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Performance of the natural cooler to keep the freshness of vegetables and fruits in Medan City

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Abstract. One application in a direct evaporative cooling system was a natural cooler. The advantages of this system were not using the electrical energy and so far also environmentally. This research aims to obtain a performance analysis of the natural cooler as a store for vegetables and fruits in Medan city. The materials for natural cooler consists of teak wood and gunny. This study makes experiments during seven days in the open air. The parameter measurement on the weather was using HOBO devices and to record the temperature changes for vegetables or even fruits is using its acquisition data. The results showed that the maximum efficiency of the natural cooler could be obtained for 43.79% in the average air temperature of 30.51ºC, the air humidity average is 85.12% with average solar radiation of 183.98 W/m^2. Experimental data were showing that the condition of freshness on vegetables or even on fruits was heavily influenced by weather conditions.

1. Introduction

According to Indonesian national data energy management blueprint book [1], the uses in fuel oil is over 60% of overall energy consumption in the year of 2005. It continues increase every year with population growth and economic development. Of course, at this moment the fuel consumption and energy quite an impact on national economic condition. It is necessary now to think about the environmentally and friendly technology that can reduce the energy consumption, especially on fuel and electrical. One type of technology that now is still useful for humans is coolers. The cooler is a device that works almost on the same principle with a heat engine which use the fluid as its refrigerant and heat transfer tool from indoors to outdoors to keep temperature of the object should be lower than the ambient temperature. In the equatorial area like Indonesia, refrigerant system is still required because it is so cheap and effective.

According [2, 3], Indonesia always exposed to the sun radiation for 10-12 hours daily and it is expected that the average intensity of solar radiation should be 4.8 kWh/m^2. In this study the natural cooler system which was observed without using electrical or mechanical energy, therefore its called as a natural cooler. This research goal was to gain the analysis performance in a natural cooler that using water for its cooling medium. Although research on natural cooler for vegetables and fruits has been applied commonly, it still more interesting time to time because it is friendly, environmentally, simple technology, and rarely to publication.

1.1. The working principle in natural cooler

The working principle in natural cooler is the event of cooling by using the evaporation (evaporative cooling). Cooling by the evaporation, is a physical phenomenon in which the evaporation liquid came from surrounding air to make cool the object. This will make the surface object being colder when the water evaporates from him, cause the water should require heat to change the liquid phase to vapor [4]. It also can be said that heat and mass transfer process is done by the water evaporation on cooling the air system, where the amount of heat is transferred from the air to water that enough to lowering the air temperature [5, 6]. In generally, the evaporation cooling system is classified into three types, which renowned as direct evaporative cooling, indirect evaporative cooling and the combined system of direct and indirect evaporative [7]. The application using the indirect evaporative cooling system can be seen as the heating process, the air ventilation, the air-conditioning in buildings or also in shopping centers. In others, the application of the direct evaporative cooling system is a natural cooler that used to store vegetables and fruits [8]. Based on the preservation research report on vegetables and fruits, requirement of low air temperatures and high humidity will delay the pathological activities that located on the high ground [9]. It can be said also, that the natural cooling system is greatly affected by weather conditions, including temperature and humidity which is suitable to be applied in subtropical and tropical regions [10, 11]. Generally, the natural cooler uses gunny as their container and the water for its cooling medium.

1.2. Efficiency of Natural Cooler

In determining the efficiency of the natural cooler, it is necessary to review the process of heat transfer that occurs around the cooler. The amount of heat transfer conduction (watt) which occur in the natural cooler walls can be calculated from equation [12]:

$$Q_{cond} = k\ A\ \frac{\Delta T}{L} \tag{1}$$

where k is the material thermal conductivity (W/m.K), A is the cross sectional area of heat transfer conduction (m^2). The parameter ΔT is the temperature difference occurs between the surface temperature of the walls of the natural cooler with the ambient air temperature (°C) and L is the thickness of the wall cooler (m).

The heat transfer convection process (watt) which will occur naturally in the natural cooler wall is

$$Q_{conv} = h\ A\ (T_s - T_\infty) \tag{2}$$

where h is the coefficient convection heat transfer ($W/m^2\ K$), A is the cross sectional area (m^2), and ΔT is a temperature difference that occurs between the surface temperature of the walls of the natural cooler with the ambient air temperature (°C). The amount of radiation heat transfer processes (watt) which occur naturally in the walls of the natural cooler is

$$Q_{rad} = \varepsilon\ \sigma\ A\ (T_s^4 - T_\infty^4) \tag{3}$$

where ε is the emissivity of the material used (wood 0.88 and gunny 0.72), A is the cross sectional area of radiation heat transfer (m^2), and σ is the Stefan Boltzmann constant ($5.67 \times 10^{-8}\ W/m^2\ K^4$). The parameter T_s is the temperature of the walls of the natural cooler (°C) and T_∞ is the air temperature around the natural cooler (°C). The amount of total heat transfer from the natural cooler that obtained from the evaporation which was occurs in the walls of the natural cooler is a combination of the natural convection heat transfer, conduction, and radiation, namely:

$$Q_{total} = Q_{cond} + Q_{conv} + Q_{rad} \quad (4)$$

So that the value of the efficiency of the natural cooler can be determined by the equation:

$$\eta_{nc} = \frac{Q_S + Q_L}{Q_{total}} \quad (5)$$

where Q_S is the sensible heat of air (watt) and Q_L is the latent heat of air (watt).

2. Method

2.1. Material

The material for the natural cooler that used in this study was made the teak wood material with a thickness of 3.5 cm as the framework with consideration of material strength was good enough, resistant to water and termites as well as relatively easy to obtain. Dimensions for them are 490 mm (width) x 530 mm (length) x 1550 mm (high).

Table 1. The main features of a natural cooler

No	Data	Description
1	Frame	Teak , k = 0,12 W/m. K at 27 °C
2	Wall coverings	Gunny, k = 0,06 W/m. K at 27 °C
3	Cooling media	Water
4	Pipe	Copper (∅ = 8 mm)
5	Water Tank	2 Tank (volume 8 liters)
6	Objects cooled	Vegetables and fruits

Figure 1. Photograph of the natural cooler.

The white gunny was used as the wall coverings with a thickness of 1 mm that used to applied to the right, left, back and front. For the roof and the base under the rack, it ia used a plywood with a thickness of 1 cm in order to make it water-resistant to prevent rapid deterioration. The water as a cooling medium should have a temperature not more than 25^{o}C. The object that placed in the natural cooler should be vegetables and fruits. The main features of the natural cooler used is shown in table 1. Photograph of the natural cooler is shown in figure 1.

2.2. Experimental Scheme
The natural cooler is connected to a data acquisition system, Agilent 3497A through the thermocouples. Six thermocouples were used in the experiments, three for the objects cooled and three is located in the natural cooler. Temperatures were measured using J type thermocouples with an accuracy of ±0.4%. A HOBO micro station data logger was used to record weather conditions such as solar radiation intensity (pyranometer with accuracy ±5%), ambient temperature (accuracy ±0,2^{o}C), relative humidity (accuracy ±2.5%) and wind velocity (accuracy ±3%). As a note, western Indonesian time or WIB (Waktu Indonesia Barat) is used in Medan city for a local time.

The experiments were carried out during seven consecutive days in May 2017, at the Solar Energy Laboratory, Universitas Sumatera Utara in Medan city, Indonesia, with geographical coordinates 3^{o}35' North latitude, 98^{o}40' East longitude. Figure 2 shows a schematic of the natural cooler and data measurement systems.

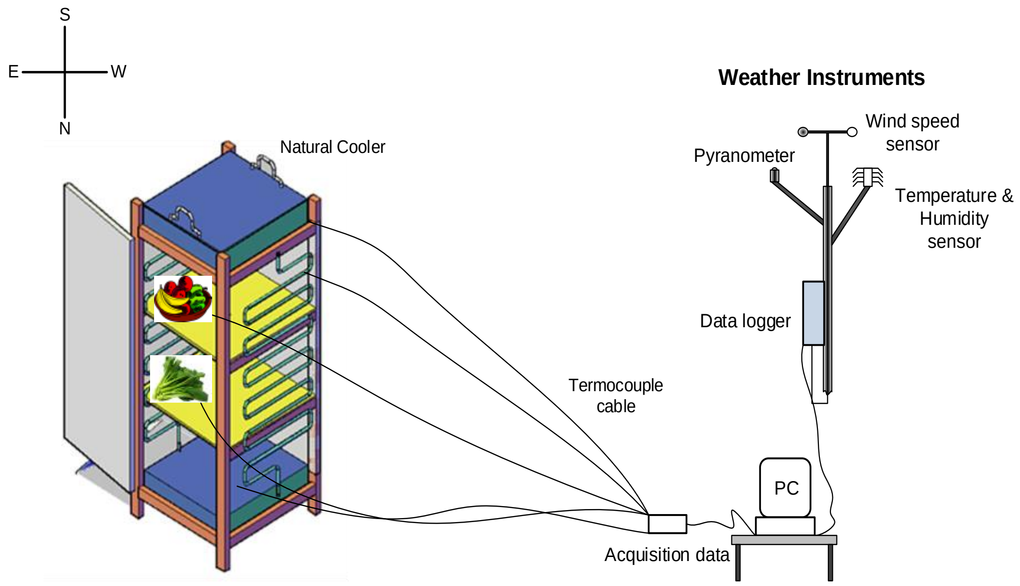

Figure 2. Schematic of the natural cooler and measurement systems.

3. Results and Discussions
The research conducted divided into several studies, namely the weather conditions, the performance of the natural cooler tested and the correlation between the performance of the natural cooler with the weather conditions during experiments.

3.1. Weather Conditions
It is necessary to review the weather conditions, therefore, the experiments were carried out in the open air conditions which exposure to solar radiation. The process of measuring weather conditions for 24 hours during seven days where the weather conditions and the measurement process are done

with every minute. Table 2 shows the parameters of the weather conditions during the experiment process is done.

Table 2 shows that the weather conditions that include temperature and humidity, wind speed and solar radiation vary every day. Figure 3 shows the typical of solar radiation and ambient air temperature during the experiment on the first day.

Table 2. Weather conditions during experiments

Date	Average Ambient Temperature (°C)	Average Air Humidity (%)	Average Speed Wind (m/s)	Average Radiation Solar (W/m^2)
1/05/2017	30.81	84.89	0.73	186.22
2/05/2017	30.51	85.12	1.17	183.98
3/05/2017	30.20	85.81	1.63	182.34
4/05/2017	30.23	85.23	1.29	183.22
5/05/2017	30.66	85.01	1.09	184.71
6/05/2017	31.01	84.78	0.67	189.32
7/05/2017	31.21	84.65	0.48	190.12

Figure 4 shown a significant correlation between changes in air temperature with the air humidity conditions, that correlated with solar radiation which occurs at the experiment location. The experimental data showed that solar radiation began to be detected from 06.20 WIB until 18.25 WIB. During the experiments takes place within seven days were obtained the average solar radiation of 186.22 W/m^2, the average air temperature of 30.81°C and humidity average of 84.89%.

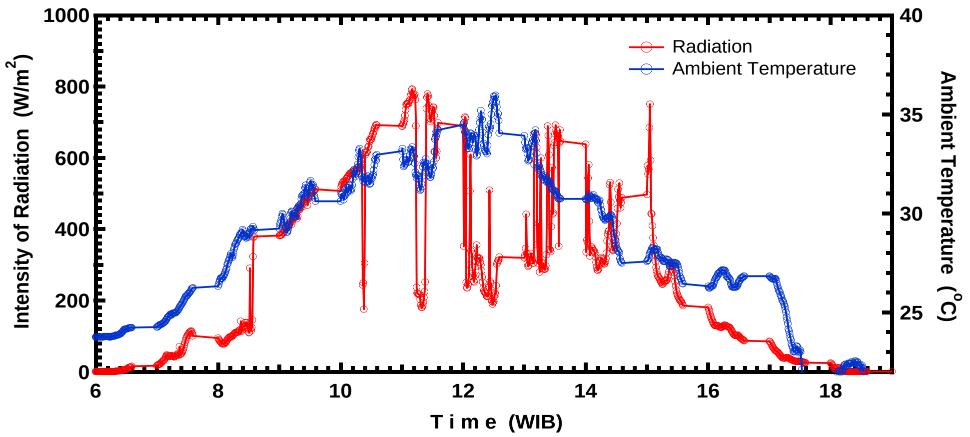

Figure 3. The typical of solar radiation and ambient temperature at first experiment.

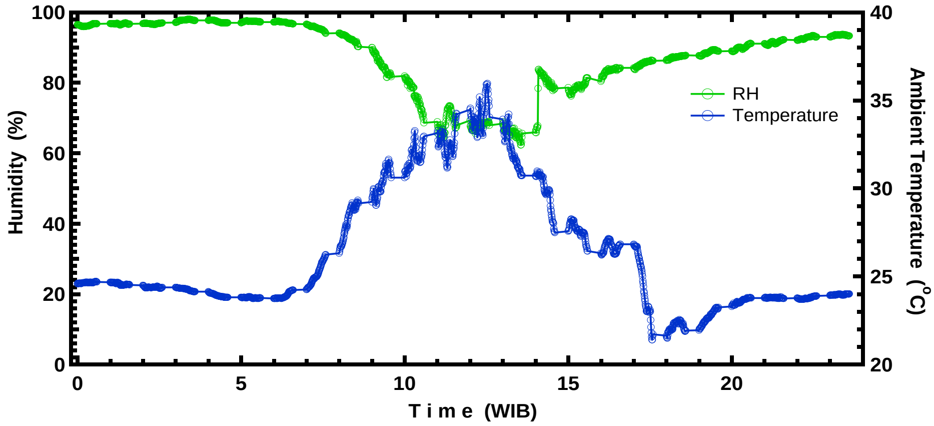

Figure 4. The typical of ambient temperature and air humidity at first experiment.

3.2. Performance of The Natural Cooler

The measuring of the temperature in the natural cooler was done by placing a thermocouple sensor on the top side, rear, right, left, vegetables and fruit. The natural cooler is tested with the condition of the backside facing east.

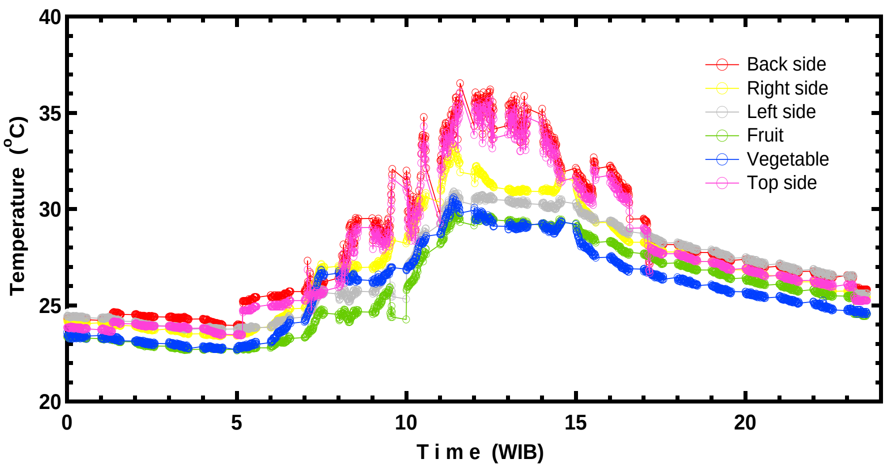

Figure 5. The typical of temperature of components at first experiment.

Figure 5 show the fluctuations in the temperature of each component was measured for the first day of the experiment. This correlates with changes in weather conditions that occur every time. The value of the temperature of each component is increasing from 07.00 WIB morning and reached a maximum temperature at 12.00 WIB - 14.00 WIB which is in line with the increase of solar radiation and ambient temperature. During experiments, the maximum temperature of vegetables and fruit ranges from 34°C - 35°C. The minimum temperature of vegetables and fruit is 22°C - 23°C, which occurred at 04.00 WIB - 05.00 WIB.

The first day The third day

Figure 6. Conditions of vegetables and fruits on the first day and third.

The fifth day The seventh day

Figure 7. Conditions of vegetables and fruits on the fifth day and seventh.

In general, the temperature on the back side of gunny is higher than the other because the back side is directly facing toward the east or the sunrise to absorb more solar radiation. To keep the vegetables and fruits as placed in so that do not quickly wither then used water in the pipe around the walls as a natural cooler. From the calculation taking into account the mass of vegetables and fruits in the cooler and the heat transfer process that occurs, then the volume of water required for the cooling process is 8 liters in the 2 tank. The average air temperature 30.66^{o}C, air humidity average of 85.07% and an average solar radiation is 185.70 W/m^2. The water are used to prevent heat from the outside air into the cooler and absorb heat emitted fruits and vegetables.

Table 3. Efficiency of natural cooler during experiments

Day	Q_S (W)	Q_L (W)	Q_{total} (W)	η_{nc}
1	0.344	31.510	79.615	40.01%
2	0.306	30.679	70.755	43.79%
3	0.344	30.143	79.120	38.53%
4	0.348	29.853	79.937	37.78%
5	0.335	31.096	77.206	40.71%
6	0.364	32.100	84.772	38.30%
7	0.373	32.682	87.121	37.94%

Therefore, the water content in the gunny must be maintained. When the undergoes drying, the heat from the surrounding environment will go into the cooler and emitted heat the fruits and vegetables which can not be absorbed by the gunny. This can result in vegetables and fruits in the cooler will naturally quickly wither. The physical condition of vegetables and fruits during the experiments can be seen in figure 6 and 7. It appears that the condition of vegetables and fruits are still good from the first day until the fifth and started having conditions wither on the seventh day.

Table 3 shows the efficiency of the natural cooler during experiments. The value of the maximum efficiency of the natural cooler obtained during the experiment was 43.79% in the second day of the experiment. The maximum efficiency of the natural cooler obtained when average air temperature 30.51°C, air humidity average of 85.12% and an average solar radiation 183.98 W/m^2. The value of the efficiency of the natural cooler is fluctuated every day.

Based on data from the measurement and the calculation that the efficiency of the natural cooler is affected by heat transfer process that occurs in the natural cooler by radiation, conduction, convection as well as heat from vegetables and fruits and varying weather conditions while experiments.

3.3. Correlation of weather conditions with Natural Coller performance

Correlation of the weather parameters which include solar radiation, ambient temperature, humidity and wind speed against the efficiency of the natural cooler was also being examined. The data used are the weather conditions and the efficiency of the natural cooler for seven days of experiments. Table 4 shown that the parameters of solar radiation, temperature, humidity and wind speed correlated significantly to the efficiency of natural cooler.

By using the multiple regression functions obtained the coefficient of determination of 0.86, it stated that the effect of weather parameters against the efficiency of the natural cooler which tested 86%.

Table 4. Correlation of weather parameters against the efficiency of natural cooler

	Ambient temperature	Humidity air	Solar radiation	Wind speed	Efficiency of natural cooler
Ambient temperature	1				
Humidity air	-0.95	1			
Solar radiation	0.66	-0.69	1		
Wind speed	-0.90	0.83	-0.68	1	
Efficiency of natural cooler	0.68	-0.58	-0.73	-0.55	1

4. Conclusions

The study investigates the performance of a natural cooler without using electricity and environmental friendly in an open air with a varying weather conditions with success. The observation of weather conditions is in the ambient temperature, humidity, and solar radiation. This research obtains an average temperature of vegetables and fruit should be in the ranges of 24.29°C during experiments. According to the experimental data and calculations, the maximum efficiency of the natural cooler is 43.79%. Based on the statistical calculation, the obtained value of the weather conditions that effected on the performance of the natural cooler tested is ranged between of 86% during the experiments. In the next study should focus on improving the efficiency of natural cooler so that the time of the freshness of fruits and vegetables can last longer and untimely.

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