CHAPTER 5

NOCTURNAL LONG WAVE PASSIVE COOLING FOR SEASONAL COOL STORAGE APPLICATION

5.1 Introduction

In this chapter, the nocturnal cooling system was implemented to generate seasonal cool storage. Cooling water will be produced and kept in a storage tank during winter and it will be used to serve building cooling load in summer. In this chapter, the concept of nocturnal cooling with thermosyphon heat pipe radiator to assist thermal load of air-conditioned building was considered. The conditions for the simulation have given in Table 5.1 when the storage tank was a rectangular shape, differed in its length but had the same 1.5 m height x 0.2 m thick. The calculations were carried out with the weather data of Chiang Mai, Thailand. With the model in the previous chapter, the percents of load reduction are evaluated when the controlled room temperature, the total rate of cooling load and the radiator area are prescribed. Figure 5.1 shows the flowchart of calculation concept.

Figure 5.2 has shown an example of an air-conditioned room with a controlled room temperature at 27.0 °C in the daytime in summer. The room had a radiator of 100.0 m^2 and a storage tank of 15.0 m^3. The calculation started from November which was the winter starting time. The stored water temperature would be reduced gradually to the lowest temperature at around 11.7 °C at 24th December. After that, the stored water temperature was raised up to around 15.4 °C at the end of February due to heat gain from the surrounding ambient of which the temperature was increasing. The produced cooling water then was used for cooling in the building during March to June which was summer period. In the Figure, the values of *UA* of the room cooling coil were estimated to be 500 and 1000 W K^{-1}. The cooling water absorbed heat in the room then its temperature was increased during the daytime and the heat was rejected to the surrounding ambient during the nighttime then the temperature in the storage tank dropped down. Since the room temperature was controlled not to exceed 27.0 ^{o}C, with higher value of *UA*, the coil could absorb higher heat rate and the highest temperature of the water temperature was found to be around 24.0 ^{o}C. In the last four months, July to October, which was rainy season, the water was not fed into the building, the water temperature was then reduced night by night to a certain value and the new cycle restarted.

Table 5.1 The conditions for seasonal simulation.

Description	**Value**	**Unit**
Floor area	45.0	m^2
Simulation interval	3600	s
Storage volume	5.0-15.0	m^3
Mass of storage water	5000-15000	kg
Radiator area to number of thermosyphon heat pipe ratio	0.1325	
Thermal conductivity of storage tank insulation	0.040	W m^{-1} K^{-1}
Storage surface area	57.21-170.43	m^2
Storage tank insulation thickness	300	mm
Radiator average heat transfer coefficient of convection	8.7	W m^{-2} K^{-1}
Radiator area	25-100	m^2
Radiator emissivity	0.9	
$UA/\dot{m}_w C_{p(w)}$	1.483	
Cooling coil effectiveness	0.773	
Cooling load	3517-35170 (1.0-10.0)	W Tons of refrigeration
Overall heat transfer coefficient at the cooling coil	500, 1000	W K^{-1}
Thermal conductivity of tested room insulation	0.051	W m^{-1} K^{-1}
Controlled space temperature	23.0-27.0	°C
Tested room insulation thickness	25	mm
Daytime operation	12	hours

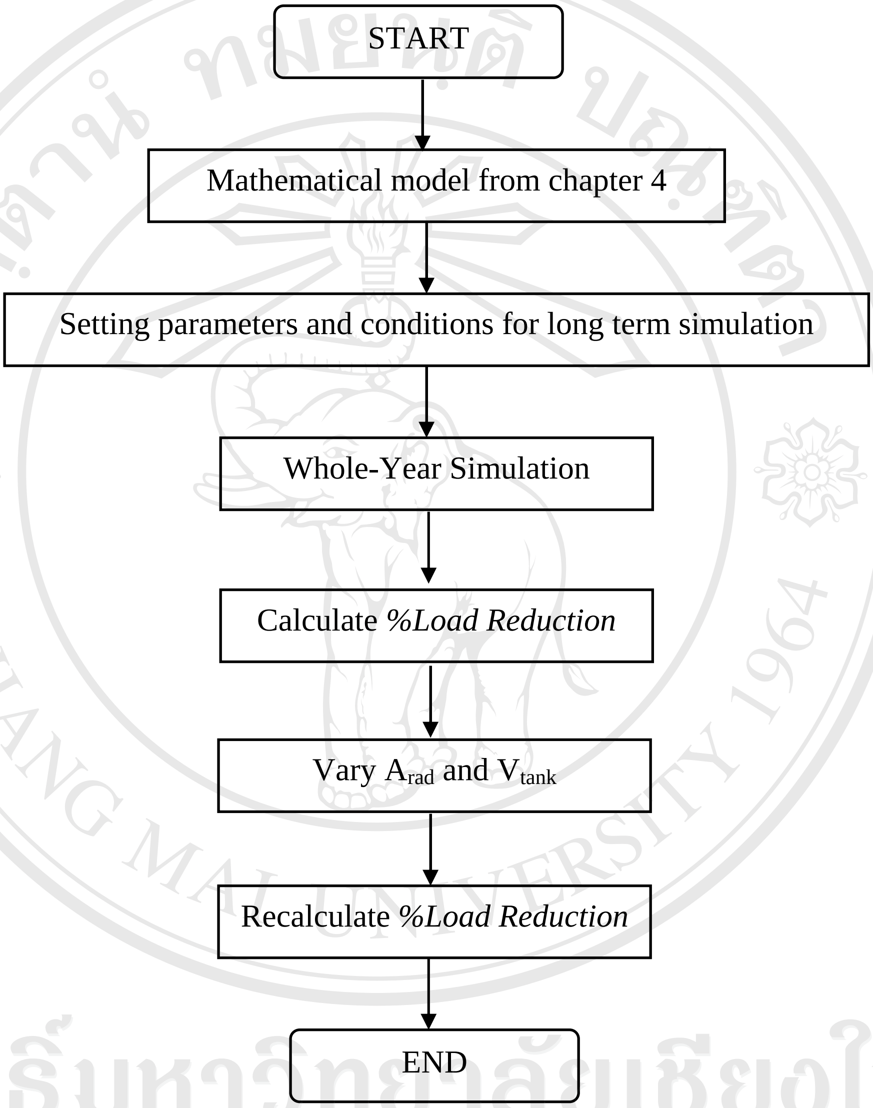
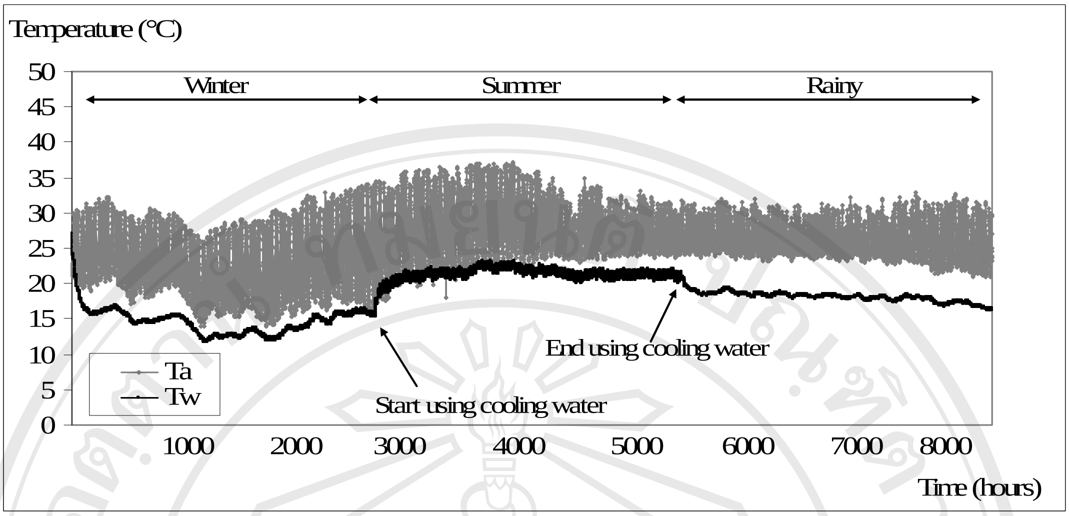
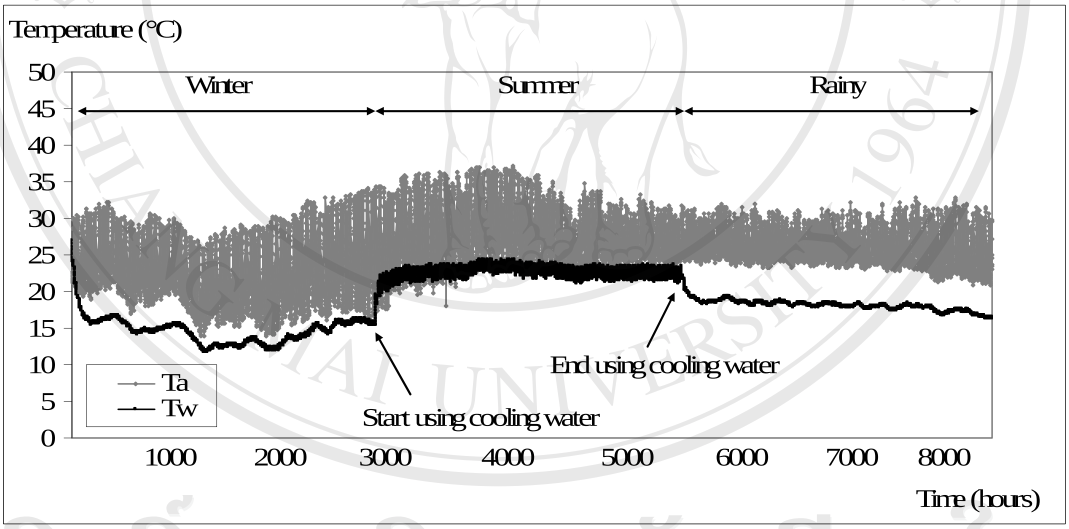


Figure 5.1 Flowchart of the long term seasonal passive cooling system.



(a) With $(UA)_{coil}$ = 500 W K^{-1}.



(b) With $(UA)_{coil}$ = 1000 W K^{-1}.

Figure 5.2 The simulated whole-year temperature of the cooling water used in summer. The passive system had a 15.0 m^3 storage tank with 100.0 m^2 radiator area. The inside air-conditioned room temperature was at 27.0°C.

Figure 5.3 has shown an example of an air-conditioned room with a controlled room temperature at 27.0 °C in the daytime in summer. The room had a radiator of 100.0 m^2, a storage tank of 100.0 m^3 and with $(UA)_{coil}$ = 500 W K^{-1}. The system had higher thermal inertia when the storage volume was larger. The stored water temperature gradually went down in the winter and then gradually went up when served the cooling load in the summer daytime.

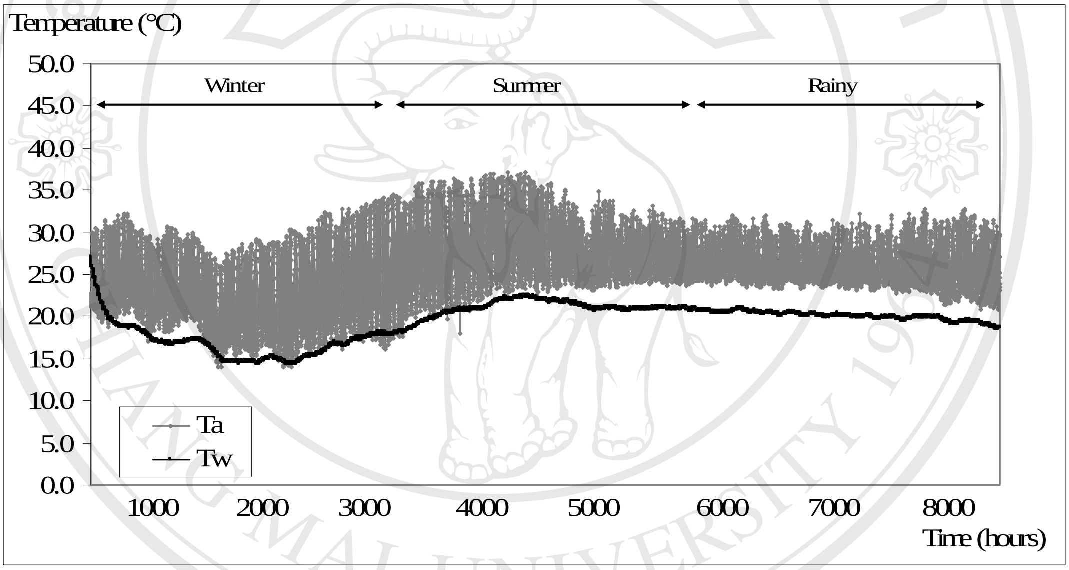


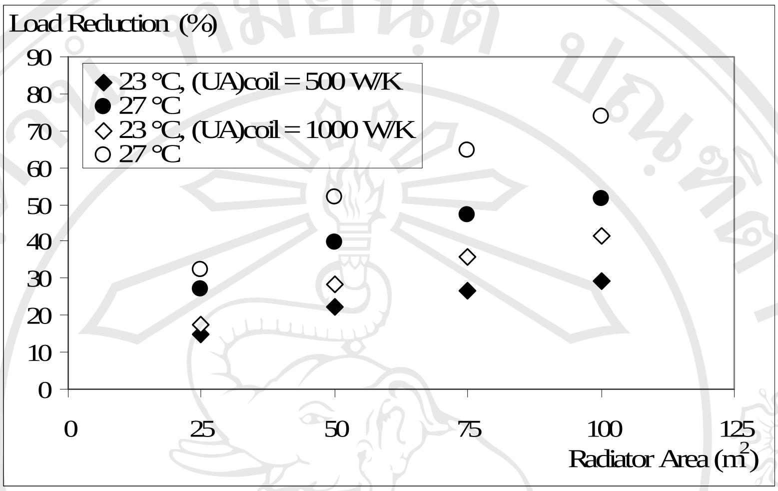
Figure 5.3 The simulated whole-year temperature of the cooling water used in summer. The passive system had a 100.0 m^3 storage tank, 100.0 m^2 radiator area and with $(UA)_{coil}$ = 500 W K^{-1}. The inside air-conditioned room temperature was at 27.0°C.

5.2 Energy Analysis

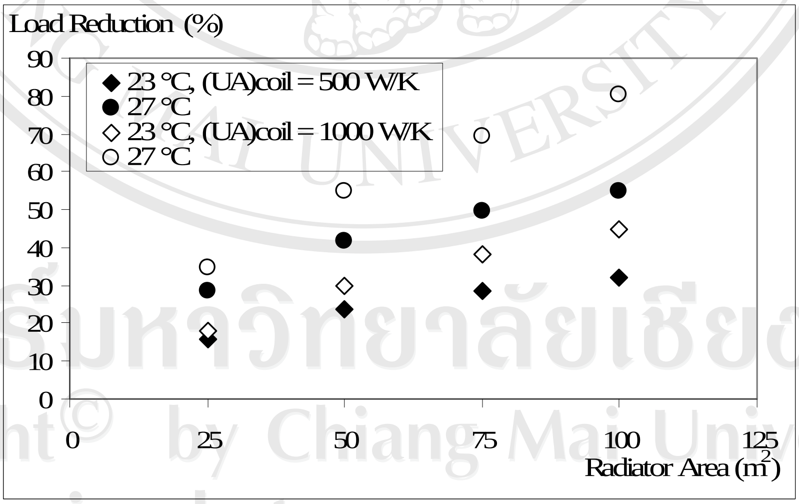
In the analysis, the room temperature is controlled by any active air-conditioning system and the cool water was fed into the room to take part of the cooling load of the active cooling.

Figure 5.4 has shown the percent load reduction at different cooling load performed by the nocturnal cooling water with various values of the radiator area, the storage volume and the controlled inside room temperature. Again, it could be seen that the cooling coil with higher value of *UA* could get more heat rate which results in higher percent load reduction. Higher value of radiator area gives more heat extraction rate during the nighttime thus lower cooling water temperature and higher percent load reduction are obtained. From our simulation, it could be noted that the size of the cooling storage tank has slightly effect on the percent cooling load reduction. With a fixed cooling load, when the size of the storage tank was over 5 m^3, the percent load reduction increased only slightly due to the high thermal inertia of the water volume which resulted in low variation of water temperature in the storage tank. But when the size was less than 5 m^3, the water temperature in the storage tank was increased quickly then the rate of rejected heat was also decreased. From the Figure, it could be seen that when the inside room temperature was higher, the potential to reduce the cooling load by the cooling water was higher but when the cooling load is higher, the percent load reduction was less.

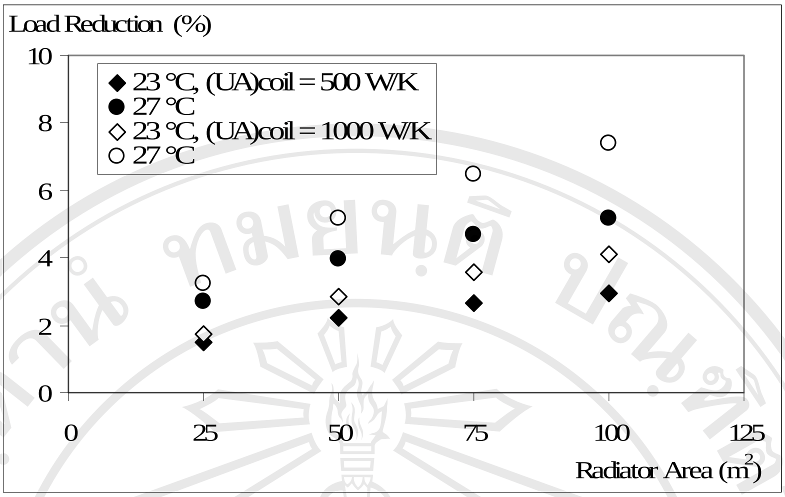
The load taken part by the passive cooling was calculated from Equation 4.15 and in this case it was found to be 10.15 GJ and 14.86 GJ during summer for Figure 5.2(a) and 5.2(b), respectively. If the cooling load was 10.0 ton of refrigeration (35.17 kW) then the percentage of the load reduction was 5.47 % and 8.01%, respectively. The results at this condition for other radiator areas and cooling loads were shown in Figure 5.4. From the Figures, when the controlled room temperature is increased and increase of the radiator area, the percent cooling load reduction is higher. If the total cooling load is higher, lower the energy saving is obtained by our technique. It could be noted that the size of the cool storage tank gave slight effect on the cooling load reduction.



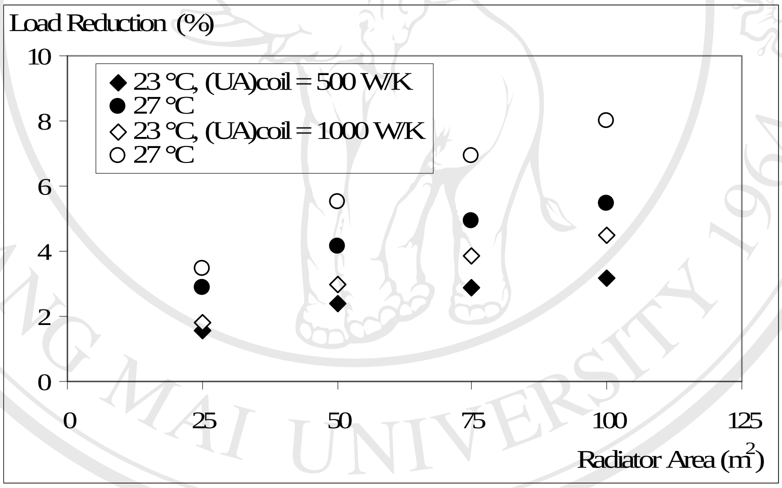
(a) 3517 W cooling load (1.0 ton of refrigeration), 5.0 m^3 storage volume.



(a) 3517 W cooling load (1.0 ton of refrigeration), 15.0 m^3 storage volume.



(b) 35170 W cooling load (10.0 tons of refrigeration), 5.0 m^3 storage volume.



(d) 35170 W cooling load (10.0 tons of refrigeration), 15.0 m^3 storage volume.

Figure 5.4 The percent cooling load reduction in the summer period (1 March -30 June) during daytime. The storage tank was 5.0 m^3 and 15.0 m^3.

The simulation program by all equations above could be simplified to an empirical correlation for predicting the percent load reduction, under the specified parameters of thermosyphon heat pipe as shown in Table 5.1, was also given as

$$\%Load\,\mathrm{Re}\,duction = 3.938 A_{rad}^{0.556} V_{\tan k}^{0.056} \left[\frac{(UA)_{coil}(T_{room} - T_w)}{\dot{Q}_{load}} \right]^{0.672}, \qquad (5.1)$$

where A_{rad} is radiator area (25.0 m^2 < A_{rad} < 100.0 m^2),

V_{tank} is storage tank volume (5 m^3< V_{tank} < 15 m^3),

$\frac{(UA)_{coil}(T_{room} - T_w)}{\dot{Q}_{load}}$ is the dimensionless term for this kind of passive cooling technique ($0.001 < \frac{(UA)_{coil}(T_{room} - T_w)}{\dot{Q}_{load}} < 3.554$).

The most appropriate value of each parameter could be found by Equation 5.1 by fixed other related parameters and then vary the interested parameter to see the effect of that parameter on percent load reduction. The designers, researchers and engineers are recommended to consider the percent load reduction companion with the investment cost to archive the optimum value.

5.3 Summary

Seasonal cool water storage was considered in this chapter. The whole year simulation for Chiang Mai, Thailand climate was done. The cool water was produced and stored in the low temperature period such as in winter and rainy seasons and it was used to serve building cooling load in the high temperature period such as summer in the daytime. The parameters in term of radiator area and volume of cooling water and a group of dimensionless term of cooling load, *UA* of cooling coil, room temperature and stored water temperature were carried out to give percent of cooling load reduction.