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Review

A review of the application of radiant cooling & heating systems in Mainland China

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ABSTRACT

A number of radiant heating/cooling systems have been applied in Mainland China in recent years for its improved thermal comfort and inherent energy saving potential. Because the systems require relatively higher temperatures for cooling and lower temperatures for heating, many natural low-grade energy sources can be directly or indirectly used. However, because of a lack of information about prior practical projects, a number of difficulties in design, construction and management of the systems have been encountered, and energy efficiency is not necessarily achieved in all situations. This paper reviews the practical applications in four major projects involving different building types located in different climatic cities and presents the associated considerations in system design. Other factors affecting the energy efficiency of the systems are identified, such as the spatial convection and radiation heat transfer processes in indoor environments and the envelope thermal properties. Further studies are needed to achieve system optimization and to realize the full energy saving potentials of radiant systems by developing analytical design methods and monitoring the actual energy use of such systems in completed projects.

Contents

1. Introduction

Radiant cooling systems were introduced into Mainland China about 15 years ago (Niu [1]), and currently there are quite a number of applications. Because the temperature of the supply water to the terminal system must be above the dew point of indoor air to avoid surface condensation, a radiant cooling system is responsible only for a portion of a full room-sensible cooling load, and the remainder of the cooling load is handled by a separate air conditioning system. Based on the system characteristics, Liu and Jiang [2] indicated that the system has many advantages in indoor environmental control and energy efficiency. The room-sensible cooling load can be handled independently by a chiller system that supplies chilled water at a higher temperature than that required in a conventional air

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Table 1
A summary of radiant cooling projects in Mainland China.

	Project name	Beijing Tiptop Apartment	Qingdao Villa	Entrance atrium of Shenzhen office building	Passenger hall of Tianjin railway station
Building information	Area (m^2)	45,000	508	720	35,000
	Design heating load (W/m^2)	25	29.67	–	69
	Design cooling load (W/m^2)	25	27.71	146	102
Radiant heating/cooling system	Category	PB[a] pipe	Capillary mats	Capillary mats	PE[b] pipe
	Pipe diameter (mm)	20–25	3.35	–	–
	Space between two pipes (mm)	300	15	–	200
	Supply hot water temperature (°C)	28	35	–	–
	Supply cool water temperature (°C)	20	16	17.5	20
Energy source	Category	Gas boiler and chiller	Ground source heat pump	High-temperature water chiller	High-temperature water chiller and CHP[c] plants
	Power used in heating[d] (kWh/m^2)	36 (heating consumption)[e]	24	–	–
	Power used in cooling[d] (kWh/m^2)	49 (cooling consumption)[e]	22	34.3 for a whole building	–
References		[9,10]	[11]	[12–15]	[16,17]

[a] PB is the abbreviation of polybutylene.
[b] PE is the abbreviation of polyethylene.
[c] CHP is the abbreviation of combined heat and power.
[d] The power used in heating & cooling includes consumption of entire HVAC system, such as chillers, boilers, pumps, air handing units, fans and so on.
[e] The energy used for entire HVAC system in Beijing Tiptop Apartment is not stated except for actual heating & cooling consumptions.

conditioning system, which handles the sensible and latent cooling loads synchronously and requires that the temperature of the cooling medium be lower than the dew point of the room air. Conroy and Mumma [3] found that the air flow rate of an air conditioning system combined with a radiant cooling system is approximately 20% of the volume of a conventional all-air system, and Feustel and Stetiu [4] indicated that the smaller flow rate leads to a reduction in ductwork dimensions, fan size and energy consumption. There are a number of opportunities to directly apply low-grade natural renewable energy sources and optimize system performance through the use of a radiant heating and cooling system. Therefore, radiant systems attract the attention of many engineers and are regarded as a solution to the reduction of energy consumption while keeping the indoor environment comfortable. However, as revealed by Niu et al. in their study in the early 1990s [5], the radiant effect of chilled ceiling could decrease the heat storage capacity of the building envelope to radiant heat and result in an increase in the start-up cooling load in the temperate Dutch climate; moreover, smaller air volume also means reduced energy saving through the operation of air-side economizers, while chilled ceiling provides increased potentials to use natural evaporative cooling. Thus, to realize the energy saving potentials of such systems, the local climate, building thermal properties, and system operation and management, among other aspects, must be taken into consideration at the early design stage, and attentions should be paid to the heat transfer process and its effects. ASHRAE Handbook [6] suggests adopt heat balance method to calculate cooling load of non-residential building, and many modern researches about radiant system modeling are also based on the heat balance method, but Causone et al. [7] revealed that radiant cooling system has an improved cooling capacity in a room with a large glazed area and the additional load cannot been directly estimated by heat balance method. This paper will review four typical projects in Mainland China and address some key considerations in radiant cooling system design with the purpose to identify existing problems and suggest needed improvements.

2. Typical projects

The very first radiant cooling system in Mainland China was applied in a residential project called Beijing Tiptop Apartments in 2001, and the system is also used for heating in winter. Because the buildings performed well and maintained a comfortable environment while providing energy efficiency, the project developed a good reputation among residents and attracted the attention of many designers [8]. In 2005, an energy-efficiency demonstration building was completed at Tsinghua University and the concept of Temperature and Humidity Independent Control Air-conditioning System (THICS) was implemented. Another example is Qingdao Villa, in which underground water is directly used for space cooling in the transit season. Another development is that, because floor heating has been used in many commercial buildings, floor cooling were discussed and found its use in some projects. Encouraged by the application of floor cooling in the new Bangkok airport, a similar design was adopted in an office building in Shenzhen and at Tianjin railway station.

2.1. Beijing Tiptop Apartments

The Beijing Tiptop Apartments were put in use in March of 2003. Basic information about the project can be found in Table 1. Building's thermal properties had been designed to be able to extend the period when the room temperature can remain in the range of 20–26 °C in the absence of heating and cooling, and only in the period with extreme weathers, will a hydronic system embedded in the concrete slab begin to operate [9]. The supply water temperatures in winter and summer are 28 °C and 20 °C which are respectively close to the upper and lower ranges of the thermal comfort so that the temperature difference between the supply water and the room is small as compared with the other projects shown in Table 1. It proved that the building can operate in the temperature range from 20 °C to 26 °C all year around [10] and that the target of indoor comfort was achieved with simple system control.