Comfort assessment of radiant cooling in building in tropical climate

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Abstract:
Radiant cooling is an alternative air-conditioning approach that has been successfully implemented in high latitude regions. In the tropics, radiant cooling is quite challenge due to its cooling performance being limited by high-moisture ambient air. This paper reports an investigation of radiant cooling in a tropical building. The study comprises physical experiments of a radiant cooling system with cooling panels installed in a room of a laboratory building. A dedicated outdoor air system using a fan coil unit was also installed to handle humidity of the room air through ventilation. A TRNSYS software was used to model the systems in order to determine the thermal comfort level in the room using predicted mean vote (PMV) index. The results show that the radiant cooling is able to use for air conditioning for human comfort in tropical buildings.

Keywords: *Thermal comfort; Radiant cooling; Predicted mean vote*

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1. Introduction

Thailand is situated in the tropics and is subject to hot and humid climate. Air-conditioning by cooling has reached saturation in commercial buildings but it is rapidly growing in urban and suburban residential houses. This causes for a concern because the air-conditioning is highly energy-intensive. Radiant cooling system is an alternative air-conditioning that uses cool panels to receive sensible heat from the space by radiative heat exchange mechanism. The cool panels also receive partly sensible heat due to natural circulation of the air in the space. Radiant cooling requires a separate air dehumidification system to handle latent loads from the space and the air ventilation. Radiant cooling systems have been used widely and successfully in North America and Europe where the ambient air is relatively dry (ASHRAE, NA;Vangtook and Chirarattananon, 2006;Fountain and Huizenga, 1995a; Fountain and Huizenga, 1995b). It offers quiet comfort and a level of energy efficiency superior to those of conventional air-conditioning system. However, radiant cooling to achieve thermal comfort is very challenge in hot and humid climate; the attempt to avoid condensation of moisture from air limits cooling capacity of a radiant cooling panel and incapacitates the system against latent load.

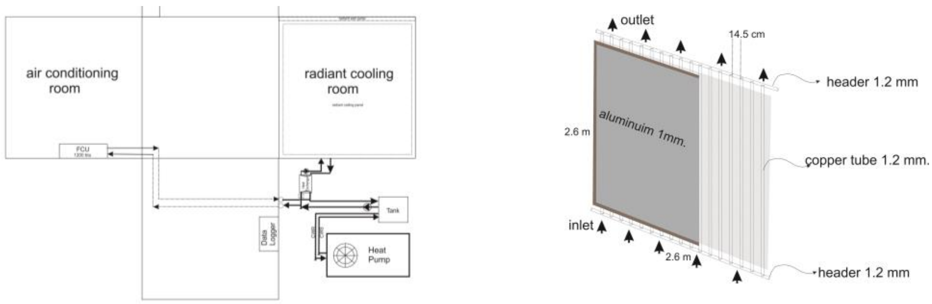
This paper reports a study on application of radiant cooling with dehumidified ventilation air under Thailand's tropical climate. For experimental investigation, a radiant cooling system was constructed at a laboratory room in Bang Khun Tien Campus, King Mongkut's university of Technology Thonburi (KMUTT) (latitude 13.57°N and longitude 100.44°E). Experiments were performed to evaluate the system cooling load and the thermal comfort condition. TRNSYS program was used to simulate the operation of the radiant cooling system. The results were compared with those from the experiments. TRNSYS was also used to simulate the operations of the radiant cooling system using the whole year tropical climate data. The study results demonstrate that the radiant cooling with dehumidified ventilation can enhance the performance of the radiant cooling system and improve thermal comfort level in the space.

2. Experiment

Fig. 1(a) shows the plan view of the experimental building used in this study. The building walls were insulated by three-inch polyurethane foam to reduce external heat gain. The same insulation was also used for interior walls but with one-inch thickness. Three-inch fiberglass matt was laid over the ceiling to reduce heat gain from roof. The right-side room was a radiant cooling room (RC room) equipped with two radiant panels: the one under the ceiling and the other on the west wall.

Nomenclature: E_e=radiation, T_{amb}=temperature of ambient air, W_{amb}=humidity ratio of ambient air, T_{dp}=dew point temperature, T_{ar}=room air temperature, T_{cp}=temperature of chilled panel (ceiling), T_{we}=temperature of chilled panel (east wall), T_{mean}=mean radiant temperature, PMV=predicted mean vote.

The interior dimension of the RC room was 2.4 m width by 2.8 m length. The height from floor to ceiling was 2.4 m. A 6 mm green glaze window with external shading was placed on the north wall. A heat-pump was used to produce chilled water supplied to the RC panels.



(a) Plan view of the experimental building (b) Radiant cooling (RC) panel

Fig.1 Experimental building and radiant cooling panel.

Fig. 1(b) shows the installed radiant cooling (RC) panels. The panels were made of aluminium plate affixed with a series of parallel straight copper tubes whose ends were connected with two headers. One header distributes evenly chilled water over the panels and the other one collects the chilled water from the panels. The panels were light-weight and fast thermal responsive. Insulation was placed to cover the tubes and beside of the panel in order to allow a privileged font surface heat transfer, to reduce heat loss, and to improve the acoustics of the room. Each RC panel had a gross heat transfer surface of 5.8 m^2.

2.1 Internal load

A wooden box was made to imitate a person living in the room. Inside the box, six 36W fluorescent lamps with 6W ballast were placed to generate internal heat load. It was assumed that all electrical energy supplied to lamps become heat. So the total internal heat load in the radiant room was 252 W. From measurement, surface temperature of the box was at 33°C when all lamps were switched on.

2.2 Simulation Tool and Comfort Assessment

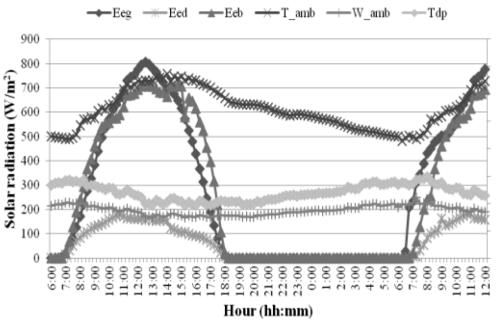
TRNSYS program was employed to simulate operation of the cooling panels in the RC room. Module 56 of TRNSYS was extensively used for simulation. Input weather file was processed by a radiation processor module to produce incident solar radiation on the exterior wall surfaces of the rooms. Module 56 also calculated heat gain through walls and through window via energy balance, using given input weather data and solar radiation. The operative temperature, that is the weighted temperature of the mean radiant temperature of the surfaces in a zone and dry-bulb temperature of air, is also calculated. Ranges of PMV for thermal comfort conditions are as follow:

Comfortable	-0.5 to 0.5
Warm	0.5 to 1.0
Cool	-1.0 to -0.5
Unacceptably warm	Over 1.0
Unacceptably cool	Under -1.0

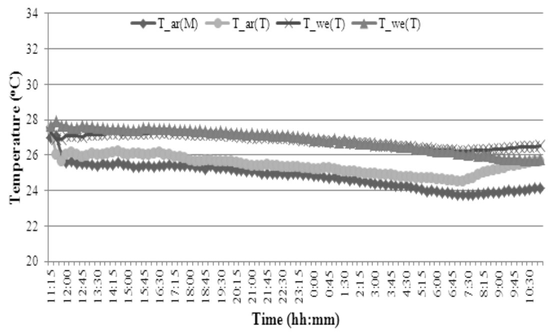
This standard adopts Fanger's recommended equations to calculate PMV based on four given physical variables of dry-bulb temperature, relative humidity, mean radiant temperature and air speed. Two personal variables of clothing insulation value and metabolic rate are also required for PMV evaluation.

3. Experimental Results

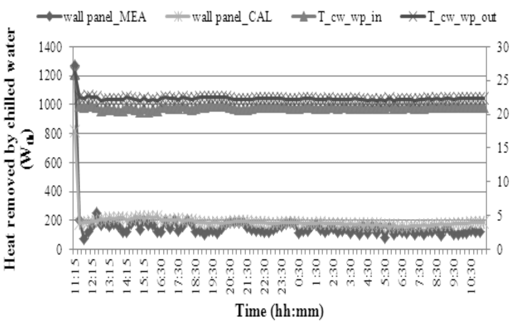
Experiments were conducted for some times, but the results measured during 18-19 January 2013 are chosen to present. The RC system was started running at 11:15 on the first experimental day (18/01/2013) and stopped at 10:30 on the consecutive day (19/01/2013). Fig. 2(a) shows solar radiations and ambient air temperature in the experimental period. The global radiation varied smoothly over the days and peaked at 800 W/m^2 noon time. The diffuse radiation was measured lower than 200 W/m^2. Temperature of the ambient air varied between 22°C and 34°C. As the experiment was conducted in dry season, the outdoor air had low moisture gain; absolute humidity was about 8-10 g/kg$_{da}$ and the dew point temperature was below 15°C. The condensation was not critical issue for the experiment even though chilled water was supplied to the panels at 19°C.



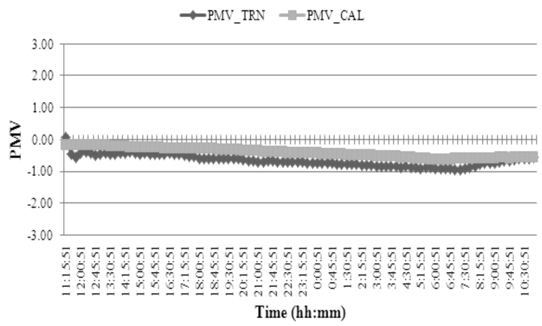
(a) Solar radiation



(b) Temperatures



(c) Radiant panel



(d) PMV

Fig. 2 Experiment during 18-19 January 2013.

Fig. 2(b) exhibits interior surface temperatures of the east wall (T_we(M)) and temperature of the room air (T_ar(M)) measured during the experiment. It can be observed that although a heat load from the box (252 W) was added into the radiant space, the temperature of the east wall decrease gradually from 28°C when the radiant cooling system operated. The temperature of the east wall reduced to 26°C at 6:45 of the next day before rising again by incident solar radiation on exterior surface of the wall. In the Fig., the room air temperature varied in the same manner but its value was approximately lower than the east wall surface temperature by 2°C. By input data of solar radiation and ambient air, and the configuration of the radiant system and the experimental building, TRNSYS simulated the temperatures of the east wall and the room air as a function of time. It can be observed a good agreement between the measurements and the simulation. In Fig. 2(c), temperatures of chilled water supply and return from the cool wall panel are presented. The rate of heat extraction by the panel is also presented and compared with that calculated from TRNSYS. From the Fig., the rate of heat extraction is approximately 200W. Not to be shown, the rate of heat extraction by the ceiling radiant panel was quite comparable to that of the wall panel. The total heat extracted by the radiant system was approximately 400 W. This implies that the panels received heat from the hot box and other loads from walls and room air. Fig. 2(d) exhibits the PMV from measurements and from TRNSYS calculation. The measured PMV values were derived from the measured data of surface wall temperatures and room air temperature. The calculated PMV values were derived from the corresponding temperatures obtained from TRNSYS simulation. From the Fig., the PMV values are slightly negative at -0.5 representing the neutral comfort condition.

4. Simulation Study

TRNSYS was used to simulate the radiant system with three schemes. In the first scheme (Scheme I), the chilled water was supplied to the cool panel at 25°C and the ventilation air was not pre-cooled and dehumidified. Temperature of the chilled water was set high in order to avoid condensation on the RC panels. Air infiltration was set at 0.5 ACH. An oscillating fan was assumed to increase the room air velocity to 0.3 m/s in order to improve comfort condition. Table 1 shows the values of common parameters for TRNSYS simulation.

Table 1 Values of common parameters in yearly simulation by TRNSYS

Item	Value
• Internal load	
- Human (Seated, very light writing ,W)	120
Sensible load (W)	65
Latent load (W)	55
- Light (1 lamp, W)	40
Radiative part	60%
Convective part	40%
Humidity	0
- Ventilation air (kg/h)	30
- Air change of infiltration (1/h)	0.5
• Flow rate of supply chilled water (kg/h)	120
• Area of radiant panel (m^2)	
- wall (west)	5.76
- ceiling	5.76
• Temperature of supply water (°C)	18 or 25
• Daytime occupancy (Sedentary activity)	
- Duration time (hr)	00:00-24:00
- Metabolic rate of occupant (met)	1.1
- Clothing insulation (clo)	0.5

Table 2 summarizes the results from the yearly simulation. From the table, when the radiant system operates under Scheme I; the thermal comfort cannot be achieved for most time in a year. People in the room would feel warm and too warm up to 88.7% of the time. The neutral comfort would be met by 11.0% and mainly in dry and cool period. Although the chilled water temperature was set to 25°C, moisture condensation on the cool panel surface still occur for 0.7% of the time.

For Scheme II, the chilled water temperature was set lower to 18°C and the ventilation air was cooled and dehumidified before supplying into the room. Room air velocity was assumed to be zero in this scheme. It can be observed that the comfort condition is improved under this scheme. Lower chilled water temperature enhances the panels to extract more heat from the room. However, the use of fan coil unit to reduce moisture in ventilation air cause the room air temperature too low and hence the people would feel cool and too cool. It should be noted that the fan coil unit also share the sensible load from the radiant cooling system. However, this scheme demonstrates the significance of the ventilation air dehumidification system.

Table 2 TRNSYS Simulations for thermal comfort and condensation evaluation

Description	**Percentage of occurrence (%)**		
	Scheme I	**Scheme II**	**Scheme III**
Too warm (PMV > 1.0)	51.1	0.0	0
Warm (0.5 < PMV < 1.0)	37.6	5.0	11.5
Comfortable (-0.5 < PMV < 0.5)	11.0	83.3	81.2
Cool (-1.0 < PMV < -0.5)	0.4	10.6	6.5
Too cool (PMV < -1.0)	0.0	1.0	0.7
Condensation	0.7	0.0	0.0

For Scheme III, the heat pipe technology was integrated to the cooling coil of the ventilation unit in order to pre-heat the intake outdoor air and to re-heat the cooled air before supplying into the radiant room. The results show that this system configuration reduces the thermal comfort condition of “Cool” and “Tool cool” but the “Warm” condition increase. No condensation occurs at the radiant panel when the ventilation air is dehumidified before it supplies into the room.

5. Conclusion

Radiant cooling was studied for its application in building in tropical climate. The results show that under hot and humid climate of the tropical region, a separate dehumidified ventilation air system is required essentially to integrate with radiant cooling system to achieve thermal comfort and to avoid the condensation.

6. References

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