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COOLING PERFORMANCE OF SPRAYING WATER AUTOMATICALLY ON THE ROOF SURFACE FOR THERMAL COMFORT IN BUILDINGS IN MANADO

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Abstract

The study aims to assess the cooling performance of the automatic water spraying on the roof surface to decrease the indoor air temperature in a humid tropical climate. The spraying water onto the ceiling can be considered as an evaporative cooling strategy. Firstly, the approach has been tested in a cell test constructed with plywood for the walls and floors, and roofs of corrugated zinc sheet. It is necessary to note that water spraying can reduce the roof surface temperature by an average of 5°C. However, the reduction of roof temperature cannot be guaranteed to reduce the average indoor air temperature directly. To reach a greater advantage of the ceiling temperature reduction is required to spray water in around 10-15 minutes and conducted continuously. Secondly, it has been applied an automatic water spraying on the roof. The utilisation of sensors, actuators and controllers are an inseparable part, with the intention of this device will respond vigorously when the roof surface temperature reached a certain threshold, and automatically turns on the pump to spray water. The device has been practising; it still needs more elaboration for its reliability and investigations about reusing water after sprayed for allowing to reduce energy consumption in the buildings.

Keywords: automatic water spraying; evaporative cooling; roof surface; thermal comfort; hot and humid climate

1. Introduction

In the construction sector, there is about 40% of energy consumption used for cooling of indoor air, especially in the humid tropical climate. The energy consumption will increase when buildings are designed unconsidered environmental conditions, used inappropriate construction materials, and ignored the protection from direct sunshine. The average buildings in humid tropical climates are facing the problem of how to maintain the comfortable conditions in the building.

Regarding of energy conservation, a passive cooling is one of the strategies that needed for a tropical humid climate condition. Indeed, in that respect are some schemes that can be utilised for buildings in hot and humid climates such as natural ventilation and soil cooling. At that time, the natural ventilation application was exclusively applied. Several series of researches conducted by Kindangen (1997, 2006) have studied the influences of architectural elements to improve the operation of natural ventilation. In addition to natural ventilation, there are other techniques, including the passive cooling strategy. Although some passive cooling strategies are still employed; however, just a few are suitable and in conformity with the humid tropical climate. Givoni (2007) noted that it should be applied the different strategy for various places that is appropriate to the characteristics of the suitable environment.

The evaporative cooling is one of the passive cooling strategies being a still less attention. Implementation of this plan will be able to conserve energy needs of the building. This scheme can economise the required energy expenditure, to make a comfortable space condition and efforts to lower the cooling load drastically. It is essential for creating a warm place that will increase the productivity of the occupants of the buildings.

The use of the evaporative roof spray cooling system is not a new idea; studies have been done dating back to as early as 1939. Because of the energy crisis, ceiling spray cooling methods have recently become acceptable and desirable (Carraso et al., 1987). The operation of roof spray cooling is a straightforward and fundamental one; the basic concept aims to wet the hot surface and cool it down with sprayed water. The primary purposes to keep the heat out before it gets in and reduces cooling costs in the buildings.

Some scientists have tried to figure out the mechanisms of the strategy and its applications. Maerafat et al. (2010) have studied the role of the evaporative cooling cavity in residences; they concluded that the application is successful and bring a broad impact on cooling strategies. Givoni (2011)

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and Joudi and Mehdi (2000) examine the indirect evaporative cooling with a cooling load varies for housing, they have concluded that the passive cooling system can reduce the room temperature, but this system will differ from one another depending on the particular climate. Kim et al. (2011) have examined the potential energy savings with direct or indirect evaporative cooling by using the outdoor breeze and concluded both these strategies could be utilised for the energy conservation.

Kettleborough et al. (1981) have conducted research on how the wet plastic plate as a heat exchanger was performed for indirect evaporative cooling. Likewise, Costelloe and Finn (2003) stated that the passive cooling with the air-water system is potentially applied in temperate or moderate climates. Tang et al. (2005) have described that the cooling with a puddle on the roof using a floating bag had good performance compared with movable insulation. Wongsuwan et al. (2006) have conducted an experimental study on the roof pond house under tropical climatic conditions; they concluded that the system could reduce 2-4°C indoor temperature lower than the outdoor.

Jain et al. (2008) have tested the insulation along the roof of the building that can be customised for the intention of cooling by using an indoor air or not which demonstrated this arrangement can work in the right way. In 1977, they had also experimentally investigated in some detail the effect of roof pond and roof spray at the ceiling surface of a thick reinforced concrete roof exposed to a hot-day sunny climate. It was seen that, by roof shower, the peak roof temperature decreased from 55 °C to 28°C as compared to a reduction from 55 to 32°C in the case of roof pond. The condition was obviously due to more efficient evaporation of water at the ceiling surface. The roof surface temperature was observed to undergo a drop of the order of 15°C as compared to 13°C in the case of the water pond.

Spanaki (2007) had reviewed the literature of some studies on the different type of roof ponds for cooling purposes; she reported that spraying system is usually preferred for larger cooling loads. The usefulness of roof spray-cooling was found to be most useful in buildings with lightly constructed, poorly insulated roofs. In relatively the same line with research of Zhou et al. (2004) that studied the effect of the difference between a grass roof and the roof by spraying water in a building with reinforced concrete (RC) construction. The conclusion is that the roof by spraying water is not suitable for an RC building with a high level of insulation in the ceiling.

Teixera and Labaki (2006) have also carried out a study of evaporative cooling in a tropical climate with using the cell tests with fibre-cement roofing without concrete slab; they concluded that the technique can be satisfactory if it is considered only the surface internal temperature attenuation for the hottest months in the region. All of these studies as described, in general, they rarely paid attention to how the spray water cooling applied onto the roof surface to the other material except for the reinforced concrete for buildings in humid tropical climates. It is reasonable to expand the same study by using other materials such as zinc for building in the humid tropics. The paper's objective is to investigate the application of water spraying automatically on to the zinc roof's buildings in a humid tropical climate.

2. Methods

2.1. Location of the Research

Manado is located in the province of North Sulawesi in Indonesia, at latitude 1.4583°N and longitude 124.8260°E, has a humid tropical climate. The hottest month is August with average temperature 27°C and the coldest one is January with average temperature 25.9°C. In general, the temperature difference between the hottest and the coldest month is not too much; their amplitude is small as presented in Fig. 1. The rains' period occurs from November to February, being the rainiest month January (452 mm).

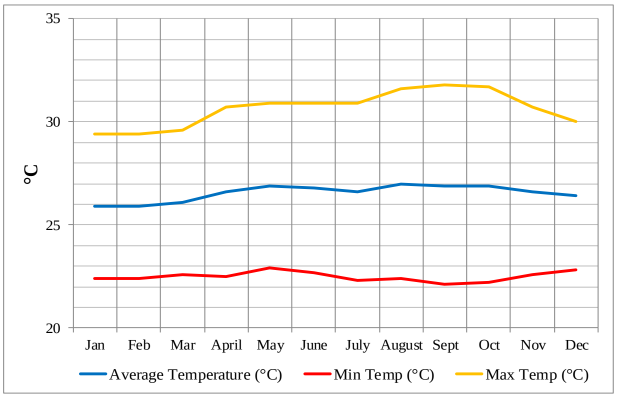

Fig. 1. Climatic data for Manado (resource: climate-data.org)

Fig. 2. The most roof's houses in Manado use corrugated zinc roof.

The most roof's houses in Manado are corrugated zinc sheets. Use of zinc roofing is very popular because of its practicality in utilisation and construction needs and its availability in the public market. There is a cultural perception triggered to use widely it; one of the reasons is due to the experience of the dangers of earthquakes ever suffered by the community; in which earthquakes damaged many buildings using heavy material roofing such as clay tiles or ceramic tiles. So, the decision to not use weight roofing material is always of their concern. It is the reason why the most houses in Manado use now zinc corrugated roof, as illustrated in Fig. 2.

2.2. Experimental Design

A cell test has been built 1.5m of length, 1.5 m of width and 2.5 m of height with plywood for the walls while the roof was made of corrugated zinc sheets. The floor of the cell test of plywood that raised about 80 cm from the ground.

This cell does not have a ceiling; roof tilted only in one direction. The cell has openings measuring 30 x 40 cm on the right and left sides (North and South). The house test is placed outdoors, in the garden, as efficiently as possible exposed to direct sunlight in the morning until the afternoon, as illustrated in Fig.3.

Fig. 3. A cell test.

Installation of spraying water using closed circuit connected to the submersible pump and perforated PVC tube placed on the high edge of the roof. A PVC pipe perforated on one side is used to spray water onto the entire roof surface when the pump turned on. Zinc roof not painted has a slope to the front wall, or the east side is higher than the rear wall or the west side.

Air temperature and relative humidity of interior, exterior and the roof surface are measured using three RC-4HC data loggers that are set up to record every 30 minutes to obtain sufficient data for analysis. The roof surface will be sprayed with water; the water temperature is measured beforehand.

An automatic roof spraying device was designed by splitting into several sub-systems and then will make to be easier to determine the components will be used. Subsystem consists of a controller, sensors, and actuators. Each element in the system requires a voltage source, the microcontroller Arduino Uno, and SSR 25-DA requires a supply voltage of 12V to the electrical current of 3A, while DHT11 and DS18B20 sensor probe and a 2x16 LCD need a supply voltage of 5V. The DHT11 sensor is used to detect the roof surface temperature while the DS18B20 sensor probe is used to measure the indoor air temperature. These sensors are very easy to use with the microcontroller Arduino, and they have an excellent level of stability and very precise calibration, as shown in Fig. 4.

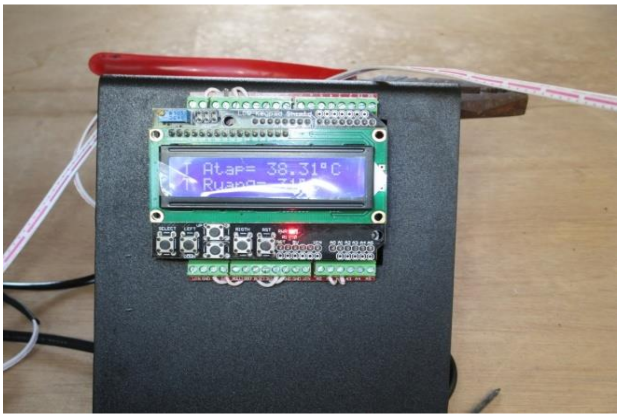

Fig. 4. An automatic spraying roof device.

The device is set up at a particular degree of the roof surface temperature as a temperature limit parameter if it exceeds the level limited, then the controller will turn on the actuator and a pump work to spray water on the roof. However, if the roof temperature is less than or equal to the degree limited the controller will turn off the actuator.

3. Results and Discussion

At the first step, it is necessary to evaluate the roof surface temperature and the indoor air one without applying the automatic roof spraying device. The weather is sunny at noon; the average of outside air temperature is 30.4°C with a relative humidity of 56.4%. In such conditions, the roof surface temperature was 38.2°C and indoor temperature 31.9°C, with a relative humidity of 50.4%. After about five minutes later, the indoor air temperature changes to be 33.7°C with a relative humidity 44.3%, however, the roof temperature is still as identical as at the beginning measured 38.2°C. The measurements at 11:00-15:00, it can be said that the roof temperature is usually higher by 5.6°C on average from the inside one.

The temperature of the water before spraying is firstly measured (i.e., 35.7°C), and then the roof surface, the outdoor and indoor air temperatures. It is important to observe the roof surface temperature reduced by 5°C on average after manually spraying water; where the temperature changes from 38.2°C to 34.2°C.

The decrease of the roof surface temperature does not significantly reduce the indoor air temperature. It shows that the indoor temperature is 33.6°C with a relative humidity 44.6%, which does not differ too much from the initial conditions measured 33.7°C. The roof surface temperature increased gradually after at least 5-10 minutes later. This measurement is performed when a window is opened with the wind speed in the room 0.8 m/s; the room temperature was recorded 33.4°C and relative humidity 45.9%.

The second step, an automatic water spraying device is initially applied to the cell test. The limit roof surface temperature is set up at 31°C; it means the device will work when the roof temperature reaches >31°C. The water spraying can reduce the roof surface temperature significantly even from 51°C to 38°C, but it is not able to drastically reduce the indoor air temperature. For the time being, the water spraying no longer able to lower the roof temperature less than 30°C, although spraying continues. This drop in temperature can reduce the roof by spraying only at 37.8°C; it is not less than that. This case compels to modify a temperature parameter as a threshold value.

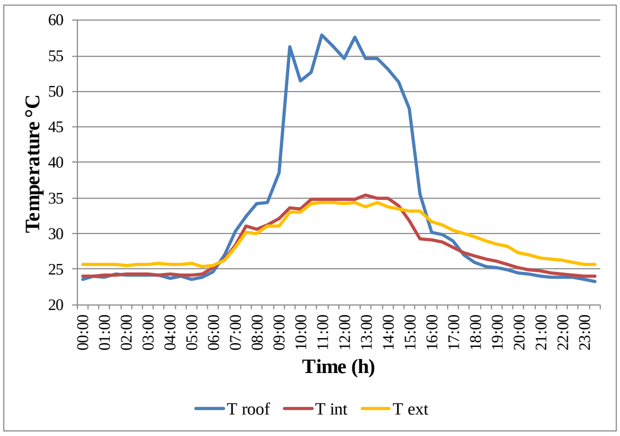

Fig. 5. Comparison of the roof surface, interior and exterior temperatures without spraying the roof.

Moreover, the temperature parameter is adjusted at 38°C; it means the motor will turn when the roof temperature reaches 38°C and water will be sprayed. For comparison of the effects of water spraying, it is necessary to separate into two conditions, namely with water spraying and no spraying. The roof surface, interior and exterior temperatures for the without water spraying conditions are shown in Fig. 5. Measurements were accomplished in the period from the end of February to the end of May in this year. It corresponds to the beginning of the hot season. For the day, the average indoor temperature is lower than the outside temperature. The roof surface temperatures start to go drastically up at 09:00 and fluctuate until 13:00, and the temperature can reach from 50 to 56°C. In the morning until the midday, the interior air temperature is higher than the exterior one; on average 0.63°C.

The phenomena caused by the proprieties of metal like zinc: it is easier and faster to absorb and emit the heat. It is the reason why at the first attempt the decreasing of roof temperature does not affect significantly to lower the interior one; even the roof surface temperature will immediately be hotter. After 15:00, the internal temperatures go down less than the outer ones.

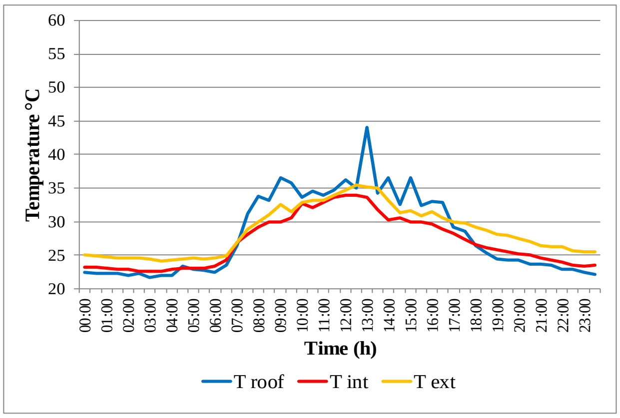

Fig. 6. The roof surface, interior and exterior temperatures with spraying the roof.

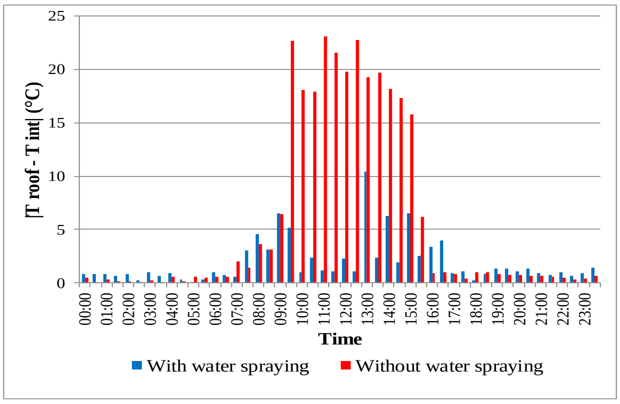

Fig. 7. Temperature differences of the ceiling surface and the interior using water spraying and without water spray.

Figure 6 shows the effect of water spraying automatically onto the roof surface. By automatic water spraying the roof surface has always maintained less than 38°C, and given effectively benefits for the daytime. It caused the indoor air temperature is lower than the exterior during the day. In fact, spraying water automatically onto the roof surface can significantly reduce the roof surface temperature, even go down to 14°C.

However, it is important to evaluate the effects of spraying water onto the ceiling with determining the temperature difference between the roof surface and the interior temperature. For this purpose the absolute value is used, the use of absolute value makes it easy to calculate the average temperature differences. The average temperature differences between two conditions are noted that for the status with sprayed water is obtained 1.93°C, while the one without sprayed water is 5.72°C, as shown in Fig. 7. It is important to note that the water spraying reduces the roof surface temperature but not influence the decrease of the indoor air temperature significantly as supported by the previous descriptions.

The water sprayer device was equipped a submersible pump with a capacity of 4,000 l/h and power 100W. Water usage per day is 2.88 m^3 even when the hot weather. The level of electricity prices in Manado is 651.10 Rupiahs per kWh; thus, the cost of electricity is 110.58 Rupiah (US$ 0.008). Prices prevailing water from local water companies is 3,500 Rupiahs per m^3; thus, the cost of water supply for 10,080 Rupiahs or US$ 0.76/day (where 1 US $ = Rp. 13,200). Therefore, the entire cost of running this system amounted to US$ 0.768/day or US$ 280.32/year. If we can reuse recycled water costs can be reduced significantly by approximately 70%; bringing the total cost per year could be saved amounted to US$ 84.1. It can be said when compared with the benefits to lower the surface temperature of the roof then the cost is worthy and reliable.

4. Conclusions

The application of the roof spraying as an evaporative cooling technique has been made. A test cell contained the plywood walls, and corrugated zinc roof had been established for this study. The roof surface is sprayed with water using a perforated tube laid on the ceiling and connect to a pump. Some measurements have been performed; the spraying water on the zinc roof surface can reduce its average temperature by 5°C. However, the roof surface temperature did not automatically reduce and directly lower the average room temperature. As for lowering the roof surface temperature, the water spraying has effectively to be repeated every 10-15 minutes and continuously practised, especially when the outside temperature is very high.

The automatic water spraying has been implemented in the cell test. This device can work efficacious, especially running water pumps to spray the roof surface when reaches 38°C or more. The advantage of using the method is to decrease the roof surface temperature compared to the indoor temperature. It is important to say here that the weaknesses of this automatic water spraying device are to use water in significant quantities. Thus, it still needs to do further work, especially to reuse water that has become hotter after spraying and how to cool return water to be reused for more economical.

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