ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PERFORMANCE OF A RADIANT CEILING PANEL ON INDOOR AIR QUALITY OF A CONDITIONED SPACE

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ABSTRACT

An This paper discusses the performance of a radiant ceiling 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 .

INTRODUCTION

In recent years, Ceiling Radiant Cooling Panels (CRCP) systems have been attracting more and more attention with the ad-vantages in comfort, health, energy conservation and so on. The operating principle of their terminal devices is to make the ceiling a kind of cold radiating surface with lowering temperature, and achieve the purpose of indoor cooling by the radiation heat transfer between the ceiling and other indoor surfaces. CRCP systems originated from Europe and developed on a global scale [1].
Stanley A. Mumma and his team (Stanley A. Mumma, 2001, 2002; Christopher L. Conroy and Stanley A. Mumma, 2001; Jae-Weon Jeong and Stanley A. Mumma, 2003a,b, 2004, 2007; Stanley A. Mumma and Jae-Weon Jeong, 2005; Yizai Xia and Stanley A. Mumma, 2006) fully studied CRCP combined with ventilation systems, and adopted the MRT method provided by ASHRAE Handbook (2012) to calculate the radiation heat transfer between cooling panels and other indoor surfaces[1].
Radiant cooling systems have been proven to be potentially more energy efficient and provided the improved thermal comfort of indoor environment Chilled water is supplied at a higher temperature to radiant cooling systems than conventional air conditioning systems. Ceiling radiant cooling panel (CRCP) system is available to control independently indoor temperature and humidity and achieves its specialty advantages for the perception of human thermal comfort. This is considered as an efficient way to deliver cold to a zone with smaller temperature gradient inside the room and to avoid local thermal discomfort compared to conventional air-conditioning system. For conventional Heating, Ventilation and Air Conditioning (HVAC) system, achieving the task of cooling a building by convection only, the supply air is directly cooled by cooling coil to keep dehumidification control and air-supply at dew point. The required temperature of a chilled water system is near the freezing point of water, thus chiller plant is not easy to have high energy efficiency rating (EER) for conventional HVAC systems. In addition, renewable energy and alternative natural cooling resources used in a conventional HVAC system have lower performance coefficient than used in radiant cooling system, due to larger temperature difference needed between chilled water temperature and room temperature. [2].
Radiant systems have some advantages over forced air systems: no filter maintenance, less distribution of airborne contaminants in the home (Mohamed, 2010), and reduced noise. Many home and hotel occupants complain about forced air noise from registers and wall AC units, as confirmed in a 1998 Davis Energy Group study (Davis, 1998) [3].

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) [4], [5].

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 included.

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 15.7º 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 (room sensible heat)	2.77kW
RLH (room latent heat)	0.1564Kw
BPF (by pass factor)	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 12ºC and then, enters the panel with 14.2ºC and exits with 16.8ºC. 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.

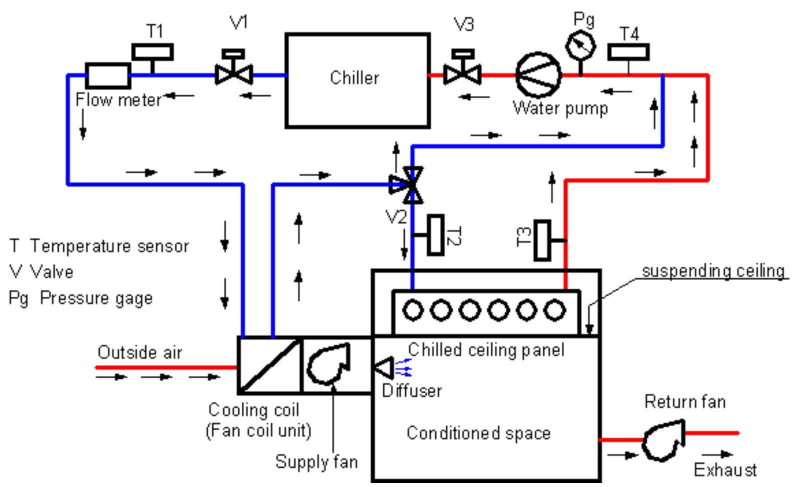

Figure 1 Schematic diagram of tested chilled ceiling panel with dedicated outdoor air system

SENSOR'S LOCATIONS INSIDE THE CONDITIONED SPACE

Sensor's locations inside the conditioned space were explained in Figure 2 and Table 2.

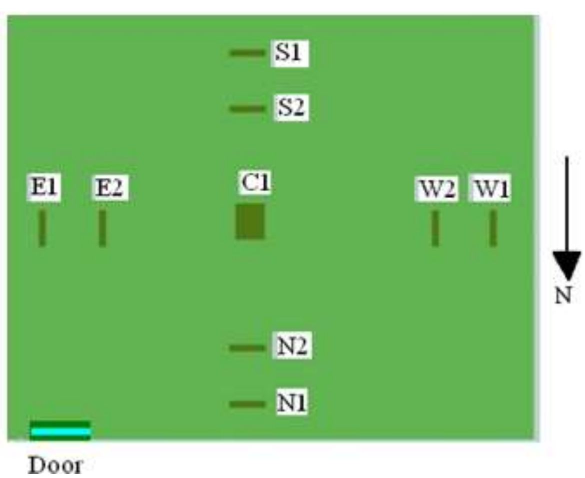

Figure 2a Plan view

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(I2OR), Publication Impact Factor: 3.785

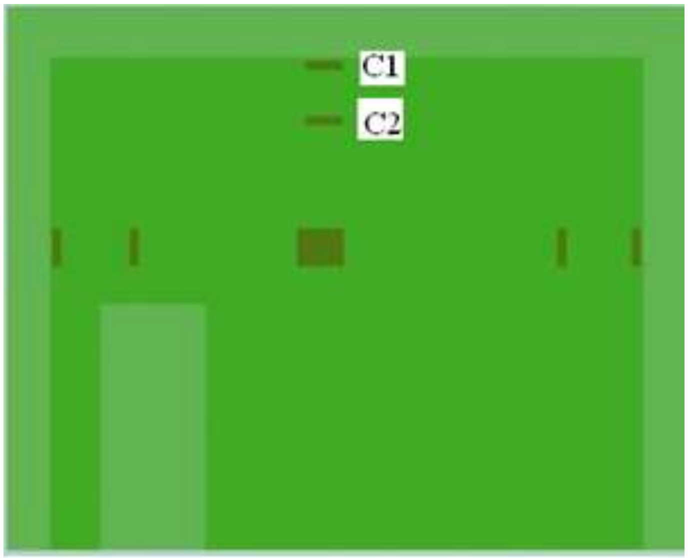

Figure 2b Elevation view

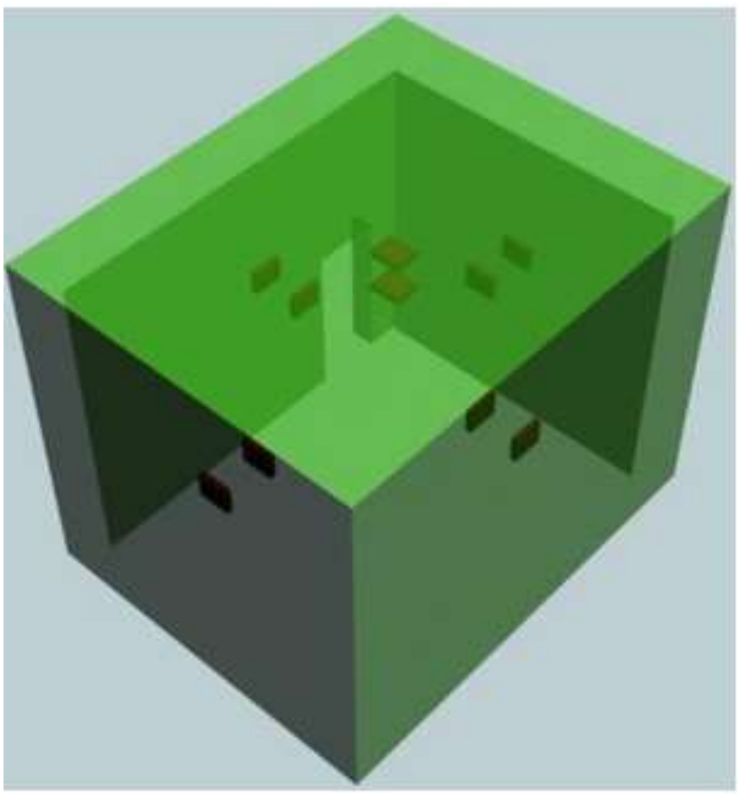

Figure 2c Isometric view
Figure 2 Conditioned space with sensor's locations

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Table 2 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 AND DISCUSSION

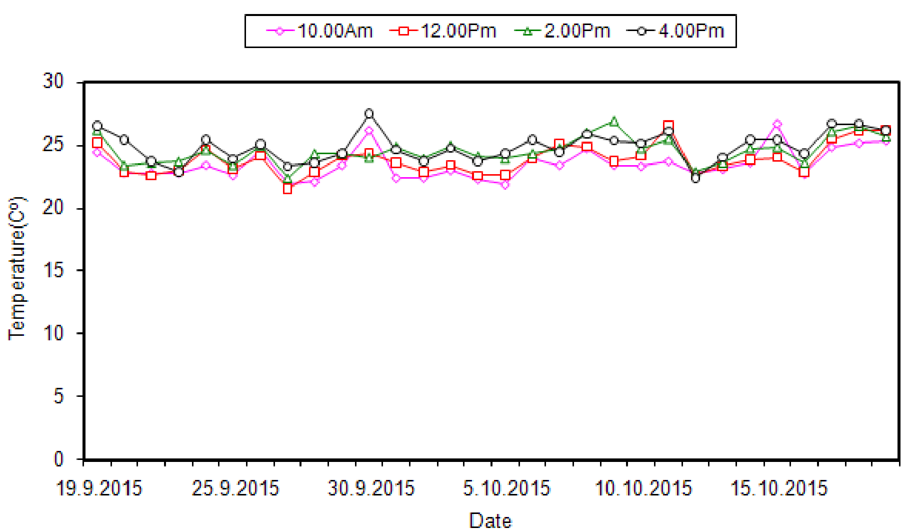

Figure 3 Inside air temperature at office center (point C2) (Table 2)

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

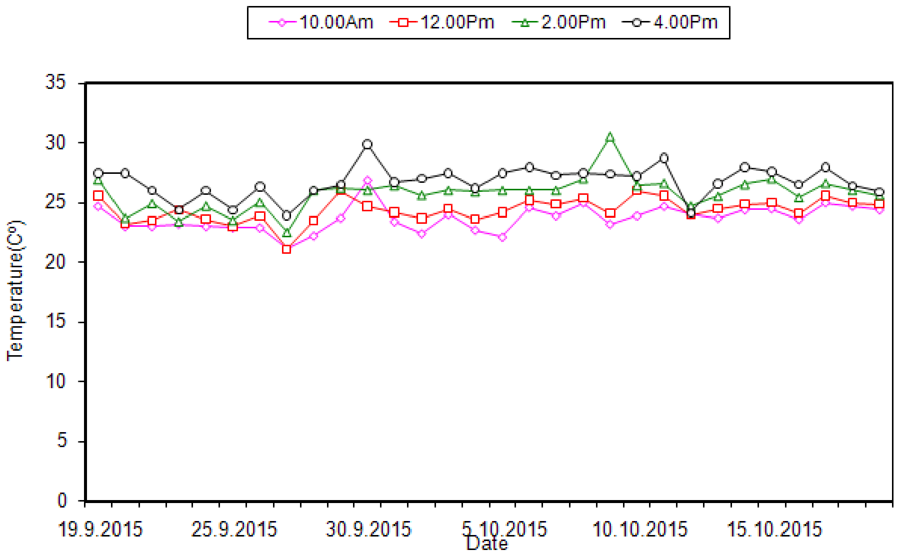

Figure 4 Inside surface temperature of the ceiling radiant panel at point C1 (Table 2)

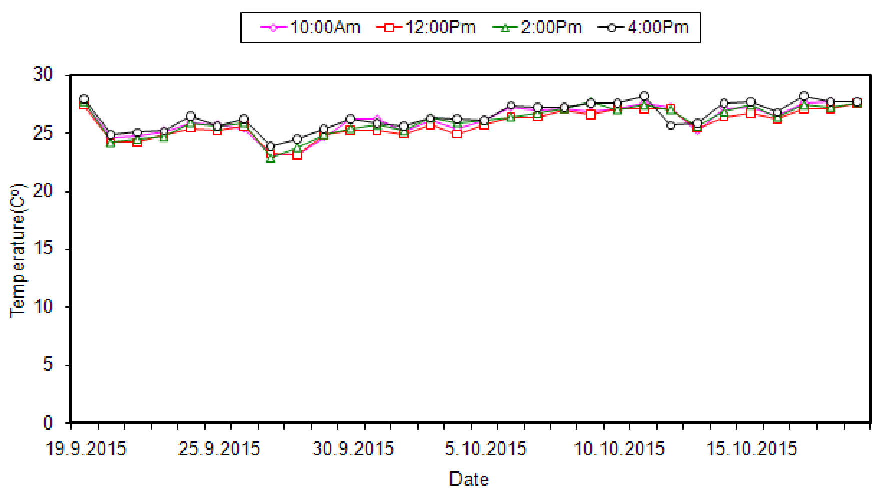

Figure 5 Inside surface temperature of the east wall at point E1 (Table 2)

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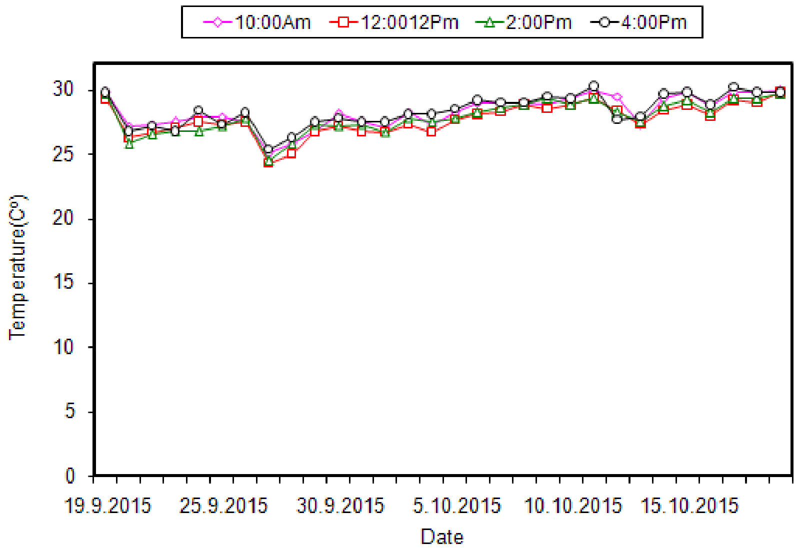

Figure 6 Inside surface temperature of the west wall at point W1 (Table 2)

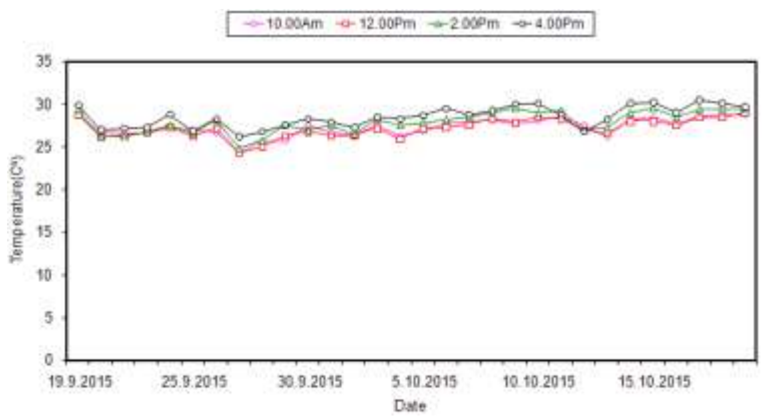

Figure 7 Inside surface temperature of the south wall at point S1 (Table 2)

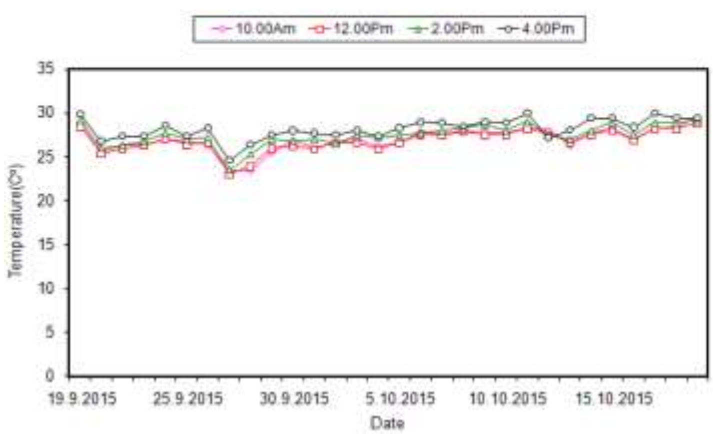

Figure 8 Inside surface temperature of the north wall at point N1 (Table 2)

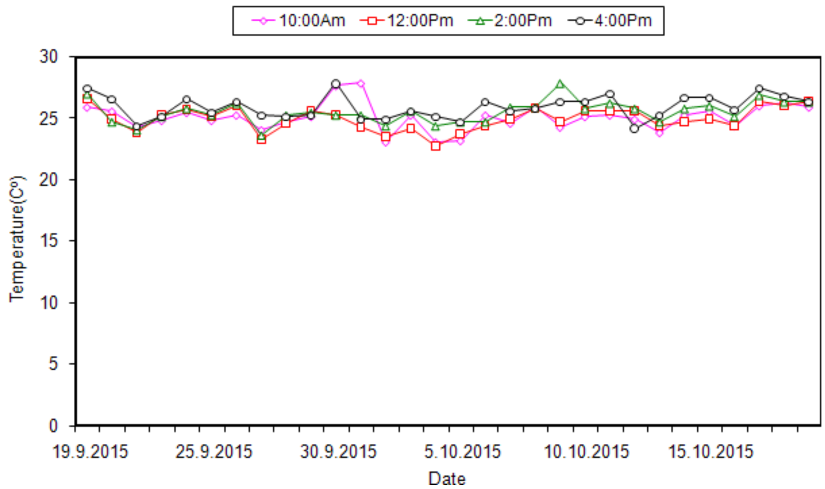

Figure 9 Inside air temperature at point E2 (Table 2)

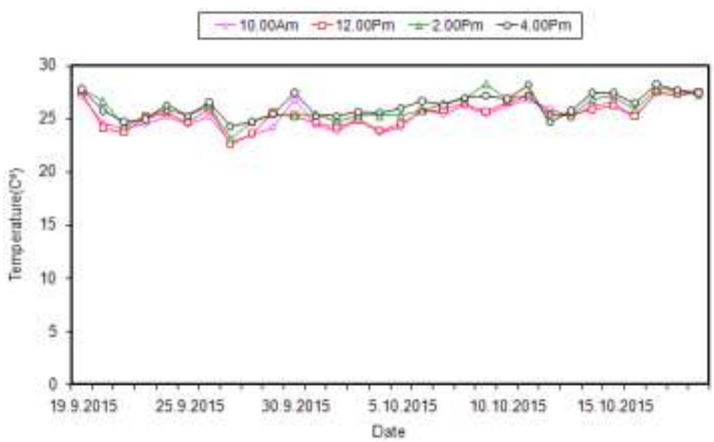

Figure 10 Inside air temperature at point W2 (Table 2)

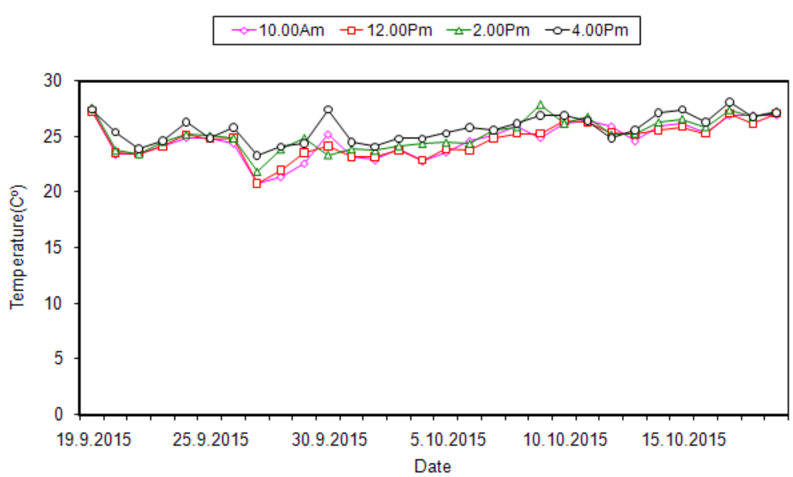

Figure 11 Inside air temperature at point S2 (Table 2)

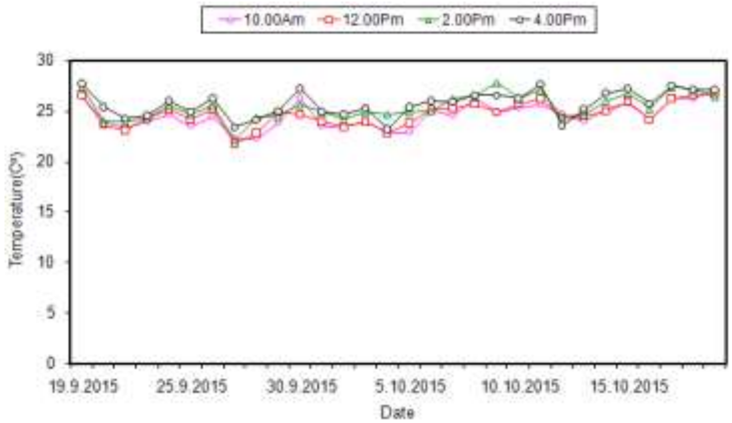

Figure 12 Inside air temperature at point N2 (Table 2)

PREDICTED VERSUS EXPERIMENTAL INSIDE WALLS SURFACE TEMPERASTURE

Table 3 illustrates predicted versus experimental inside walls surface temperatures of the office.

Table 2 Location of the sensor's points inside the office

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

***Point location: Center of each wall surface (tangential point) and 1.2m from the floor.**

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 4 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.***

CONCLUSION

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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