A Field Study of Experimental of Radiant Cooling for Residential Building in a Tropical Climate

S. Wongkee, S. Chirarattananon, and P. Chaiwiwatworakul
The Joint Graduate School of Energy and Environment, King Mongkut’s University of Technology Thonburi, 126 Pracha-Uthit Road, Bangmod, Tungkru, Bangkok 10140 Thailand.
n_satinee@hotmail.com; surapong@jgsee.kmutt.ac.th; pipat_ch@jgsee.kmutt.ac.th

Abstract—This paper presents an experimental study of radiant cooling for building air-conditioning in a tropical climate. To prevent condensation of moisture on the cooling panel, the temperature of chilled water supplied to the panel was limited. This led to the limitations of heat extraction capacity at the panel and its application to only space with low thermal load and low metabolic rate activity of people in the space. In addition to compare energy saving of radiant cooling system and air conditioning which the result of this paper the radiant cooling system can be used to achieve 70% for energy saving.

Index Terms—radiant cooling, thermal comfort, tropical climate

I. INTRODUCTION

Thailand is located in a tropical region and hot humid climate. In the summer, the weather is higher than other season of the year. In addition, the housing was rapidly expansion in the community. To result the air-conditioning expansion increased approximately 21% in 2012 and has higher energy consumption.

In radiant cooling system, the cool panels receive thermal radiation load and some heat convected to it from ventilation air. This configuration has been suggested to offer quiet comfort and a level of energy efficiency superior to the conventional air-conditioning system, [1], [2]. Several studies on radiant floor and ceiling system for cooling have been conducted about comfort, cooling capacity, and energy savings in US, Japan, China, Korea, and many European countries [3]. In US, Corina [4] reported that a building equipped with radiant cooling system can be operated in any US climate with low risk of condensation, and can save on average 30% of the energy consumption and 27% of the peak demand due to space conditioning by employing radiant cooling system instead of the traditional all-air system. And Mumma [5], [6] discussed the major concerns given in the US about the radiant cooling system, such as condensation concerns, cooling capacity concerns, and initial cost concerns compared to conventional systems.

This paper reports an experimental study on application of radiant cooling panels compared air conditioning for energy consumption under the hot and humid climate of Thailand. Cooling panels were installed on the ceiling and a wall of an experimental room in a laboratory building in Bang Khun Tien campus, King Mongkut’s University of Technology, Thonburi. Radiant panels for cooling must be controlled to prevent the surface condensation; the cooling capacity of the panel would be limited in hot and humid weather conditions.

II. HEAT EXCHANGE CALCULATION AND COMFORT ASSESSMENT

Calculation of Heat Exchange: From the temperature measurements, the following equations were set to determine the amount of heat flux on the cooling panels. The total heat flux \( q_o \) is the summation of the convective \( q_c \) and the radiative \( q_r \) heat flux that can be computed from Eq. (1) and (2):

\[
q_o = q_c + q_r \quad q_c = h_c(T_s - T_a) \\
q_r = \varepsilon F \sigma(T_s^4 - T_{a,ref}^4)
\]

where \( h_c \) is coefficient of heat convection, W/(m².K). \( T_s \) is temperature of wall surfaces (°C). \( T_a \) is temperature of the room air (°C). \( \varepsilon \) is the emissivity function. \( F \) is the geometric view factor and Stefan-Boltzmann constant \( (\sigma=5.67\times10^{-8}W/m^2K^4) \). The natural convective heat transfer coefficient in Eq. (2) is for cool surface facing downward and in Eq. (2) is for vertical surface:

\[
h_c = 1.52(\Delta T)^{1/3} \quad \text{and} \quad h_c = 1.42\left(\frac{\Delta T}{L}\right)^{0.25}
\]

Knowing the temperatures of the cooling water supply and return from the panels and the rate of cooling water flow, the total cooling load from the radiant cooling space can also be determined using Eq. (3):

\[
\dot{Q}(t) = \dot{m}c_p[T_{sw}(t) - T_w(t)]
\]
Assessment of Thermal Comfort: Thermal comfort of subject was assessed using thermal sensation scale PMV, a parameter based on four physical variables of dry-bulb temperature, relative humidity, mean radiant temperature, air velocity and two personal variables of metabolic rate, and thermal insulation of the subject’s clothing. Values of PMV ranges from -3 to +3, namely, +3=hot, +2=warm, +1=slightly warm, 0=neutral, -1=slightly cool, -2=cool, -3=cold. PMV can be calculated using an equation proposed by Fanger. Mean radiant temperature ($T_{rm}$) is one of the variables required for PMV evaluation. It is defined as the uniform temperature of a black enclosure that would lose or receive heat from the surrounding through thermal radiation as would a person [7] and can be calculated from Eq. (4) where $T_j$ is the temperature of room surface j.

$$T_{rm}^4 = \sum_j F_j T_j^4$$  \hspace{1cm} (4)

In determining thermal comfort condition, the values of input parameters set as follows: Activity = sleeping, Metabolic rate (M)=0.8 met or 46.56W/m$^2$, Work rate (W)=5 W/m$^2$, Clothing level ($l_{cl}$)=0.29 clo, $R_{cl}$=0.04 m2-K/W, DuBois surface area ($A_0$)=18 m$^2$, Skin temperature ($T_{sk}$)=33.7°C, Air speed ($V_a$)=0.1 m/s.

III. EXPERIMENTAL ROOM AND MEASUREMENT SETUP

The experiment room will be a single story building that measure 3 m wide, 3 m long, and 2.65 m high. The walls on the northern and the southern facade comprise window glazing and opaque walls combined gypsum board and polystyrene insulation inside interior of walls surface of both. The eastern and western facades comprise 8 cm brick walls combined polyethylene insulation illustrated in Fig. 1.

Radiant cooling panels: Fig. 1(a) shows a picture of the test room with the two panels. A 5.75 m$^2$ radiant panel constructed from copper coil bonded to black-painted aluminum sheet has been installed on the ceiling. Another 5.75 m$^2$ of radiant panel was installed on the western facade.

Cooling water supply and its control: Fig. 2 shows a diagram of the cooling water supply and control system. Cooling water flowing to the cooling panels was supplied and circulated with a constant rate by a pump. Temperature of the cooling water on the secondary side of a heat exchanger was controlled by a solenoid valve operated based on signal from a temperature sensor placed in the cooling water loop. If the temperature of the cooling water is above its a set point (i.e. 25°C), the solenoid valve will turn on so that chilled water at 18°C from a heat pump will be supplied to the primary side of the heat exchanger to cool the cooling water.

Measurement: A number of sensors (PT-100) were installed in the test room to measure temperature of the interior wall surfaces, the cooling panels and the room air. Temperatures of the cooling water supplied to and returned from the cooling panels were also measured. Two rotameters were installed to measure flow rates of the two cooling panels. Heat flux sensors were placed on the cooling panel surfaces and wall surfaces to measure the amount of heat transfer. The data from the sensors...
were transmitted and recorded in a personal computer at every one minute.

IV RESULTS AND DISCUSSIONS

This experiment was chosen to present in hot and humid period of 3-4 April 2013. The experiment conducted for a room with nighttime function (bedroom) and start at 17.00-06.00 in the morning. The activity of human in the room was assumed sleeping. The primary aims were to compare energy consumption of air conditioning room and radiant cooling room and show thermal comfort could be achieved in the both room. The calculation in the above section was performed to produce results for comparison.

Figure 3. Measurements results of temperatures of radiant cooling room.

For experiment of radiant cooling with nighttime application, the chiller was started from 17:00 to produce cooling water suppling to the radiant panels. From the plots in Fig. 3 temperature of the cooling water supply \( T_{cw,in} \) and return \( T_{cw,out} \) remained steadily at 23°C and 24.0°C. Temperatures of the ceiling panel \( T_{cp} \) and of the wall panel \( T_{wp} \) were constant at 25.5°C, 1°C above the returned cooling water temperature. Temperature of the south wall \( T_s \) decreased from 32°C to 31.5°C. This resulted from the presence of the cooling panel in the room although part of heat also loosed to the environment due to low temperature of ambient air. Fig. 3 showed as well that temperature and relative humidity of the room air were about 26°C and 86%, respectively.

Figure 4. Measurements results of temperatures of air conditioning room.

For experiment of air conditioning room with nighttime application, the chiller was started from 17:00 to produce cooling water suppling to the radiant panels. From the plots in Fig. 4 temperature of the cooling water supply \( T_{cw,in} \) and return \( T_{cw,out} \) remained steadily at 19°C and 24.5°C and 5.5°C above the returned cooling water temperature. Temperature of the south wall \( T_s \) decreased from 32°C to 31.5°C. Fig. 3 showed as well that temperature and relative humidity of the room air were about 26°C and 86%, respectively.

Figure 5. Evaluation of thermal comfort conditions of both cases.

Fig. 5 exhibits the calculated values of PMV, and mean radiant temperature over the period of experiment. It can be found that the PMV values varied within ±1 of both case. Fig. 6(a) exhibits the plot of heat absorbed by the wall cooling panel. Square line was the measured values from the heat flux sensors placed on the panel surface. The triangle line was the heat flux calculated using the equations described above. The circle line in the plot was calculated from the measured values of cooling water temperatures and its flow.

Figure 6. Heat extraction by the cooling panel installed on the wall and ceiling.

Figure 7. Heat extraction from radiant cooling room and air conditioning room.
Fig. 7 shows that heat extraction from the radiant cooling room and air-conditioning room. The calculation is the measured values of cooling water temperatures and its flow. Results implied that energy consumption for radiant cooling system and conventional air conditioner are lower 500 W and 1500 W, respectively. Energy savings can be obtained approximately 70% by using radiant cooling instead of air conditioning.

V CONCLUSION

The results in this paper demonstrate that radiant cooling can be used to achieve energy saving 70% by using radiant cooling instead of air conditioning. For this experimental the result of radiant cooling can’t be used to achieve thermal comfort in hot and humid climate. Due to the hot weather in April and need to avoid condensation of air moisture on the panel and cooling capacity per area is limited to 30 W/m2. But this also offers good opportunity for energy conservation as very low energy means can probably be used to reduce temperature of supply water to the required level.

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REFERENCES


Satinee Wongkee was born in Trang, Thailand. I am recived the B.Arch. (1998), M.Arch (2005) degree in Interior Architecture from King Mongkut’s of Technology Ladkrabang I am Ph.D student, Energy Division, Joint Graduate School of Energy and Environment (JGSEE), King Mongkut’s University of Technology Thonburi (KMUTT). Miss. Wongkee is an associate architect, Architect Council of Thailand License G.V. 394

Surapong Chirarattanon was born in Bangkok, Thailand. He received the B.E. (1969), M.E. (1970), and Ph.D. (1973) degrees in Electrical engineering from University of Newcastle. He is a Professor, Energy Division, Joint Graduate School of Energy and Environment (JGSEE), King Mongkut’s University of Technology Thonburi (KMUTT). His Current interests include daylighting and industry energy conservation. Prof. Chirarattanon is a senior member, Institute of Electrical and Electronics Engineers (USA.)

Pipat Chaiwiwatworakul was born in Bangkok, Thailand. He received the B.E. (1994), M.E. (1998), and D.E. (2006) degrees in Mechanical engineering from Asian Institute of Technology. He is a lecturer, Energy Division, Joint Graduate School of Energy and Environment (JGSEE), King Mongkut’s University of Technology Thonburi (KMUTT); and Center for Energy Technology and Environment (CEE). His Current interests include daylighting and building heat transfer. Dr. Chaiwiwatworakul is an associate mechanical engineer, Controlled–Engineer License G.V. 10553