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STUDY OF PERFORMANCE OF HEAT EXCHANGER USING WATER AND SAND FOR ZINC ROOF COOLING WITH AUTOMATIC WATER SPRAYING

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ABSTRACT

The purpose of this study is to compare the performance of a heat exchanger using water and sand as a cooling medium to cool the surface of the zinc roof by spraying water automatically. The heat exchanger consists of cooling coil made of 3/4” diameter copper formed the sinusoidal curve and planted 10 cm of depth in 1 x 1 x 0.2 m acrylic container filled with water or sand. Water is automatically sprayed onto the surface of the zinc roof and then flowed into a heat exchanger. Comparing the performance of a heat exchanger using water and using sand shows that they basically have a performance that can lower the water temperature used for spraying onto zinc roofing surfaces. The water-to-water heat exchanger that uses water as a cooling medium is more effective in the morning until noon, while the water-to-sand heat exchanger that uses sand as a cooling medium will be more effective during the day until late afternoon. In general, the water-to-water heat exchanger is more able to lower water temperatures compared to the water-to-sand heat exchanger. This system essentially demonstrates its usefulness and capacity as one of the passive cooling strategies that can lower the zinc roof surface temperature which in turn lowers the indoor air temperature.

Keywords: heat exchanger, water, sand, zinc roof surface temperature, performance assessment.

INTRODUCTION

Architects and engineers are currently trying to design energy-efficient buildings; the maximum use of natural potential as a source of energy and for applications as building materials. The consideration of climate factors in designing becomes the most important thing to get a design that fits and matches the local environment and climate. Buildings in humid tropical climates face overheating problems as a result of hot and humid climate pressures. This condition will lead to disruption of occupant comfort and can lead to energy wastage, especially to cool the room if not taken seriously. Energy consumption will increase when construction is designed without considering local environmental conditions, improper use of construction materials and ignoring the use of direct sunlight protection elements. Buildings in humid tropical climates face the problem of how to maintain thermal comfort conditions in their occupancy space.

In the face of excessive warming, the passive cooling strategy is one of the schemes to save energy consumption and also to achieve the thermal comfort required, especially for humid tropical climate conditions. One of the usual passive cooling strategies applied is comfort ventilation. Except for the strategy, it is still rare to find other potential strategies and other viable uses, which are certainly compatible with the humid tropical climate. Indirect evaporative cooling is a passive cooling strategy that is feasible to apply to buildings here, which is still not known to the public for the benefits and ways of their application. Implementation of this strategy was investigated by some researchers who concluded that its application could reduce interior temperature as expected [1, 2, 3]. This strategy can also be applied in order to save the energy needs of the building and create a comfortable space as well as efforts to reduce drastically cooling loads in rooms using air conditioners.

The evaporative roof spray cooling system is not a new idea; studies have been done since early 1939. Due to the energy crisis, the roof spray cooling method became recently accepted and desirable [4]. The operation of roof spraying cooling is very easy and basic; The basic concept is to wet the hot surfaces and cool them with sprayed water. Then, some researchers were trying to get a better and effective method of applying this strategy. Some of them, Maerafat and Haghighi [5] were examined the use of evaporative cooling cavities in residential homes, they concluded that its application was very successful in bringing a good impact on cooling. Similarly, Givoni [6] and Joudi and Mehdi [7] were examined indirect evaporative cooling with varying cooling loads for housing concluded that passive cooling systems could reduce room temperature, but these systems had to differ from one another depending on the particular climate. Kim *et al*. [8] were examined the potential for energy savings by using direct or indirect evaporative cooling using an external air system and concluded that both strategies can be utilized for energy conservation.

The use of mobile insulation on the roofs of buildings that can be set for cooling purposes has been investigated by Jain and Rao [9], integration of this system by using a roof pond or not indicating that the system is working properly. In 1977, they also experimentally investigated in detail the ability to reduce the temperature between the roof pond and spraying the roof on the surface of reinforced concrete roofs that were exposed to heat during hot weather. It was found that the roof temperature decreased from 55 °C to 28 °C by spraying compared to a

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reduction from 55 °C to 32 °C for the case of roof ponds. The condition is clear because of the more efficient evaporation of water on the roof surface. The roof surface temperature decreases to 15 °C compared to 13 °C in the case of using a roof pond.

The use of some materials and the way for indirect evaporative cooling attracted some researchers to examine it, one of them was Kettleborough and Hsieh [10] who conducted research on how the wet plastic plate as a heat exchanger was performed for indirect evaporative cooling. Likewise, Costelloe and Finn [11] stated that the passive cooling with the air-water system is potentially applied in temperate or moderate climates. Tang and Etzion [12] described that the cooling with a puddle on the roof using a floating bag had good performance compared with movable insulation. Wongsuwan *et al*. [13] 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.

Spanaki [14] 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*. [15] 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 roof. Kindangen *et al*. [16] reported that water spraying can reduce the zinc roof surface temperature by an average of 5 °C and to gain a greater advantage of the roof temperature reduction is needed to spray water in approximately 10-15 minutes and carried on continuing.

The use of galvanized zinc material as roof covers is very popular in Indonesia. Galvanized zinc is widely used as roofing materials. This is because the roof structure is very simple, inexpensive and very easily obtainable on the market. According to the data from the Bureau of Statistics of the North Sulawesi Province [17], 92.41% of houses use galvanized zinc roofs, as described in Table-1.

Table-1. Types of roof materials in North Sulawesi Province, Indonesia.

Types of roofing	Percentage of houses (%)
Concrete roofing	1.85
Clay Tile Roofing	1.00
Shingle roofing	2.21
Galvanized zinc roof	92.41
Asbestos roofing	0.41
Roof of palm fibers	2.10
Others	0.02

Almost most of the houses and buildings in North Sulawesi province and even Indonesia, in general, are roofing of zinc or aluminum. The use of zinc is very popular because it is very practical in its use and is always widely available in the market. Another reason is the socio-cultural aspects of the local community. There is a cultural perception that has led to widespread use of zinc; one of the causes is the earthquake disaster experienced by residents in North Sulawesi and surrounding areas in 1898 when the great earthquake that occurred has caused many buildings, especially those using heavy roofs such as clay or ceramics to be damaged and destroyed. Thus, considerations and decisions not to use heavy roofing materials are always of their concern. This is the main reason why most houses in North Sulawesi Province, especially in Manado use corrugated zinc as a lightweight roofing material.

All these studies as described, they only see in general how evaporative cooling is applied to the roof of the building, but this can lead to another problem: how to make water after spraying becomes cooler for reuse. Water after being sprayed onto the surface of the zinc roof will become hotter, for reuse required cooling process for cooling with water spraying becomes more effective. Re-cooling can be overcome by applying heat exchangers. Methods to improve the performance of heat exchangers have been made by researchers such as Lunsford [18] and the Bureau of Energy Efficiency [19] applied methods to improve shell-and-tube exchanger performance. The methods consider whether the exchanger is performing correctly, to begin with, excess pressure drop capacity in existing exchangers and the use of augmented surfaces and enhanced heat transfer. He argued that shell-and-tube exchanger rating programs may be used to evaluate these exchanger performance issues. Like Lunsford, Sahin *et al.* [20] studied thermo-economic performance optimization for a single pass counter-flow heat exchanger model. In the considered model, the irreversibilities due to heat transfer between the hot and cold stream are taken into account. They determined an objective function as the actual heat transfer rate per unit total cost considering lost exergy and investment costs, and they concluded that the optimal performance and design parameters which maximize the objective function have been significant factors.

Of the overall performance evaluations, however, no performance evaluation has been found of the type of heat exchanger by using different cooling media. The purpose of this paper is to compare the performance of heat exchangers that use water and sand as a cooling medium.

METHODS

Location of research

The study was conducted in Manado located in Indonesia's North Sulawesi province, at latitude of 1.4583°N and a longitude of 124.8260°E. As part of the humid tropics, Manado has the hottest month in October with an average temperature of 29.10 °C and the coldest in

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January with an average temperature of 26.90 °C. In general, the temperature difference between the hottest and coldest months is not too large. The rainy period occurs during November–March, with the largest average rainfall occurring in January (465 mm). The amplitude of daily and monthly temperatures in a year is small. The average high relative humidity ranges from 64% in October and 81% in January and March, as presented in Figure-1.

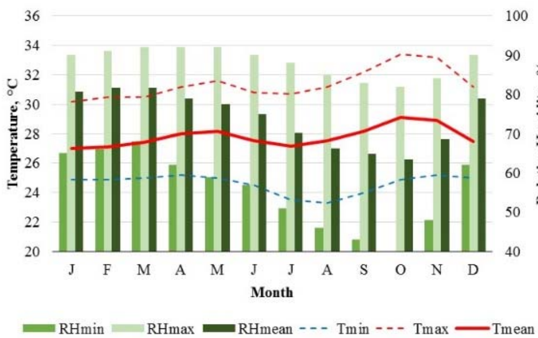

Figure-1. Climatic data for North Sulawesi province, Indonesia.

A test cell and a heat exchanger modeling

A test cell has been built with a length of 1.50 m, a width of 1.50 m and a height of 2.50 m. The walls are made of plywood and the roof is made of corrugated galvanized zinc with a surface area of 3.80 m2. In regard to eliminating the influence of the soil moisture, the plywood floor is raised about 80 cm from the ground. This is similar to the house on stilts made of wooden boards that are widely traded and built in this region.

To investigate the effect of water spraying on the reduction of zinc roof surface temperature, this test cell has no ceiling and no ventilation. The slope of the roof in one direction forms an angle of approximately 30°. This test cell has two windows measuring 30 × 40 cm, located on the right and left (North and South) to avoid direct sunlight that can penetrate through the window. Test cells are placed outdoors so they can be exposed to direct sunlight as effectively as possible from morning to evening, as illustrated in Figure-2.

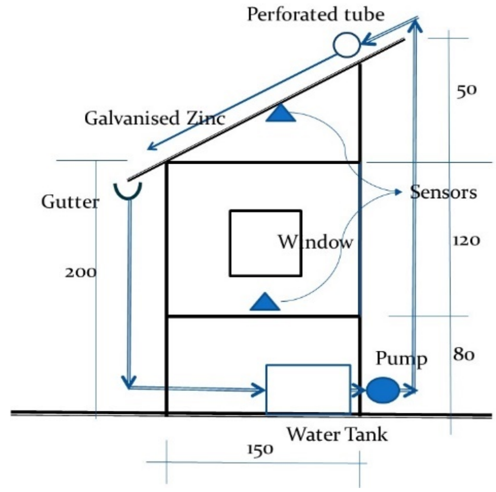

Figure-2. The schematic section of a test cell.

Measures were taken to check the performance of the heat exchanger using RC-4HC data logger that measures temperature and relative humidity. The five pieces RC-4HC data logger were used with the appropriate placement. One data logger is placed in roof gutters that take in water after spraying, is given as a reference temperature of the incoming water where the temperature must have been hotter. One data logger is ready at the end of the copper pipe to record changes in water temperature leaving the heat exchanger. A data logger to record the temperature of the water or sand in the heat exchanger as a cooling medium. A data logger is placed in the cell test for recording the temperature in the room and other data logger is placed and affixed to the inside of the zinc roof to measure and record the temperature of the roof surface.
A heat exchanger made of acrylic plates with a size of 1 x 1 x 0.2 m. The copper pipe is used as a cooling coil with a size 3/4' of diameter and 6.5 m of length mounted in an acrylic box. An acrylic box filled with water or sand as a coolant in which the copper pipe buried as high as about 10 cm from the surface of the water or sand. At the terminal of the copper pipe where the water will be provided with a plastic hose to the tank, as shown in Figure-3. The water spray is installed by a closed circuit connected to a submersible pump with a capacity of 4000 l/h and 100 W power, and a hollow polyvinyl chloride (PVC) tube placed at the highest edge of the roof. The PVC pipe is perforated every 2.50 cm to form a straight line. These holes are used to spray water on the entire surface of the roof when the pump is turned on.

(a) (b)

Figure-3. The heat exchanger design: water and sand as media cooling.

Automatic water spraying device

The automatic roof spraying device is designed and installed by applying a subsystem consisting of sensors, controllers and actuators as illustrated with a block diagram in Figure-4. The one wire digital temperature sensor - DS18B20 is used to detect the roof surface temperature and attached under the roof, while the DHT11 digital temperature and humidity sensor are used to measure indoor air temperature and humidity and placed in the middle of the room. These sensors are very easy and suitable to use with the Arduino micro-controller and the Solid-State Relay (SSR) 25-DA, having very precise stability and calibration levels.

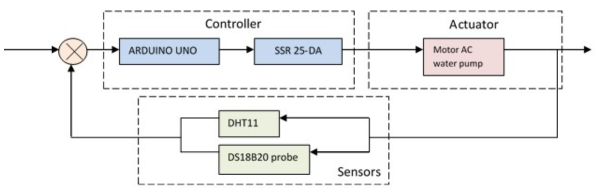

Figure-4. A block diagram of an automatic water spraying device.

The automatic water spraying device is set to work when the roof surface temperature reaches a certain degree as a lower threshold; for this purpose, at the initial test, a threshold is set at 31 °C and then the final setting at 38 °C as described in the flowchart of actuator activation in Figure-5. If it reaches or even exceeds the threshold value, the controller will turn on the actuator and the pump will work to spray water onto the roof surface. However, if the roof surface temperature drops from the threshold value, the controller will turn off the actuator and the pump will not work anymore. The measurement results for roof surface temperature and room temperature can be read on the LCD monitor [16].

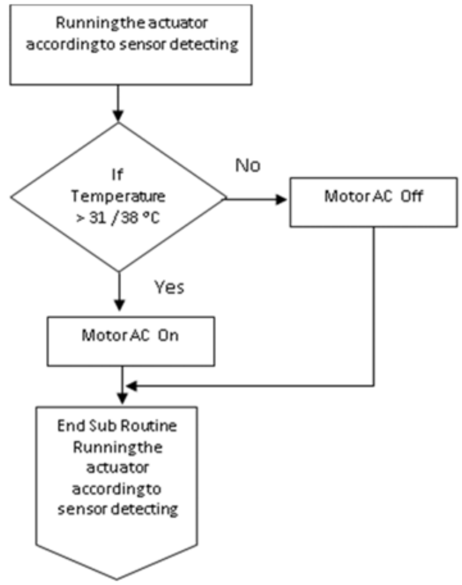

Figure-5. A flowchart of an actuator activation.

RESULTS AND DISCUSSIONS

The first step, the temperature threshold adjusted at 38 °C; that means water will be sprayed onto the roof surface when the temperature reaches 38 °C. This temperature threshold determination is the result of previous research in the framework of the implementation of automatic water spraying [2]. Measurements are conducted from July to October. The roof surface temperature drops drastically from night to morning and again fluctuates until 13:00, the temperature can reach a maximum value of 50 °C to 56 °C. This phenomenon is caused by metallic properties such as zinc and aluminum: easier and faster to absorb and radiates heat. After 15:00, the interior temperature drops lower than the exterior temperature. Roof surface temperatures can always be maintained to be less than 38 °C and provide an effective benefit during the day. This causes the air temperature in the room lower than the exterior during the day. Automatic spraying of water onto the roof surface can significantly reduce roof surface temperature, even lower by 14 °C.

The next step is to investigate the performance of heat exchangers using water or sand as a cooling medium to reduce the water temperature to be reused after roof spraying. Measurements are made when water flows to the start of a copper pipe in a heat exchanger, this is called water-in; while the term water-out is water that has passed through the heat exchanger, which will be forwarded to the water tank. The expected process occurs in a heat exchanger is cooling water after spraying onto the surface of the zinc roof.

Figure-6 shows the state of the water temperature at entry and exit to and from the heat exchanger compared to the water or sand temperature as the cooling medium in the heat exchanger, as well as for roof surface temperature and indoor temperature. Roof cooling occurs effectively from 8 a.m. to 3 p.m., where spraying of water occurs not

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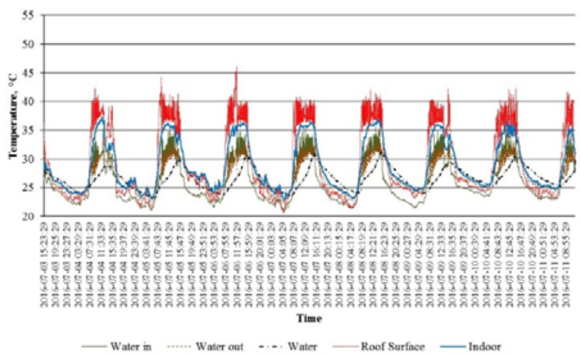
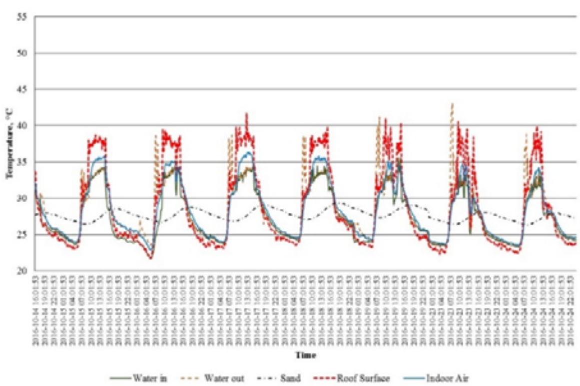
continuously depending on whether the surface temperature of the roof has passed the threshold temperature set at 38 °C or not; the process of cooling water by a heat exchanger depends on the presence or absence of spraying, so that the curves for incoming and outgoing water are not continuous.



(a)



(b)

Figure-6. The performance of a heat exchanger using water (a) and using sand (b) as a cooling medium.

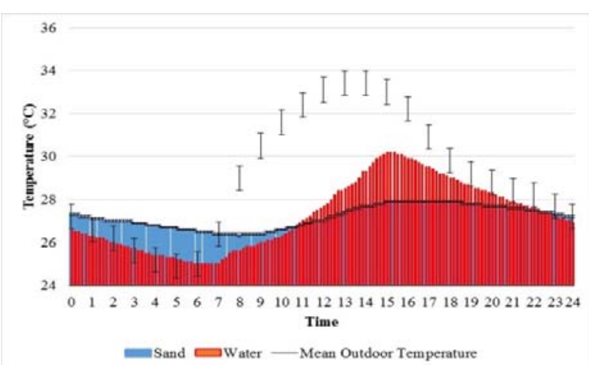
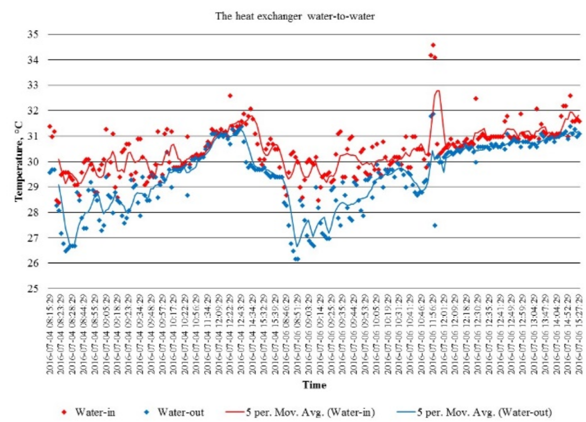
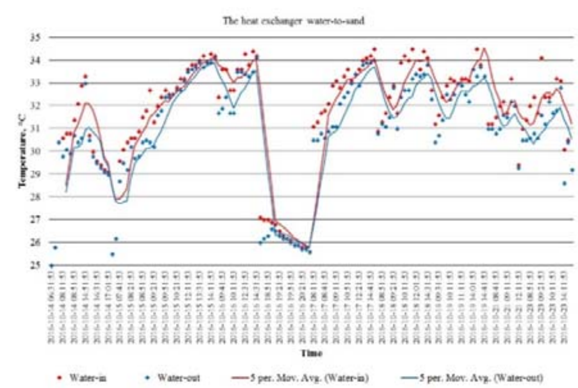


Figure-7. Sand and water temperatures of a heat exchanger vs mean outdoor temperature.

The comparison of water and sand temperature as a cooling medium in a heat exchanger shows that the water temperature reaches a minimum at 25 °C at 06:00 and a maximum of about 30 °C at 15:00. While the sand temperature reaches a minimum value at 26 °C at 08:00 and a maximum of about 28 °C at 17:00. Characteristics of both materials, resulting in a similar average performance to cool water used for spraying; but more optimal water cooling performance occurs at 08:00 - 11:00 hours compared to the performance by sand. The more optimal cooling performance with sand occurs at 11:00 onwards, as shown in Figure-7. It also shows that the ability of heat exchangers that use water as a cooling medium to cool incoming water works more effectively in the morning from 8:00 to 11:00 while those using sand as a cooling medium are more effective from 11:00 to 17: 00. This phenomenon is also reinforced by comparing indoor air temperature between cooling with water and with sand as illustrated in Figure-6.



(a)



(b)

Figure-8. The ability of water-to-water (a) and water-to-sand (b) heat exchangers to lower the water temperature to be sprayed onto the roof.

For more details, data is prepared for spraying time only, as shown in Figure-8. This shows the difference between the temperatures of water-in and water-out to and from the heat exchanger; for the water-to-water heat exchanger obtained an average temperature difference of 1.01 °C while for an average water-to-sand heat exchanger of 0.63 °C. This condition essentially explains that the heat exchanger uses water or sand as a coolant can work well to reduce the temperature of water entering after spraying to the roof surface. The decrease in mean temperature between incoming and outgoing water that occurs in water-to-water heat exchangers is greater than what happens in water-to-sand heat exchangers. The standard deviation (SD) of the average difference between incoming and outgoing water in a water-to-water heat exchanger is 1.1 whereas in a water-to-sand heat exchanger is 0.59. The decrease in water-in temperature, on average, is more effective on cooling by using water.

CONCLUSIONS

Experimental analysis of heat exchanger performance using water or sand has been performed. To cool water that has been sprayed onto the roof surface is used the heat exchanger. Spraying water on the surface of the zinc roof on the test cell using an automatic water spraying device, where this device has been able to work well to turn on the water pump and to spray it onto the roof surface when the roof surface temperature reaches 38 °C or more. Spraying water onto the roof surface in an effort to cool its surface temperature requires a large quantity of water, so the effort to reuse sprayed water is done using a heat exchanger. The water is supplied to a heat exchanger where the cooling medium uses water or sand, its cooling performance is measured and then compared against each other.

The role of a heat exchanger can lower the water temperature, after spraying the roof surface, which has become hot. The water-to-water heat exchanger can lower the average temperature of water-in by 1 °C with an SD of 1.1 whereas the water-to-sand heat exchanger is 0.63 °C with SD 0.59. The ability of a water-to-water heat exchanger, which uses water as a cooling medium, to cool incoming water is more effective in the morning while the more effective use of sand occurs at mid-day until late afternoon. This is the benefit of using heat exchangers both using water and sand as a cooling medium. The next work is to make the prototype heat exchanger and installation more effective. The design of this prototype can be used as a means to lower the temperature inside buildings in a humid tropical climate.

REFERENCES

[1] Kindangen J.I. 2017. Pendinginan Pasif untuk Arsitektur Tropis Lembab (Passive Cooling for Humid Tropical Architectures), Yogyakarta, Deepublish, 241 p.

[2] Kindangen J.I. and Umboh M.K. 2017. Design of Evaporative-Cooling Roof for Decreasing Air Temperatures in Buildings in the Humid Tropics, in Proceedings of Engineering International Conference, Semarang, AIP Conference Proceedings 1818, 020023, http://dx.doi.org/10.1063/1.4976887

[3] Givoni B. 1994. Passive and Low Energy Cooling of Buildings, New York, Van Nostrand Reinhold.

[4] Carraso A., Pittard R., Kondepudi S.N. and Somasundaram, S. 1987. Evaluation of a direct evaporative roof-spray cooling system, in Proceedings of the 4th Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, 94-101.

[5] Maerefat M. and Haghighi, A.P. 2010. Natural cooling of stand-alone houses using the solar chimney and evaporative cooling cavity, Renewable Energy, 35.9: 2040–2052, https://doi.org/10.1016/j.renene.2010.02.005

[6] Givoni B. 2009. Indoor temperature reduction by passive cooling systems, Solar Energy, 85.8: 1692–1726, https://doi.org/10.1016/j.solener.2009.10.003

[7] Joudi, K.A. and Mehdi, S.M. 2000. Application of indirect evaporative cooling to variable domestic cooling load, Energy Conversion and Management. 41.17: 1931-1951, https://doi.org/10.1016/S0196-8904(00)00004-2

[8] Kim M.H., Kim J.H., Kwon O.H. and Choi A.S. 2011. Energy conservation potential of an indirect and direct evaporative cooling assisted 100% outdoor air system, Building Services Engineering Research & Technology, 32.4: 345-360, https://doi.org/10.1177/0143624411402637

[9] Jain S.P. and Rao K.R. 1974. Movable roof insulation in hot climates, Building Research and Practice, 2.4: 229-234, https://doi.org/10.1080/09613217408550323

[10] Kettleborough C.F. and Hsieh C.S. 1983. Thermal performance of the wet surface plastic plate heat exchanger used as an indirect evaporative cooler, Journal of Heat Transfer, 105.2: 366-373, https://doi.org/10.1115/1. 3245587

[11] Costelloe B. and Finn D. 2003. Indirect evaporative cooling potential in air–water systems in temperate climates, Energy and Buildings, 35: 573-591, https://doi.org/10.1016/S0378-7788(02)00161-5

[12] Tang R. and Etzion Y. 2005. Cooling performance of roof ponds with gunny bags floating on water surface as compared with a movable insulation, Renewable Energy, 30: 1373-1385, https://doi.org/10.1016/j.renene.2004. 10.008

[13] Wongsuwan W., Fongsamootre T. and Cole M.O.T. 2006. Experimental studies on the roof pond house under tropical climatic conditions, KKU Engineering Journal .33. 2: 133-139

[14] Spanaki A. 2007. Comparative studies on different type of roof ponds for cooling purposes: Literature review, in Proceedings of 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy and Advanced Ventilation Technologies in the 21th Century, Crete Island, Greece, 1009-1015

[15] Zhou N., Gao W., Nishida M., Kitayama H. and Ojima T. 2004. Field study on the thermal environment of passive cooling system in RC building, Energy and Buildings, 36.12: 1265-1272, https://doi.org/10.1016/j.enbuild. 2003.09.012

[16] Kindangen J.I., Tondobala L. and Umboh M.K. 2018. Experimental Analysis of Cooling Performance of Spraying Water Automatically on the Galvanized Zinc-Roofs, International Journal of Engineering and Technology. 10.2:414-422, http://doi.org/10.21817/ijet/2018/v10i2/ 181002014

[17] Bureau of North Sulawesi Province Statistic Centre. 2016. Sulawesi Utara dalam Angka 2015, BPS Sulut, Indonesia, Manado.

[18] Lunsford K.M. 2006. Increasing Heat Exchanger Performance- Technical Papers, Bryan Research & Engineering, Inc., Texas, 1-13

[19] Bureau of Energy Efficiency, 2006. Energy Performance Assessment of Heat Exchangers, 56-73, Available: http://www.em-ea.org/Guide%20Books/book-4/ [Accessed:12 June 2018]

[20] Sahin B., Ust Y., Teke I. And Erdem H.H. 2010. Performance analysis and optimization of heat exchangers: a new thermoeconomic approach, Applied Thermal Engineering, 30.2-3: 104-109, https://doi.org/10.1016/ j.applthermaleng.2009.07.004