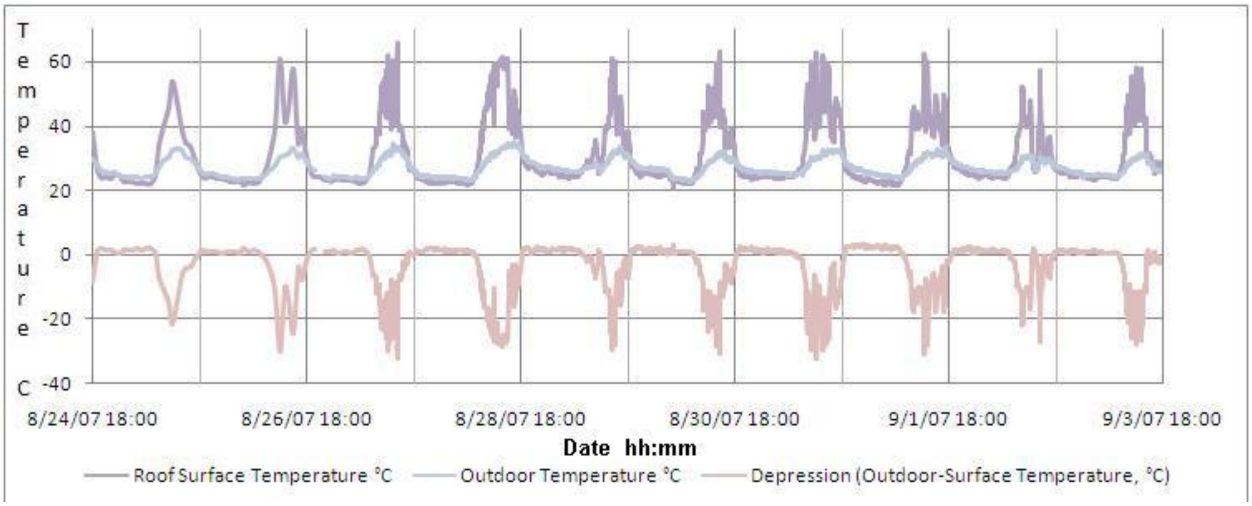

Figure 5. Measured Roof Surface and Outdoor Temperatures, Aug 2007.

Table 2 shows a calculation for the hourly cooling power (rate of heat loss by radiation to the night sky) with an emissivity of 0.9 and a Stefan Boltzmann constant of 5.67 x 10^{-8} W/(m^2.K^4) for Kuching. The averge cooling power for the night on June 21is 37.71 W/m^2. The temperature of 0.3 m^3 of 28°C water at 9 pm, cooled by 3 m^2 surface area reaches 23.65°C by 7 am in the morning.

Table 2 Average night cooling rate based on average sky temperature on June 21.

Time Period	Average Sky Temperature [°C]	(Water temperature, K)^4- (Sky temperature, K)^4 [10^6 K^4]	Av night cooling power [W/m^2]	Water temperature at the end of the hour [°C]
9-10pm	17.7	1067	54.44	27.53
10-11pm	18.08	928	47.36	27.11
11pm- 12	18.14	834.8	42.6	26.7
12-1am	17.84	786.2	40.12	26.3
1-2 am	17.4	757.3	38.65	25.9
2-3 am	17.05	721.2	36.81	25.51
3-4 am	16.83	676.5	34.52	25.12
4-5 am	16.65	632.6	32.28	24.74
5-6 am	16.42nd hi	598.1	30.52	24.38
6-7 am	16.15	570.7	29.12	23.65
Average			37.71	

The average night cooling power for the whole year for Kuala Lumpur is shown in Figures 6 and 7 in the next subsection. The pattern is the same for the Georgetown and Kota Baharu.

The cooling power is also similar to the 40W/m^2 given by Parker (2005) for a 50% cloud covered sky in a humid climate. According to Parker, when the sky is completely overcast by clouds, there is still about 7W/m^2 of cooling power.

4.2.2. Night time temperature and water temperature with radiative heat loss to night sky. West Malaysia

The nightly maximum outdoor temperatures in the West Malaysian cities, shown in Figures 6 and 7 for Kuala Lumpur, are about 26°C, 1 degree C higher than that for Kuching. But the skies are less cloudy and cooling power from radiative heat loss to the dark night sky can be considered. Georgetown and Kuala Lumpur are shielded from the North East Monsoon from October to March by the range of mountains that runs from north to south in the middle of the peninsular.

Figures 6 and 7 also show that for Kuala Lumpur, the average night cooling power for a year, from radiative heat loss to the night sky is of about 40W/m^2, similar to those given by Parker (2005). The temperature of water cooled by a 3m^2 surface area with 0.9 emissivity, shown by grey balls, is less than 25°C in the morning. The year average of the nightly maximum and minimum sky temperatures are about 20 and 16°C respectively.

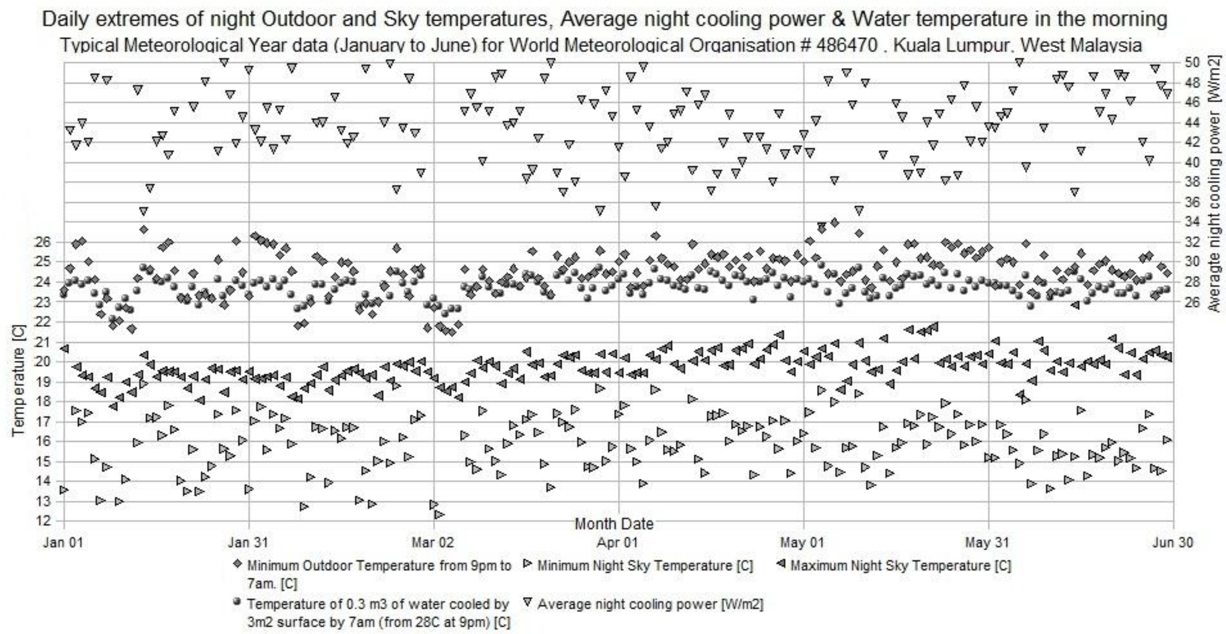

Figure 6. Night Outdoor and Sky Temperatures, Av. Cooling Power & Water Temperature in the morning, Jan to June.

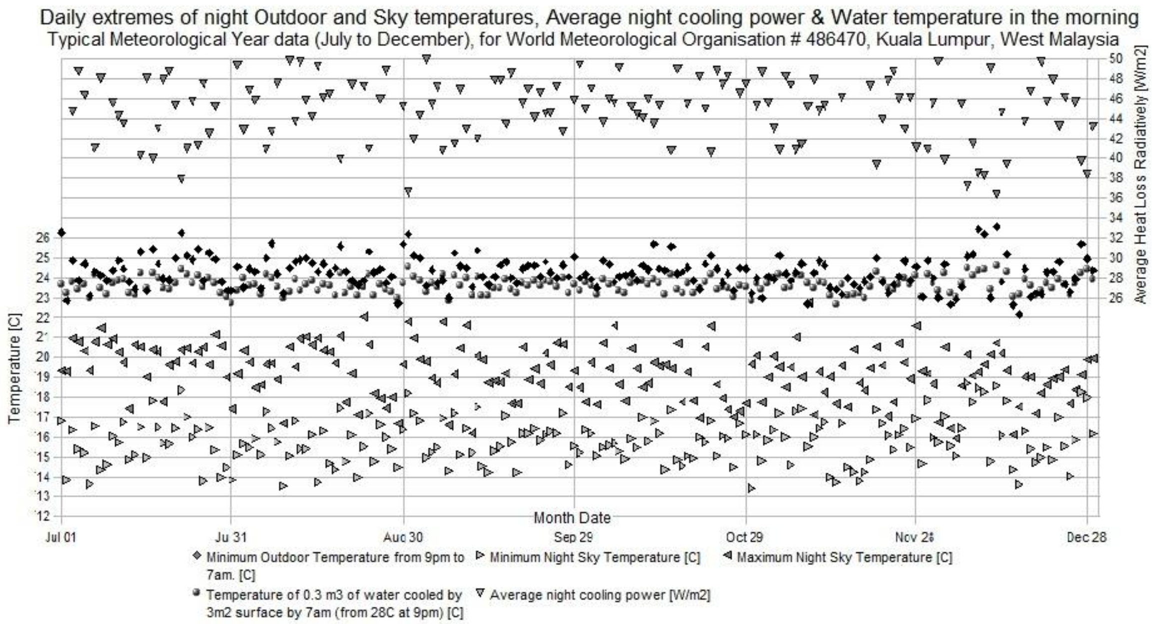

Figure 7. Night Outdoor and Sky Temperatures, Av. Cooling Power & Water Temperature in the morning, July to Dec.

Results for Penang and Kota Baharu are similar to those shown in Figures 6 and 7 for Kuala Lumpur.

4.2.3. Methods of cooling water at night require small power.

At night, the water may be cooled with an open-loop system, where the water is circulated over a slightly inclined metallic surface. If one end of the metallic roofing sheets higher by 0.5 meter, the power required for lifting 0.253 liters per second of is 8W based on 50% pumping efficiency.

Alternatively, a closed-loop collector that is similar to the solar collector for making domestic hot water can be used. EnergyPlus auto sized that the water flows at 0.253 liters per second and the pump power to circulate the water is 6.5 W.

Hence renewable energy from a small photovoltaic panel may be used for both close-loop and open-loop systems.

4.3. Simulation For The Externally Shaded, Occupied, UNIT1W With A Hydronic Radiator.

Figure 8 shows a north view of UNIT1W and its neigbouring UNIT2W. The view below the louvers, which are on the 0.5 m high walls between the top of the doors/windows and ceilings is sectioned to show the interiors.

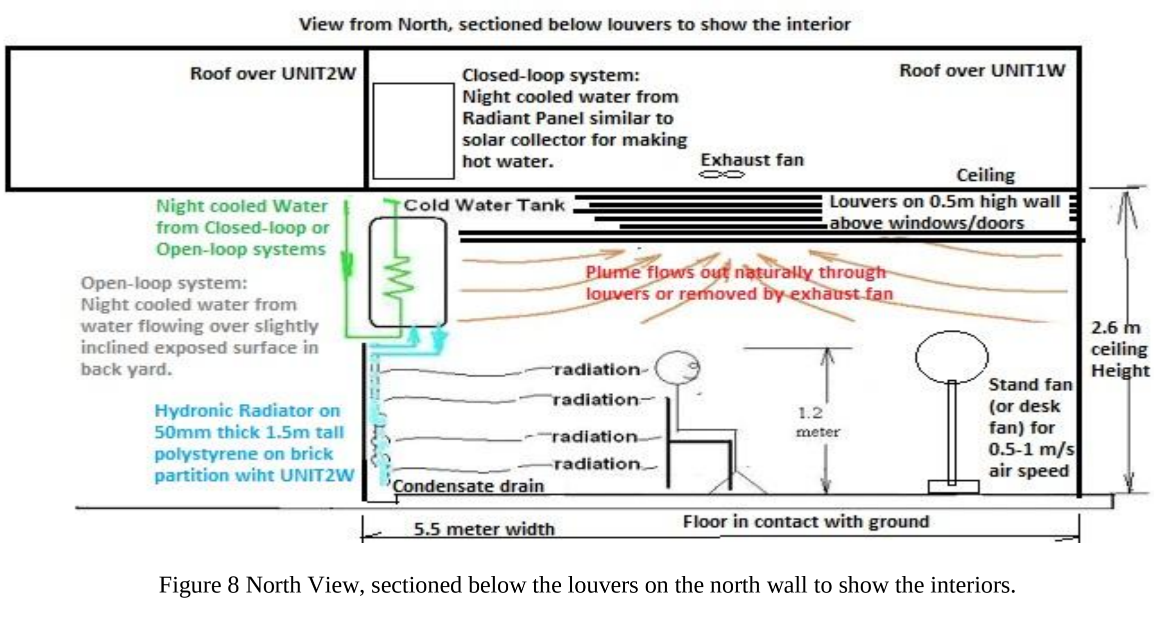

Figure 8 North View, sectioned below the louvers on the north wall to show the interiors.

50 mm thick polystyrene is used to insulate the hydronic tubes from the 1.5 meter tall bottom brick partition between UNIT1W and UNIT2W. To achieve a good view factor with the occupant and high emissivity, the tubes are covered with a matt black metallic plate. Because of the high humidity, dew may form on the metallic surface and a small drain is recommended to be constructed on the inside edge of the floor below.

Table 3 shows the schedules for occupancy, clothing, lights and equipment for when UNIT1W is occupied. The activity level is the product of metabolic rate in W/m^2 given by ASHRAE and 1.6 m^2 surface area of a human body.

Table 3 Schedules of occupancy, lights and equipment for an occupied UNIT1W used for simulation.

Time	Number of Occupants	Activity Level [Watts/person]	Clothing insulation [clo]	Lights [watts]	Equipment [Watts]
0:01- 6:00	2	64 (sleeping)	1	16	0
6:01- 7:00	2	64	0.6	128	0
7:01- 12:00	1	112 (standing)	0.6	57.6	100
12:01-17:00	1	96 (seated)	0.6	57.6	45
17:01-18:00	1	96	0.6	57.6	45
18:01-22:00	2	96	0.6	57.6	45
22:01-24:00	2	64 (sleeping)	1	16	100

The controls in the EnergyPlus's ZoneHVAC:LowTemperatureRadiant:VariableFlow object is set to circulate water from the tank to the hydronic radiator when the operative temperature in UNIT1W is at 29.5°C with maximum flow of 0.08 liters per second when the operative temperature is 30°C.

Figure 9 shows that the hydronic radiator reduces the maximum inside face temperature of the bottom partition from 30.2°C to 27°C and reduces the maximum operative temperature of the externally shaded, occupied UNIT1W from 30.7°C to 30.2°C. The temperature of the water in the tank increases from 25°C at 4pm when water circulation starts, to 27.7°C at about 8pm when the operative temperature drops back down to 29.5°C.

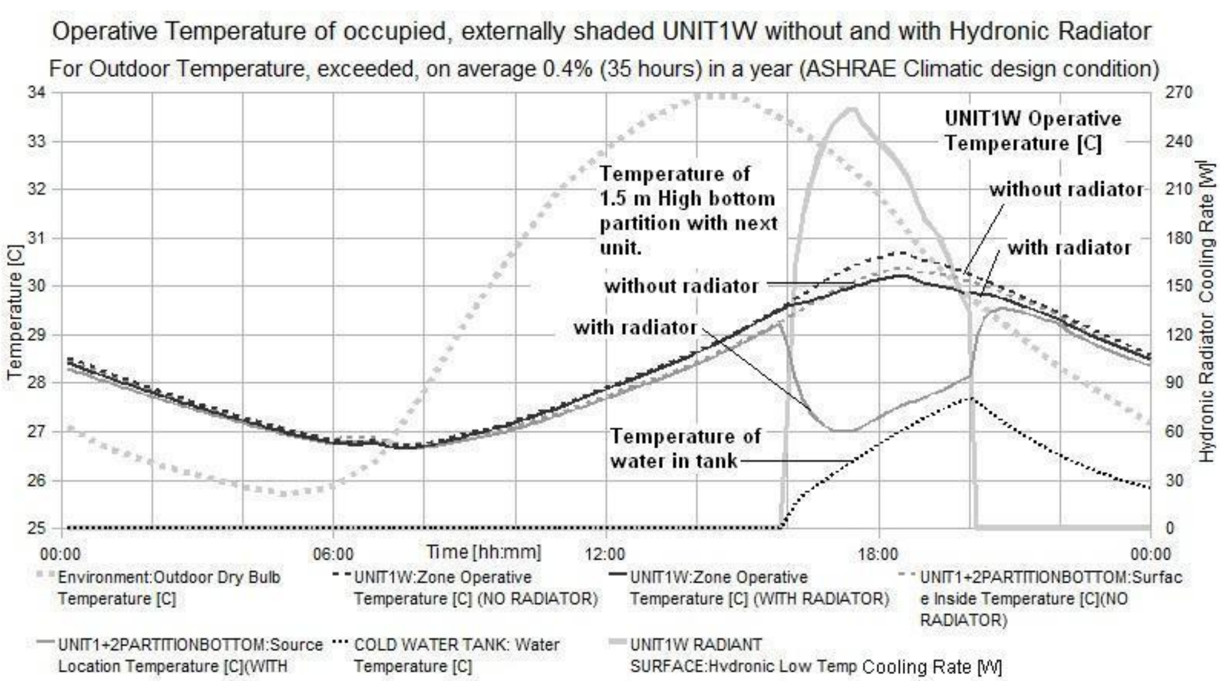

Figure 9. Effect of radiator on the operative temperature of an occupied externally-shaded low cost corener unit.

When 60 parallel lengths of 7.5 meter long tubes are used along the 1.5 meter tall bottom partition, the speed of the water flow is 10mm per second. The volume of water inside the tubes is 0.06 liters. EnergyPlus sized the rated power of the circulating pump as 20W, which can come from the same photovoltaic for the night cooling pump.

For fresh air, the air heat balance includes a default of 0.00944 m^3/s of outdoor air per occupant.

EnergyPlus simulations use surface and air heat balance based on 'well-mixed' or 'well-stirred' indoor air. The next subsection shows that the indoor air is actually stratified into a hotter upper layer and a cooler lower layer.

4.4. Stratification of air in a single story building and reduction of air speed for thermal comfort.

Malaysian Standard MS 1525 (2007) describes an air speed of 0.5 to 1 m/s as 'generally pleasant when comfortable or warm, but causing constant awareness of air movement'. This subsection is to show that the air speed of 1 m/s used earlier in this study can be lowered.

Figure 10 shows that the indoor air is stratified into a hotter upper layer (the plume) and a cooler lower layer (environment of the occupant). The temperature in the plume is hotter by up to 2 degree C from noon to 6pm.

Figure 8 showed the louvers in the 0.5 meter wall between the top of the doors/windows and the ceiling and an exhaust fan. If the windows or doors are opened, the plume may flow out naturally due to the stack effect when the outdoor air is below 30°C and/or assisted by wind, if present. Otherwise, the slow moving exhaust fan may be used.

The maximum operative temperature in the environment of the occupant is thus below the simulated 'well-stirred' 30.2°C and the contribution of cooling sensation due to air speed to thermal comfort can thus be reduced. The air speeds can thus be lowered.

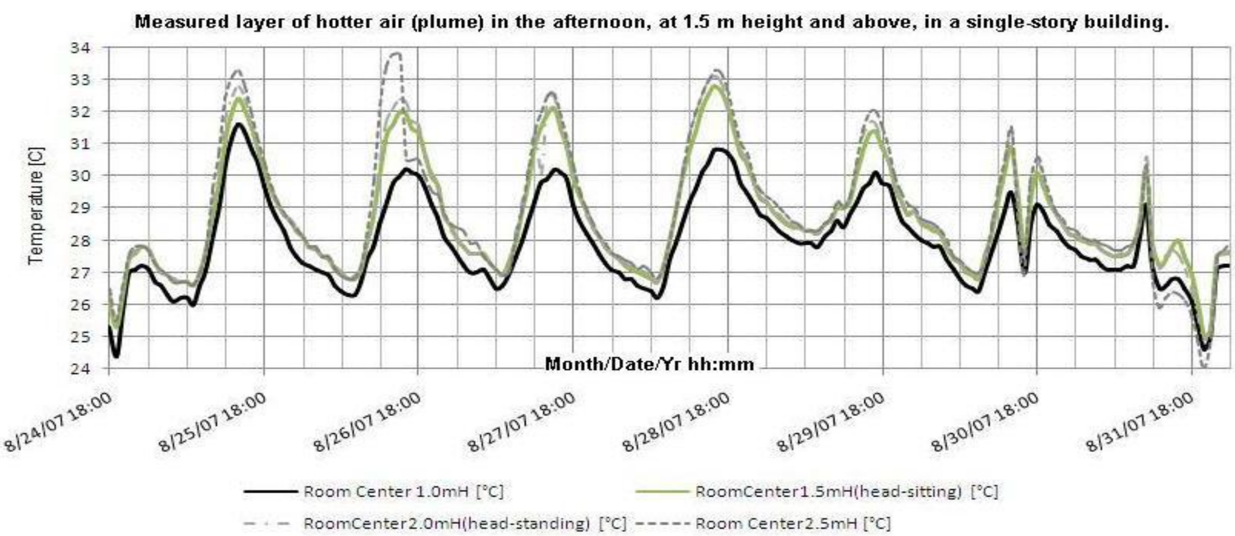

Figure 10. Measured indoor air temperatures at various heights in the center of a single story building, Aug 2007.

Based on the Aynsley and Szokolay, (1998) cooling sensation of $\Delta T = 6*(v-0.2) - 1.6*(v-0.2)^2$, for air speed v, up to 2 meters per second, when the 1 m/s air speed is lowered to 0.7 and 0.6 m/s, the loss in cooling sensation is, respectively 1.2 and 2.1 degree C. The speed of the stand fan or desk fan can thus be lowered to around 0.7 meter per second to reduce this 'constant awareness of air movement'

The use of air movement for thermal comfort is supported by reports from Arens et al., (2009) who reported that ASHRAE is making provision for 'elevated air speed' in its Themal Comfort Standard 55-2004.

5. DISCUSSION.

There is potential to extend the hydronic radiator/s to residential buildings that are bigger than the low cost housing used in this study and Isa et al. (2010) estimates that there are 1.6 million units of terraced houses in Malaysia. However, as dew may retard radiative heat transfer, when panels similar to a solar collector for making hot domestic water is used for cooling water at night are used, electric resistance wires may be required on the flat glazed surface.

6. CONCLUSION

With the diurnal pattern in the 24 hour per day for Malaysian weather, a hydronic radiator with night cooled water can keep the operative temperature of the air in the environment of occupant in modern low cost housing in Kuching below 30°C. The occupant would be comfortable. Unlike the conventional air conditioner, the radiator can be used air movement of between 0.5 to 1 m/s.

7. ACKNOWLEDGEMENTS

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