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Performance of Low Cost Alternative Radiant Cooling Panel in Malaysia

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Abstract

Radiant panel cooling is still considered uncommon in Malaysia due to unavailability of local manufacturers with limited architects or engineers who are familiar in the system. The initial construction cost for radiant cooling system may be higher than air system and not forgetting the need for a smaller supplementary air system to dehumidify the air to avoid condensation which is an inherited problem of the system in hot and humid region. Promotion and public awareness is lacking in the country and very much dependable on government demonstration program of green technology application where only a few governments owned building having such system. With the aim of long term energy and cost saving this study looks into the development of custom design and locally assembled low cost radiant cooling panel and how its performance in comparison to its overseas and more expensive counterpart could help in provide alternative cheaper building cooling system. Custom build cooling panels with selected materials were constructed and tested to find out its cooling capacity. Finite Element Method (FEM) software was used to establish a design chart to assist in the design and sizing of the alternative radiant panel for Malaysian residential house. The experiment shows that cooling performance in term of mean surface temperature and its cooling capacity is almost identical to its overseas counterpart. Use of cooling radiant panel with free night cooling of water as its chill water supply shows a significant energy saving potential while at the same time provide an acceptable room thermal comfort. Given the local made product having similar performance and suits local condition the technology could grow and be applied with confidence.

Keywords: *Radiant cooling panel, energy savings, thermal comfort, cooling capacity, night cooling*

1.0 Introduction

Radiant system is used to condition space to produce a selected air temperature much like a traditional convection system or air system does. The objective is to save energy or to overcome adverse local comfort condition [1]. In this system, building surface is converted to radiant heat transfer panel that can be used for heating or cooling application. The radiant heat transfer does not directly affect the room air temperature. The long wave radiation heats or cools the surrounding surfaces, which then indirectly heats or cools the room air. The radiant cooling system basically consists of heat absorbing surface, chill water supply as the cooling medium, distribution pipe and control system. Some are integrated with building structure or embedded surface system and some are in the form of panel system with open air gap. Radiant panel cooling system is still considered uncommon in Malaysia due to lack of local manufacturer, suppliers and the high risk of surface condensation of cooling panel in this tropical hot and humid climate which makes its unpopular and prevent its growth. No doubt radiant cooling technology is not new especially in the western with its temperate climate, its application in this part of the world is still rare due to various factors that hinders the development of radiant cooling system [2]. Even in the latest Malaysian green building products and services directory publish by Malaysian Green Building Confederation [3] there is no radiant based cooling product or service provider was listed. Such product will have to be imported should the system were to be applied locally thus cost of acquiring such product is a something to be considered beforehand. It is likely that product availability and competition from various readily available suppliers prompts building designer to choose other more common cooling system rather than a greener and cheaper technology in the long run.

2.0 Literature Review

Malaysian building stills widely use active cooling system like Package Terminal Air Conditioner (PTAC) and Air Handling Units (AHU) which requires high energy source to run. On the contrary studies shows that more and more country are adopting hybrid cooling such a cool ceiling panels and walls system which have demonstrated efficient cooling performance and high potentials in energy saving [4]. Furthermore study by Azhaili [5] on the use of radiant panel cooling with night cooled water have showed some potential in this region. Radiant cooling is an alternative Ventilation and Air Conditioning (VAC) system which allows the enhancement of energy efficiency and thermal comfort [2]. No local standard or guide is available in design and application of such system in Malaysia however international standard such as ISO 11855, ASHRAE Chapter 6 of HVAC Systems and Equipment as well as EN 1264-2:2008 are some references that provide some guide in the design, capacity calculation, dimensioning and installation of such system. Since the introduction of the National Green Technology Policy in 2009, the government of Malaysia has been encouraging local universities and research institution to increase its research development and innovation of green technology [6]. This is possible through certain funding mechanism, domestic and foreign direct investment, as well as financial incentives for graduate and post graduate students in line with the government strategy to develop skilled, qualified, competent and productive human resources in the field. In line with this agenda, this study explores the use of locally available material to be used as cooling panel for indoor cooling purpose as radiant cooling in Malaysia is deemed to have a market potential as the climate is hot all year long and building cooling with reduced energy consumption and energy saving is essential choice among government and privately owned building [7].

An experiment was carried out to test locally, cheaper and easily available material to replace the more expensive imported radiant cooling panel and was tested with passively cooled water source. At the same time the feasibility of using passively cooled water or night cooled water in combination with the custom build radiant panel is examined.

3.0 Methodology

3.1 Radiant Cooling Panel Make Up And Test Rig

The custom build radiant panel proposed was a 0.3m by 0.6m panel of a manageable size for the purpose of performance testing. The panel was constructed with an aluminum angle frame that will house an aluminum sheet as the heat transfer layer and gypsum screed with embedded pipes or tubes as well as an insulation layer as shown in Figure 1.

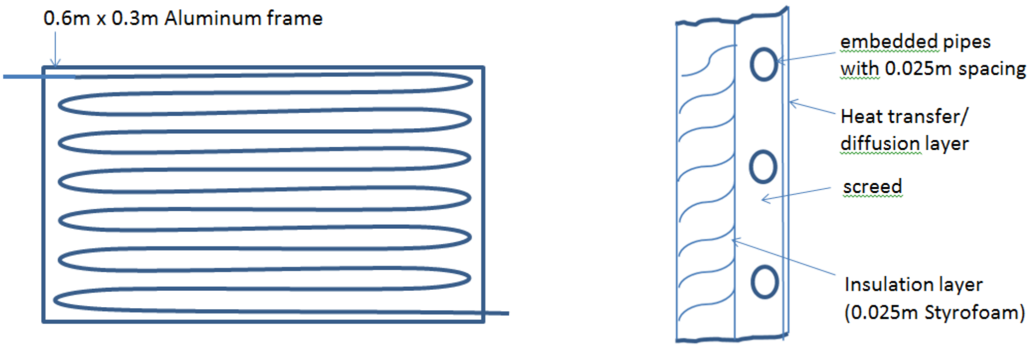


Figure 1: Schematic of proposed cooling panel layout and section (not to scale)

Cooper tubes and cross linked polyethylene (PEX) are two common material used as conduit to transfer the cooling or heating medium with metal or aluminum sheet as the diffusion layer where the panel normally double as heating during winter or cooling radiant surface during the summer. In Malaysian all year hot and humid climatic condition, only cooling function is needed therefore expensive copper or PEX pipe could be replaced with a much cheaper material to carry chill water as the cooling medium. A variety of panel make up as shown in Table 1 was constructed and compared to find out the performance of these material to the more common copper tube. A variety of material was used as the diffusion layer to find out the performance in term of surface temperature variation.

Table 1: Proposed radiant panel make up to be tested

Embedded pipes type	Heat transfer/diffusion layer make up	Proposed panel size
5mm copper tube	Cement board	0.18 m^2
5mm silicon micro tube	Aluminium flat sheet	
5mm LDPE micro tube	Galvanized Iron sheet	
	Perspex	
	Ceramic tile	
	Glass	
	Laminate cover w wall paper	

The intention here was to determine if silicon or LDPE tube can be used to replace copper tube in the radiant panel before proceeding to test a variety of diffusion layer material. Figure 2 shows the schematic drawing of a double loop system that consists of a 1000 liter insulated chill water tank, daytime radiator panel unit as well as outdoor night cooling unit.

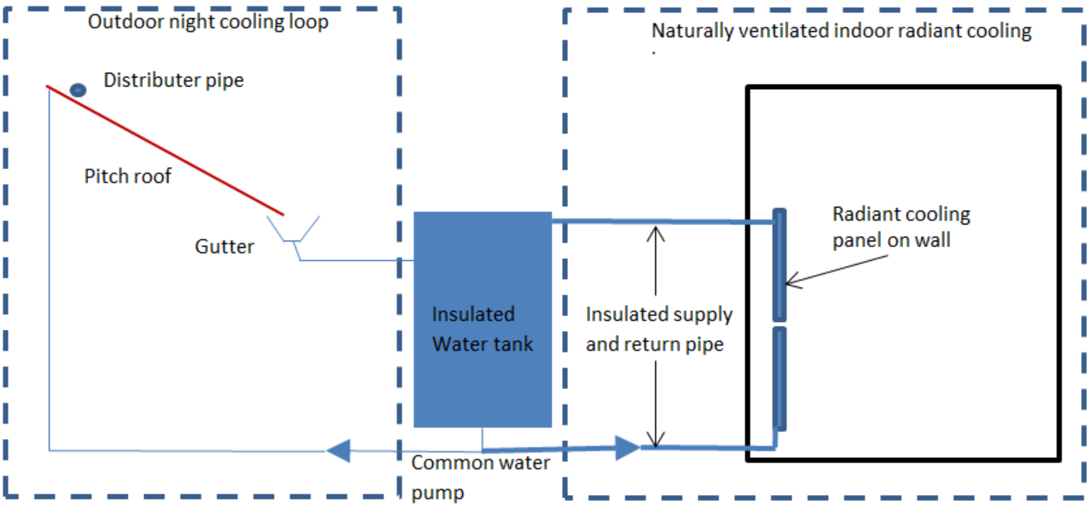


Figure 2: Schematic of night cooling loop and daytime radiant cooling loop

The night cooling unit was used to produce cool water of about 25ºC to 26ºC by night cooling process and the water in turn was used to charge the radiator panel during the day time. Night cooling processes involved the pumping of water to the roof top distributor pipe and free fall over the roof before returning to the water tank. While on the roof, heat was rejected from the water via combined radiation, convective as well as evaporation process to cool down the water.

After the night cooling process, the water in the tank was then pumped to radiant panel during the day at a certain flow rate where the surface temperature of the panel will be measured. Thermocouple was be placed at the center of each panel and connected to a temperature data logger with an uncertainty of ±0.5ºC. The tank temperature and the ambient data were also recorded. From the measured radiant surface temperature, the cooling capacity was calculated and was used as a basis to determine if copper could be replace by other cheaper tube material such as silicon or LDPE tube. It should be mentioned that the average surface temperature taken at the center of the cooling surface area determines the heat flow density. The following equation was used to determine the cooling power of the radiant cooling panel [8].

For ceiling cooling the heat flow density is given by;

$$q = 8.92\,(\theta_s - \theta_i) \tag{1}$$

Where

θ_s = surface temperature in °C

θ_i = indoor operative temperature in °C

For wall cooling the heat flow density is given by;

$$q = 8\,(\theta_s - \theta_i) \tag{2}$$

For floor cooling the heat flow density is given by;

$$q = 7\,(\theta_s - \theta_i) \tag{3}$$

The experiment was repeated again to test multiple panels with a variety of diffusion layer material. The assumption is that the alternative tube material and non-metal as diffusion layer can replace the more common copper or PEX tube and metal sheet as the diffusion layer that would greatly reduce the cost of building radiant cooling panel.

To assist in the design of radiant cooling system, design chart which relates the mean water temperature and the heat flux as well as the mean surface temperature was required. Standards such as EN 1262-2 2008 [9] and ISO 11855-2 2014 provides calculation method to determine the heating and cooling capacity of a radiant system with certain thermal boundary condition and specific type of radiant system or construction. The capacity have to be calculated for a selected ambient (standard) indoor room temperature (for heating often 20ºC and for cooling often 26ºC) at the maximum or minimum surface temperature. Other condition includes heat transfer between cooled surface and space occurs in accordance with the basic characteristic curve as stated in the standard, temperature drop between supply and return of cooling medium $\sigma = 0$, turbulent flow in pipe, no lateral heat flow and panel is thermally decoupled by thermal insulation from struture of building. Parameters such as pipe spacing, thickness, heat conductivity, diameter, heat diffusion device characteristic as well as contact between the pipes and heat diffusion device or the screed characteristic need to be met before using the calculation method. Radiant system that do not meet these conditions should be tested according to standard such as EN14240 [10] or EN 1262-2 2008 [9]. The test also specifies that the radiant panel to be tested under steady state condition while meeting all the thermal boundary condition.

The proposed panel makes up and the experiment rig as shown in Figure 1 and 2 was not sufficient to allow for the determination of the panel cooling capacity under the thermal boundary condition and parameter specified. ISO 11855-2 2014 allows for the use of finite element analysis method (FEM) to determine the cooling capacity of the panel that does not correspond to any defined system type given. Therefore FEM analysis software FEMM 4.2 was used to determine the cooling capacity of the proposed panel. Method for the verification of any FEM software or calculation program and the acceptable tolerance value is given in Annex D [8]. With this FEM method, the design chart was able to be established specifically for the custom build radiant panel.

3.2 Validation of FEMM

Validation of result produced by FEMM software package was done by comparing the result to the a test example provided in ISO 11855-2 annex D. FEMM computed results of the steady state heat flow problem with the boundary condition as well as material properties defined by annex D will be compared to results given in annex D as shown in Figure 3 and Table 2.

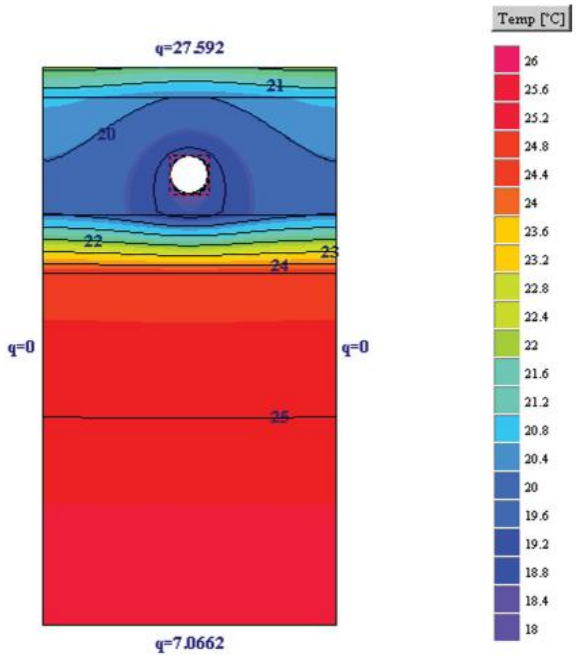
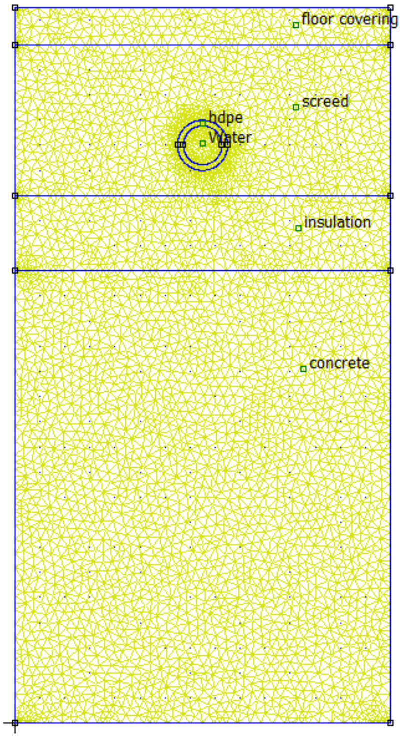


Figure 3: Results of temperature distribution form annex D ISO 11855

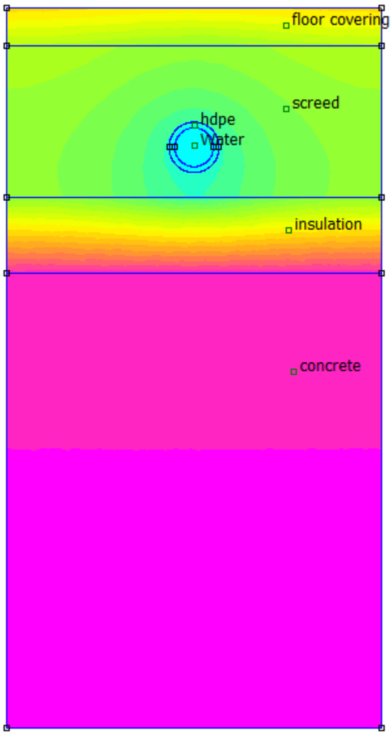
Table 2 Results of the calculated temperature distribution

y [m]	*T* (x = 0 m) [°C]	*T* (x = 0,0375 m) [°C]	*T* (x = 0,075 m) [°C]
0,285	22,201	22,064	21,893
0,246	20,086	19,788	19,11
0,205	20,728	20,414	19,765
0,164	24,809	24,806	24,802
0,123	24,944	24,943	24,943
0,082	25,082	25,081	25,081
0,041	25,219	25,219	25,219
0	25,357	25,357	25,357

The accepted verification is within 0.3K for surface temperature and the calculated heat flow within 3% of the value shown in the table. Figure 3 shows the mesh generated by FEMM software before the analysis was done. The problem boundary condition was defined according to annex D and Figure 4 shows an output in the form of surface temperature and heat flux density plot.



(a) Mesh generated by FEMM for steady state heat flow problem defined by Annex D ISO 11855



(b) Density plot of surface temperature and heat flux calculated by FEMM

Figure 4: FEMM mesh and result output

Comparison of four points with given coordinates between the result generated by FEMM and annex D is summarized in Table 3. The error calculated was within 0.3K as specified by annex D therefore the FEMM software package is sufficient for use for this project.

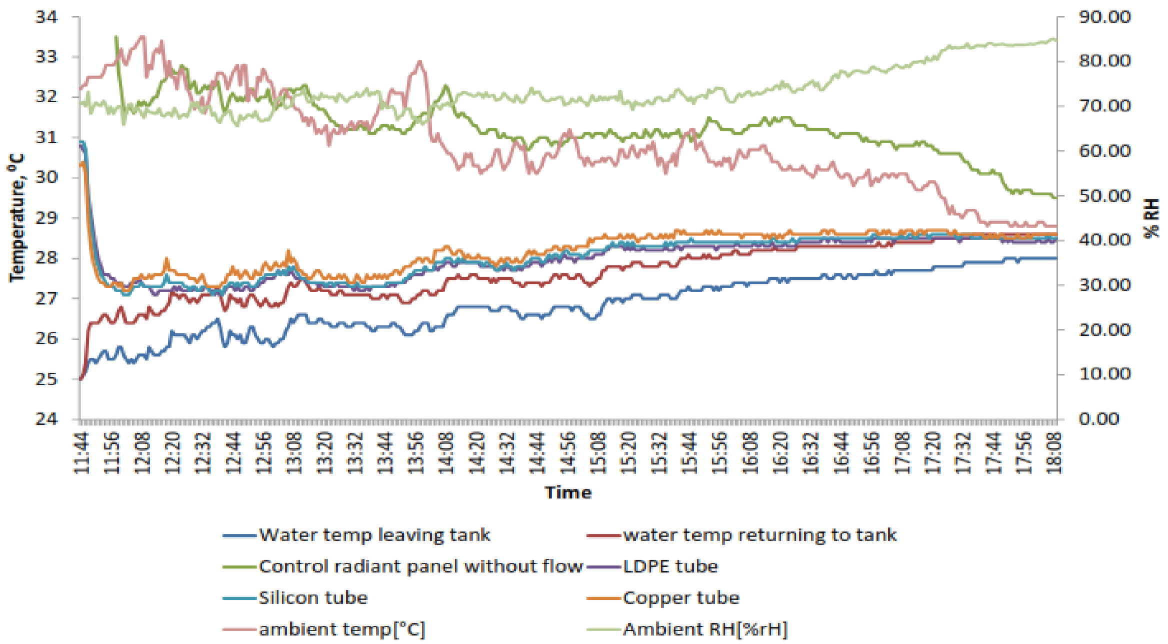
Table 3: Verification for calculated surface temperature (in Kelvin) distribution by FEMM

	X=0.075		
	Annex D	FEMM	error (a-b)
Y	a, K	b, K	
0.246	292.26	292.278	-0.018
0.205	292.915	292.953	-0.038
0.123	298.093	298.098	-0.005
0.04	298.369	298.377	-0.008

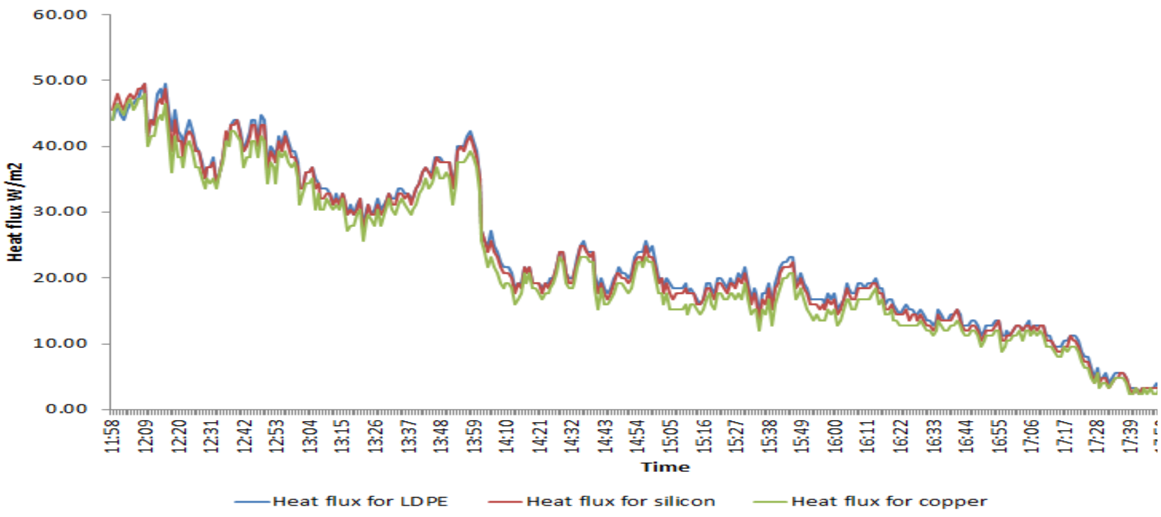
4.0 Results and Discussions

4.1 Radiant Cooling Panel Performance With Alternative Material

The radiant panel experiment was carried out on 18th November 2015 where the water supply for the radiant panel was cooled by the night cooling process. The post night cooling water temperature was about 25ºC. The water was then pumped at a rate of 1200 l/hr to the radiant panel loop which consists of 4 panels when the ambient temperature exceeded 30 ºC. Only 1 panel was isolated from the chill water supply and serve as a control. The control panel was made up from copper tube as the cooling medium conduit. Figure 5 shows the every minute surface temperature measurement for each of the panels with silicon, LDPE and copper tube between 11am to 6pm as well as the calculated heat flux using the wall cooling heat flow density equation (Eq. 1). During this time the water temperatures in tank have increase from 25ºC to 28 ºC and generally the surface temperature of the three panels are about 1 ºC higher than the average water temperature flowing through the panels. It can be seen from Figure 5 that all three panel charged with chill water have almost the same surface temperature with only about 1% or 0.2ºC temperature discrepancies on average. The almost identical surface temperature resulted in an almost identical heat flux exchange at the surface of all three panels. The panel with LDPE and silicon tube seems to register slightly lower surface temperature than the copper tube. This was most probably due to the location of the thermocouple probing point where close proximity of the probing point to the cooling medium conduit registered a cooler surface temperature. The surface temperature discrepancies across the panel surface were also small due to the fact that the tube spacing in the panel was only about 0.025m (1 inch) apart. The measured temperature difference across the copper panel was not more than 0.2ºC.



(a) Surface temperature of multiple test panels



(b) Calculated heat flux exchange for multiple test panels

Figure 5: Surface temperature and calculated heat flux for multiple test panels with different tube material.

This surface temperature discrepancy between different tube materials is not significant considering the fact that such small temperature does not affect the thermal comfort condition expressed as PMV index as shown in a sample calculation in Table 4. The surface temperature is expressed as Mean Radiant Temperature.

Table 4: Sample PMV calculation for 2 sets of measurement reading for three panels test

Sample	Air Temperature	Mean Radiant Temperature	Relative Air Velocity	Relative Humidity	Clothing	Metabolic Rate	PMV
	[℃]	[℃]	[m/s]	[%]	[clo]	[met]	
Set 1	27	27.3	0.5	80	0.5	1.1	0.24
	27	27.1	0.5	80	0.5	1.1	0.22
	27	27.2	0.5	80	0.5	1.1	0.23
Set 2	28	28.3	0.5	80	0.5	1.1	0.68
	28	28.4	0.5	80	0.5	1.1	0.70
	28	28.6	0.5	80	0.5	1.1	0.72

Remark: Accepted thermal state as per ISO 7730 [category A (-0.2<PMV<0.2), category B (-0.5<PMV<0.5), category C (-0.7<PMV<0.7)]

PMV is an index that predicts the mean of the votes of a large group of people on the 7 point thermal sensation scale [11]. PMV six main parameters are the air temperature, mean radiant temperature, relative air velocity, relative humidity, clothing and metabolic rate. It is shown here that the PMV is not sensitive to the silicon or LDPE in place of cooper tube.

From this experiment it can be established that a typical radiant cooling panel with copper tube as cooling medium conduit can be replaced with either silicon or LDPE tube for cooling purpose only. In temperate climate, the radiant cooling panel normally will double as a heating panel during the heating season thus requires copper tube or equivalent material such as PEX tube to carry both hot and chill water according to different season of the year. Malaysian climate is consistently hot all year therefore radiant heating for space heating is not required and that the radiant panel can be designed to provide radiative cooling only.

As mentioned previously, multiple panels were tested for different diffuse layer material type to determine its performance to a more typical copper tube and metal diffuse layer type. Figure 6 present the result of multiple radiant panels with variety of diffusion layer material which was conducted on 22nd November 2015.

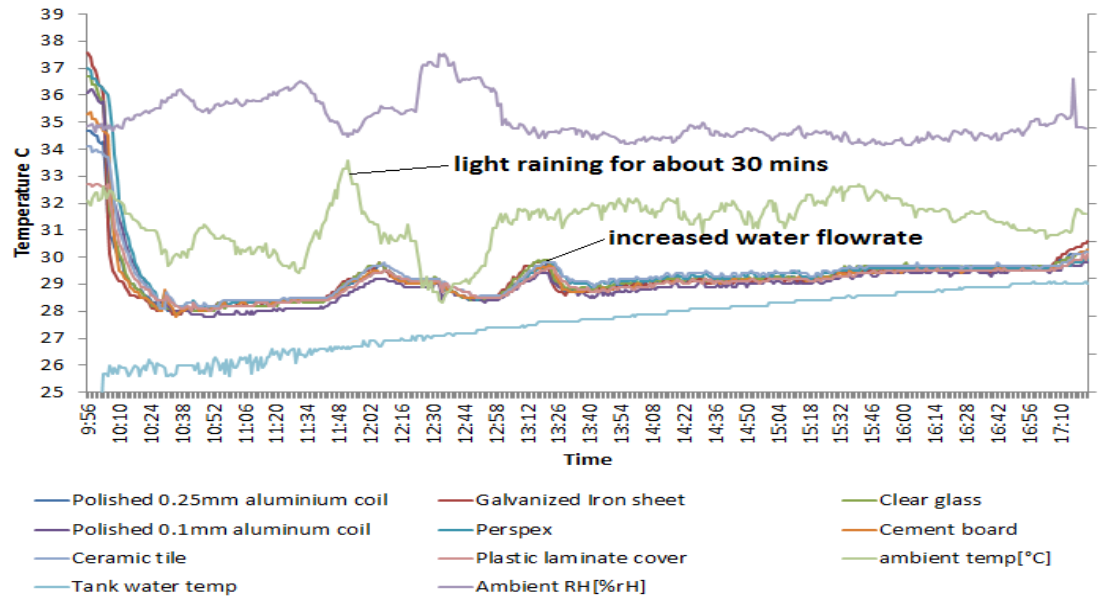


Figure 6: Surface temperature comparisons of multiple test panels with different diffusion layer material

The final water temperature in the water tank after the night cooling was recorded as 24.6ºC. The water was pumped to the radiant loop after the ambient temperature exceeded 30 ºC at a lower rate of 650 l/hr. The initial temperature of all the radiant panels was incidentally high due to direct solar radiation on the panel surface early in the morning before it drops to around 28 ºC after the pump was turned on. In the first two hours the surface temperature increased steadily before it peaks at around 12.30pm and started to drop. This is due to windy condition and eventually light rain at that point of time which last about 30 minutes. Later afterwards the flowrate was increased to 1200 l/hr around 1.30pm in the afternoon. Prior to increase of flowrate, the surface temperature of the panels experienced steep increase due to the climbing ambient dry bulb temperature following a light rain event. The flowrate was then increased to maximum to counter this effect. The increase of flowrate has resulted in a significant surface temperature drop before the surface temperature gradually increased to 29ºC at a slower rate. It can be seen from Figure 6 that polished 0.1mm aluminum coil panel records the lowest surface temperature although it does not differ much to rest of the panel surface material as shown in Table 5.

Table 5: Mean surface temperature discrepancies of various diffusion layer material in reference to polished 0.1mm aluminum panel

Diffusion layer material type	Polished 0.25mm aluminium coil	Galvanized Iron sheet 0.25mm	Clear glass 6mm	Perspex 10mm	Cement board 6mm	Ceramic tile 6mm	Plastic laminate cover 0.1mm
% difference to polished 0.1mm aluminum coil (average value)	0.33%	0.37%	0.62%	0.95%	0.32%	0.97%	0.22%
in °C	0.1	0.1	0.2	0.3	0.1	0.3	0.1

Surface temperature of polished 0.1mm aluminum records the lowest as the section has the least heat conduction resistance. Surface temperature of other material varies closely with maximum value of 0.3 ºC difference depending on the heat conduction resistance value of the material in question. 6mm thick cement board used as diffusion layer could perform as good as a metal panel such as aluminum. This suggest that silicon tube as the cooling medium conduit attached to 6mm cement board can function as a radiant cooling ceiling and perform as well as a copper tube and metal aluminum as its diffuse layer. Such alternative to the typical copper and metal radiant section is significant in term of reducing the first cost of installing the radiant cooling system to cool building. Plastic laminate being a protective layer rather than diffuse layer was tested as well to find out the performance of radiant cooling panel without any stiff or supportive diffuse layer gave some resistance to heat transfer but not better than the polished 0.1mm aluminum panel. However bare screed with protective layer such as plastic laminate is not practical even though cheaper in construction as the stiff outer layer not only act as a diffuse layer but also as a support for thin screed layer of the radiant panel.

4.2 Determination Of Cooling Power For Design Purpose

FEM analysis was used to determine the cooling capacity of the proposed radiant panel under different controlled boundary condition and for both ceiling and wall orientation. FEM analysis was done for silicon tube as the cooling medium conduit and three different type of diffuse layer material which are the polished aluminum sheet, cement board and ceramic tile. Figure 7 shows a sample output from FEMM 4.2 program that was carried out for all types of material mentioned. To enable the analysis to be done, a steady state boundary condition was set that was practical to site condition. For ceiling oriented radiant surface, the top side boundary condition of the section was set to 34ºC whereas the bottom side was set to room operative temperature of 29 ºC. For wall oriented radiant surface, the back side boundary condition was set to 33ºC whereas the front side was set to room operative temperature of 29 ºC. Operative room temperature of 29ºC was selected due to two reasons. The first was that the night cooling process had a limitation to provide cooler water temperature as the night cooling loop depended on the night sky and ambient temperature to cool down the water. The final water temperature eventually was not less than the night air dry bulb temperature. After considering the heat gain and efficiency of the night loop system as well as the water storage tank, water temperature in the order of between 25 ºC and 27 ºC could be supplied in climatic condition such as in Kuching Malaysia. Another compounding factor was the dew point temperature in this region is very high due to the high air humidity normally in the range between 19 ºC and 29 ºC. Cold surfaces with this temperature range would lead to condensation and that moisture tends to accumulate on the surface or being absorbed by non-water tight material before water droplets is visible [12]. Too low radiant surface temperature could lead to a fungal problem. The second reason was that temperature up to 30 ºC can be taken as a comfortable room temperature as showed by other researchers such as Djamila et al. [13], Hussein et al. [14], Nguyen et al. [15], Candido et al. [16], as well as thermal environment conditions for human occupancy standard such as ANSI/ASHRAE [17]. Other local researcher such as Rahman [18], Abdul Shukor A.M. & Young [19], I. Hussein & Abdul Rahman [20], Sapian et al. [21] as well as Luther et al. [22] have also put temperature of about 30ºC in their thermally acceptable comfort range according to their respective field study findings. Therefore the custom build radiant panel is designed to operate under this condition.

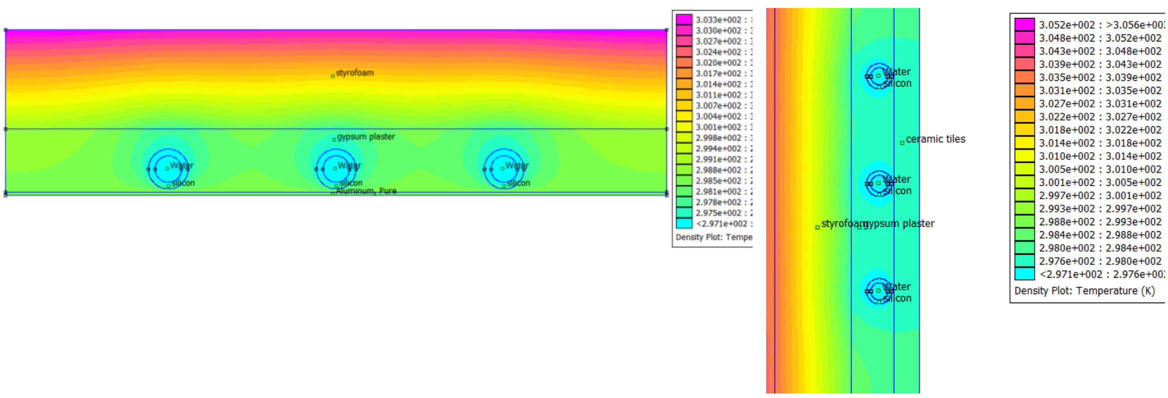


Figure 7: FEMM 4.2 output for ceiling and wall surface radiant cooling panel

Figure 8 presents the summary of calculated cooling capacity of the radiant panel under both horizontal and vertical orientations depending on the location of the radiant panel weather it is on ceiling or wall surface. The cooling rate (in W/m^2) was plotted against the temperature difference between the mean surface temperature θs and indoor temperature θi . The slope of the line represents the panel surface to space heat transfer coefficient which included both convention and radiation heat transfer process and varies according to panel location or orientation between 8 to 9 W/m^2 K [1]. Typically the radiation heat transfer coefficient component is consistent at 5.5 W/m^2 K, for surface temperature between 15ºC to 35ºC whereas the convective heat exchange coefficient varies according to space and surface temperature difference as well as air velocity [23].

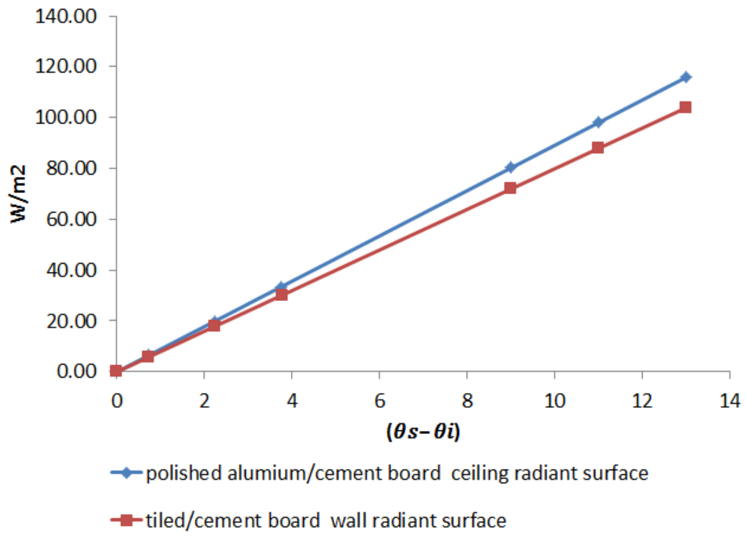
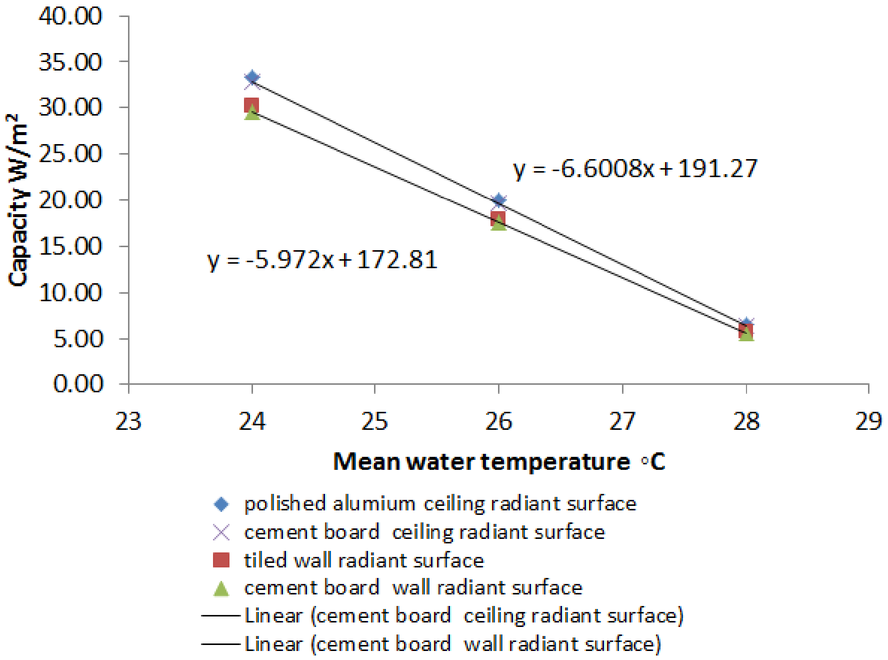
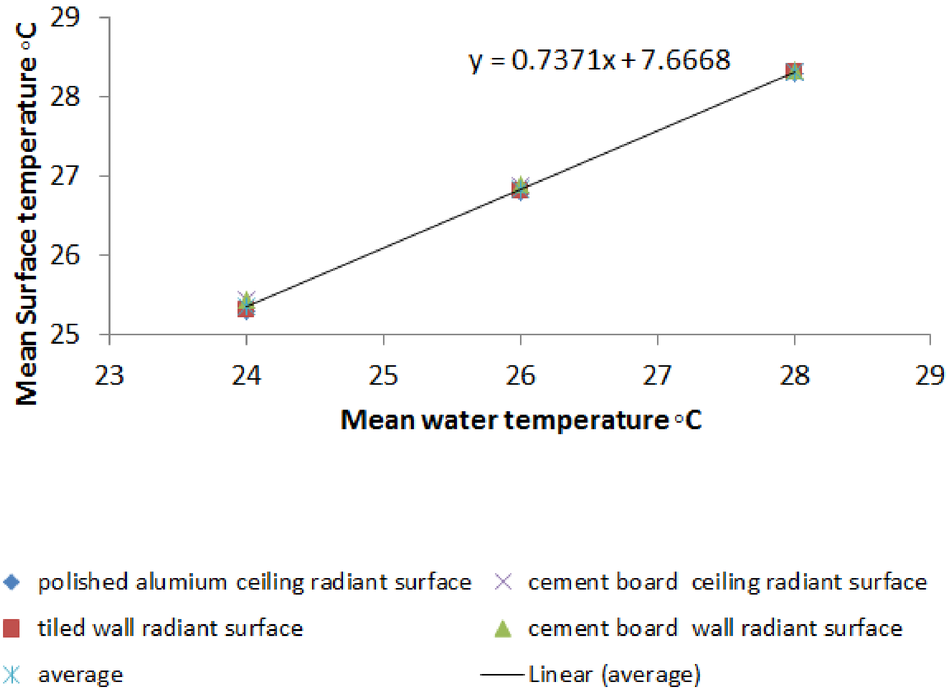


Figure 8: Calculated cooling capacity of ceiling and wall oriented radiant cooling panel

It should be mentioned here that the heat flux capacity produced by FEMM above was determined given the indoor temperature of 29ºC with water temperature ranging from 24ºC to 28ºC. From Figure 9 (a) the cooling capacity of polished aluminum ceiling and cement board ceiling was almost identical and represented by a common linear line as shown in the figure. The same is also true for tiled wall and cement board radiant surface which is represented by another linear line. Furthermore the mean surface temperature for all four diffusion material discussed here was also almost identical with only about 0.3ºC discrepancies from average of the four values as shown in Table 6. Figure 9 (b) shows the linear relationship which relates the mean water temperature and surface temperature for all four material.



(a) Mean water temperature vs cooling capacity



(b) Mean water temperature vs mean surface temperature

Figure 9: Average water temperature charts for 0.025m (1") spacing silicon tube

The linear line could also represent a range of diffuse layer material as shown in Table 4 which has a minimal discrepancy of not more than 1% or 0.3ºC in comparison to a polished aluminum as a reference material. As mentioned before this amount of discrepancy is not significant to PMV calculation as shown earlier. Therefore the establish design chart shown in Figure 9 could be used to calculate the area required to provide radiant cooling for a certain room size.

The following demonstrates in brief the proper design steps for a radiant panel by using the design chart established above for selected material type. To calculate the ceiling radiant cooling capacity for a house area of 100 m^2 an example is given as follows. Given room condition of 29ºC and relative humidity of 75%, the local dew point is 24ºC therefore the supply temperature should not be lower than this temperature to avoid condensation. Taking 2 ºC as Delta T the mean water temperature is 25 Cº. From the design chart in Figure 9 the cooling capacity would be about 26 W/m^2 with a surface temperature of 26ºC. Therefore with active surface of 100 m^2 the total sensible capacity from the ceiling radiant surface would be 2.6 kW.

Table 6 Mean surface temperature in ºC and cooling capacity in W/m^2 for 4 selected diffuse layer materials for design indoor temperature of 29ºC

Water temp, ºC	Polished alumium ceiling radiant surface	Cement board ceiling radiant surface	Tiled wall radiant surface	Cement board wall radiant surface	Average	Polished aluminium ceiling radiant surface	Cement board ceiling radiant surface	Average	Tiled wall radiant surface	Cement board wall radiant surface	Average
	Mean surface temperature ,ºC					Cooling capacity, W/m^2					
24	25.3	25.4	25.3	25.4	25.4	33.4	32.8	33.1	30.2	29.5	29.8
26	26.8	26.9	26.8	26.9	26.8	20.0	19.7	19.8	17.9	17.5	17.7
28	28.3	28.3	28.3	28.3	28.3	6.5	6.4	6.5	5.7	5.6	5.6
	Discrepancy from average					Discrepancy from average					
24	0.3%	-0.3%	0.2%	-0.3%	0.3%	0.8%	-0.8%	0.80 %	-1.2%	-1.2%	1.20 %
26	0.2%	-0.1%	0.1%	-0.2%	0.2%	0.7%	-0.7%	0.70 %	-1.1%	-1.1%	1.10 %
28	0.1%	0.0%	0.0%	-0.1%	0.1%	0.7%	-0.7%	0.70 %	-0.6%	-0.6%	0.60 %

From the design chart it is clear that this capacity could be increased if the mean water temperature is reduced however the supply water piping should be insulated to prevent condensation. Extending cool surface radiation to wall or providing a supplementary air system is required should the sensible capacity of 2.6 kW from the ceiling radiant system is not sufficient for the total cooling load of the house. However a downsized air system is still required to handle the latent cooling load of the house and whatever excessive sensible cooling load that the radiant system cannot handle. Wall radiant cooling capacity should provide additional sensible cooling capacity if it was included in the design.

4.3 Cost analysis

For a hot and humid country all year like Malaysia, only radiant cooling system is applicable to provide the required indoor cooling by lowering the mean radiant temperature to an acceptable thermal comfort standard in this case no more than 30ºC indoor temperature coupled with correct indoor air movement speed. Use of radiant panel with chill water sourced from a night cooling process which is renewable and free makes the application more viable as the surface temperature of ceiling and wall could be lowered to slightly higher than the mean water temperature supplying the radiant system. Normal operation requires water temperature of lower than 20 ºC to maintain an indoor air temperature of 24ºC or less which is the generally accepted water and room temperature in temperate climate application [1]. This kind of operation condition would eventually lead to condensation problem in hot and humid country like Malaysia. However by using a higher water temperature and setting a higher operative room temperature of up to 30ºC, the energy saving advantages of using radiant cooling system in Malaysia can still be appreciated to a certain extent. It is also noted that the cost of acquiring such system is still high owing to the unavailability of local manufacturers, suppliers, installers and even designers or engineers to design and build such system in local set up. Table 7 presents the actual cost of making a 0.3m x 0.6m size radiant panel as was used in the experiment for all types of diffuse layer material with silicon as the common tubing material. Cement board panel shows a lower overall panel construction cost compares to other surface material and could be used for both ceiling and wall orientation radiant panel surface as shown in the cooling capacity output analysis. The typical copper tube and metal diffuse layer for the same size would cost about RM 35 whereas cement board with silicon tube would only cost about 34% of the copper and metal panel. The importing of patented radiant cooling panel or components normally consisting copper tube or PEX pipe from overseas would incur such a heavy cost especially with the depreciating RM currency. However with the local made product having similar performance and suits local condition the technology could grow and be applied with confidence.

Table 7: Actual cost breakdown for 0.3m x 0.6m size radiant panel constructed entirely with local material

Common internal component	Material price for every 0.3 m x 0.6 m diffuse layer surface area in RM						
	6mm cement board	0.25mm polished aluminum	0.25mm galvanized Iron sheet	6mm Glass	0.1mm polished aluminum	10mm perspex	6mm mm ceramic tile
Diffuse layer type	1.43	5.33	9.30	6.00	3.33	39.00	6.00
Alum angle frame	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Screed	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Silicon tube 5mm	4.80	4.80	4.80	4.80	4.80	4.80	4.80
Styrofoam insulation	1.60	1.60	1.60	1.60	1.60	1.60	1.60
Total (RM)	**11.97**	**15.87**	**19.84**	**16.54**	**13.87**	**49.54**	**16.54**
% from cheapest	**100%**	**133%**	**166%**	**138%**	**116%**	**414%**	**138%**
cooling medium conduit type	RM/m						
Silicon tube 5mm	4.80						
Copper tube 5mm	24.00						
LDPE tube 5mm	7.20						

The application of this radiant panel with night cooled water source provides more savings in comparison to the conventional air cooling system as shown in Table 8. The energy savings in this example was simulated for a low cost single storey house using Energy Plus software with Malaysian climate condition. Radiant cooling with free night cooled water supply shows a promising annual energy saving of up to 85% in comparison to conventional air conditioning. This is in agreement with ASHRAE [24] which states that cooling panel have the highest energy saving potential in term of simple payback period with the advantages of controlling both air and mean radiant temperature that made total human thermal comfort easier to satisfy.

Table 8: 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 operational cost (RM)	Monthly operation cost (RM)	% of conventional air conditioning operating cost	Remark
Conventional air conditioning	55.79	15498	4804	400	100	24 hrs air conditioning
Radiant cooling with mechanically cooled water supply	32.00	8889	2756	230	57%	24hrs operation
Radiant cooling with free night cooled water	8.24	2289	710	59	15%	

5.0 Conclusions

From the experimental work, it can be showed that cheaper and workable radiant cooling panel can be constructed with local materials that serves as an alternative to imported and expensive radiant cooling panels. The cooling performance in term of mean surface temperature and its cooling capacity is almost identical as shown in Table 5 and Table 6 for a range of locally available material such as cement board, glass, ceramic tiles, galvanized iron sheet as well as polished aluminum sheet. A common design chart for all the diffuse material type tested with silicon tube was developed to assist in the design and sizing of the radiant panel. Use of cooling radiant panel with free night cooling of water as its water supply shows a significant energy saving potential while at the same time provide an acceptable room thermal comfort.

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