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Seasonal cooling load reduction of building by thermosyphon heat pipe radiator in different climate areas

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A B S T R A C T

In this study, a concept of using thermosyphon heat pipe radiator to extract heat from water in a storage tank to generate cooling water during the nighttime was proposed. The cooling water could be used to serve the cooling load in a room during the daytime. A tested room with artificial load was constructed and a heat transfer model to calculate the water temperature during the nighttime and the room temperature during the daytime was developed. The simulated results agreed well with those of the experimental data. The model was used to find out the possibility of this concept for seasonal cooling load reduction of the similar building in the areas of different climates. The selected sites were Bangkok and Chiang Mai, Thailand and also Alice Springs, Australia where they are hot and humid, hot and semi-humid, and hot and semi-arid, respectively. Cooling water was produced during winter and used to serve cooling load in an air-conditioned building in summer. It found that, among three cities, Alice Spring showed a highest potential followed by Chiang Mai and Bangkok. The effect of controlled room temperature and *UA* of the room cooling coil on summer load fraction were shown.

1. Introduction

Cooling water could be produced during nighttime by nocturnal cooling which was one of the passive cooling methods. By rejecting heat to the surrounding ambient in the nighttime, the temperature of cooling water could be dropped down and the produced cooling water was kept in a storage tank and used to serve room cooling load in the daytime. The common technique was to feed water by a water pump through a metal radiator in the night [1–5]. There was heat dissipating to the ambient air by convection and to the sky by radiation then the water temperature leaving the radiator was reduced and then the cooling water was kept in a storage tank. Wannaree and Kiatsiriroat [6] proposed a new technique that had no water flow by water pumping. A thermosyphon heat pipe radiator was used to extract heat from stored water and the heat was transferred to the surrounding ambient. Evaporator of a thermosyphon heat pipe was dipped in a water tank and its condenser was attached with a metal plate exposed to the surrounding ambient. During nighttime, the condenser was cooled down by convection to the surrounding air and by radiation to the sky then there was a temperature difference between the evaporator and the condenser then there was heat transfer from the stored water at the evaporator to the condenser and then to the surrounding ambient thus the water temperature in the tank could be reduced. The stored cool water could be used to serve cooling load during the daytime in any building with or without electrically-operated air-conditioning. With some experiments for a non air-conditioned room in Chiang Mai, Thailand, the temperature in the room during the summer daytime could be reduced around 4.0–5.0 °C from the ambient temperature.

A model of cooling water production by thermal convective and radiative nocturnal cooling from thermosyphon heat pipe radiator was developed and verified with the experimental results of a tested room having artificial load by Chotivisarut and Kiatsiriroat [7]. In this research, their model was applied to seasonal analyses for Bangkok and Chiang Mai, Thailand where the climates are hot and humid, hot and semi-humid, respectively and Alice Springs, Australia where the climate is hot and semi-arid. Cool water was produced during winter and used to serve cooling load in an air-conditioned building in summer. The sizes of the radiator and the storage tank affecting the summer cooling load were considered.

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2. The tested room

An experimental room with a thermosyphon heat pipe radiator was constructed similar to that is given in Fig. 1. The radiator consisted of a set of thermosyphon heat pipes made of 48 copper tubes which the operating parameters of thermosyphon heat pipe are shown in Table 1.Its condenser section was attached with an aluminium sheet of 6.36 m^2 and acted as the radiator in the nighttime. The evaporator section was dipped in a well-insulated rectangular water storage tank of 1.0 m^3. The radiator was installed on a 45° tilting roof of the tested room. Cooling water in the storage tank was fed through six cooling coils each of 0.87 m^2 installed at the ceiling of the room which was well-insulated. The room cooling load was generated during the daytime by a set of electrical heaters. The room had dimensions of 3.0 × 3.0 × 2.5 m.

The rates of heat generation in the tested room were 500, 1000, 1500 and 2000 W. During the daytime, a 45 W submersible pump was used to circulate cooling water from the tank into the tested room. The mass flow rate of the cooling water in the experiment was controlled at 0.017 ± 0.001 kg s^{-1}. The ambient dry bulb/wet bulb temperatures, the stored water temperature, the room temperature, the radiator temperature, the inlet and outlet temperatures of the room cooling coil were recorded by a set of integrated circuit sensors with ±0.1 °C accuracy. The experiments were done in February under the climate of Chiang Mai, Thailand. The minimum nighttime ambient temperature was always below 15.0 °C but the daytime ambient temperature was rather high of which the maximum temperature difference during a day might be over 20.0 °C. The sky was quite clear thus high radiative heat transfer from the radiator surface to the sky could be obtained.

3. Simulation model

As shown in Fig. 1, the radiator extracted heat from the storage tank during nighttime to reduce the water temperature in the tank. The cooling water could be fed into the room through heat exchanger which was a set of cooling coils installed at the ceiling in the daytime to cool the air in the room.

Table 1
The operating parameters of thermosyphon heat pipe.

Description	Value	Unit
Outside diameter	19.05	mm
Inside diameter	17.55	mm
Tube thickness	0.75	mm
Thermal conductivity of copper tube	400.0	W m^{-1} K^{-1}
Evaporative section length	1.5	m
Adiabatic section length	0.2	m
Condenser section length	1.5	m
Filling ratio	0.6	
Working fluid	R-134a	

3.1. At the storage tank/radiator (nighttime)

The energy balance at the water storage tank and the radiator as shown in Fig. 2(a) during the nighttime when the tank was well-insulated could be

$$Q_{gain} + Q_{conv} - Q_{rad} = Q_{stored}. \qquad (1)$$

Q_{gain} was heat gain from surrounding (J), Q_{conv} was convective heat transfer (J), Q_{rad} was radiative heat transfer (J), Q_{stored} was stored energy in the storage tank (J). In numerical form, the equation could be

$$\frac{k_{ins}A_{tank}\Delta t}{L_{ins}}\left(T_a^i - T_w^i\right) + h_{rad}A_{rad}\Delta t\left(T_a^i - T_{rad}^i\right) + \varepsilon\sigma A_{rad}\Delta t \times \left(\left(T_{sky}^i\right)^4 - \left(T_{rad}^i\right)^4\right) = m_w C_{p(w)}\left(T_w^{i+1} - T_w^i\right), \qquad (2)$$

or

$$T_w^{i+1} = \frac{\Delta t}{m_w C_{p(w)}}\left[\frac{k_{ins}A_{tank}}{L_{ins}}\left(T_a^i - T_w^i\right) + h_{rad}A_{rad}\left(T_a^i - T_{rad}^i\right) + \varepsilon\sigma A_{rad}\left(\left(T_{sky}^i\right)^4 - \left(T_{rad}^i\right)^4\right)\right] + T_w^i, \qquad (3)$$

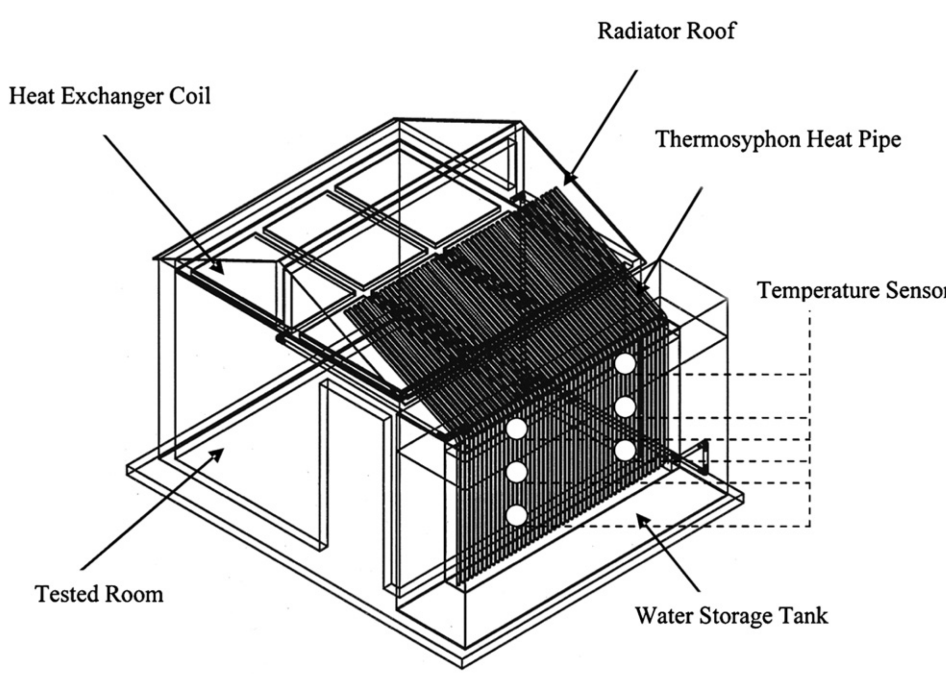

Fig. 1. The concept of using thermosyphon heat pipe radiator for nocturnal cooling in the tested room.