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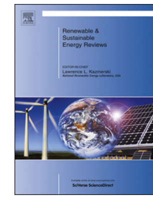

Application of radiant floor cooling in large space buildings – A review

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A B S T R A C T

In large space buildings such as airports, convention centers, atriums, and entrance halls, the envelope is dominated by glass façades and skylights; this indoor thermal environment is characterized by high-intensity solar radiation and high-temperature internal wall surfaces. A radiant floor is an effective sensible heat removal terminal due to its direct absorption of solar radiation and longwave radiant heat exchange with the wall surfaces. This paper focuses on the performance of radiant floor cooling in large spaces and reviews recent achievements and progress related to its application. The feasibility of radiant floors is considered in terms of enhancing cooling capacity, thermal comfort, and system efficiency, and several projects, including Bangkok Airport in Thailand and Xi'an Airport in China, are introduced. Based on the complex conditions of indoor heat sources in large spaces, e.g., high-intensity solar radiation and high-temperature wall surfaces, the heat transfer process of a radiant floor from the indoor space to the chilled water is presented, and a detailed description of the key factors that influence performance is given. Research concerning the prediction of the performance of radiant cooling floors with solar radiation is also summarized; these efforts can benefit the estimation of the cooling capacity both for local and entire systems in large spaces. Several other application issues are mentioned, including anti-condensation on the floor surface, the impact of thermal inertia on cooling load regulation, the design capacity of the system, and the influence of outdoor air infiltration.

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1. Introduction

Radiant floor cooling has the potential to improve indoor thermal comfort and energy efficiency as well as floor heating, as it transports energy using water and operates at a temperature close to that of the indoor space, which increases the efficiency of the cooling energy distribution and production [1,2]. However, radiant floor cooling systems are not as popular as floor heating systems due to their inherent risk of condensation and low cooling capacity [1,3,4]. In typical buildings, the maximum cooling capacity of the radiant floor is only 30–40 W/m^2 [5–8].

With the development of dehumidification technology, moisture condensation at the floor surface can be avoided by supplying handled dry outdoor air [9–11]. The application of radiant floor cooling has been extended from western and northern European areas, where the outside air humidity is relatively low during the summer season, to regions where the humidity level is much higher, such as Thailand, the United States and China [12–15]. Rhee et al. [15] summarized the regional expansion of the radiant heating and cooling system application in detailed.

There exists a special case for a radiant floor to process over 100 W/m^2 of heat gain, i.e., when there is direct solar radiation on the floor [1,16]. Large space buildings such as airports, atriums, and entrance halls are always dominated by glass façades or skylights, and the indoor environment is characterized by high-intensity solar radiation and high-temperature wall surfaces in summer [17]. As a result, radiant floor cooling has been employed much more frequently in these types of large spaces, and its potential to achieve higher cooling capacity has been demonstrated in previous research. The radiant floor cooling system in Suvarnabhumi International Airport in Bangkok, Thailand (hereinafter referred to as Bangkok Airport) was dimensioned to remove 70–80 W/m^2 of heat, and the radiant floor could absorb up to 50 W/m^2 by radiation [12]. In Terminal 3 of Xi'an Xianyang International Airport in China (hereinafter referred to as Xi'an Airport), the field-measured cooling capacity of the radiant floor increased significantly to 110–140 W/m^2 when there was high-intensity solar radiation on the floor (e.g., 120–170 W/m^2) with a duration of 10–30 min [18]. In this large space, the energy consumption for cooling transportation was significantly reduced in the radiant floor cooling system compared with a conventional all-air system, which represents a considerable proportion of the energy consumed by the entire HVAC system (i.e., 30–50% [19,20]).

The estimation of cooling capacity while considering the impact of solar radiation and high-temperature wall surfaces forms the basis of radiant floor system design. Design and estimation methods are regulated in standards such as the European Standards and ASHRAE Handbook [21–23]. However, previous analyses and calculations of the thermal output of radiant cooling systems only take into account the heat transfer from the indoor air and wall surfaces without considering shortwave radiant heat caused by solar radiation. Many recent studies examining the complex conditions of indoor heat sources in large spaces have illustrated the superior performance of radiant floors. These results represent a significant contribution to the study and application of radiant floor cooling systems.

This paper focuses on the progress of radiant floor cooling in large space buildings. First, the indoor thermal environment characteristics of large spaces and the feasibility of radiant floor cooling are introduced. Recent research achievements related to the application of radiant floor cooling in large spaces are reviewed, including findings concerning the heat transfer process, cooling capacity calculation, and anti-condensation on the floor surface.

2. Feasibility of radiant floor cooling

2.1. Indoor environment characteristics of large spaces

In order to satisfy rapid development, large space buildings continue to be the dominant design for commercial buildings, as displayed in Fig. 1. This building type features high ceilings, large-span spatial structures, extensive fenestration for aesthetic purposes, and full use of natural light. According to a site survey conducted by Gao et al. in six modern railway stations, the glazing ratio of the wall and roof reached 0.3–0.7 and 0.35–0.1, respectively [24]. It is clear that the indoor environment characteristics of large spaces – intensive solar radiation and high-temperature indoor structure surfaces – are distinct from those of common buildings.

2.1.1. Intensive solar radiation

Because of the large outer building envelope areas and glazing ratios in large space buildings, the average solar radiation density reaching the floor in large spaces is much higher than that in common buildings. For example, when the outdoor solar radiation intensity was 500–750 W/m^2 in the departure hall of Xi'an Airport, the solar radiation passing through the low-E glass (with a shading coefficient of 0.3) and reaching the floor surface ranged from 120 to 170 W/m^2, as shown in Fig. 2(a) [18]. In Beijing South Railway Station, the sunlight coming in through the skylights was also shown to be of high intensity, as illustrated in Fig. 2(b) [25].

2.1.2. High-temperature envelope

Most of the walls in large space buildings are adjacent to the outdoor environment and exposed to solar radiation; this is why