Building and Environment 122 (2017) 23–34

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Cooling ceiling assisted by desk fans for comfort in hot-humid environment

Yingdong He, Xiang Wang*, Nianping Li**, Meiling He, De He, Kuan Wang

College of Civil Engineering, Hunan University, Changsha, Hunan 410082, China

ARTICLE INFO

Article history:
Received 5 March 2017
Received in revised form
17 April 2017
Accepted 29 May 2017
Available online 31 May 2017

Keywords:
Thermal comfort
Cooling ceiling
Desk fans
Radiant cooling
Hot-humid environment

ABSTRACT

This study aims to investigate the effect of using cooling ceiling and desk fans on comfort in hot-humid environment. A series of experiments was conducted in an experimental room at 26, 28 and 30 °C (relative humidity was 70%). The obtained results indicate that the combination of cooling ceiling and desk fans reduced warm sensation and improved comfort in hot-humid environment, which mainly resulted from the improvement of local conditions of upper body parts. This combination also lowered humid sensation and improved perceived air quality but the local airflow by desk fans caused draft risk at 26 °C. Besides, cooling ceiling could only meet the 80% acceptable demand at 28 °C, while cooling ceiling and desk fans made more than 80% subjects feel acceptable at 28 and 30 °C. Also, the combination exerted more significant effects on increasing acceptability to both humid environment and air quality than using cooling ceiling alone. Besides, the preferences of subjects for cooler environment, stronger air movement and drier environment were significantly weakened under hot-humid conditions. In addition, the combination had potentials of energy conservation since it could extend acceptable range and reduce the energy for dehumidifying indoor air.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Radiant cooling system has advantages of both saving energy and improving comfort in modern buildings [1–5]. Also, radiant cooling system is beneficial to maintaining indoor air quality [1,6]. Under this circumstances, many researches on radiant cooling system have been carried out in recent years.

Brunk [7] compared radiant cooling system with other conventional convective systems and found that radiant cooling system could reduce the energy cost of air conditioning system. Feustel and Stetiu [1] reviewed many previous studies on hydronic radiant system and drew the conclusion that radiant system could provide draft-free cooling, reduce space requirement, increase indoor air quality and lower the energy consumption as compared to all-air systems. Kim et al. [3] analyzed the performance of a radiant panel system through simulation, and they attributed the potential of energy conservation to the lower mean radiant temperature and operative temperature in the radiant cooling environment, a feature which made it possible to improve air temperature. Similarly, Catalina et al. [8] simulated the thermal environment produced by cooling ceiling. The obtained results showed that the black globe temperature was lower than air temperature by 0.6–0.9 °C while draft risk was low. Meanwhile, Corgnati et al. [9] obtained the similar results. A few researchers hold the opinion that subjects could feel cooler in radiant cooling environment [3,7]. Zhao and Liu [10] studied the radiant cooling floor in the large space building and stated that radiant cooling system was superior to all-air system in terms of saving energy and producing comfortable environment. Seo et al. [11] proposed a new type system which coupled radiant floor cooling with outdoor air cooling, and then they claimed this system could save more than 20% energy as compared to existing radiant floor cooling system. Further, using radiant cooling system and displacement ventilation could not only lowers draft risk but also improves the effectiveness of ventilation and contributed to producing better indoor air quality [12]. Similarly, when personal ventilation was combined with radiant cooling ceiling, air quality of breath zone for occupants could be improved [13]. Hu and Niu [14] summarized several typical radiant heating/cooling systems in China in recent years and they claimed that radiant heating/cooling systems owned great energy-saving potential but the cooling capacity needed to be expanded and advanced humidity control system should be used simultaneously.

* Corresponding author.
** Corresponding author.
E-mail addresses: xiang.wang3@wsu.edu (X. Wang), linianping@126.com (N. Li).

http://dx.doi.org/10.1016/j.buildenv.2017.05.037
0360-1323/© 2017 Elsevier Ltd. All rights reserved.

Likewise, Miriel et al. [15] considered that radiant cooling system was suitable for buildings with low cooling loads meanwhile the surface temperature of radiant panels should be controlled in case of condensation. Lim et al. [16] claimed that supply water temperature for radiant floor cooling system in residential buildings should be controlled according to the dew point of indoor air to prevent condensation. In the review of Novoselac and Srebric [5], it was indicated that the surface temperature of radiant cooling component must be at least 1 °C higher than dew point and separate ventilation have to be turned on prior to radiant cooling system to avoid condensation. In another study which stimulated radiant cooling system with dehumidified air ventilation in buildings in tropical climate, the results showed that indoor environment would not be comfortable if fresh air from outside was not cooled and dehumidified [17].

Besides, some researchers conducted their studies with subjects participating in to identify the effect of radiant cooling system on subjective comfort. Nagano and Mochida [18] undertook a series of experiments in a room with cooling ceiling and they then reported uniform temperature distribution in this room and actual thermal sensation was lower than the predicted value. Imanari et al. [2] carried out experiments in a meeting room with radiant ceiling panels as compared to all-air system. The obtained results revealed that subjects felt more comfortable with radiant cooling system. In the study of Kitagawa et al. [19], it was found that producing low air velocity indoors made subjects cooler in the radiant cooling environment. Meanwhile, Hodder et al. [20] found that the participants thought indoor air was more fresh with radiant ceiling and floor. Tian et al. [21] undertook a field investigation in a building with radiant cooling system in Canada which showed that the actual percentage of dissatisfaction was lower than the calculated PPD (predicted percentage of dissatisfied), and they attributed this to the uniform distribution of temperature and lower draft risk. He et al. [22] carried out a field study in office buildings with hot-humid climate. This study showed that sometimes radiant cooling ceiling was unable to fully cool the indoor air which then made indoor environment uncomfortable. Meanwhile, condensation was observed sometimes due to the high level of humidity.

According to the review of previous studies, it is clear that radiant cooling system has large potentials in terms of saving energy and maintaining comfort. However, some problems are still unsolved which hinder the wider application. To begin with, most of previous studies on radiant cooling system were conducted in comfortable environment suggested by ASHRAE Standard [23]. Although radiant cooling system could make occupants feel cooler [3,7], few studies tried to explore whether this effect still exists in hotter environment. Secondly, in the regions with humid climate like south of China, indoor relative humidity could even be higher than 70% even if there is convective cooling system [24,25]. In our previous field study [22], it was found that indoor humidity could even be as high as about 80% sometimes and there was condensation problem in the rooms with chilled ceilings although separate humidity control system was used. This means that condensation risk exists if applying radiant cooling system in humid regions. In addition, our previous study reported that radiant cooling system might not fully cool the indoor room in the regions with extreme hot climate in summer [22]. Similarly, it was found in one previous study that if cooling load was too high, radiant cooling system was unable to cool the entire room [26]. In other words, occupants are probably uncomfortable under this condition and need compensatory cooling to maintain comfort. Therefore, more researches on applying radiant cooling system in hot-humid environment are in need.

This paper aims to investigate the effect of combining chilled ceiling and desk fan on thermal comfort in hot-humid environment. A type of low-energy desk fan (maximum power: 3 W) was used as compensatory cooling device for maintaining comfort under extreme condition (hot-humid) in summer. A series of experiments was conducted in an experimental room with cooling ceiling in July 2016. Subjects were exposed to the environments at 26, 28 and 30 °C, respectively (relative humidity was kept at around 70%) and filled questionnaires as requested. During the experiments, environmental parameters were recorded. This study provides an energy-efficient way for maintaining comfort in the buildings with radiant cooling system under extreme condition. This study also helps with reducing condensation risk when applying radiant cooling system in hot-humid regions.

2. Methodology

2.1. Experimental facilities

The experiments were carried out in an experimental room (4.3 m × 2.7 m × 3.0 m) in a laboratory building at Hunan University, Changsha, China. Changsha, a big city in central-south of China, is characterized by hot-humid climate in summer and the relative humidity outdoors could reach about 80% [27]. The size of experimental room is the same as some normal office rooms in the same building. There were two seats (one office chair and one office desk for each seat) in the room. The chairs and desks were the same as those used in the same building. A partition (about 1.1 m high, aluminum alloy surface and 20 mm thick rubber layer inside) situated in the central of the room to weaken the interaction effect of desk fans in two seats. There was one window in the north wall. During the experiments, plastic extrusion plate (50 mm thick) and thick curtain were used to cover the window thus decreasing the influence of outdoor environment. Totally, the cooling ceiling was made of 12 radiant panels. The radiant panels had aluminum alloy surface and the size of each one was 1200 mm × 600 mm × 20 mm. The diameter of capillary tubes inside the panels was 3.4 mm and the gap between two adjacent tubes was about 10 mm. Besides, rubber insulation layer (about 20 mm thick) was attached to the back of each panel to ensure it could provide cooling downwards to the room and subjects. All panels were supplied with cool water which was recirculated by a cooling-water machine. The supply water temperature could be adjusted within the range from 10 to 24 °C. To minimize the difference of panel surface temperature, reverse return system (pipes) was used. So, for all panels, the length and size of pipes were the same. Also, some pre-tests were before the formal experiments and it was confirmed that the surface temperature differences among different panels were quite small and the surface temperature could be higher than the dew point. As for the desk fan, the size was 180 mm × 180 mm × 270 mm (length × width × height). The fan could produce local airflow at two levels of speed (about 1.6 and 2.2 m/s near in front of subjects) and the corresponding power were 2 and 3 W, respectively. The layout of experimental room as shown in Fig. 1 was similar to those in the same building to create an environment close to normal office room. Moreover, additional air cooling system was used to supply fresh air, maintain indoor air temperature and humidity. And the jet was 2.6 m high above the floor (near the north wall).

The important physical parameters were recorded during the experiments. Air temperature was measured at 0.1, 0.6 and 1.1 m above the floor at measure point, while global temperature, relative humidity and air velocity were measured at 0.6 m above the floor. Surface temperature of panels was measured using Pt100 thermometers. The measure points for panel surface temperature were set closer to the participant at north seat because the data recorder (connected to all Pt100 sensors at measure points) was placed a little closer to the north seat so as to avoid blocking the door (south)

Download English Version:

https://daneshyari.com/en/article/4911444

Download Persian Version:

https://daneshyari.com/article/4911444

Daneshyari.com