Passive Cooling of Air at Night by the Nocturnal Radiation in Loei, Thailand

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ABSTRACT

This preliminary study aims to investigate experimentally the natural nocturnal cooling of air in a house model under the weather conditions of Loei Province, Thailand during two months of early rainy season. A house model volume about 10.0 m^3 was constructed to measure the heat removal. The air was used as the working fluid for the heat convection from the sky radiator areas of 0.88, 1.78 and 2.66 m^2 to the conditioned space. It was found that the temperature gap between the radiative plate of the sky radiator and ambient temperature in the clear sky condition was bigger than that in the cloudy sky condition. The radiative plate temperature was about 5 ^oC below ambient temperature making the inlet air temperature into the house model by 2-3 ^oC below ambient temperature that can be used air as the working fluid for the nocturnal cooling in Loei Province.

Keywords: *Nocturnal Cooling, Sky Radiator, Night Radiation*

1. INTRODUCTION

The increasing of air temperature appearing in the global warming needs the air conditioner for living in the hot humid climate area such as in Thailand. Non-greenhouse gases emitting is required in the process of the air conditioning system while the system consumes a lot of electrical power that the power plant pollutes the environments and affects to the global temperature increasing indeed. Therefore, the environmental friendly air conditioning systems and renewable energy consumption are required. The nocturnal radiative cooling is an alternative method to be used for air conditioning system. It's not only less energy consumption but also non-greenhouse gases emitting. The cooling of the atmosphere due to infrared emission to space depends on the radiative and thermal properties of the atmosphere and of the Earth surface.

The nighttime air temperature in Loei Province which is in the North Eastern of Thailand is about 25^o C [1]. This temperature would to be suitable for the nocturnal cooling which was less studied in Thailand. A simulation of radiant cooling in an experimental room under the hot humid climate of Thailand by using TRNSYS program were done comparing to the results from the experiments [2-3], while the feasibility study of desiccant air-conditioning system by conducting an experimental analysis to investigate the performance and energy saving in the air-conditioning system was studied [4].

This preliminary study was to investigate experimentally the natural nocturnal cooling of air in the model house under two different sky conditions such as clear sky, and cloudy sky in the humid climate of Loei Province.

2. THE NOCTURNAL RADIATIVE COOLING

During the night, the upper earth layer cools because of infrared radiation loss from the earth's surface. This radiation loss is the difference between the Stefan-Boltzmann radiation from the earth's surface and the radiation from the atmosphere, which depends on air temperature, water vapor content, carbon dioxide and ozone concentrations, and cloudiness. Since the ratios of carbon dioxide and ozone in the atmosphere are usually constant, the intensity of night radiation loss depends on mostly on water vapor content and air temperature. Heat exchanging of the adjacent air and earth surface is also dominated by convection and conduction. When the air temperature and humidity are low, and the sky is clear, radiative heat loss from the earth surface is very high.

An amount of radiative cooling depends on the characteristic of the sky radiation and the characteristic of the radiating surface described as equation [5]

$$q_r = \varepsilon_r(\sigma T_r^4 - \varepsilon_s \sigma T_a^4),$$

where T_r is the sky temperature and T_a is the ambient temperature. ε_r is the atmospheric emissivity and ε_s is the surface emissivity. σ is the Stefan-Boltzmann's constant. The first term may be either directly measured or estimated from meteorological data and the second term may be from determined experimentally using appropriate equipment. The atmospheric emissivity is sensitive with the sky conditions and height (H) expression by [6]

$$\varepsilon_r = 0.1216\, e^{-0.00012H} - 1. \qquad \text{(H in meter)}$$

According to the temperature decreasing linearly in the low atmosphere (up to 11 km), the sky temperature (T_r) can be estimated by [7]

$$T_r = T(h = 0) - \gamma h, \qquad \text{(degree Celsius)}$$

where the temperature gradient γ is about 6.5 ^{o}C/km.

Radiator efficiency (η) is defined as the ratio of the actual radiative cooling rate of a surface (q_{out}) over some idealized cooling rate (q_{in}):

$$\eta = q_{out}/q_{in}.$$

Where $q_{in} = (1 - \varepsilon_s)\sigma T_a^4$ and

$$q_{out} = mc(T_{inlet} - T_{outlet}).$$

m is the flow rate. c is the heat capacity of the working fluid (for air = 1.0035 kJ/kg.K), while T_{inlet} - T_{outlet} is the temperature difference passing through the radiator.

3. THE EXPERIMENTS AND RESULTS

The experiments were performed under the weather conditions of Loei Province, Thailand as the hot humid climate during the early rainy season (May to June). A house model with dimensions of 2m×2m×2.5m has volume about 10.0 m^3 was constructed to use in the experiments located on the roof floor of the Science Center (see Fig. 1a). The sky radiator was the aluminum sheet painted black (see Fig. 1b) with the area can be changed from 0.88 m^2 to 1.78 and 2.66 m^2 under the varying of air flow rates respectively.

Fig. 1 (a) The house model used in the experiments (b) The Area changeable sky radiator

The air used as the working fluid flows beneath the radiative plate into the house conducted by the insulated air ducts. The sky radiator inclines of 17° to the horizontal (as the located latitude), even though, its nocturnal radiation is not effected [8]. A low electrical power air blower was installed to circulate the air in the system (see Fig. 2).

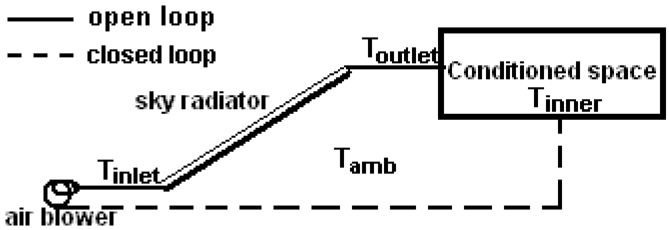

Fig. 2 The schematic diagram of the experimental measurements.

A four-channels data logger was used for measuring the temperatures at inlet, outlet, room interior and ambient air. The temperature was measured every 5 minutes during nighttime at 6 pm to 6 am of the next day while the air velocity in air-duct was measured at the beginning and at the end of each experiment by an anemometer. The air flow rate can be calculated by

$$\text{Air flow rate} = \rho v A \qquad \text{(kg/s)}$$

where ρ = air density (approx. 1.12 kg/m^3 at 25 °C),

v = air velocity (m/s),

and A = cross sectional area of air flow path (m^2).

The results of the measuring is shown that the temperature of the radiative plate is approximately 5°C, and the air temperature (inlet air temperature) is approximately 1.5°C below ambient temperature, but the air temperature in the house model (in-house air temperature) is over ambient temperature according to its flow rate too low (about 0.0002 – 0.001 kg/s).

This temperature is obviously in the clear sky condition. The ambient temperature declines about 0.6^{o}C/hour during the night in the clear sky condition depend on the wind speed and about 0.4^{o}C/hour in the cloudy condition. Samples of temperature measuring from the experiments under two sky conditions subjected to three surface areas of the sky radiator of 0.88, 1.76 and 2.68 m^2 are shown in Fig. 3 – Fig. 8.

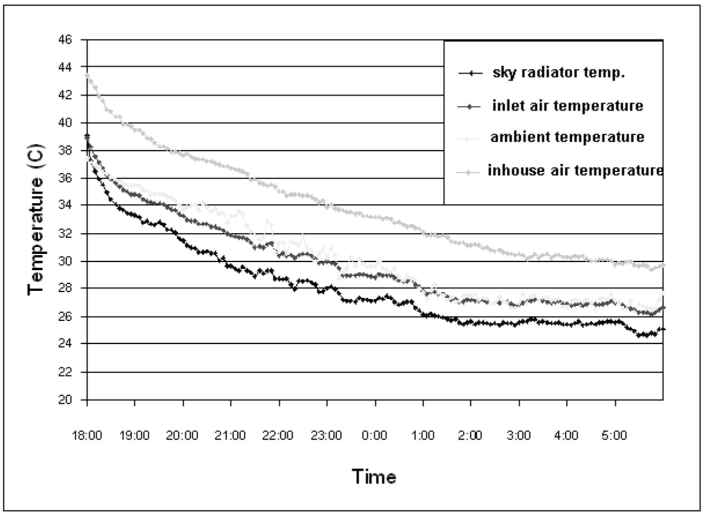

Fig. 3 The temperatures during nighttime of May 6, 2007 under the clear sky condition with the sky radiator area of 0.88 m^2 and the air flow rate 0.0003 kg/s.

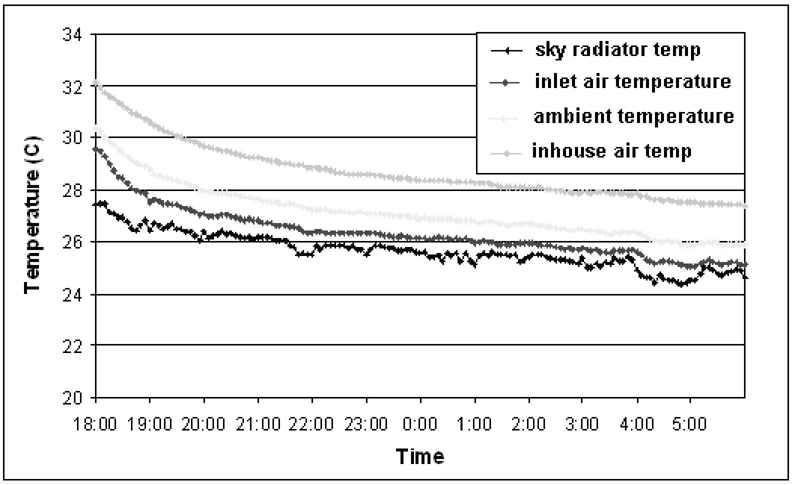

Fig. 4 The temperatures during nighttime of May 12, 2007 under the clear sky condition with the sky radiator area of 1.78 m^2 and the air flow rate 0.0005 kg/s.

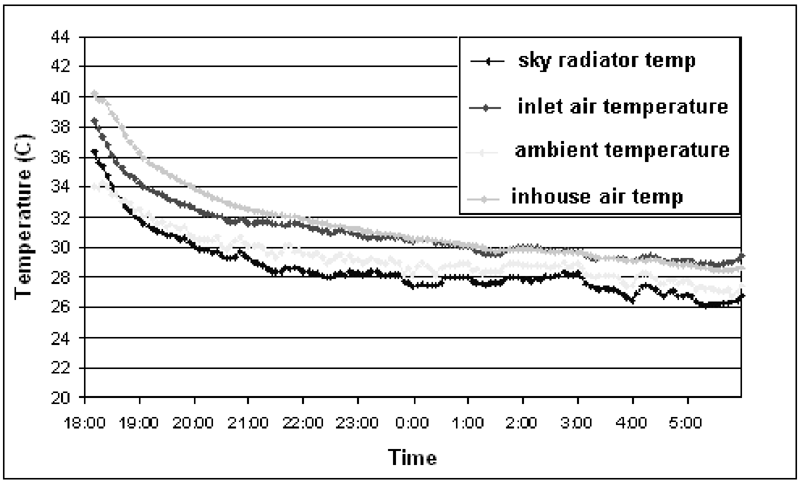

Fig. 5 The temperatures during nighttime of May 9, 2007 under the clear sky condition with the sky radiator area of 2.66 m^2 and the air flow rate 0.0002 kg/s.

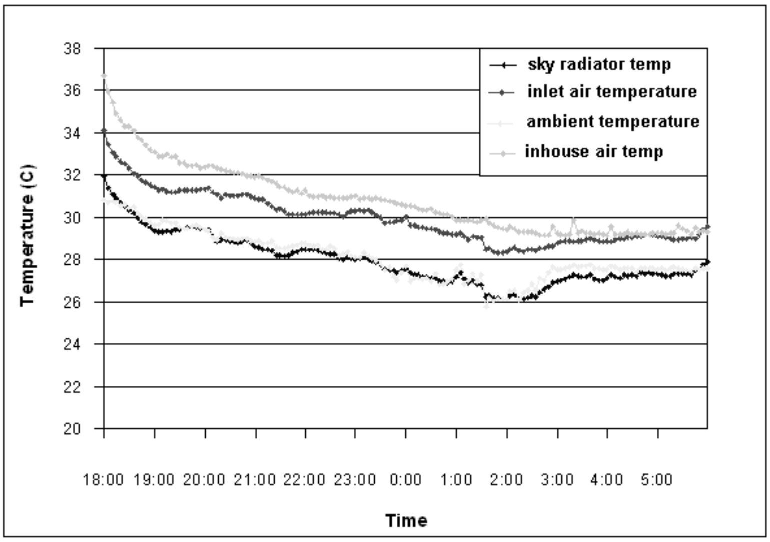

Fig. 6 The temperatures during nighttime of May 15, 2007 under the cloudy sky condition with the sky radiator area of 0.88 m^2 and the air flow rate 0.0005 kg/s.

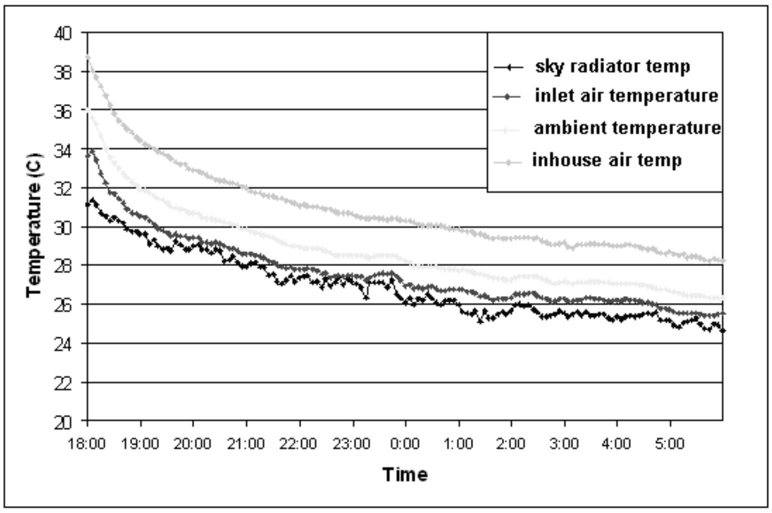

Fig. 7 The temperatures during nighttime of May 13, 2007 under the cloudy sky condition with the sky radiator area of 1.78 m^2 and the air flow rate 0.0003 kg/s.

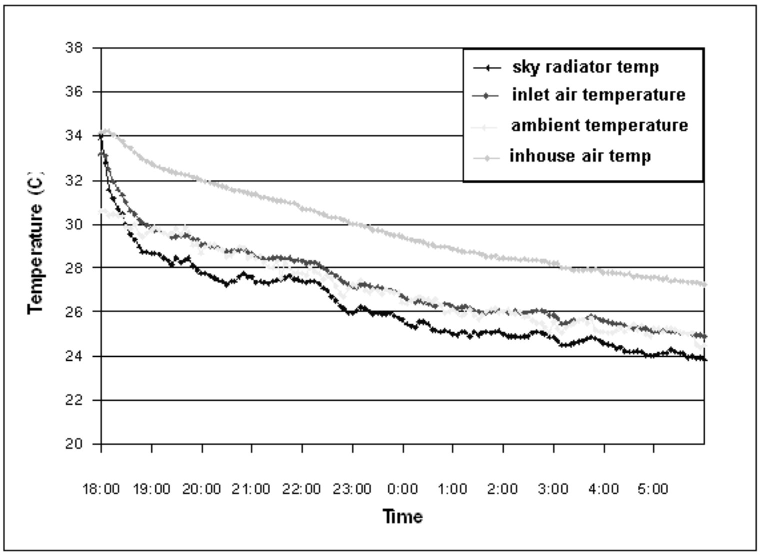

Fig. 8 The temperatures during nighttime of May 20, 2007 under the cloudy sky condition with the sky radiator area of 2.66 m^2 and the air flow rate 0.0002 kg/s.

The effect of the air flow rate to the inlet air temperature was calculated by plotting the temperature difference of the ambient and the inlet air temperature as shown in Fig. 9 under the clear sky and cloudy sky conditions. The efficiency of the sky radiator with the equation of Boon-Long [5] was also calculated for all experiments. The results of the efficiencies are shown in Table 1.

Table 1 The efficiency of the sky radiator under the variety weather conditions and air flow rates.

Date	Radiator area (m^2)	Air flow rate $\times 10^{-3}$ (kg/s)	Type of loop	Efficiency (%)
May 3, 2007	1.78 (clear sky)	5.9	Open	**0.44**
May 4, 2007	1.78 (cloudy sky)	4.8	Closed	**0.06**
May 5, 2007	0.89 (clear sky)	9.5	Closed	**0.94**
May 6, 2007	0.89 (clear sky)	3.2	Closed	**0.17**
May 7, 2007	1.78 (cloudy sky)	4.8	Closed	**0.12**
May 8, 2007	1.78 (cloudy sky)	2.0	Closed	**0.12**
May 9, 2007	2.66 (clear sky)	1.2	Closed	**0.11**
May 10, 2007	2.66 (clear sky)	1.6	Closed	**0.23**
May 12, 2007	1.78 (clear sky)	5.4	Open	**0.46**
May 13, 2007	1.78 (cloudy sky)	2.8	Closed	**0.10**
May 14, 2007	0.89 (clear sky)	9.5	Open	**0.89**
May 15, 2007	0.89 (cloudy sky)	4.8	Closed	**0.09**
May 16, 2007	1.78 (cloudy &rain)	5.5	Open	**0.05**
May 19, 2007	1.78 (cloudy sky)	2.4	Closed	**0.08**
May 20, 2007	0.89 (cloudy sky)	1.6	Open	**0.03**
May 21, 2007	0.89 (cloudy sky)	1.2	Closed	**0.07**
June 8, 2007	1.78 (clear sky)	6.3	Open	**0.56**
June 9, 2007	1.78 (clear sky)	6.3	Closed	**0.81**
June 13, 2007	2.66 (cloudy &rain)	9.5	Open	**0.19**
June 14, 2007	2.66 (cloudy &rain)	6.3	Closed	**0.04**
June 15, 2007	1.78 (cloudy &rain)	6.3	Open	**0.05**
June 16, 2007	1.78 (cloudy sky)	3.2	Closed	**0.32**
June 17, 2007	2.66 (cloudy &rain)	1.6	Open	**0.03**
June 18, 2007	2.66 (cloudy &rain)	0.8	Closed	**0.02**
			Average	**0.25**

4. DISCUSSION AND CONCLUSION

The gap of ambient temperature and sky radiator temperature in the clear sky condition was bigger than that in the cloudy sky condition due to the effect of the protection of the infrared radiation. The slopes of ΔT versus the flow rates represent the radiative capability of the sky radiator (Fig. 9).

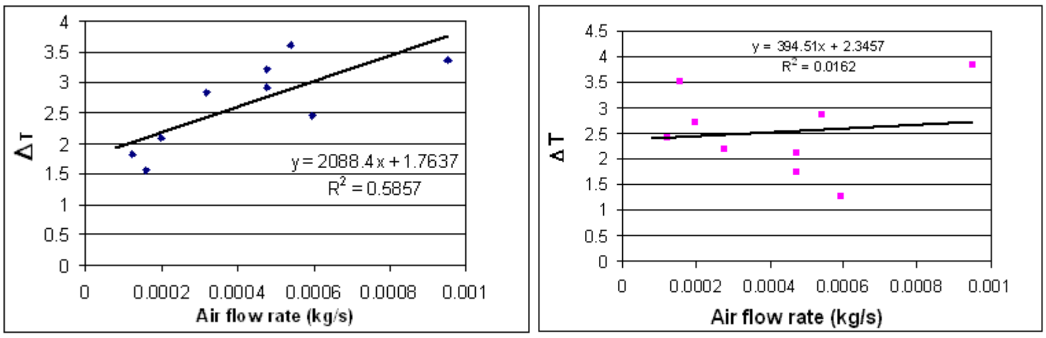

Fig. 9 The effect of the air flow rate to the averaged different temperatures (in Celsius) of inlet air and ambient temperatures in the clear sky condition (left) and in the cloudy sky condition (right).

The percentage efficiency of the sky radiator using air as working fluid seem to be low due to the air flow rate and the radiator area, especially in the cloudy sky condition. The inlet air temperature is still closed to the ambient temperature because of heat capacity of the air. Water can be used as the working fluid to maintain the inlet temperature below the ambient temperature corresponding to the sky radiator temperature [9]. Water can exchange the heat from the sky radiator better than that of air, so that the inlet temperature will be closed to the sky radiator temperature. But the experiment must be improved.

The experiment in the laboratory scale was performed in the sky condition of Loei Province to investigate the radiative cooling using air as working fluid. The inlet air temperature was below the ambient temperature by averaged of 2 - 3 ^oC, while the air temperature in the house model was above the ambient temperature by averaged of 1 – 2 ^oC. The radiative cooling using air as working fluid under clear sky condition can be made in Loei Province according to the sky radiator temperature under the ambient temperature by averaged of 5 ^oC. The experiment should improve the sky radiator area and the air flow rate occurring to the cooling load of the house model.

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