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Experimental Studies on the Roof Pond House under Tropical Climatic Conditions*

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ABSTRACT

Thermal performance of a model roof pond house was evaluated experimentally. The house model of 1 m x 1 m x 2.8 m was simply constructed and tested at Chiang Mai University located in Chiang Mai province (700 km North of Bangkok). The roof pond system, a type of passive cooling method, was designed for a combination of trickle roof and intermittent water spraying techniques. Three-layer shading devices made of plastic sheets were also installed above the roof to reduce radiation exposure and enhance heat convection. The roof pond house was tested for various water flow rates, separation of shading devices and solar radiation. The roof pond operated with high water flow rate, installed with larger space, could enhance temperature reduction. It was experimentally demonstrated that it is possible to maintain the indoor temperature 2-4 °C lower than the outdoor temperature using this roof pond system in a tropical climate.

***Keywords* :** roof pond, passive cooling, intermittent water spraying, experimental study

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1. Introduction

During daytime in summer, the indoor condition of hillside regions of Chiang Mai is often uncomfortable. It is often not possible to achieve thermal comfort in offices or houses without air conditioners. Energy consumption of air-conditioning (vapor compression) systems contributes substantially to the country energy usage, especially during the peak time of summer (March-April). Alternative methods of cooling may be employed to reduce energy usage of conventional air conditioning systems.

Among numerous methods available, passive cooling using roof pond system has been considered appropriate for those who cannot afford vapor compression air conditioning. Experimental investigations of passive cooling methods have been undertaken in some previous studies (Nahar *et al.*, 1999; Nahar *et al.*, 2003; Rincon *et al.*, 2001; Runsheng *et al.*, 2004). Various roof pond techniques are possible, e.g. skytherm, energy roof, skybird, cool pool, water-retaining roof, trickle roof, and intermittent water spraying. Water spraying method is simple, inexpensive, and suitable for the tropical climate. Typically water is sprayed on the roof for 40 seconds every 5 minutes to reduce heat absorption due to solar radiation. Trickle roof is operated by water flowing above corrugated roof. Then, water is circulated through wall and roof to carry heat away. Water evaporation during its operation does not disturb indoor humidity, so that the trickle roof is suitable for house under hot and humid climate.

In a previous study, thermal ventilation experiments were carried out for two similar testing houses by Fongsamootre *et al*. (2003), using water-retaining roof. It was shown that the roof pond system reduced temperature inside the experimental house by approximately 2.0 ^{o}C during daytime, and increased the indoor air temperature by about 1.5 ^{o}C at night. However, indoor absolute humidity was not affected by the operation of the roof pond system.

In this paper, two identical houses were compared experimentally. One house was equipped with the combined trickle roof and intermittent water spraying methods. The other was the conventional insulated-roof house. This study aimed to reduce the heat load from the roof in hot and humid regions by identifying suitable passive cooling technique. The comparison of internal temperature measurement in both experimental houses allows the effectiveness of the modified roof pond system to be studied.

2. Experimental Set-Up

Two experimental houses were constructed and placed on the roof of a three-story building at Chiang Mai University. They were 3 m apart to avoid the shade from each other and from surroundings as shown in Figure 1. One of them was equipped with a roof pond system, and the other was a well insulated-roof house. The house dimensions are 1.0 m x 1.0 m x 2.8 m, with typical Thai-style roof and gable using corrugated cement tile. The walls were made of gypsum board covered by plastic for waterproofing. No ventilation was provided, and no windows or any openings on all facades, except one door.

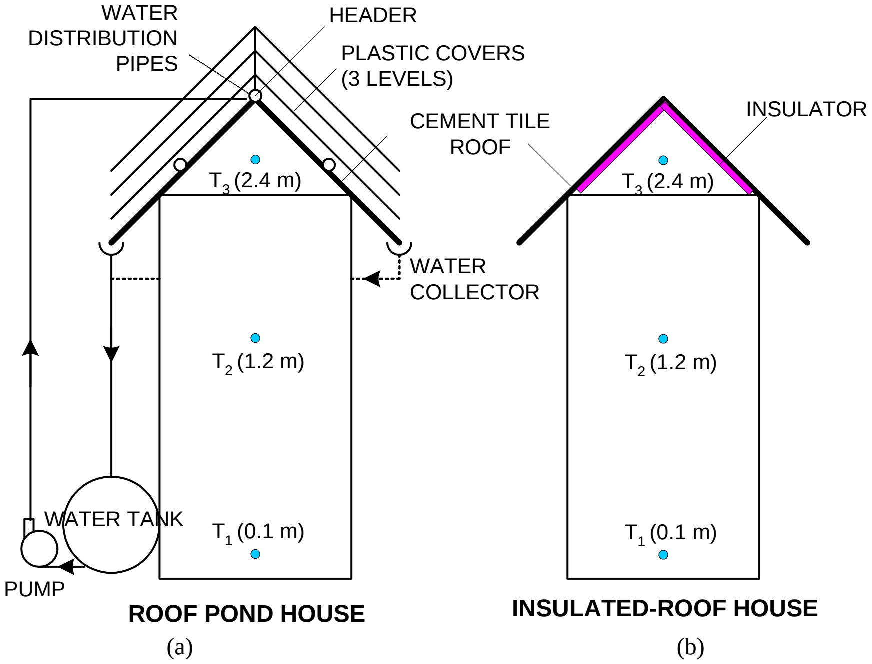

Figure 1 *Two identical experimental houses, (a) equipped with roof pond system, (b) with well insulated roof.*

For the house with roof pond system, a water cooling system was used. It consisted of a 200-L horizontal cylindrical water tank, a 0.5 hp water pump and piping system. Three layers of plastic covering supported by steel frames were installed on top of the roof, giving three layers of air gap. The other house was insulated beneath the roof (Figure 1(b)). The insulator was a glass wool type, rapped by aluminum foil, and 2-in thickness.

During roof pond operation, water was pumped from the storage tank to the top of the roof and flowed out from the perforated header, through tile grooves and back down to the tank. Figure 2 shows that cooling water was flowing through the cement tile grooves to the water collector.

Figure 2 *Flow of water through the grooves of the cement tiles of the roof pond house*

Indoor and outdoor temperatures of both experimental houses were measured using Type-K thermocouples, and recorded by a DR130 Yogokawa data logger. Indoor temperatures were measured at 3 elevations; 0.1 m, 1.2 m and 2.4 m from the ground. Three parameters were varied for different test cases:

- Water flow rates of 10 L/min, 20 L/min and 30 L/min.
- Spaces between plastic covering of 5 cm, 10 cm and 15 cm.
- Three sky conditions; clear sky, partly cloudy sky and cloudy sky.

The level of temperature reduction by the roof pond system was determined from temperature differences of the experimented houses as indicated on Figure 1. Two types of water spraying header were used; only one header on the top corner of the gable, and with two additional headers on both sides as indicated on Figure 1. The reason for increasing the number of headers was to obtain more wet area of roof and heat removal rate. However, the experimental results showed no differences due to this factor. As mentioned by Fongsamootre *et al*. (2003) the relative humidity condition could not be affected by the roof pond system. Therefore, the variation of indoor humidity would not be considered.

3. Result and Discussion

3.1 Influence of cooling water flow rates

Temperature profiles of roof pond house, using cooling water at flow rate 30 liters/min, are illustrated in Figure 3, which shows that the roof pond system could reduce house temperature by about 2.0 – 4.0 ^oC for a 12 hour period (11:00 – 23:00 hr), afterward indoor temperature increased to ambient condition. Temperature reductions for three flow rates were investigated, showing that higher flow rate gives larger differences. Temperature difference is defined as the difference between indoor temperature ($\Delta T = T_{w/0,roof\ pond} - T_{w/,roof\ pond}$) at each level of two experimented houses, without and with roof pond installed.

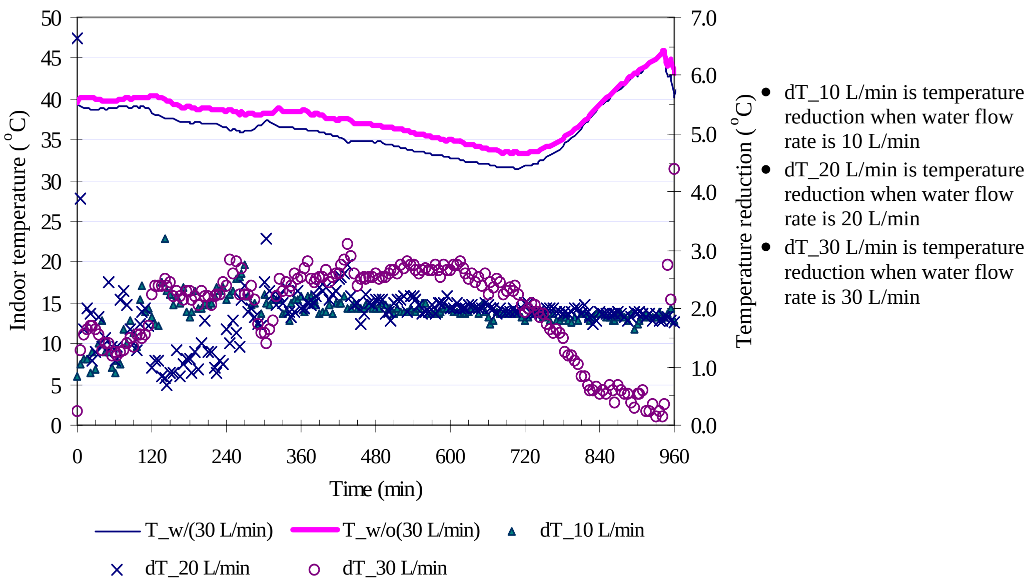

Figure 3 *Indoor temperature and temperature difference of the roof pond system at various cooling water flow rates.*

The maximum temperature reduction obtained from 30 L/min, the averaged values from three levels were about 1.6 ^oC (38.0 – 36.4 ^oC). However, ΔT at 2.4-m height was always insignificant, so that the averaged temperature differences were calculated based on ΔT of 0.1-m and 1.2-m heights. If temperatures from three levels were averaged over inside air volume as given by Equation (1), maximum temperature reduction was also obtained from 30 L/min flow rate, about 1.6 ^oC (38.3 – 36.7 ^oC).

$$\bar{T} = \frac{\int_0^V T dV}{V} \quad (1)$$

$\bar{T}$ is averaged temperature over air volume
V is volume of air inside the experimented houses

Therefore, the roof pond house was usually at lower temperature than the regular house, for all flow rates. These three flow rates were lower than those used in Fongsamootre *et al*. (2003), showing that a lower water flow rate could be used effectively for the purpose.

3.2 Air gap spaces of covered plastic cloths

The influence of spacing between each layer of shading device interval of the plastic cloths was studied. Three values of air gap were tested; 5, 10 and 15 cm, height beyond this was easily damaged under windy condition. The shading device installed above the roof helped to reduce heat absorption from solar radiation, and to enhance cooling by heat convection. In Fongsamootre *et al*. (2003), they suggested number of plastic shading layers of three. Therefor, three plastic layers were used in this study. The results of temperature reduction are shown in Table 1. Negative temperature differences of 2.4-m height were resulted from heat accumulation. Plastic covers acted as the shield and reduced heat reflection back to the atmosphere, especially in case of no ventilation fan. Therefore, heat accumulated under the roof was the drawback of these three-layer shading devices.

Air gap (cm)	$\Delta T(^oC)$ at height from ground of				Average indoor temperature (^oC)	
	0.1 m	1.2 m	2.4 m	Average	w/	w/o
5	1.5	0.2	-0.4	0.4	33.9	34.3
10	1.9	0.0	-0.5	0.5	37.5	38.0
15	2.4	0.4	-0.3	0.8	39.8	40.6

Table 1 *Effect of air gap spacing between plastic shading on temperature reduction*

Experimental results demonstrated the better heat removal by higher air gap spaces, under no water circulation condition. The maximum spaces of 15 cm gave best temperature reduction of approximately 0.8 ^oC. However, when the shading device concept is applied to reduce heat load, appropriate esthetic should be considered. Three levels of covers on top of roof might not be either practical or economical.

3.3 Roof pond performance under various sky conditions

Thailand is situated between 5^o 37' N and 20^o 27' N, with year round relative humidity about 64% to 84% (TMD, 2005). The sky condition was bimodal and mostly partly cloudy. Clear sky normally occurs during winter (November – January) and part of summer (March – April). Other periods are usually under partly cloudy and cloudy conditions. Wongsuwan and Kumar (2005) roughly classified sky conditions into four types; clear, partly cloudy, cloudy and very cloudy skies. They used values of daily global radiation on aperture plane and ratio of daily diffuse horizontal radiation on daily global horizontal radiation to characterize sky conditions. Seven days in April, during which are experiments were conducted, could be classified as three sky conditions, namely clear, partly cloudy and cloudy conditions. The house equipped with roof pond with water circulation had temperature reduction approximately 1.6 ^oC;

- from 38.0 ^oC to 36.4 ^oC for clear day condition,
- from 39.0 ^oC to 37.4 ^oC for partly cloudy day condition.

However, under cloudy sky condition, roof pond could not enhance temperature reduction significantly.

3.4 Comparison between roof pond system and well insulated-roof house

Two experimented houses were compared under similar climatic conditions, one with roof pond operation and the other with glass-wool insulated roof. In the roof pond house, cooling water rate about 10 L/min was circulated through top of the roof, and three-layer shading devices (with 10 cm gaps) were installed on the top of cement tile. The indoor temperatures of two experimented houses were found not significantly differences. Water temperature in the storage tank varied between 40 to 50 ^oC, which corresponded to thermal energy storage of 16.7 MJ/day. The cooling water provided extra energy storage capacity. Hot water could make the roof pond system merit and competitive to insulation. In environmental point of view, hot water has usefulness and harmless. In contrast, the glass-wool insulator may cause cancer to user if its seal is broken.

4. Conclusion

An experimented house equipped with the roof pond system was tested for seven days. The roof pond was a combination of trickle roof and intermittent water spraying. This system was consisted of three-layer plastic shading devices, one 0.5 hp pump, and one 200-L storage tank. Shading device was simply made of plastic cloths and supported by metal frame. Water was circulated through top of the roof with flow rate lower than 30 L/min. It was proof to reduce indoor temperature of experimented house. The roof pond operation was practical under usual sky conditions; clear and partly cloudy skies. Heat accumulated in the storage tank could be utilized as extra hot water. Larger spaces between three-layer shading devices provided better temperature reduction. The roof pond requires simple operation, without special monitoring and maintenance. However, awareness should be paid on esthetic and wind damage. In brief, the roof pond system is a potential candidate to achieve better comfort conditioning of house in hot and humid area.

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