Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 143 (2017) 100–105

Energy Procedia

www.elsevier.com/locate/procedia

World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference, WES-CUE 2017, 19–21 July 2017, Singapore

Design method of radiant cooling area based on the relationship between human thermal comfort and thermal balance

Song Gao[a], Yang Li[b], Min Zhao[c], Yuang Wang[a], Xiaohu Yang[a], Chun Yang[d*], Liwen Jin[a*]

[a]*Group of Building Environment and Sustainability Technology, Shaanxi Engineering Research Center of Building Environment and Energy, School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an, 710049, China.*
[b]*School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China.*
[c]*China Northwest Architecture Design and Research Institute Co. Ltd., Xi'an, 710016, China.*
[d]*School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, 639798, Singapore.*

Abstract

The radiant cooling air conditioning system has been widely applied, due to its features of better thermal comfort and efficient energy-saving. Most of the research on radiant cooling air conditioning system tends to concentrate on its cooling performance and energy-saving potential. However, the design methods of radiant cooling air conditioning system to guide its engineering application are rare. On the basis of the simplified human thermal balance equation and the linear relationship between the sensible heat loss and human thermal comfort achieved in our previous studies, the cooling performance of cooled surface is analyzed and then the method for determining the area of cooled surface is proposed in this paper. The numerical model is validated by experimental data and the calculation methods of cooled area are investigated with different boundary conditions. In addition, the PMV values in different heights and around human body are analyzed in detail. The results show that the calculation methods on account of the features of cooled surface could accurately predict the cooled area to maintain human thermal comfort under different conditions. Therefore, it is possible to determine the area of cooled surface in view of the relationship between human thermal comfort and thermal balance. This study could provide the guidelines for both the assessment of human thermal comfort and the system design of radiant cooling air conditioning system.

Peer-review under responsibility of the scientific committee of the World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference.

* Corresponding author. Tel.: +86-29-83395127;
E-mail address: lwjin@mail.xjtu.edu.cn

1876-6102
Peer-review under responsibility of the scientific committee of the World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference.
10.1016/j.egypro.2017.12.655

Keywords: Radiant cooling; Human thermal comfort; Human thermal balance; PMV model.

1. Introduction

Radiant cooling air-conditioning system has been increasingly prevailed, thanks to its advantages of better thermal comfort and efficient energy-saving provision. Compared to conventional convective air conditioning system, the directly radiant heat exchange between human body and cooled surface makes people feel more comfortable [1]. In addition, the decreases of radiant temperature asymmetry and air temperature gradients could be the reasons for the better human thermal comfort under radiant cooling air conditioning system [2]. To have a better knowledge of the features of radiant cooling systems, a great deal of research on it has been done already.

K. Nagano [3] researched on the control conditions of radiant cooling ceiling for human body in supine position with Predicted Mean Vote (PMV), and the results show that direct cooling effect by radiation could be achieved with less energy than convective system. S.G. Hodder [4] found that the vertical radiant temperature asymmetry has an insignificant effect on the overall thermal comfort of the seated occupants subject to the hybrid system composed of cooling ceiling and displacement ventilation system. Koichi Kitagawa [5] investigated the effect of humidity and small air movement on human thermal comfort under a radiant cooling ceiling by subjective experiments, and it is concluded that the most comfortable sensation vote is obtained when people feel slightly cool. D.L. Loveday [6] verified the feasibility of the design standard BS EN ISO7730 established based on the experimental studies on conventional convective system for radiant cooling system. In addition, some studies pointed out that the traditional design criteria, such as these based on dry-bulb temperature and operative temperature, are insufficient and the effect of radiation heat transfer on human thermal comfort should be considered when it comes to radiant cooling system [7-8].

As discussed above, it could be learned that the existing studies on radiant cooling system focused on either its cooling performance or the effects of environmental factors on human thermal comfort. However, the research on the design methods of radiant cooling system is rare. With the aim to establish the method determining the area of cooled surface, both the characteristics of human thermal comfort subject to radiant cooling system and the cooling performance of cooled surface are investigated in detail in this study.

2. Simplification of the PMV model

The widely acknowledged Fanger's PMV model based on personal and environmental variables is accurate for thermal comfort assessment of occupants in near-sedentary and stationary conditions [9]. Fanger [10] correlated the PMV to the difference between the actual heat loss and the required heat loss for thermal comfort from human body by Eq. (1):

$$PMV = [0.303\exp(-0.036M) + 0.028]L \tag{1}$$

where M is the metabolic heat production, and L is the human thermal load, defined as the difference between internal heat production and heat loss to the environment for a person hypothetically kept thermal comfort. The human thermal comfort level is affected by environmental conditions and human thermal balance. Due to the characteristics of radiant cooling system, the PMV model was reasonably simplified for near-sedentary human body in our previous studies, as shown in Eq. (2) [11]:

$$PMV = -0.0406Q + 1.5117 \tag{2}$$

where Q is the total sensible heat loss from human body , consist of radiative and convective heat losses, $W \cdot m^{-2}$. In addition, it has been concluded that the human thermal comfort subject to radiant cooling system could be directly evaluated from human sensible heat loss instead of complicated environmental factors [12]. So, based on Eq. (2), the methods to determine air-conditioning load and cooled surface area of radiant cooling system are investigated in this study.