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Radiant heating and cooling systems based on capillary micro tubes

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ABSTRACT

Radiant heating and cooling systems based on capillary micro tubes have been gaining much popularity due to large operational area, space saving, small difference between temperatures of flowing water and air inside the room and consequently improved energy efficiency. The objective of this review is to find out fields of applying capillary micro tubes, to discover advantages and limitations and analysis of future development. Based on research results it can be concluded that heating system based on capillary mats is an effective and promising solution for residential and public buildings.

Content

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1. Introduction

The energy efficiency is the foreground trend in the building sector. In most European countries energy use must be reduced to approximately 20 kWh/m^2/year by 2020 [1-3]. Novel solutions in heating, ventilation and cooling (hereinafter HVAC) systems along with advance of thermal resistance of a building must be developed to decrease energy consumption.

Capillary micro tubes have been applied in a building sector recently. The first HVAC system based on capillary mats set in the building was established approximately in 1996 [2, 4-6].

HVAC system based on capillary micro tubes is a particular case of radiant hydronic cooling or heating systems. Radiant heating and cooling (hereinafter RHC) system can be defined as a system that radiant heat transfer covers more than 50 % of heat exchange within a conditioned space [7-10]. The radiant heat transfer provides thermal comfort due to absence of directed flows of air, even heating and cooling, quiet operation and absence of dust motion [2, 4, 5].

Conventional air conditioning systems or all-air systems only depend on the convective heat transfer for heating or cooling, and they should warm or cool the entire room air, resulting in high energy consumption and increased fan power [11-15]. Compared to HVAC systems, the RHC systems generally utilize the water as thermal media, which has much higher thermal capacity than air [15-19]. Thus much less energy is required to heat or cool the conditioned space because relatively low pumping energy is required [16]. The high temperature of flowing water in radiant cooling systems enables a chiller to perform with higher efficiency, which leads to the great reduction in primary energy consumption [20-22]. Aside from that, it is possible to use renewable energy as heat sources of the RHC systems, because renewable energy, such as geothermal or solar energy, can efficiently provide water in suitable temperature for low temperature heating or high temperature cooling [7, 8, 23-26].

2. Research overview on the hydronic radiant heating and cooling

2.1. Review method

For the literature review, published articles were searched on Science Direct. The keywords for the search are: «capillary micro tubes», «capillary tube system», «capillary mats heating cooling», «radiant heating and cooling system», «hydronic heating and cooling systems», «capillary ground exchanger».

The searched articles consisted of papers on RHC systems in general and capillary tubes systems in particular. The articles that have a direct relation with the capillary micro tubes systems were sorted out based on the title, abstract and conclusions. After all, the most interesting 92 articles on RHC systems in general were selected for more detailed analysis. Some standards or handbooks were also observed in order to review the general information of the concept, design and comfort criteria of the RHC systems. Catalogs of capillary mats production companies were studied in order to review the existing solutions.

2.2. Historical change and research trend

The history of application of RHC systems has started thousands years ago. The first mentioned RHC system is Roman hypocaust, which supplies hot combustion gases through cavity walls and floors [27-28]. The brief history of Roman hypocaust was reviewed by Bansal [29], the scientists also suggested using the idea of hypocaust along with modern HVAC systems.

Another type of traditional RHC was Korean Ondol. It used hot combustion gas from cooking fireplace to heat the floor of living rooms [27-28, 29, 31-32]. Since 1970s the Korean floor heating system has been transformed into hydronic floor heating system in order to improve energy efficiency [32].

In European countries the floor heating systems is embedded in 30 – 50 % of new residential buildings [11]. Also it is widely used in commercial and industrial applications, thus researching and developing the RHC is becoming more popular [33-35].

The RHC systems with capillary micro tubes have been recently started to be developed. The first paper dedicated to capillary mats was published in 2013 [2]. Since when there were a growing number of papers dedicated to it [4-6, 36-37].

2.3. Research topics

The research topics dedicated to RHC systems can be divided into three major groups:

- Issues of thermal comfort in the space where the RHC system is installed [12, 33, 38-45].
- Issues of thermal performance evaluation [9, 19, 20, 46-67].
- Issues of system configuration or control strategies for the practical applications [68-79].

The RHC systems used along with solar generation units is promising trend of research [80-87]. The RHC systems based on capillary micro tubes are slightly explored. There is a paper dedicated to analysis of thermal conditions in experimental rooms with embedded capillary mats in combination with solar heating system [6]. The temperature distribution around the tubes integrated into the prefabricated building sandwich element and sufficiency of micro tubes heating and cooling were examined by T. Mikeska in 2013 [2]. The comparison of applying low temperature radiant heating systems on walls, ceiling and floor was studied by Bojic M. [71]. The capillary micro tubes systems also were explored as heat ground exchanger [36].

3. The design of capillary micro tubes systems

The capillary micro tubes are usually implemented with diameter of approximately 4 mm made of polypropylene (PP) [2, 4, 5]. Tubes are combined in mats with fixing systems and round distribution tubes with an outer diameter of 20 mm. The micro tubes spacing is approximately 10 – 30 mm. The mats' width is usually from 150 mm to 1 m, length – from 1 m to 6 m. Since tubes are made of PP, they are pliable and can be used on any arc-shaped walls. Basic forms of mats are shown on fig. 1.

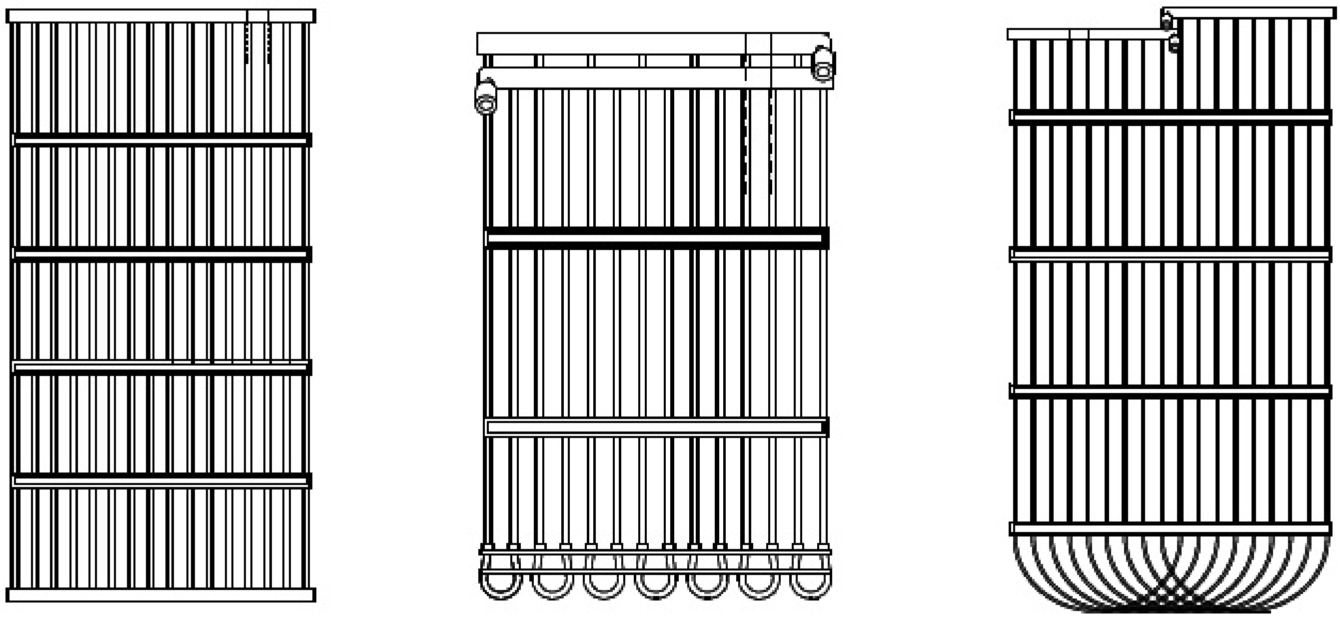

Figure 1. Basic forms of capillary micro tubes mats.

3.1. Special aspects of engineering design

The RHC system based on capillary mats is usually constructed in a same way as traditional RHC system does, but it has special aspects.

Taking into account projects of electricity, low current systems and a ceiling construction, layout of mats is built with fastening in hydraulic zones into each space of a building [5]. Traditional systems of cooling and convectional boxes can also be used in addition to capillary mats to offset peak loads [4]. Capillary mats' fabricator provides the designer an information about tubes friction. It usually does not exceed 1.5 meter of water column.

Concept scheme of cooling using capillary mats consists of two isolate contours. Heat-exchange unit divides two contours and usually consists of a pump, a reserve tank, manometer, thermometer, protection and stop fitting [6]. There should be a dew point sensor in every space of a building.

4. The application areas for capillary tube systems

RHC systems based on capillary mats can be applied in both buildings that were already built (historic buildings) and buildings under design. Capillary systems provide heating, cooling or both at the same time. Along with heating and cooling functionality capillary mats can be used as ground heat exchanger as an element of geothermal unit [36]. Ways of applying capillary mats are given in Table 1.

Table 1. Ways of applying capillary mats.

	Way of applying	Example of applying
Ceiling	– plastered ceilings	Office Noordeinde, the Hague
	– metal modular ceiling	The building of Allianz Treptowers, Berlin
	– drywall ceiling	Olympic Village, Vancouver
	–reinforced-concrete ceiling: prefabricated elements	Offices, the Cologne, Germany
	– exposed wiring	The Royal Penguins aviary, Berlin
Ceiling	– exposed wiring on metal guiding rails	
Floor	– heat-insulated floor: under self-smoothing concrete	
Walls	– plastered walls;	The Tonkovce Castle. Maly Mager, Slovakia
	– drywall walls: • prefabricated drywall panels; • under drywall construction	The German Heart Institute Berlin
Building structure	– prefabricated sandwich panels made of high performance concrete [2]	
Ground heat exchanger	– horizontal ground exchange collector	
Others	– convectional box	Office spaces
	– hypethral swimming pool	
	– lounge chairs	Wellness centre

The cooling capacity of a radiant cooling system may be limited by the dew-point temperature, the vertical air temperature, radiant asymmetry or an acceptable temperature of the cooled surfaces [88-92]. The heating and cooling capacity of the RHC systems depends on many aspects, such as the total heat transfer coefficient between the surface of the investigated element and the air in the room, the emissivity of different surfaces in the room, the view angle between the surfaces and the occupant, and the spacing between the tubes [2], the thermal resistance between the fluid flowing in the pipe and the surface of the element.

Depending on the way of applying, RHC system based on capillary mats provides various values of cooling capacity [4]. Correlation between the cooling capacity and temperature difference ΔT_U between water and inside air with different application options is shown on the fig. 2.

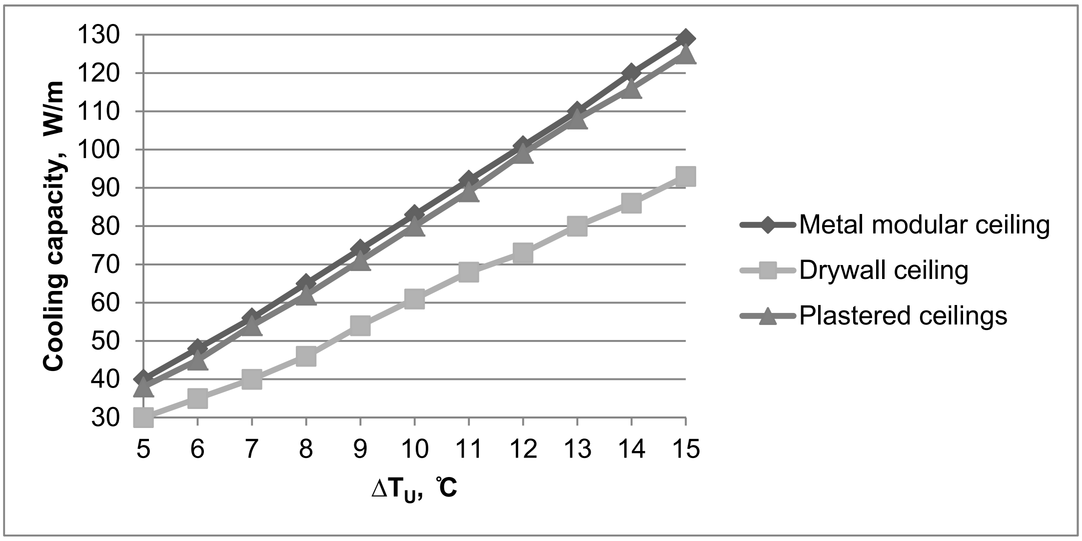

Figure 2. Correlation between the cooling capacity and temperature difference ΔTU between water and inside air with different application options

4.1. Horizontal ground heat collector

Horizontal ground heat collector has extremely high value of specific area of thermal conductivity, thus more heat energy is generated from 1 m^2 of ground area [37]. Individual heat capacity depends on soil structure. The ground collector is usually embedded below of depth of ground freezing. When capillary mats are located on 50 % of ground area the average value of heat capacity is 18 W/m^2 [36].

5. Advantages and limitations of capillary tube systems

Capillary tubes systems have its specific advantages and limitations. The specific gravity of capillary micro tubes mat is only 870 g/m^2. The amount of water in working system is 0.430 l/m^2. This advantage is extremely useful for applying in historic buildings because of comparatively low construction heights, thus capillary systems can be used during reconstruction. Small surface mounting (between 10 to 12 mm) allowed saving operational area of the space. Capillary systems are very flexible concerning vaults and ceiling cuts.

Another benefit of radiant cooling systems is the small difference required between the temperatures of the cooling or heating water and the room air. Thus, low-grade heat sources can be used, such as ground water and sea water in case of cooling, and solar energy, wind energy and geothermal energy in case of heating. Thermal comfort can be achieved in the space with a flowing cooling water temperature only 4 K lower than the average operative temperature in the room. In residential houses heating and cooling could be provided with one ceiling system.

One more benefit is that radiant system has a high degree of self-regulation. This high degree of self-regulation can be achieved in low-energy buildings, because heat losses from such a building are generally low. This passive control takes place without the installation of an additional controlling system.

The major disadvantage of capillary system is high initial costs of the heat-exchange unit and capillary mats. Another disadvantage is the slow response to a control system of radiant cooling systems. This slow response is mostly because of the fact that system needs to activate a large volume in a building structure, e.g. a floor or a ceiling.

Also the system needs an installation of a proper filtering system to avoid clogging the tubes in practice.

5.1. The comparison of traditional RHC and capillary micro tubes systems

The capillary micro tubes systems provide more even distribution of a temperature around the tube that provides improved thermal conditions. The capillary radiation system can create a small stratified vertical temperature distribution. The indoor air temperature distribution was uniform and stable.

The most common types of RHC systems’ pipes are metal-plastic or cross-linked polyethylene (PEX or XLPE) with diameter of more than 16 mm, embedded on the floor in parallel (serpentine) or spiral way in the building structure (floors, ceiling, walls) or in the center of the concrete slab in multi-storey buildings. The tubes spacing is approximately 150 mm. The flow temperature is 35 – 40℃.

Capillary micro tubes systems in comparison with traditional RHC systems can be embedded not only in the building structures but also before the fine finish and in process of reconstruction of historical building. The operational area consists of mats made of connected capillary tubes with the diameter 3.6 – 4.5 mm and tube spacing approximately 10 – 30 mm, the flow temperature is 28 – 30℃.

The differences between traditional RHC and capillary micro tubes systems are shown in Table 2.

Table 2. The comparison of traditional RHC and capillary micro tubes systems.

Characteristics	Traditional RHC system	RHC system based on capillary micro tubes
Diameter of tubes	> 16 mm	3.6 – 4.5 mm
Material of tubes	metal-plastic or cross-linked polyethylene (PEX or XLPE)	polypropylene (PP)
Spacing tubes	150 mm	10 – 30 mm
Way of tubes’ layout	serpentine or spiral	parallel
The flow water temperature for heating	35 – 40℃	28 – 30℃

6. Conclusion

In this paper, the review of applying radiant heating and cooling systems based on capillary micro tubes was accomplished. Capillary mats technology is a novel solution in HVAC systems conducive to improve energy efficiency of a building. In comparison with traditional RHC systems capillary mats provide better thermal comfort along with reduced energy demands to heat or cool circulating water. The applying capillary mats as ground heat exchanger or solar generator along with RHC system embedded in the building can entirely supply the residential house with heat. The major technology’s objection is high initial demands.

The performance of capillary micro tubes is slightly explored, thus it needs further observation.

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Лучистые системы отопления на основе капиллярных матов

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КЛЮЧЕВЫЕ СЛОВА

лучистые системы отопления;
капиллярный мат;
водяная система отопления;
низкотемпературное отопление;
энергоэффективность

АННОТАЦИЯ

Лучистые системы всё чаще применяются при строительстве зданий в европейских странах, поскольку имеют большую операционную площадь и, как следствие, являются высокотемпературной и энергоэффективной системой отопления. Целью этой статьи является обзор применения капиллярных матов, рассмотрение их недостатков и преимуществ, а также анализ возможности дальнейшего использования и развития. По результатам обзора можно сделать вывод, что системы отопления на основе капиллярных матов являются эффективным и перспективным решением для жилых и общественных зданий.

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