Energy and Buildings 82 (2014) 130–141

Contents lists available at ScienceDirect

Energy and Buildings

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

Experimental and numerical investigation of the radiant panel heating system using scale room model

Shaimaa Seyam*, Ahmed Huzayyin, Hesham El-Batsh, Sameh Nada

Mechanical Engineering Department, Benha Faculty of Engineering, Benha University, Benha, Egypt

ARTICLE INFO

Article history:
Received 18 November 2013
Received in revised form 14 June 2014
Accepted 1 July 2014
Available online 9 July 2014

Keywords:
Radiant panel heaters
Numerical techniques
Experimental measurements
Thermal comfort

ABSTRACT

Radiant heating panel systems provide high thermal comfort because of low noise level and few required equipments. These panels are installed on walls, floor, and roof in a scale room model. This study aims to investigate the performance of radiant panel heaters. Temperatures inside the room and on its walls were experimentally measured. A numerical model was also employed to study flow pattern inside the room and to predict temperature distribution. The turbulent flow was solved by using RNG k-ε turbulent model. Heat transfer by radiation was modeled by using DO radiation model. The results showed that the used numerical technique could accurately predict temperatures distribution in the room. The model was used to study the effect of panel heater locations and sizes on the air flow and air temperature distributions. The heat transfer rates were also calculated numerically as well. It was found that the minimum heat transfer rates were achieved by using the heating panel on the floor, and the scale room model was able to simulate the full-size room within a small percentage error about 20% especially in heater load and the temperature distribution was about less than 1%.

Contents

* Corresponding author.
E-mail address: shaimaa.abdelhamid@bhit.bu.edu.eg (S. Seyam).

http://dx.doi.org/10.1016/j.enbuild.2014.07.003
0378-7788/

1. Introduction

Panel heaters use controlled-temperature surfaces on the floor, walls, or ceiling. The temperature is maintained by circulating water, air, or electric current through a circuit embedded in the panel. A controlled-temperature surface is called a radiant panel if 50% or more of the heat transfer is achieved by radiation to other surfaces [1]. The radiant panel systems characterized by better thermal comfort level than that of other heating systems, the simplified structural systems because of the few parts which simplify the maintenance and operation, as a result, eliminating noise. However, they are slow response time possible non-uniform surface temperatures.

Myhren and Holmberg [2] and Chen [3] discussed different heating systems using CFD simulations (a surface-to-surface radiation model and a low R_e level k-ε turbulence model) to investigate draught problems, differences in vertical temperature gradients, air speed levels and energy consumption in their work area. It has been found that the radiant heating system offers the best comfortable environment and better than the warm air heating system. They generally concluded that low temperature heating systems may improve indoor climate, giving lower air speeds and lower temperature differences in the room.

Causone et al. [4] and Okamoto et al. [5] developed model evaluations for estimating heat fluxes from ceiling radiant panels. After comparing the values estimated by theoretical method to the experimental data, the calculated values closely matched the values obtained from experiments, which means that this calculation method is practical in estimating the radiant panel performance in the design phase.

Well known in the North of Europe, water ceiling panel systems are mainly used to provide cooling. However, as well as for a radiant floor, this system can be used for heating in winter and cooling in summer. This was experimentally studied by Miriel et al. [6], the studied ceiling panel system was made of copper pipes with rigid aluminium diffusion fins. The used materials presented a good heating conductivity and the ceiling radiant panel was fast-acting. For Tian et al. [7], used ceiling ventilation improves the general thermal comfort and reduces the risk of local discomfort.

For Karadağ et al. [8], they used the standard k-ε turbulence flow model in studying ceiling panel systems. The studies showed that this model is appropriate for the solution of free convection. They found that when the room dimensions and temperature difference between the ceiling and interior air are increased, the Nusselt number over the floor increases as well.

Most residential buildings in Egypt were built by wall bricks and cement, and with small rooms especially for the high population rate areas. Many researches were conducted about hydronic floor heating system [9–15] and their efficiency and thermal comfort in building. The installation of these types in Egypt was difficult especially to install on the floor with a significant thickness. The idea of installing a hydronic heating system [14,15] (using a circulated water in pipes below ceramic floors) inside the building, was totally rejected because of small spaces of residential buildings in Egypt and many installed components of hydronic heating systems. Therefore, it was recommended to use electric radiant heating panels [16] as mats, very easy installation with a plug-in-power supply, no components around the system only mats, easy to install in different ways on floor or walls, and the verities in their sizes and designs, also with easy temperature control. The goal of this paper is testing the heating panels made by CMB Co. in a scale room model with these specifications.

The main objective of the paper is to study the effect of heating panels' locations and different sizes in a scale room model on temperature distribution, heat transfer and air convective current and motion, and compare the results to a full scale room.

2. Experimental study

2.1. Scale room model description

The scale room model was heated using panel heaters. The panel heaters were provided by CMB Co. The heating panels COSYSTONE E are constructed from three layers, as shown in Fig. 1a, the first layer is an insulation of 25-mm thickness placed in outer surface and made from fiber, the second layer is the convection channels of 5-mm arranged between the front layer and the insulation, the third layer is the electric heating wires embedded in the thin front layer 3-mm thickness which made from a composite material and finished by epoxy with gray color, this front layer is heated up to 85 °C depending on the ambient conditions, the heater surface was corrugated based on its decoration.

The model room, shown in Fig. 1b and c, was constructed from the heating panels to facilitate heating the room from bottom, top, and side walls. The dimensions of the model room were selected to fit the dimensions of the heating panels. In addition, the dimensions of the half-scale room model were selected to simulate a real room of 3.24 m height × 5.68 m length × 3.66 m width. Therefore, the scale room model has the dimensions of 1.62 m height × 2.84 m length × 1.83 m width with no doors or windows. A steel 1042 frame structure was installed and welded together. The heating panels were arranged beside each other to form the walls. The scale room model was approximately insulated by the outer surface of heater insulation.

2.2. Measuring instrumentations

Temperature measurements were obtained by using thermocouple wire connections of type T. Three temperature settings of thermocouple were selected to be calibrated which are ice water (0 °C), human body temperature (37 °C), and boiling water (at 100 °C) using calibrated mercury thermometer. The uncertainty evaluation for the thermocouple was Type A. The signals obtained from the thermocouples were displayed on a digital temperature indicator type SHIMADEN, Japan, model SR1-8Y-1W, and with a resolution of 0.1 °C and display accuracy of ±(0.3%FS + 1 digit) which its uncertainty evaluation of Type B. the combined uncertainty was calculated according to Ref. [17]. It was found that, the highest standard deviation of thermocouple readings over 10 trials was at 37 °C, and the expanded uncertainty for the combined system was 37 ± 0.5 °C. The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 1.96 which based on effective degree of freedom over a hundred, providing a level of confidence of approximately 95%.

During this study, the scale room model was heated by using a single heater of dimension 0.4 m × 0.6 m at the floor center as shown in Fig. 2. In order to obtain steady state conditions, the heater was powered on continuously for five days until constant temperatures were obtained at different walls. The six faces are labeled (N, S, E, W, T, and B) which stand for North, South, East, West, Top and Bottom, and the origin is located and labeled by "o" as shown in Fig. 2.

2.3. Measurement locations

Due to the symmetry of the room, the measurements were obtained in a quarter of the room. The temperatures were measured by using three sets of thermocouple wire connections as follows: nine thermocouple probes were distributed on the quarter surface of the heater as shown in Fig. 3a, four thermocouple probes were distributed on the surfaces of the walls, and thirty three