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Design on Nocturnal Cooling Radiator for Cooling Provision

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Abstract. As a natural passive cooling technology, nocturnal radiator can reject heat into the sky by electromagnetic infrared radiator exchange. In order to take full use of nocturnal radiator for cooling provision at night, this paper put forward two types of novel nocturnal cooling radiators in panel structure with different forms which is covered with high emissivity film installed horizontally against on the building roof. Both ends of the panels are connected to sub-catchment and thermal insulation material is spread below the panels. Fluent software is utilized to simulate the cooling performance of radiators and analysis the outlet temperature of water. Based on simulation results, the proposed radiator can satisfy sizable cooling requirement as the heat rejecter with low initial cost and operation fee for practical project utilization.

Introduction

It is well known that cooling energy consumption has a large proportion in the total energy use especially in hot climate countries. In order to achieve indoor thermal comfort, a great amount of energy need to be consumed for cooling and heating. Consequently, it is of great importance to search renewable energy, which can restrict energy expenditure in the buildings.

Under the circumstance, the use of passive cooling techniques can well improve the current situation. Radiative cooling techniques are based on the principle of heat loss by long-wave radiator emissions, from a body towards another body of lower temperature, which is considered as the heat sink [1]. By exploiting the “atmospheric window” in the range of wavelengths 8-13μm to achieve the objectives of cooling.

Long-wave radiator happens during the daytime and nighttime, which is referred to as solar radiator in daytime and nocturnal radiator cooling in the nighttime. By applying cooling radiator in the buildings to achieve the the purpose of cooling. But as it is pointed out by Eicker and Daliband [2], nocturnal radiative cooling is still not applied widely in today’s buildings. Sikula et al use hybrid roof panel and solar energy to evaluate the usability [3]. By Hollick’s paper, night cooling radiator is not just limited to the night time [4]. Man studied a novel nocturnal cooling radiator which was used as a supplement heat sink [5]. Matsuta et al. studied a solar heating and radiative cooling system using a solar collector-sky radiator [6]. The performance of nocturnal radiative surfaces with the convective heat gain inhibited by a polyethylene film covering the radiative surface has been studied by Mostrel and Givoni [7]. Research focused on the high-emissivity paints for nocturnal radiative surfaces was studied by Harrison and Walton [8].

Based on different application, the passive nocturnal cooling system can be classified into passive system and hybrid system. But the direct application of radiative cooling has several limitatiffons. Firstly, the cooling of capacity of nocturnal radiative cooling can not match the building cooling loads and can not be used at daytime when the peak building cooling loads exists. And furthermore, the cooling performance of the radiative cooling is influenced by cloud and ambient temperature. Therefore the first system is rarely applied in the structure. The existing buildings usually work with the cooling tower to exclude the unbalanced cooling load. But in actual running processes, the limiting conditions such as location, viewing conditions, noise problems will influence the running of cooling tower. Then we can use the night cooling radiator to work as a supplemental cold source to achieve the aim of economic and environmentally friendly energy utilization.

Study on night cooling radiator still exist too much and in this paper, we will propose two different radiators and simulate the operation performance of the two radiators. And the cooling performance was investigated during the simulation. Thus the feasibility and effectiveness of the cooling system was investigated and analyzed. It provides theoretical basis for the popularization and application of nocturnal cooling radiator.

Modeling and Description of the Nocturnal Radiator

When design the radiator, the running condition will be referred to the following assumptions [9]:

(1)Heat loss from back and the edge of the radiator can be negligible.

(2)The operation of the radiator is a steady-state process.

(3)The heat flow and water in the radiator is one-dimensional along its length direction.

(4)The distance between the pipes of the radiator should be minimum.

In the present design of the radiator, one consists of aluminum panels painted with high emissivity materials with 3mm circular arc groove on the top of plate. The other consists of aluminum panels painted with high emissivity materials with 3mm mechanical dent on the upper surface. And below the radiator we will use insulation material to reduce heat loss. Based on these assumptions, the shape of radiators is shown in the Fig.1 and Fig.2.

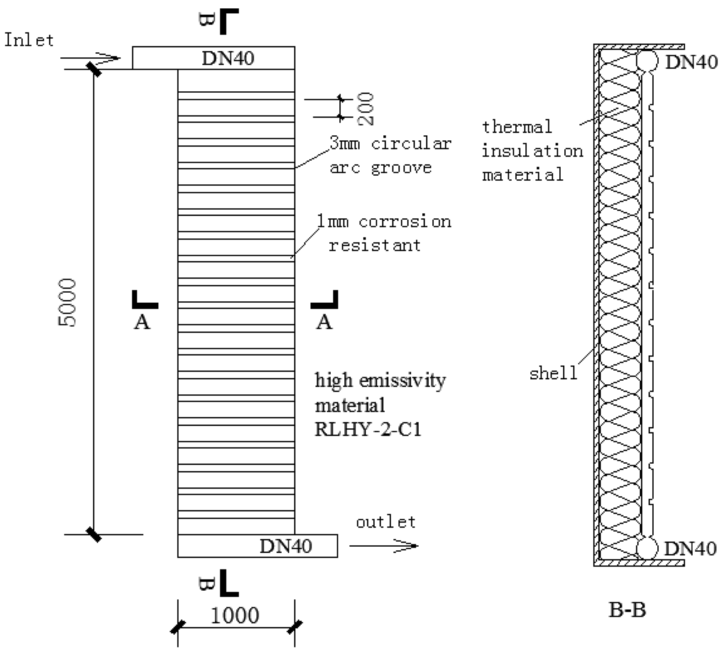

Fig. 1 Design parameters of the nocturnal radiator type 1

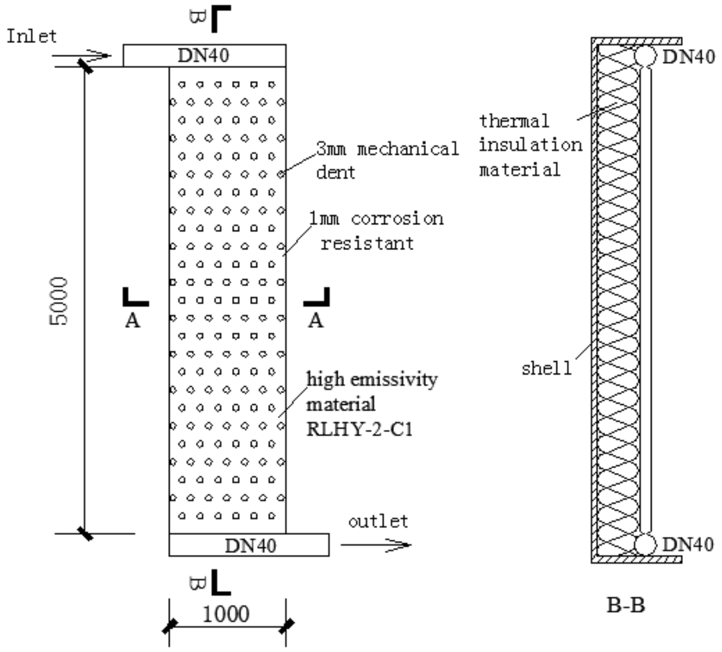

Fig. 2 Design parameters of the nocturnal radiator type 2

The heat transfer between the radiator and the sky consists of convective and radiative heat transfer. It can be calculated by the following equation:

$$q_a = h_{rad}(T_r - T_{sky}) \tag{1}$$

In the expression h_{rad} is the radiative heat transfer coefficient, and can be known from the next equation:

$$h_{rad} = 0.000000227\tau\varepsilon T_a^{\ 2}. \tag{2}$$

In the previous equation, the is the infrared transmittance of the wind screen (if there is no wind screen, the τ =1). ε is the infrared emissivity of the radiator.

Convective Heat Transfer

The convective heat exchange between the radiator and the ambient air is calculated by the following equation:

$$q_w = h_{\mathrm{wind}}(T_{rad} - T_{amb}). \tag{3}$$

T_r and T_a are the temperature of radiator and ambient air, h_w is the heat transfer coefficient.

The heat transfer coefficient is influenced by wind velocity v. With no wind screen, the heat transfer coefficient will be calculated by the following equation [10]:

$$h_{wind} = 2.8 + 0.76v \text{ If } 0.5 \le v < 5. \tag{4}$$

$$h_{wind} = 3.5 \quad \text{If} \quad 0 \le v < 0.5. \tag{5}$$

Radiative Heat Transfer

$$q_R = \varepsilon\ \sigma\ (T_r^4 - \mathrm{T}_s^4) \tag{6}$$

In the previous equation, T_s is the temperature of black body that has the same emitting power as the sky. And can be calculated by the infrared radiation intensity based on the Stefan Boltzmann Law.

Outlet Water Temperature

The temperature of outlet water T_{out} can be calculated by the following equation:

$$T_{out} = T_{th} + (T_{in} - T_{th}) / e^{\frac{hA}{mc_p}} \tag{7}$$

In the previous expression, the T_{in} is the inlet fluid's temperature, h is the heat transfer coefficient between the fluid circulating under the radiator and the ambient air, A is the area of the radiator, m is the mass flow rate and the c_p is the heat capacity.

Results and Analysis

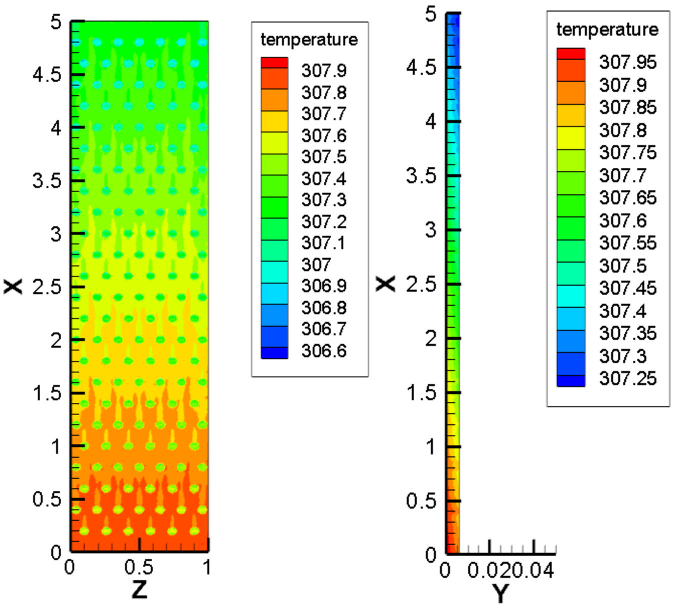

Fig. 3 (m=0.5kg/s) Temperature field variation of type 1

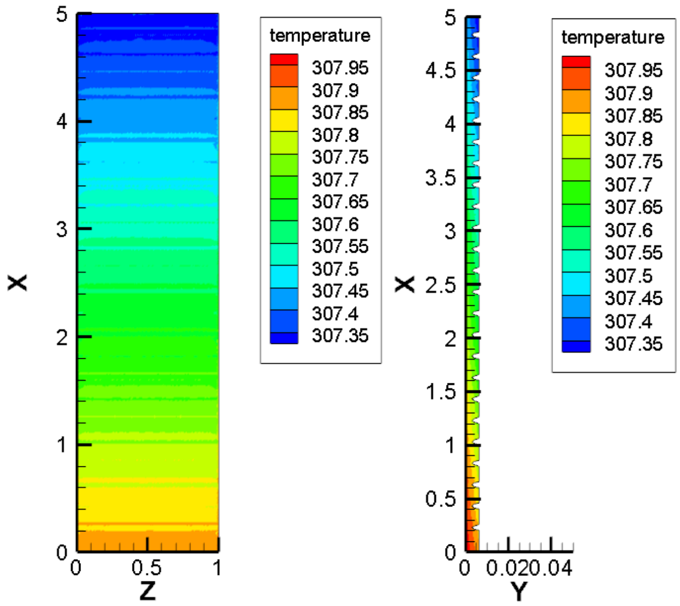

Fig. 4 (m=0.5kg/s) Temperature field variation of type 2

From the calculated result, the temperature distribution of radiators is shown above Fig.3, Fig.4 when the mass flow rate is 0.5kg/s. It is shown that temperature variation in the plate and outlet temperature of cooling water. The inlet water temperature is 308K, and the outlet water temperature of the first shape is 307.25K, and the second outlet water temperature is 307.45K.

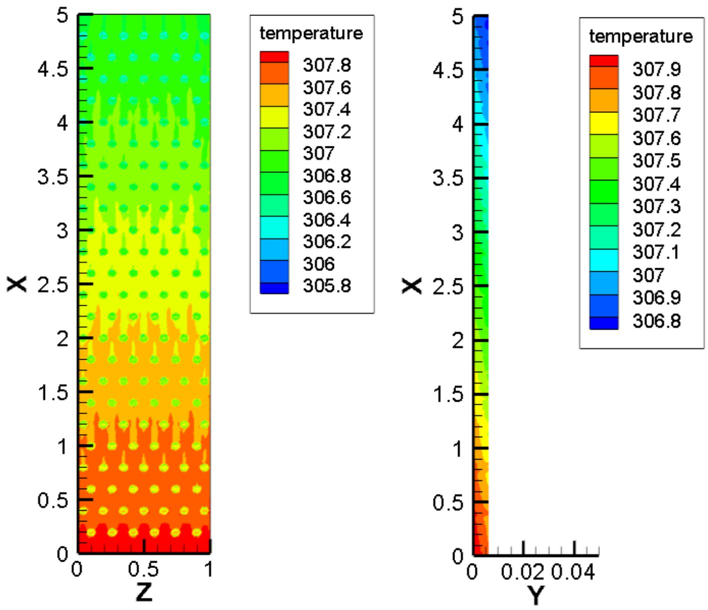

Fig. 5 (m=0.3kg/s) Temperature field variation of type 1

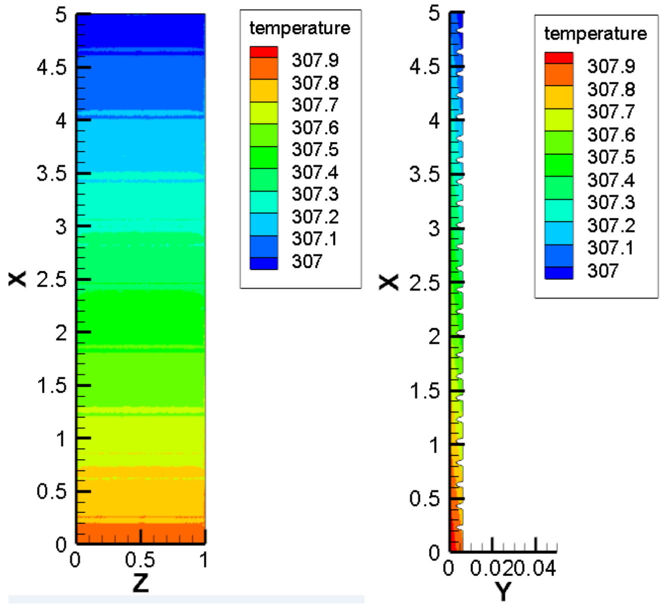

Fig. 6 (m=0.3kg/s) Temperature field variation of type 2

By changing the mass flow rate to simulate under different flow velocity the temperature field of nocturnal cooling radiators, and the cooling performance is improved and the outlet water temperature of the first form is 306.90K, and the second is 307.09K.

Discussion

As shown above, the cooling capacity can be provided by the two nocturnal cooling radiators. Through comparison, the first form with 3mm circular arc groove had better cooling performance than with 3mm mechanical dent, and the cooling performance improved with the decrease of the flow velocity. When increasing the length of nocturnal cooling radiator to 5m or longer, it will have 5K or more temperature difference.

Conclusion

Based on the simulated results, it's feasible to be used in practical engineering as a supplementary heat sink to cool water. And nocturnal cooling radiator with 3*mm* circular arc groove could have better cooling capacity and can be in actual utilization.

Acknowledgement

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