

Rainwater Circulation Cooling System for Open Cattle Shed on a dairy farm

Jungsoo Mun¹ and Mooyoung Han²

¹PhD candidate, Department of Civil and Environmental Engineering, Seoul National University, Seoul, Republic of Korea, Jsmun21@snu.ac.kr

²Professor, Department of Civil and Environmental Engineering, Seoul National University, Seoul, Republic of Korea, myhan@snu.ac.kr

ABSTRACT: Rainwater has the virtue of providing sustainable water resources and, with proper management, minimizing natural disasters such as flood and drought. Recently rainwater has occupied the attention as both cooling and heating source as well as the restoration of a water cycle. In this study, a rainwater circulation cooling system (RCCS) was used for cooling the cattle shed on a dairy farm in hot weather. When RCCS was operated for three hours in the afternoon from 12:00 to 15:00, the inside temperature of average 27.9 °C was lower than the ambient average 28.7°C. In contrast, when RCCS was not operated in the afternoon, the inside temperature of average 29.5 °C was higher than the ambient one of average 28.1°C. Temperature decrease reached about 2.6°C due to RCCS operation compared with no RCCS operation at the hottest time of a day. Thermal regime of the rainwater tank installed underground was also investigated. It shows that a rainwater storage tank has a possibility to function as a cooling source in the summer. These results indicate that rainwater is able to be considered for a range of uses, including energy saving as well as prevention of flood and drought.

Keywords: Rainwater circulation cooling system, Rainwater storage tank, Heat source, Dairy farm, roof

1. INTRODUCTION

Rainwater, as a circulatory resource, has the virtue of providing sustainable water resources and, with proper management, minimizing natural disasters such as drought. Water plays a key role in the circulation of global energy as well as being essential for living things. Therefore, it is possible to consider rainwater as an eco-friendly energy resource for energy saving. Rainwater harvesting system has been usually considered for water supply and flood control [1]. However, in monsoon region,

the use of collected rainwater as an energy resource for cooling can easily be contemplated under the weather condition of plenty of rainfall in summer, as in the Republic of Korea (Figure 1).

Water flowing over or sprayed on the surface of a building will reduce the cooling load in summer [2]. There have been several fundamental studies on the effect of evaporative cooling on buildings [3, 4], and also several studies of evaporative cooling in factories, warehouses and distribution centers [5, 6].

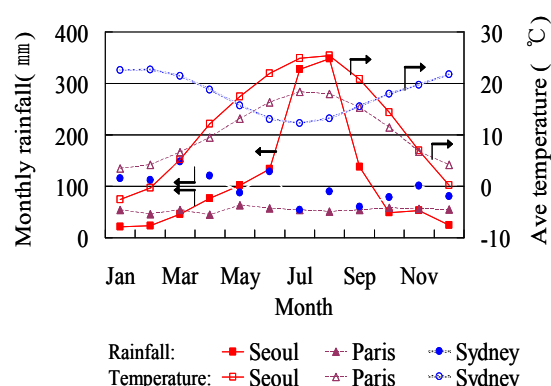


Figure 1: Average monthly rainfall and temperature in several cities in the world over 30 years (1961–1990)

It is necessary to use extra facilities and an additional supply of water in the existing cooling systems when using water spray. On the other hand, when a rainwater utilization facility is installed, it can minimize the need for additional facilities for water cooling and has the advantage of saving water due to circulation of rainwater from the roof into the storage tank. Moreover, when the rainwater storage tank is installed underground, heat transfer to the soil can be used for reducing the temperature of the recycled water. Since the use of fossil fuels for cooling is decreased, there is an additional benefit in reduction of derivative pollution problems like global warming.

One of the major industries affected by increases in ambient temperature is livestock industries, such as dairy farming. A cow's milk production depends on external environmental factors as well as genetic and physiological factors. In particular, fluctuating temperatures in accordance with the seasons have an influence on milk yield. A decrease in impregnation rate and milk yield caused by heat stress has been a great shock to dairy farmers in hot weather [7, 8, 9].

Although studies were carried out to investigate the effect of shade and fan cooling systems equipped with sprinklers for reducing heat stress in cows in summer [10-14], there is little information about

using stored rainwater for reducing high temperatures in the cattle shed.

In this study, 1) the effect of flowing water on the roof of the cattle shed using the rainwater circulation cooling system (RCCS), which is using the rainwater utilization facility equipped in the cattle shed as a cooling source, was analyzed by measuring inside and ambient temperatures of the cattle shed, and 2) the thermal regimen of the rainwater tank installed underground was investigated.

2. MATERIALS AND METHODS

2.1 Rainwater circulation cooling system

The rainwater utilization facility in a dairy farm, located in Paju, Gyunggido, the Republic of Korean was used for RCCS. Milking cows of 38 heads were raised in the cattle shed and stored rainwater through the roof is used for their drinking water and for cooling the shed. A schematic diagram of the cattle shed and rainwater utilization facility is shown in Figure 2 and Table 1.

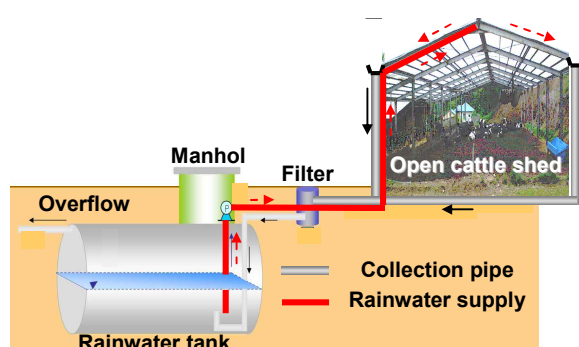


Figure 2: Schematic diagram of RCCS in a dairy farm

About 500 m² of roof area, having a slope of 17/100, on the cattle shed was used for the catchment. Rainwater falling on the roof was collected in a storage tank through a gutter, water pipe and filter (Wisy WFF 150 filter, German) by turns.

Table I: Introduction of RCCS.

Facilities	Specifications
Catchment area	500 m ² (13m×14m) + (9m×35m)
Roof material	F.R.P
Roof slope	17/100
Treatment facility	Filter (WFF 150)
Rainwater tank	Polymer pre-coated steel tank, 45 ton
Pump	0.5 HP, Height 25m
Overflow pipe	D = 100 mm

A polymer pre-coated steel tank of 45 m³ was used for the rainwater storage tank, which was installed underground. PVC pipeline, with nozzles every 10 cm, was established on the center of the roof to direct flowing rainwater down the roof. One end of the pipeline on the roof was connected to the rainwater tank for supplying stored rainwater, and rainwater was circulated through RCCS during its operation.

2.2 Methods

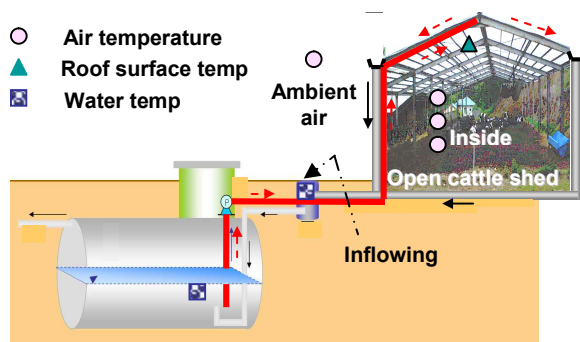
The experiment was performed on the 29 and 30 Aug 2005, two days in late summer that had similar peak temperatures and humidity. The weather conditions are shown in Table 2. The RCCS was operated for one day and not for the other day.

Seven points were selected for measuring temperature in order to examine quantitatively the reduction of temperature in the cattle shed using the rainwater cooling facility and to investigate the effect of heat dispersion in the storage tank. The temperature of the inside roof surface, the ambient air and inside three points of 1 m, 2 m, and 3 m from the bottom in the cattle shed was measured.

Table II: Weather conditions.

Parameters	29 Aug	30 Aug
Max temperature (°C)	28.7	28.4
Relative Humidity (%)	83.5	84.4
Cloud cover (%)	7.6	8.3
Wind velocity	1.0	1.4
Remarks	No RCCS operation	RCCS operation

The temperature of stored rainwater and inflowing rainwater from the roof to the storage tank were also measured (Figure 3).

**Figure 3:** Points of temp measurements

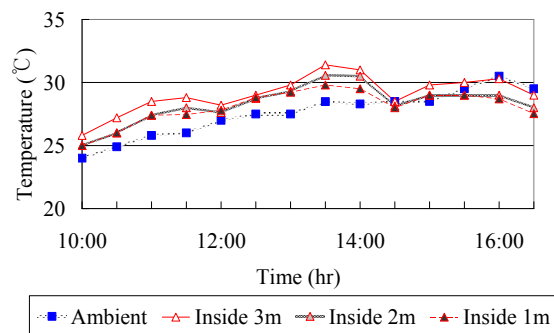
The roof surface temperature was measured using a digital thermometer (id900s-surface thermometer, Korea). Inside and ambient temperatures were measured using a thermo recorder (TR-71U, Japan). Temperature of inflowing and stored rainwater was measured using a Multimeter (HACH Sension 378, USA).

The experiment was performed with and without RCCS operation. The temperature was measured over the time of 10:00 to 16:30 at half an hour intervals. The rainwater was supplied for three hours from 12:00 to 15:00 at the rate of two ton/hr (total six tons). When RCCS was being operated, the temperature was measured every 2 minutes from 12:00 to 12:20, right after the water supply was turned on, and at 15:20 to 15:32, right after the rainwater supply was cut off, to observe the small change of temperature in a short time.

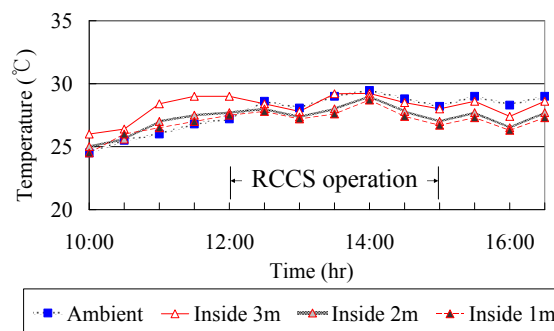
3. RESULT AND DISCUSSION

3.1 Ambient and inside air temperature of the cattle shed

The temperature change with and without RCCS operation is shown in Figure 4.



(a) No RCCS operation



(b) RCCS operation

Figure 4: Temperature variations with and without RCCS operation

The inside temperature at 2 m high was compared with the ambient one. When RCCS was not operated, the temperature at 1 m and 2 m from the bottom were almost same as average 28.9 °C and 29 °C respectively. The temperature of average 29.7 °C at 3 m high was about 0.7 °C higher than that at 2 m high. When RCCS was operated, the inside temperature from the bottom to the roof increased with height. The temperature at 1 m and 2 m from the bottom were almost same as average 27.6 °C and 27.8 °C respectively. The temperature of average 28.6 °C at 3 m high was about 0.9 °C higher than that at 2 m high.

The ambient temperature of average 28.7 °C from 28 to 29.5 °C during RCCS operation was higher than that of average 28.1 °C from 27.5 to 28.5 °C in case of no RCCS operation. However, as shown in Figure 5, the inside temperature of average 27.9 °C from 27.3 to 29 °C at 12:00~15:00 during RCCS operation was about 1.6 °C lower than that in case of no RCCS operation. In other words, when RCCS was not operated, the inside temperature was higher than that of ambient one. However, inversely, with RCCS operation, the inside temperature was lower than the ambient one. The inside temperature at the hottest time of the day at 13:30 was 27.9 °C with RCCS operation and was 30.5 °C without RCCS operation. Thus, the temperature fell down about 2.6 °C with RCCS operation.

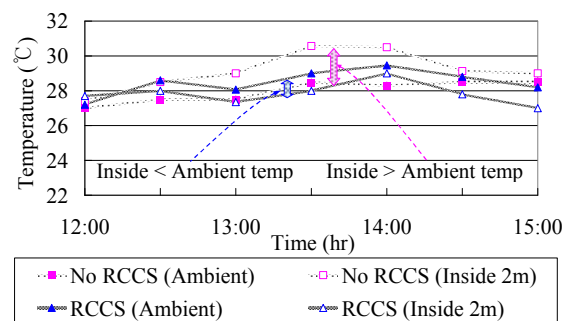


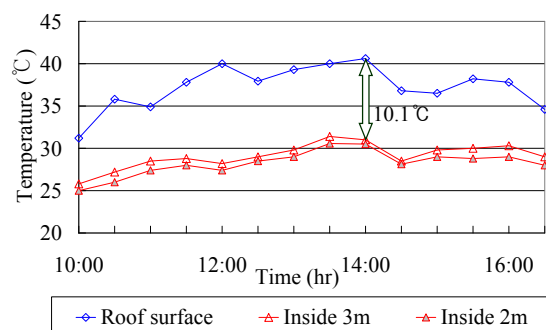
Figure 5: Ambient and inside air temperature with and without RCCS operation

3.2 Roof surface temperature

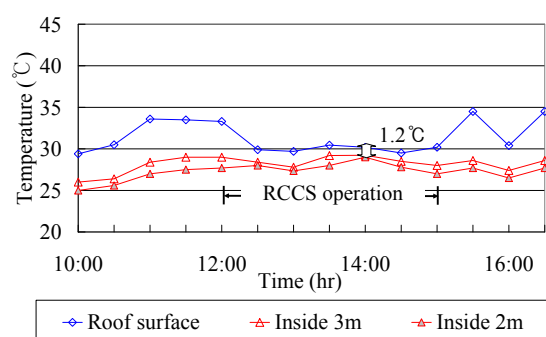
The roof temperature was average 38.5 °C from 36.5 to 40.5 °C without RCCS operation and was average 30 °C from 29.5 to 30.5 °C with RCCS operation. This means that the temperature of the roof surface declined with RCCS operation by about 8.5 °C (Figure 6).

Temperature difference between the roof and the inside were 10.1 °C without RCCS operation, and 1.2 °C with it. We measured the temperature right after starting and stopping RCCS operation at time intervals of two minutes to observe the temperature

change in a short time during RCCS operation (Figure 7).



(a) No RCCS operation



(b) RCCS operation

Figure 6: Roof surface and inside air temperature variation with and without RCCS operation

It is shown that the roof temperature fell down dramatically right after RCCS was operated, and the inside temperature became lower than the ambient one.

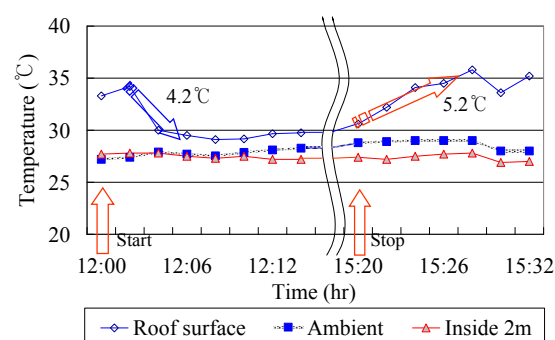


Figure 7: Temperature changes right after starting and stopping RCCS operation

Moreover, right after the shutdown of RCCS operation, the temperature of roof surface increased, although the inside temperature was lower than that of outside within a certain period of time.

3.3 Change of water temperature in the storage tank during RCCS operation

During RCCS operation, rainwater from the roof flowed into the rainwater storage tank again. As shown in Figure 8, the temperature of water flowing into the storage tank increased a little at first and then became nearly constant.

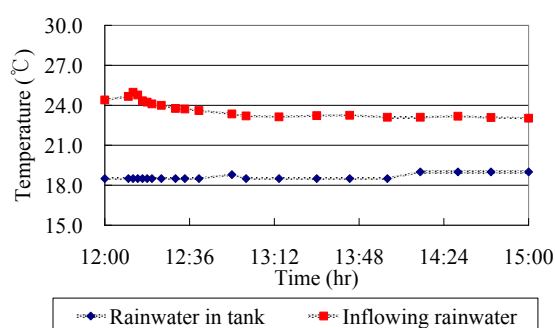


Figure 8: Temperature of inflowing rainwater and stored rainwater in rainwater tank during RCCS operation

The temperature of rainwater coming from the roof was 23.7 °C on average. Water temperature in the rainwater tank was nearly constant at 18.5 °C and, 2 hours later, increased 0.5 °C. It shows that there was no great change of temperature in the storage tank. The difference of water temperature between supply rainwater and inflowed rainwater to the storage tank was 5.2~4.7 °C. This result indicates that a rainwater storage tank is able to be considered for use as a cooling source in the summer.

4. CONCLUSION

In this study, when a simple RCCS (rainwater circulation cooling system) was operated for cooling the cattle shed in a dairy farm, the cooling effect of flowing

water on the roof was examined and thermal regime of the rainwater tank installed underground was investigated.

When RCCS was not operated, the inside temperature was higher than ambient one. However, inversely, with RCCS operation, the inside temperature was lower than ambient one. The inside temperature at the hottest time of the day at 13:30 was 27.9 °C with RCCS operation and was 30.5 °C without RCCS operation. It means that the temperature fell by about 2.6 °C with RCCS operation. The rainwater temperature in the storage tank increased a little of 0.5 °C after the operation of RCCS for 3 hours. The rainwater storage tank is able to be considered for a cooling source in the summer.

These results indicate that rainwater is able to be considered a multipurpose resource, including energy saving as well as preventing flood and drought. RCCS is expected to be very effective for cooling when it is applied to a factory, farm and office building that have broad roofs.

REFERENCES

- [1] Han, M, Mun, J. 2007. Particle behaviour consideration to maximize the settling capacity of rainwater storage tanks. *Water Science and Technology*. Vol 56. No 11. pp73–79. UK.
- [2] Shin, U, Lim, D, Jang, M & Baek, N. 2000. The Experimental study for thermal performance of roof evaporative cooling system. *Journal of the Architectural Institute of Korea; Planning & design*, Vol 16. No 4. pp 109-115. South Korea.
- [3] Choi, Y, Kim, S, & Kim, Y. 1999. A Study on the Building Cooling Load Reduction by Using Evaporative Cooling. *Proceedings of the Architectural Institute of Korea; Planning & design*. Vol 19. No 1. 1999-04. South Korea.
- [4] Choi, D, Lee, B. 2006. Effects to Affect Indoor Thermal Environment of the Top Floor caused by Evaporative Cooling of Roof Water Spraying. *Journal of the Architectural Institute of Korea; Planning & design*. Vol 22. No 5. pp287-294. South Korea.
- [5] Gandhidasan, P. 1989. Simplified model for the behavior of a roof-spray cooling system. *Applied Energy*, Vol 34, pp69-77. UK.
- [6] Somasundaram, S, Carrasco, A. 1988. An exp-experimental and numerical modeling of a roof-spray cooling system. *ASHRAE Transaction*, OT-88-04-2, pp1091-1097. USA.
- [7] Bober, M, Becker, A, Valtorta, S, Kratt, P, Mertsching, H, Johnson, H & Shhanklin M. 1980. The relationship of growth hormone and thyroxine to milk production under heat in Holstein cows. *Journal of Animal Science*, Vol 51 No 1. pp261-268. USA.
- [8] Maust, L, McDowell, R, & Hooven, N. 1972. Effects of summer weather on performance of Holstein cows in three stages of lactation. *Journal of Dairy Science*. Vol 55. pp 1133. USA.
- [9] Romance-ponce, R, Beede, D, Thatcher, W, Israel, L & Wilcox C. 1982. Influences of environment and its modification on dairy animal health and production. *Journal of Dairy Science*. Vol 65. pp2213. USA.
- [10] Choi, D, Kwon, D, Kang, H, Seong, H, Han, J and Choi, H. 1999. Effect of the blowing fan for reducing heat stress in lactating dairy cow. *Journal of livestock housing and environment*. Vol 5. No 3. pp181-188. South Korea.
- [11] Chung, T, Lee, H, Kim, C, Kim, D, Lee, Y & and Lee, I, 1996. Effects of sprinkler and fan cooling system in loose barn on the physiological parameter and milk productivity in Holstein cows during summer. *Journal of livestock housing and environment*, Vol 2. No 1. pp41-52. South Korea.

- [12]Kendall, P, Nielsen, P, Webster, J, Verkerk, G, Littlejohn, R & Matthews, L. 2006. The effects of providing shade to lactating dairy cows in a temperate climate. *Livestock Science*. Vol 103. pp148-157. Netherlands.
- [13]Brown-Brandl, T, Eigenberg, R, Nienaber, J, Hahn, G. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: analyses of indicators. *Biosystems engineering*. Vol 90. No 4. pp451-462. UK.
- [14]Eigenberg, R, Brown-Brandl, T, Nienaber, J & Hahn, G. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 2: predictive relationships. *Biosystems engineering*. Vol 91. No 1. pp111-118. UK.