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Performance Test of Indirect-Direct Two Stage Evaporative Cooler Based Water Sprayer with Primary Air Velocity Variation

Sumar Hadi Suryo, Bambang Yunianto, Nazaruddin Sinaga and Yurianto and Eflita Yohana
The Department of Mechanical Engineering at the University of Diponegoro Jl. Prof. Sudharto, SH., Tembalang, 50275 Semarang, Indonesia

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Corresponding Author:
Sumar Hadi Suryo
The Department of Mechanical Engineering at the University of Diponegoro Jl. Prof. Sudharto, SH., Tembalang, 50275 Semarang, Indonesia

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Abstract: Evaporative Cooler (EC) is an air conditioning device that have advanteges compared to device using refrigeration cooling system like low energy use, simply manufactured and environmental friendy (not using CFC/ Chlorofluorocarbon). EC is compatible to cool buildings in hot and dry regions. But, one of the EC type, indirect-direct two-stage evaporative cooler, is wider in use (more humid regions) and have better effectivity. Indonesia is country that have wide variety of ambient air condition like hot, cold, dry and humid. This study will present the planning, making and testing experimentally performance indirect-direct two-stage evaporative cooler using water sprayer in Indonesia. Moreover, this study uses variation of primary airflow fan speed 33, 66 and 100%. The result is highest performance that achieved is in the primary airflow fan speed 33% which provided 101% effectivity that change condition of air from 33.0°C and 58.7% RH to 26,1°C and 94.7% RH.

INTRODUCTION

Air conditioning for human activities in the world is one of the needs of today's society as a result of global warming, air pollution and also to meet the standards in doing various jobs. One of the air conditioning tools is the evaporative cooler (with evaporative cooling system) which has the characteristic of energy use more efficient than the refrigeration system (Wang and Sanhn, 2000).

Evaporative cooler uses the principle of evaporative cooling where the process is air conditioning using evaporation from water to cool the air flow directly or indirectly so that the dry bulb temperature becomes lower (cold). The existing evaporative cooling is divided into 3 kinds based on the cooling scheme of Direct Evaporative Cooling (DEC), Indirect Evaporative Cooling (IEC) and Indirect-Direct Evaporative Cooling (IDEC). If viewed based on the use of wet media to drain the water, evaporative cooling system is divided into 4 types, namely the use of water sprayer, evaporative pads, rigid media and rotary wheel (Wang, 2000).

In direct evaporative cooling, the cooled air stream is directly contacted with wet media so that it can be to lower the temperature and raise the moisture. While IEC has the same system with DEC but it uses heat exchanger to contact air of product from DEC with air of IEC product indirectly, so that, air of IEC product can decrease air temperature with permanent absolute humidity level. In a two-level indirect-direct evaporative cooler which uses the IDEC system, the direct evaporative cooler is connected in series after the indirect evaporative cooler.

Therefore, the IDEC system has a cooler air product result than DEC and IEC. The use of water sprayer to create water mist and other media in the evaporative cooling system also has different characteristics. The effectiveness of evaporative cooler produced by wet media type of water sprayer is relatively higher than some other media (Wang and Sanhn, 2000).

Evaporative cooler is a very suitable tool for cooling buildings in areas with hot and dry air conditions (Heidarinejad *et al*., 2009). Thomas *et al*. (1980) and Panchal *et al*. (1983) conducted performance tests using the plate-type evaporator. The performance differs according to the shape of the plate element in the case of the shell-and-plate type heat exchanger. Uehara *et al*. (1982-1984) carded out performance tests using three different types of plate evaporators to decide the optimum shape for such an evaporator. Evaporative coolers have been popularly used and studied for air conditioning in space for human activities in various countries with relatively high and dry temperatures such as countries in the Americas, Australia and Middle East Asia. Here are some advantages of using an evaporative cooler compared to a vapor-compression refrigerant (El-Dessouky *et al*., 2004).

- Reduce energy consumption and capacity on power plant
- Reduce the rate of burning of fossil-based fuels on power plants and reduce air pollution from emissions
- Using water as a working fluid (not a CFC-based fluid)
- The manufacturing technology used is easy/simple

Previous research on two-level indirect-direct evaporative cooler has been done by Heidarinejad, G., in Iranian state by using air input simulator (air variation regulator). The air input simulator is regulated so it can be represent various weather conditions in several cities in Iranian countries ranging from 33-46.6°C dry ball temperature with 17.1-26.6°C wet ball temperature (overall it is a relative area very hot and dry). The result is that the effectiveness of this tool can range between 108-111% and the use of electric energy from this two-level indirect-direct evaporative cooler is only 33% of the value used by vapor-cooled compression. A model-based predictive controller was developed by Elliott and Rasmussen (2009). for a dual-evaporator A/C system which could be used to trade between energy efficiency and the fluctuation of indoor air temperature (Elliott and Rasmussen, 2013).

It is noted that the operating characteristics of a variable speed direct expansion A/C system, relating its output total cooling capacity to its output Sensible Heat Ratio (SHR) at various combinations of compressor and fan speeds were extensively studied (Li and Deng, 2007; Xu *et al*., 2010; Xia *et al*., 2017). Controlling indoor humidity at an appropriate level is critically important since it directly affects building occupant's thermal comfort, indoor air quality and the operating efficiency of building A/C installations (Chowdhury *et al*., 2008)

A study of temperature and humidity in Gowa district, Indonesia, conducted by Nasrullah in the year 2013-2014, obtained data that the temperature in the area ranged from 19.10-35.90°C with a relative humidity between 25.60-93.80%. Although, the air conditions in each region in Indonesia are different, the research will be used as a reference to represent conditions in Indonesia that are sometimes hot and sometimes cold sometimes dry and sometimes humid.

It is often necessary to increase the moisture content of the air circulated through occupied spaces. One way to accomplish this is to inject steam. Alternatively, liquid water can be sprayed into the air. Both cases are shown schematically in Fig. 1a. The temperature of the moist air as it exits the humidifier depends on the condition of the water introduced. When relatively high-temperature steam is injected, both the humidity ratio and the dry-bulb temperature would be increased. This is illustrated by the accompanying psychrometric chart of Fig. 1b. If liquid water was injected instead of steam, the moist air may exit the humidifier with a lower temperature than at the inlet. This is illustrated in Fig. 1c. The example to follow illustrates the case of steam injection. The case of liquid water injection is considered further in the next section (Moran).

Due to Indonesia's conditions that sometimes have hot and dry air, then the use of indirect-direct evaporative cooler two levels with water sprayer usage is considered

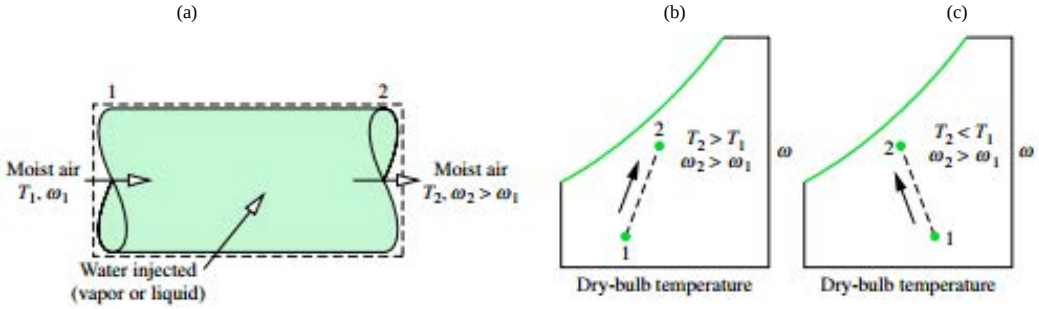

Fig. 1(a-c): Humidification: a) Control volume; b) Steam injected and c) Liquid injected

very potential to be utilized. Therefore, this research will discuss about the design, manufacture and testing of performance/performance indirect-direct evaporative cooler two levels with the use of water sprayer is simple, precisely and has a good effectiveness so that later can be successfully produced and used in bulk in buildings in Indonesia and then get the benefits mentioned above. This study also examined the effect of the rotation speed of the primary airflow fan on the effectiveness of this refrigerant.

MATERIALS AND METHODS

Flow chart of research

Designing and making tools: The design of the two-level indirect-direct evaporative cooler tool is done by drawing the schematic of the tool first, after that the selection of components and geometry determination are done. This designing will be made in accordance with previous studies which have been referring to research by Heidarinejad in 2009 but with some changes/ modifications to this tool. Schematic tool and its testing is made using CorelDRAW X7 Software. Figure 2 is a two-level indirect-direct evaporative cooler scheme that will be made for later research.

At points 1-5 use thermometer and hygrometer measuring instruments that will be calibrated with ISO certified calibrators. While point 4 uses a thermometer on the calibrator that is connected with thermocouple.

After the tool scheme has been designed, then the next step is the selection of tool components. This two-level indirect-direct evaporative cooler tool uses simple components to assemble, easy to find in the market and affordable prices. This is in accordance with the intent of the research is to make this tool into a simple tool both in terms of manufacture and when the use and maintenance later. Components for making tools are aluminum plates, aluminum tubes, two fans, reverse osmosis pumps and six water sprayers as well as the installation of the hoses and the assembly of parts of the appliance is very easy by using welded joints, glue, sealer and also nuts and bolts

After designing the scheme and component selection is done, then geometry is designed from the two-level indirect-direct evaporative cooler tool and made its manufacture. Figure 3 is a tool after completion.

Calibrate of measuring instrument: Measuring instrument calibrate performed by a test measuring gauge with calibration tool placed close together in a room at the low and high measurement range. In this calibrate process, recording on 4 different air conditions, resulting in recording data 4 temperature and relative humidity data of 4 measuring instrument and calibration tool. The data recorded and presentation into a graphs with axes of X is

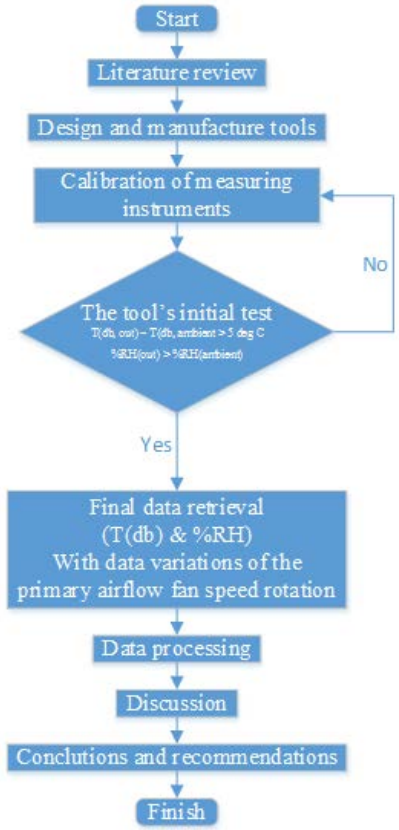

Fig. 2: Diagram of the research flow

the value read by the measuring instrument and the Y axis the values on calibration tool. Once presentation, then the points then sought the value equation of its line. Equations of lines used in this journal is the equation of a line are linear. So at the time of testing later, the value read on the measuring instrument will be inserted into the equation for find the Y value (value should if using calibration tool) representation graph and the calculation of the equation of a line is carried out using Microsoft Excel software 2016.

Based on the calibrate that have been made against the recording data using the equation of a line that has been created, the biggest difference between the value of the measuring instrument with calibration tool (points 1-5) on the temperature and the relative humidity is of 0.5°C and 0.8%. Therefore be generalized that the value of the accuracy of the measuring instrument is the value the accuracy value calibration tool plus calibrate accuracy value. For the accuracy of the temperature measuring instrument is of ±(1.2°C+0.5°C) equals±1.7 °C for range measurement 21.8-35.0°C. As for the relative humidity that is of ±(4% RH+0.8% RH) equals±4.8% RH measurement range for 54.9-69.2% RH.

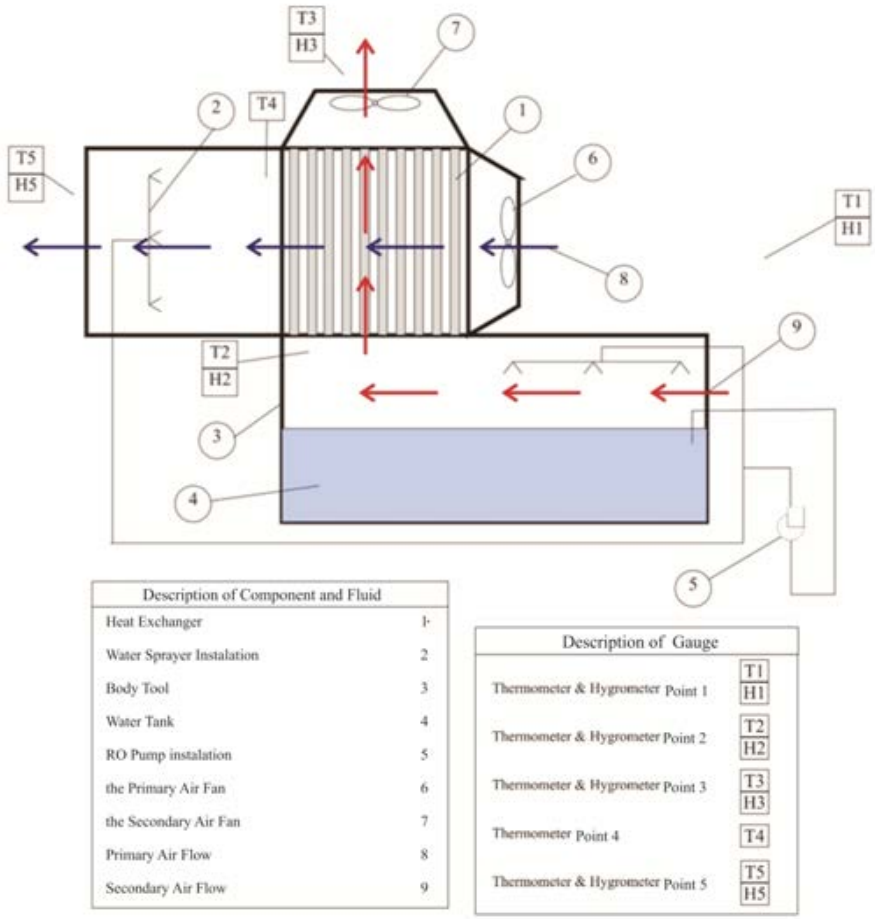

Fig. 3: Schematic and testing point two level indirect-direct evaporative cooler

Testing and data analysis: Testing conducted in Indonesia, particularly the city of Semarang, in December 2017, during the 45 min recorded value on gauge every 5 min. A variation on this test is with the primary air flow fan speeds 33, 66 and 100%. Testing conducted as many as 3 times each variation.

On testing tool-direct indirect evaporative cooler two levels, firstly, data is data the average based on testing as much as 3 times each variation (33, 66 and 100%). At each testing, calibrated data using the equations have been obtained and are rounded to 1 decimal. Each of these data will be equipped with the value of the standard deviation on the measurement point 5 (calculated using the formulas in Microsoft Excel 2016).

Analysis on the research of these the first was the calculation of the effectiveness of the tools of indirect-direct evaporative cooler two levels on some part of it will be done and depicted on the graph to see the increase in performance of indirect-direct evaporative cooler two levels on each 5 min of it up to 45 min. In the calculation of the effectiveness of this data is also required temperature ball wet environment. Wet ball temperature of air environment is calculated using website counters the nature air psikometri diagram on page http://www.flycarpet.net/en/PsyOnline. The calculation of efficiency and evaporative cooling effect of direct evaporative cooler is as follows (Wang and Sanhn, 2000):

$$\varepsilon_{sat} = \frac{T1\text{-}T2}{T1\text{-}TW}$$

Where:

T1 = Temperature of the air entering the direct-indirect evapoarative cooling (°C)

T2 = Temperature of the air coming out-direct evapoarative indirect cooling (°C)

TW = Wet ball temperature of air entering the direct-indirect evapoarative cooling (°C)

Next up is the basic plot of the data in the diagram-an psikometri. In this scheme will be made from air condition processes going on inside this tool into the air along with basic product plotan comfortable conditions of the SNI (Standart of Indonesian) will be described using

a website service provider processing process in the diagram psikometri online that also at the address http://www.flycarpet.net/en/PsyOnline. From the graph it will be seen whether air products from this tool can present a comfortable air or not. The last is to be served also a comparison chart between the effectiveness of indirect-direct evaporative cooler with two levels of effectiveness of indirect evaporative cooler if stood on its own.

RESULTS AND DISCUSSION

The results of this research that is generally measuring instrument can already read well and corresponding measurement theory. But few erorr on initial measurement of minute occurs due to the level of sensitivity (speed of reading) from each sensor is a bit different from each other and the stability of the tool to reach steady state conditions approaching it.

The value of standard deviation testing with rotary speed of 33% fan on 5 point testing temperature obtained value ranges between 0.3°C and the best is 0.1°C. For testing at the speed of fans 66%, the value of the standard deviasinya ranges between 0.5°C and it is best to 0.2°C. And on the speed of rotation of the fan 100%, the default value of deviasinya is the range between 0.3°C and the best is 0°C. This can be check that the testing be done by as much as 3 times on each variation has a fairly uniform value due to the fairly low standard of deviasinya

Based on the results of the experiment, the obtained results on the speed dial of primary air flow fan of 33% (0.9 m sec^{-1}) it maximum tool effectiveness 101% with decrease in temperature of 6.9°C and humidity rise become a 94.7% RH (air environment 33°C and 58.7% RH), on the speed dial of primary air flow fan of 66% (1.8 m sec^{-1}) applies maximum tool effectiveness 94% with decrease in temperature of 6.0°C and humidity rising into the air (94.4% RH environment 33.2°C and 61.2% RH) and on the speed dial of primary air flow fan of 100% (2.7 m sec^{-1}) maximum tool effectiveness applies with 86% decrease in temperature of 5.4°C and increase moisture into 88.9% RH (32.8 environmental air °C and 61.5% RH). Calculation of cooling effectiveness value is the highest effect on playback speed techniques fan 33, 66% and then happens 100%, respectively (air flow rate 0.9, 1.8 and 2.7 m sec^{-1}). This is in accordance with the theory because of the longer time of contact between two surfaces that are different of the temperature, then heat transfer that occurs will be more and more. Figure 4 diagram of liquid psikometri of comfortable standards of SNI (Standard of Indonesian) and the achievement test results of this tool (Anonymous, 2001) (Fig. 5).

In the picture above, numbers 1-3 in a row indicate the line of cooling process with fan speeds 33, 66 and

Fig. 4: Two levels indirect-direct evaporative cooler results

100%. While the number 4 in the picture above shows the scope of the comfortable standard of SNI (Standard of Indonesian) No. 03-6572-2001. Then, if there are air condition or in this point, then the liquid air.

Based on the above picture, it can be observed that all of cooling is performed indirect-direct evaporative cooler two levels based on testing with testing of air condition did not work air products provides the comfortable standard category entry SNI (Standard of Indonesian). However, if only in terms of the temperature is comfortable, then on the primary flow fan putas speed 33% con is capable of presenting a comfortable temperature in effect amounted to 26.1°C (under 27.1°C). But if in terms of moisture, then all tests are not capable of serving the air with comfortable humidity. It is reasonable if the suitable that this liquid cooling tool tool by raising the humidity whereas from testing done, air condition environment s from the beginning have a high humidity (above comfortable standard SNI (Standar of Indonesian)). However, if this appliance is used in a condition it is very hot and dry (summer drought in Indonesia), for example on the conditions of 34.0°C and 30.0% RH, then this tool is very convenient to present the potential of the air. The tagline is done testing back to prove it.

But if using the air with air condition as in the testing done on this research, hence, the tagline an attempt of direct incorporation of such direct evaporative cooler two levels with air conditioning air-vapor compression system) The air out of a direct evaporative cooler direct two levels can be forwarded to become the air enters (pre-cooling) to the air conditioning air-vapor compression system). In addition, to that it also can use dessicant cooling system. It is so potentially to cool the air and makes the air with moisture in the SNI (Standard of Indonesian).

Here in Fig. 6 liquid comparison chart between the effectiveness of best air output indirect-direct evaporative

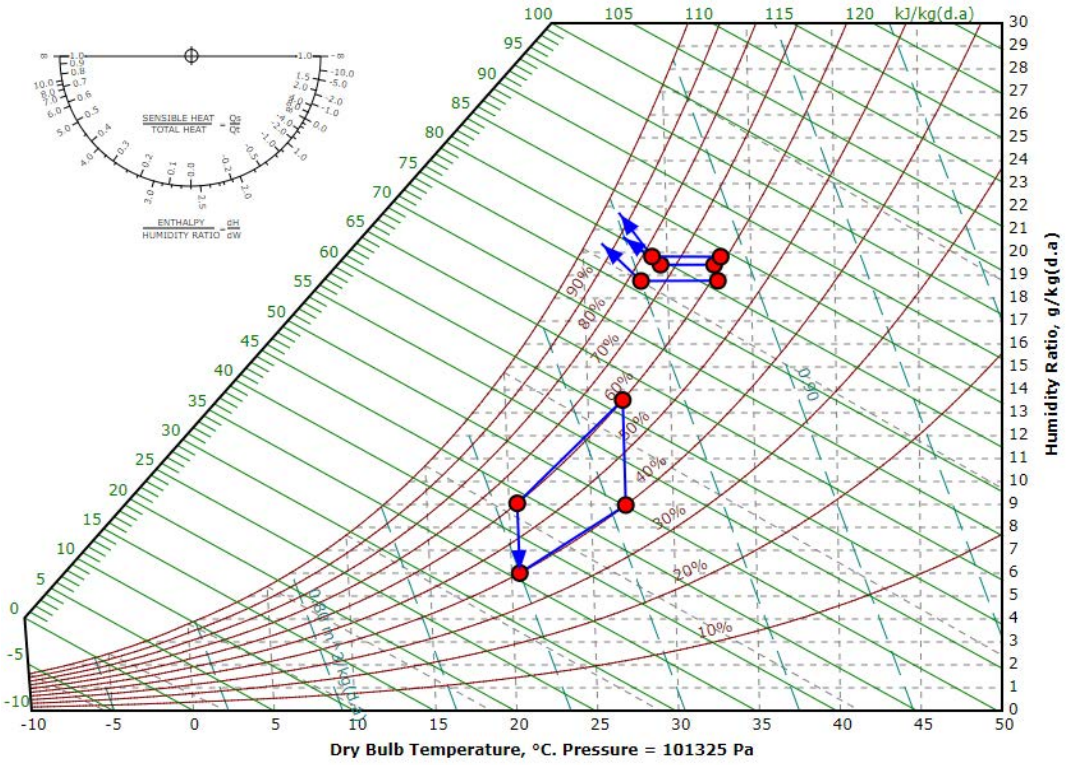

Fig. 5: The test results are compared with the standard comfortable air condition SNI in the psychometrics diagram

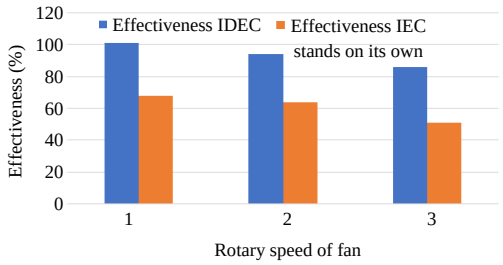

Fig. 6: Comparison of IDEC effectiveness

cooler two levels compared to if using indirect evaporative cooler that stands on its own. Can be seen in the above image that, in all of the testing, the improvement of the effectiveness of the tool from the IEC became IDEC is >30%. Figure 6 is high enough, so that, the use of the IDEC than IEC much better if in terms of the drop in temperature.

CONCLUSION

The conclusion that can be drawn from these studies is indirect-direct evaporative cooler two levels is a cooling appliance are cheap, energy-efficient and environmentally friendly because it does not use CFC-based refrigerant. Experiment of performance tools, based on the standard of comfortable SNI (Standard of Indonesian), then this tool on the air condition testing didn't show the standards of the comfortable humidity, but in terms of the temperature, then the tool is able to achieve a comfortable temperature conditions is amounting to 26.1°C. IDEC effectiveness when compared to stand-alone IEC has the distinction of being much >30% higher if using the IDEC. This tool is very potential if used in summer/the drought in Indonesia because the environmental relative humidity low enough.

RECOMMENDATIONS

Recomendations that can be drawn from this research tool is better if you use a water sprayer that can produce water droplets are smaller and more discharge, so, the surface area of contact heat transfer bigger. On the heat exchanger is made with different tube formation, use a stager or fin-fin modifier direction and made thinner in order for better heat transfer. Need for research on the cooling capacity, energy consumption and the use of the pre-cooling with air or vapor-compression to get variation results.

REFERENCES

Anonymous, 2001. [Procedures for designing ventilation systems and air conditioning in buildings (In Indonesian)]. Staffing Now, Inc., Florida, USA.

Chowdhury, A.A., M.G. Rasul and M.M.K. Khan, 2008. Thermal-comfort analysis and simulation for various low-energy cooling-technologies applied to an office building in a subtropical climate. Appl. Energy, 85: 449-462.

El-Dessouky, H., H. Ettouney and A. Al-Zeefari, 2004. Performance analysis of two-stage evaporative coolers. Chem. Eng. J., 102: 255-266.

Elliott, M.S. and B.P. Rasmussen, 2009. A model-based predictive supervisory controller for multi-evaporator HVAC systems. Proceedings of the International Conference on American Control Conference, ACC'09, June 10-12, 2009, IEEE, Hyatt Regency Jacksonville Riverfront, St. Louis, Missouri, MO, USA, ISBN:978-1-4244-4523-3, pp: 3669-3674.

Elliott, M.S. and B.P. Rasmussen, 2013. Decentralized model predictive control of a multi-evaporator air conditioning system. Control Eng. Pract., 21: 1665-1677.

Heidarinejad, G., M. Bozorgmehr, S. Delfani and J. Esmaeelian, 2009. Experimental investigation of two-stage indirect/direct evaporative cooling system in various climatic conditions. Build. Environ., 44: 2073-2079.

Li, Z. and S. Deng, 2007. An experimental study on the inherent operational characteristics of a Direct Expansion (DX) air conditioning (A/C) unit. Build. Envir., 42: 1-10.

Panchal, C.B., D.L. Hillis and A. Thomas, 1983. Convective boiling of ammonia and Freon 22 in plate heat exchangers. Proceedings of the ASME/JSME International Joint Conference on Thermal Engineering Vol. 2, March 20, 1998, ASME, Honolulu, Hawaii, New York, USA., pp: 261-268.

Thomas, A., D. Hillis, C. Panchal, J. Lorenz and D. Yung *et al*., 1980. Experimental tests of 1 MWt OTEC heat exchangers at Argonne national laboratory. Proceedings of the 7th International Conference on Ocean Thermal Energy Conversion (CON-800633) VOL. 2, June 2-5, 1980, Department of Energy, Washington D.C., USA., pp: 12.1-1-12.1-8.

Uehara, H., H. Kusuda, M. Monde, T. Nakaoka and H. Sumitomo, 1984. Shell-and-plate-type heat exchangers for OTEC plants. J. Solar Energy Eng., 106: 286-290.

Wang, S.K., 2000. Handbook of Air Conditioning and Refrigeration. 2nd Edn., McGraw-Hill, New York, ISBN-13: 978-0070681675.

Xia, Y., S. Deng and M.Y. Chan, 2017. Inherent operational characteristics and operational stability of a variable speed direct expansion air conditioning system. Appl. Therm. Eng., 113: 268-277.

Xu, X., L. Xia, M. Chan and S. Deng, 2010. Inherent correlation between the total output cooling capacity and equipment sensible heat ratio of a direct expansion air conditioning system under variable-speed operation (XXG SMD SHR DX AC unit). Applied Therm. Eng., 30: 1601-1607.