EFFECT OF A RADIANT PANEL COOLING SYSTEM ON INDOOR AIR QUALITY OF A CONDITIONED SPACE

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ABSTRACT

This paper discusses the effect of a radiant cooling panel system on an indoor air quality (IAQ) of a conditioned space. In this study, ceiling radiant cooling panel, mechanical ventilation with fan coil unit (FCU) and 100% fresh air are used. Temperature sensors are located at different locations inside the conditioned space in order to sense dry bulb temperatures, relative humidity to compare it with standard ASHRAE comfort values. The present investigation indicates that the radiant cooling system not only improves the indoor air quality but also reduces the building energy consumption in the conditioned space.

Keywords: Air conditioning, Ceiling radiant cooling panel, Chilled water, Ventilation system with fan coil unit (Fresh air).

INTRODUCTION

Air-conditioning systems are designed to control indoor temperature and humidity, and to provide fresh, filtered air to building occupants. The majority of air-conditioning systems currently in operation are all-air systems, meaning that they employ air not only for the ventilation task, but also as a heat and humidity transfer medium (Corina Stetui, January 1998).

Mechanical heating and cooling of indoor space has been practiced for a long time. The thermal structure at Bath, England and Rome, Italy, represent the first known type of large-surface radiant heating system. Anecdotal information suggests that, around the same time, the Turks were cooling their dwelling by tapping cold river water and circulating through interstices in wall or floors (Corina Stetui, January 1998).

In early 1990s, interest in the ceiling radiant cooling panel (CRCP) began to increase once the condensation issues had been addressed by independent ventilation system designed to meet the entire space latent load and the required ventilation rate. First of all, the energy conservation and indoor air quality (IAQ) benefits of the decoupled (or hybrid) system began to attract attention. In addition, it was also indicated that traditional negative perceptions on the CRCP system need no longer bet valid (Jae-Weon Jeong, Stanley A. Mumma, April 2004).

Significant energy savings by the radiant cooling systems and their relative advantages (cooling panels/chilled beams in combination with a dedicated outdoor air system can reduce cooling and ventilation energy consumption by 25 – 30% relative to a variable air volume system) (Kurt w. Roth, Detleft Westphalent, Jon Dieckmann, Sephir D. Hamilton, William Goetzler, July 2002), (E T. Mohamed, July 2009).

DESCRIPTION OF THE COOLING SYSTEM

In this system the radiant cooling panels are attached to the ceiling of the conditioned space. Radiant cooling ceiling panels contain chilled water running through the pipes that are bonded to the non-visible side of the panels. The panels absorb sensible heat transmitted mainly by thermal radiation and convection from the conditioned space. The chilled water is then pumped to a chiller, recooled and returned to the ceiling again. The ventilation air is dehumidified and cooled by fan coil unit from the same chilled water source (water chiller). The removal of the exhaust air and 100% fresh air are include.

DESIGN DATA FOR THE CONDITIONED SPACE

Design data for the conditioned space is explained in Table (1).

Table 1 Design data for the conditioned space

Location	Faculty of Engineering, University of Khartoum, Sudan (Latitude 15.7^o N)
Application	Office building
System description	Ceiling radiant cooling panel with 100% fresh air
Outside conditions	DBT = 45°C & WBT = 26°C
Inside conditions	DBT =25°C & RH = 50%
Room size	4.22m x 2m x 3.05m (height)
Occupancy level	2 persons
Lighting	2 fluorescent tube Lamps, (1)1200mm,T12
RSH	2.77kW

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RLH	0.1564Kw
BPF	0.12
Other assumption	All walls and ceiling are exposed to the sun, no moisture generation source except occupants, ventilation, and infiltration. Ambient temperature under floor air is 29°C
Supply air temperature	12°C
Mean panel temperature	15.5°C
Panel cooling capacity	0.613kW

DESCRIPTION OF THE EXPERIMENTAL ROOM

The space conditioned under the experimental test is selected as small office is shown in Figure 1 which has dimensions of 4.22 m x 2 m with height of 3.056 m. All walls of the office consist of common brick (24 cm thick). The ceiling is made of 12 cm concrete, 2 cm air gap, 2 cm polyethylene insulation foam and 0.4 cm plywood. The floor is constructed of 39 cm concrete; 3 cm cement mortar and 3 cm tile. The 0.95 cm x 0.76 cm window is made of a single clear glass with thickness of 3 mm where the door has dimensions of 1.95 m x 0.82 m soft wood (4 cm thick). Four panels insulated at the top are used. Each of them has dimensions of 1.3 m x 1.05 m with thickness of 4 mm. The chilled water passes to the fan coil unit to reduce the ambient temperature so as to supply an air temperature of 12^{o}C and then, enters the panel with 14.2^{o}C and exits with 16.8^{o}C. Cooling load of the space was calculated by using computer program (Matlab) for transient heat flow (sensible heat load) through the walls and ceiling. Other heat loads were determined by the standard ASHRAE method. Then, the ceiling radiant cooling panel system was designed.

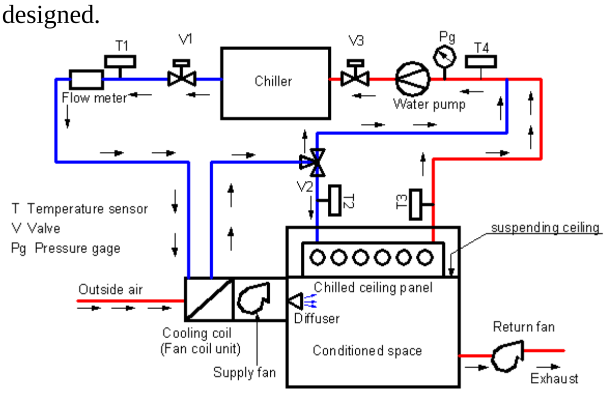


Figure 1. Schematic diagram of tested chilled ceiling panel with dedicated outdoor air system

CRCP/DOAS WITH 100% FRESH AIR

Figure 2 explains CRCP/DOAS with 100% fresh air.

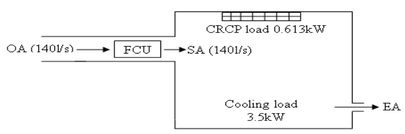


Figure 2. CRCP/DOAS with 100% fresh air

Once the thermodynamic properties of the air before and after the cooling coil (States O and S Figure 3), the design cooling coil load Q_{FCU} (fresh air FCU capacity) is calculated using equation below.

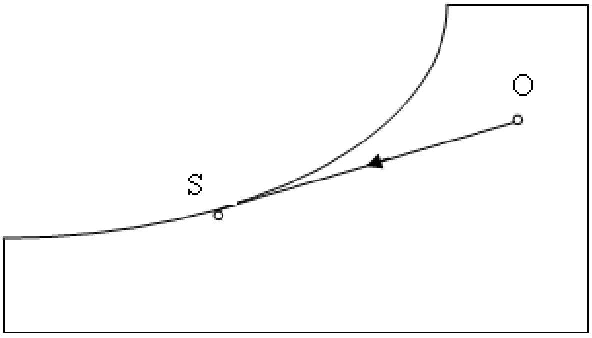


Figure 3 thermodynamic properties of the air before and after the cooling coil of FCU

$$Q_{FCU} = q_{ven}\rho(h_o - h_s) = \frac{q_{ven}(h_o - h_s)}{v_o} \tag{1}$$

$$Q_{FCU} = \frac{q_{ven}(h_o - h_s)}{v_o} = \frac{0.14(80.7 - 34.1)}{0.921} = 7kW = 2TR$$

VAV SYSTEM WITH 100% FRESH AIR

Figure 4 shows VAV system with 100% fresh air. In some applications of air conditioning systems, 100% fresh air is needed to apply such as hospitals (sterilizing and surgery rooms) and medicine's factories. For sterilizing rooms' number of air changes per hour ranges between 15 to 25. In this study the sterilizing room is used, the number of air changes per hour is selected as 19.6. Therefore, the ventilation flow rate is calculated as follows:

$$\dot{V}_{ven} = \frac{Volume\ of\ the\ conditioned\ space \times ACH}{3600} \tag{2}$$

$$\dot{V}_{ven} = \frac{Volume\ of\ \ conditioned\ space \times ACH}{3600} = \frac{8.44 \times 3.05 \times 19.6}{3600} = 140 l/s$$

Both supply air and cooling coil capacity of VAV system is calculated as below:

$$\dot{m}_{supp} = \frac{ERTH}{h_R - h_S} \tag{3}$$

$$\dot{m}_{supp} = \frac{3.5}{50.31 - 34.1} = 0.22 kg/\sec = 0.22 \times 0.921 = 202.62 l/s$$

$$FCU\ capacity = \dot{m}_{supp}(h_o - h_S) = \frac{\dot{V}_{supp}(h_o - h_s)}{v_o}$$

$$FCU\ capacity = \dot{m}_{supp}(h_o - h_S) = \frac{\dot{V}_{supp}(h_o - h_s)}{v_o} = \frac{0.20262(80.7 - 34.1)}{0.921} = 10.25kW \tag{4}$$

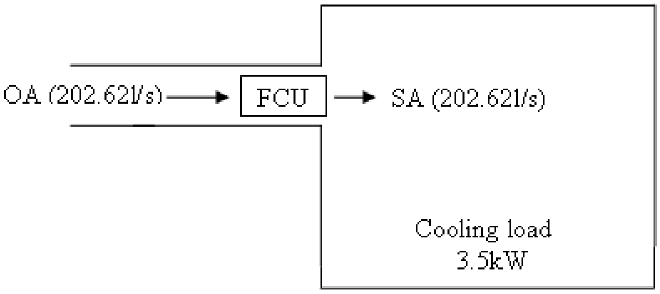


Figure 4. VAV with 100% fresh air

COMPARISON BETWEEN CRCP/DOAS & VAV SYSTEM FOR PEAK POWER DEMAND

Table 2 describes comparison between CRCP/DOAS & VAV system for peak power demand.

Table 2 Comparison between CRCP/DOAS & VAV system for peak power demand

Design consideration	100% fresh air	
	CRCP system	VAV system*
Supply air flow rate (l/s)	140	202.62
Panel sensible cooling load (kW)	0.613	0
Cooling coil capacity (kW)	7	10.25
Supply fan (kW)	0.0325	0.04
Round window exhaust fan (kW)	0.0325	0
Water pump (kW)	0.0192	0
Ceiling fan capacity (kW)	0	0.125
Total energy (kW)	7.7	10.42
Power savings (kW)	0	2.72
Power savings % of CRCP over VAV system	0	26.1

SENSOR'S LOCATIONS INSIDE THE CONDITIONED SPACE

Sensor's locations inside the conditioned space were explained in Figure 5 and Table 3.

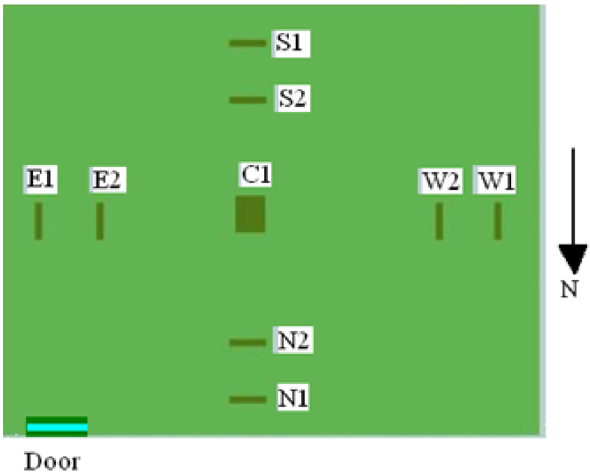


Figure 5a. Plan view

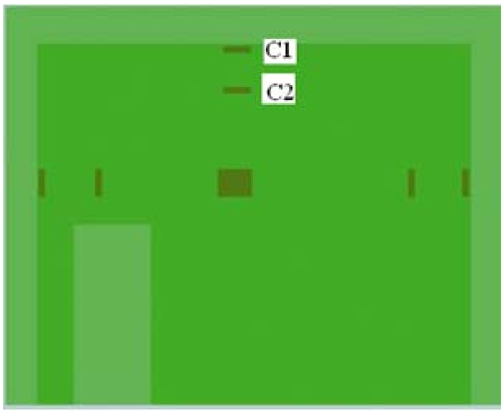


Figure 5b. Elevation view

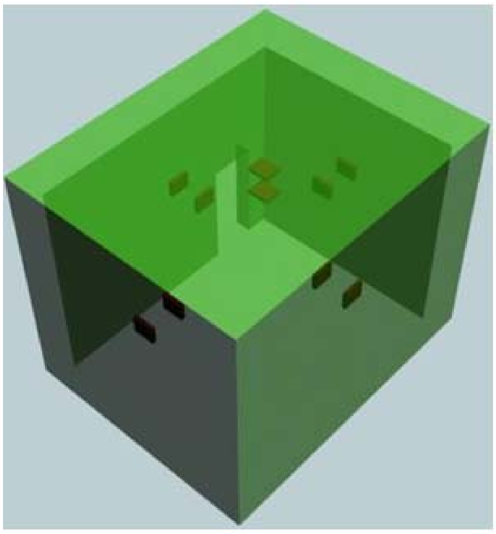


Figure 5c. Isometric view

Figure 5. Conditioned space with sensor's locations

Table 3 Location of the sensor's points inside the office

Point	Location
E1*	Center of east wall, 120cm from floor
W1	Center of west wall, 120cm from floor
S1	Center of south wall, 120cm from floor
N1	Center of north wall, 120cm from floor
C1**	Center of ceiling radiant panel cooling
E2***	Perpendicular point, 25cm away from center of east wall, 120cm from floor
W2	Perpendicular point, 25cm away from center of west wall, 120cm from floor
S2	Perpendicular point, 25cm away from center of south wall, 120cm from floor
N2	Perpendicular point, 25cm away from center of north wall, 120cm from floor
C2	Office center, 120cm from floor

* Points E1, W1, S1, and N1 represent inside walls surface temperatures of the office.
** Point C1 indicates panel surface temperature.
*** Points E2, W2, S2 and N2 illustrate perpendicular walls of inside air at the office.

RESULTS & DISCUSSIONS

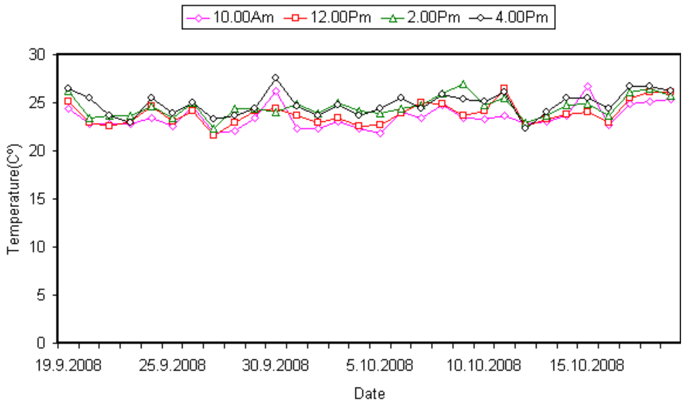


Figure 6. Inside air temperature at office center (point C2) (Table 2)

From Figure 6 it will be observed that the inside air temperature of the conditioned space shows uniform distribution. Temperature lies between 23°C to 26°C. According to ASHRAE, the acceptable comfort condition temperature varies between 22°C to 25°C in summer. Hence the result in Figure 3 indicates that the panel system gives reasonable performance and provides comfortable conditions.

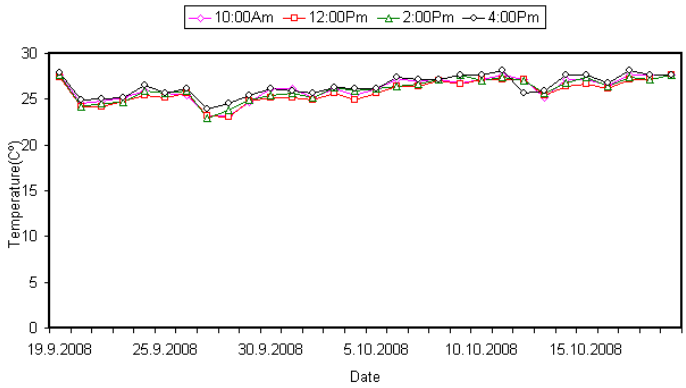


Figure 7. Inside surface temperature of the east wall at point E1 (Table 2)

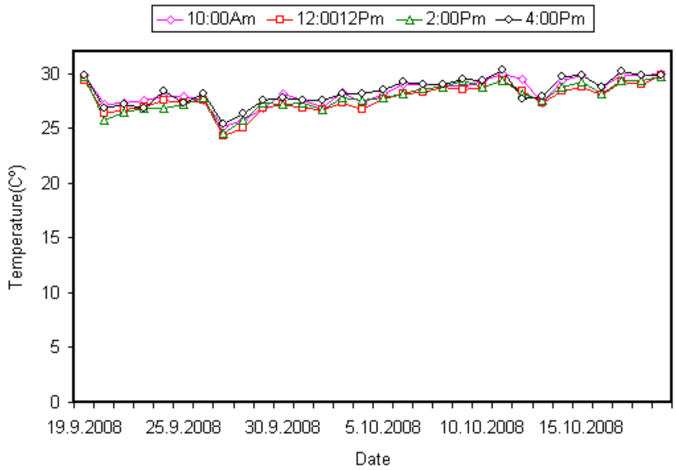


Figure 8. Inside surface temperature of the west wall at point W1 (Table 2)

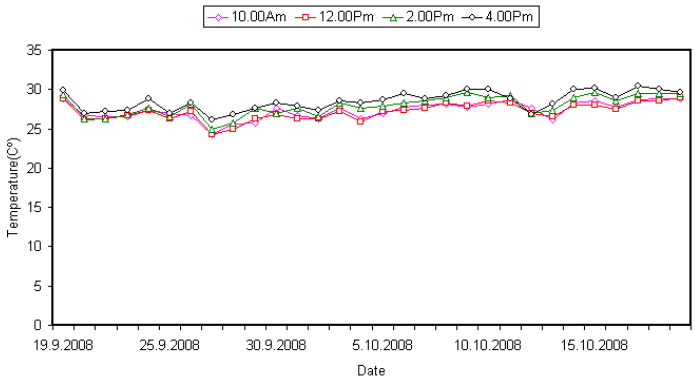


Figure 9. Inside surface temperature of the south wall at point S1 (Table 2)

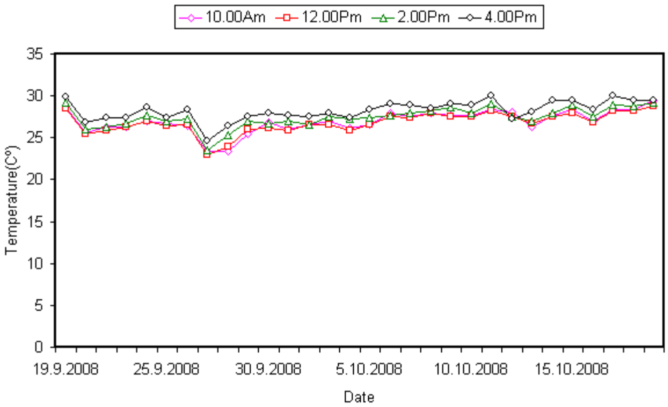
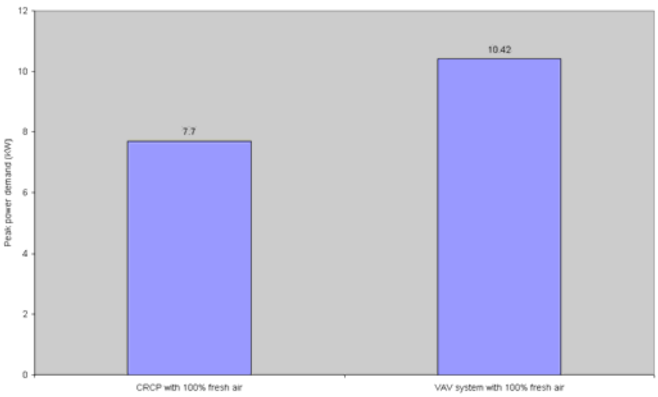


Figure 10. Inside surface temperature of the north wall at point N1 (Table 2)



Fiure 11**.** Comparison between CRCP/DOAS and VAV system for peak power demand

Figure 11 shows a comparison between CRCP/DOAS and VAV system for peak power demand through this study. It is clear that from this figure the CRCP/DOAS system with 100% fresh air can save more than 26.1% of input power over a VAV system with 100% fresh air. The reason for this is that the CRCP/DOAS uses minimum supply air (140l/s) than VAV system (202.62 l/s) in case if 100% fresh air is used in each respectively. The other reason is attributed to the energy used by its pump (19.2W) which is less than by fan (40W) in VAV system.

PREDICTED VERSUS EXPERIMENTAL INSIDE WALLS SURFACE TEMPERASTURE

Table5 illustrates predicted versus experimental inside walls surface temperatures of the office.

Table 5 Predicted vs. experimental results of inside walls surface temperatures of the office

Surface temperature*	Predicted (°C)	Average of experimental work (°C)
E1	26.75	26.16
W1	26.8	28.14
N1	27	27.37
S1	26.73	27.78
C1	25	25.06

Table 3 shows summary of average temperature of inside walls surface (Figure 4 to 8) of inside air building. These results confirm that, the application of computer simulation in engineering sciences is expected to render reasonable results.

AVERAGE TEMPERATURE OF PERPENDICULAR WALLS OF INSIDE AIR AT THE OFFICE BUILDING (EXPERIMENTAL RESULTS)

The average temperatures of perpendicular walls of inside air at the office building which have been obtained during the period of experimental testing were summarized in Table 4.

Table 6 Average temperatures of perpendicular walls of inside air at the office (experimental work)

Surfaces of the office*	Temperature (°C)
E2	25.42
W2	25.79
N2	25.15
S2	25.18
C2	24.18

***** Point location**:** 0.25m from center of each wall surface and 1.2m (seating level) from the floor.

Table 6 shows average temperatures of perpendicular walls of inside air (Figure 3 and 9 to 12) at the office building. It is clear that, these temperatures are close to inside air design temperature (25°C).

CONCLUTIONS

From the study of the radiant panel system according to Khartoum climatic conditions, the following conclusions can be drawn:

- The present investigation indicated that the radiant cooling system improves the human comfort (100% fresh air is used).
- The results obtained in this study demonstrate that the ceiling radiant cooling panel system creates uniform temperature distribution inside the conditioned space. Moreover, the predicted inside walls surface temperatures and temperatures of perpendicular walls of inside air are shown to be in reasonable agreement with those measured as indicated in the experimental results.
- The current study showed that the ceiling radiant cooling panel system improves indoor air quality (low noise and minimum supply air are used when compared with conventional cooling system)
- Electrical services reduction for the mechanical equipment can be achieved due to smaller chiller, fans and pumps.

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ACRONYMS

CRCP	Ceiling Radiant Cooling Panel
DOAS	Dedicated outdoor air system
VAV	Variable air volume
ASHRAE	American society of heating, refrigeration and air-conditioning engineers
DBT	Dry bulb temperature
	Humidity ratio
ACH	Number of air changes per hour for room
ERTH	
FCU	Fan coil unit