

# Development and Testing of Regenerative Evaporative Cooler

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**Abstract**— This paper presents development and testing of a regenerative evaporative cooler. A conventional direct evaporative cooler has been modified by adding a water to air, heat exchanger in the path of outgoing air stream. The heat exchanger cools the air further by using cooled water available in the collecting tank Experiments have been conducted to study the performance of the regenerative evaporative cooler. It has been found that the efficiency and COP of regenerative system increases by 20-25%. The regenerative cooler having higher cooling capacity may be advantageous as it may attract more people for maximum utilization of this low energy consuming device leading to energy conservation in residential and commercial buildings.

**Keywords**— Direct evaporative cooler, Regenerative cooler, Energy efficient cooler, Saturation effectiveness

## I. INTRODUCTION

The evaporative cooler uses one of the oldest principles of air conditioning known to Man, cooling of air by the evaporation of water. It is the most common form of house hold cooling found in arid areas. The popularity of evaporative cooling in such areas is due to its relatively low initial cost and operational cost compared to refrigerated cooling. Conventional direct evaporative coolers consist of a water reservoir, a pump that draws water from the reservoir and discharges it through spray nozzles directly into the air stream or through the cooling pads.

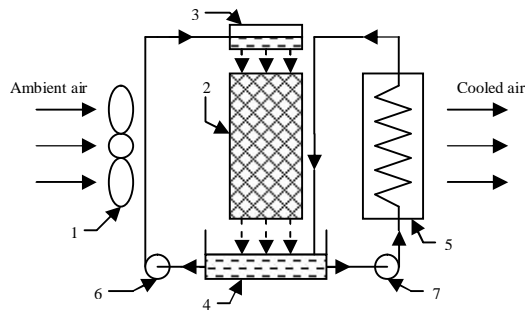
Now a days most of the buildings and offices use conventional air conditioning systems which are based on vapour compression refrigeration system. These systems consume substantial power and they may be harmful to environment also. In developing country like India, majority of population depend on low cost cooling devices such as direct evaporative cooler. Therefore it is very much needed to develop improved/more efficient coolers. Several researchers have made attempt to develop evaporative coolers by way of adding/modifying designs. Reference [1], [2], [3] -[4], have pointed out that in the regions where wet bulb temperature is low, two stage evaporative cooling system, which combines indirect and direct evaporative cooling offers energy and cost saving potential. Reference [5], found that most zones (particularly northern region) of

India where the wet bulb temperature is usually below 25°C, indirect system can achieve comfort conditions similar to refrigerated systems .Also the comfort offered by indirect evaporative system is superior to that achieved by direct evaporative system. Reference [6], stated that when evaporative cooling technology is evaluated as an energy conservation measure rather than the sole source of cooling, the opportunities for application become unlimited. Reference [7], found that the coefficient of performance of the combined evaporative cooling system was at least 20 % greater than those achieved when employing either the indirect evaporative cooling or direct evaporative cooling system alone. Reference [8], analyzed the potential of indirect evaporative cooling in every climatic condition. Reference [9], [10] applied evaporative cooling to different office buildings, resulted in huge cost savings in operational cost. This system can provide a cost effective, comfortable and healthy environment. Reference [11], performed comparative study of two different evaporative systems: an indirect evaporative cooler allowing only heat transfer and a semi indirect ceramic evaporative cooler allowing heat and mass transfer both. Reference [12], presented rock bed regeneration as a means of indirect evaporative cooling. Reference [13], has tested performance of an indirect evaporative cooler experimentally. Reference [14], presented an energy saving potential of an indirect evaporative cooler. Reference [15], explored the potential of reducing the annual energy consumption of a central air-conditioned building through advanced evaporative cooling systems. Reference [16], evaluated the performances of cellulosic pads made out of Kraft and NSSC corrugated papers in three flute sizes, experimentally. Majority of researchers have presented their analysis based on two or three stage evaporative coolers, none have attempted to study the regenerative type heat exchanger, which utilizes tank water to further cool the air in second stage. In the present work a heat exchanger has been added to direct evaporative cooler. The regenerative evaporative cooler has been fabricated and tested under Indian climatic conditions. Performance of regenerative system has been evaluated in terms of overall effectiveness and COP.

## II. PRINCIPLE OF WORKING

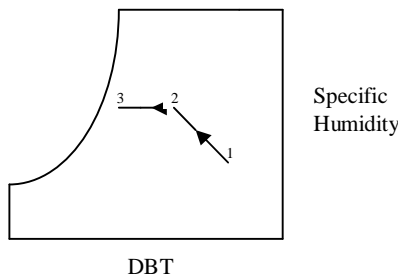
The regenerative evaporative cooler first cools the air when it comes in contact with water in the wet cooling pads. During evaporation of water in air stream, the required heat is taken from air and air gets cooled. This is known as direct evaporative cooling. This air is further passed over a heat exchanger and is cooled further indirectly.

The water of sump is cooler than that of air stream. Therefore the sump water is supplied through the heat exchanger with the help of a pump. The arrangement of all components is shown in Fig. 1 and cooling processes have been represented in Fig.2.



- 1-air blower
- 2-cooling pad
- 3-water distributor
- 4-water collecting tank
- 5-heat exchanger
- 6-circulating pump for direct cooler
- 7-circulating pump for heat exchanger

Fig. 1 Schematic Diagram of Experimental Set up



- 1-2 cooling in Direct Evaporative Cooler
- 2-3 cooling in heat exchanger

Fig. 2 Processes on psychrometric chart

### III. EXPERIMENTAL TEST SET UP

A commercially available direct evaporative cooler was improved by adding a regenerative heat exchanger. It had three aspen wood pads and a cooler fan. A heat exchanger has been fabricated with aluminium tubes having 7 mm diameter and was fitted in front of the cooler. A separate pump was used to supply water from tank to heat exchanger. A number of thermocouples were fitted to measure dry bulb and wet bulb temperatures at various points. These thermocouples were connected to datalogger for recording of temperatures. Hot wire anemometer was used for measuring air flow rate at different points on the downstream of air.

### IV. METHODOLOGY

The experiment was conducted in the summer month of May, with three different flow rates. Cooler was run for sufficient time to attain steady state conditions. Dry bulb temperature and Wet bulb temperature for ambient air were recorded by thermocouples. Temperatures of cooled air were recorded before and after the heat exchanger. Temperatures of collecting tank's water and exit water from heat exchanger were also recorded. Air flow rates were measured by using Hot wire anemometer. Sufficient number of observations was taken. Experiments were repeated number of times. The saturation efficiency of direct evaporative cooler without heat exchanger was calculated by

$$\eta_D = (T_1 - T_2) / (T_1 - T_1')$$

The efficiency of Regenerative cooler was calculated by using following equation

$$\eta_R = (T_1 - T_3) / (T_1 - T_1')$$

Where

$T_1$  = DBT of air at inlet

$T_1'$  = WBT of air at inlet

$T_2$  = DBT of air at outlet of direct evaporative cooler

$T_3$  = DBT of air at outlet of heat exchanger

Coefficient of performance for direct evaporative cooler ( $COP_D$ ) and Regenerative cooler ( $COP_R$ ) were calculated by using following equations

$$COP = (\text{Mass flow rate} * \text{Sp. Heat} * \text{Temp. difference}) / \text{Power input}$$

Where

Mass flow rate = Sp. Density \* Air velocity \* Cooler duct area

$$= (1/\text{Sp. volume}) * \text{Air velocity} * \text{Cooler duct area}$$

Cooler duct area is = (0.37 \* 0.46) m<sup>2</sup>

Sp. Heat of air is = 1.0057 KJ/Kg ° C

$$\begin{aligned} \text{Power input} &= 700\text{w (fan)} + 18\text{w (pump1)} + 18\text{w (pump2)} \\ &= 736\text{w} \\ &= 0.736\text{kw} \end{aligned}$$

### V. RESULT AND DISCUSSIONS

Experiments were performed during summer seasons, using direct evaporative cooler with and without second stage heat exchanger. The cooler was operated for sufficient time to attain steady state conditions. Efficiency of the regenerative evaporative cooler has been computed and is presented in Table I and COP of the regenerative evaporative cooler has been computed and is presented in Table II. The overall efficiency of regenerative cooler was found to be in the range 74-81 % and net improvement in the efficiency was observed to be in the range of 20-25 %. The COP of regenerative cooler was found to be in the range 7-14 and net improvement in the COP was observed to be in the range of 20-25 %.The variation of efficiency with different air flow rates is shown in fig. 3 and the variation of COP with different air flow rates is shown in fig. 4.

TABLE I  
VARIATION OF EFFICIENCY WITH MASS FLOW RATES

Air flow rate kg/s	Efficiency of Direct evaporative cooler in %	Efficiency of Regenerative evaporative cooler in %	% increase in Efficiency
0.44	66.47	80.72	21.44
0.58	67.79	83.25	22.81
0.81	60.40	74.52	23.38

TABLE II  
VARIATION OF COP WITH MASS FLOW RATES

Air flow rate kg/s	COP of Direct evaporative cooler	COP of Regenerative evaporative cooler	% increase in COP
0.44	5.77	7.01	21.49
0.58	9.11	11.19	22.83
0.81	11.27	13.93	23.60

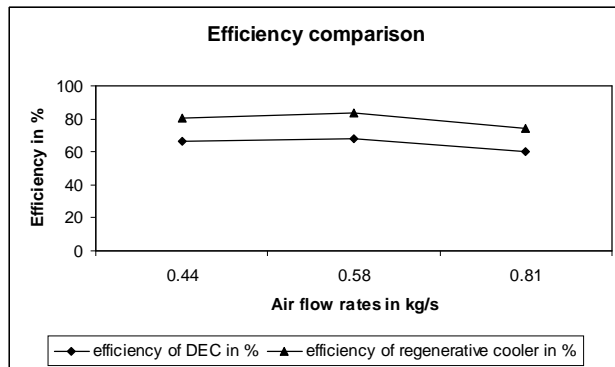


Fig. 3 Variation of efficiency with Air Flow Rates

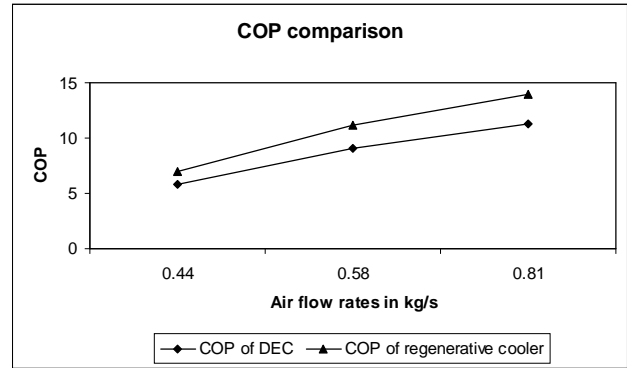


Fig. 4 Variation of COP with Air Flow Rates

### VI. CONCLUSIONS

It may be concluded that there is considerable improvement in efficiency and COP (20-25 %) of direct evaporative cooler with regenerative heat exchanger. Percentage increase in efficiency is almost same for each flow rates. The cost comparison shows that there is slight increase in cost because of an additional pump and a heat exchanger but increase in cooling efficiency is substantial. Thus regenerative evaporative cooler is advantageous for providing more cooling compared to an ordinary direct evaporative cooler, which can make the cooler more useful for providing thermal comfort in residential and commercial buildings. It may also attract more people for maximum utilization of such a low energy consuming device leading to energy conservation in buildings.

### References

- [1] Stanley A. Mumma, Rodrieguezanza Guan M., "Rock bed regeneration as a means of indirect evaporative cooling," *Journal of ASHRAE Trans.* Vol. 85, 2, (4), pp 787-795 , 1979
- [2] Neil Eskara, "Indirect / Direct evaporative cooling system," *ASHRAE journal*, Vol. 22(5), pp 22-25, 1980
- [3] C.E Janeke., "Free cooling: A total HVAC design concept," *ASHRAE Trans.*, vol. 88(1), pp 27-43, 1982
- [4] R. Navon and H. Arkin., "Feasibility of direct-indirect evaporative cooling for residences, based on studies with a desert cooler," *Journal of Building and Environment*, vol. 29(3), pp 393-399, 1994
- [5] S.Datta, P.N.Sahgal, S.Subrahmaniyam, S.C.Dhignra and V.V.N. Kishore, "Design and operation of evaporative cooling systems," *Journal of Australian refrigeration, air conditioning and heating*, vol. 41(2) , pp 28-36, 1987,
- [6] W.K. Brown, "Fundamental concepts integrating evaporative techniques in HVAC systems," *ASHRAE Trans.* Vol. 96(1), pp 1227-1235, 1990
- [7] Bourhan Tashtoush, Tahat Mahmood, Ahmad Al Hayajneh, Victor A. Mazur and Probert Doug, "Thermodynamic behavior of an air conditioning system employing combined evaporative water and air coolers," *Applied Energy* , vol. 70, pp 305-319, 2001,
- [8] M. Renato Lazzarin, "Introduction of a simple diagram-based method for analyzing evaporative cooling," *Applied Thermal Engineering*, vol. 27(11-12), pp 2011-2025, 2007

- [9] D.C. Haley, "Evaporative cooling, now-any where," *ASHRAE Trans.*, vol. 92, 1B (2), pp 901-909, 1986
- [10] Richard D. Osbaugh and Tom B.Moore., "Applying two stage evaporative Cooling," *ASHRAE journal*, vol. 30(7), pp 26-30, 1988
- [11] F.J. Rey martinez., Gomez E.Velasco, Herrero Martin R., Gutierrez J. Martinez and Diez F. Varela, "Comparative study of two different evaporative systems: an Indirect evaporative cooler and a semi indirect ceramic evaporative cooler," *Energy and Buildings*, vol. 36(7), pp 696-708, 2004
- [12] S.A. Mumma and J.M. Rodriguez-anza, "Rock bed regeneration as a means of indirect evaporative cooling", *Ashrae Trans.* , Vol. 85(2), pp 787-795, 1979
- [13] J.L Peterson and B.D. Hunn, "Experimental Performance of an indirect evaporative cooler", *Ashrae Trans.*, vol. 98(2), pp 15-23, 1992
- [14] G.P.Maheshwari, F. Al-Ragom, R.K. Suri, "Energy saving potential of an indirect evaporative cooler", *Applied Energy*, vol. 69, pp 69-76, 2001
- [15] Ankur Khandelwal, Prabal Talukdar and Sanjeev Jain, "Energy savings in a building using regenerative evaporative cooling", *Energy and Buildings* vol. 43(2-3), pp 581-591, 2011,
- [16] Mahsa Barzegar, Mohammad Layeghi, Ghanbar Ebrahimi, Yahya Hamzeh and Manouchehr Khorasani , "Experimental evaluation of the performances of cellulosic pads made out of Kraft and NSSC corrugated papers as evaporative media", *Energy Conversion and Management* , vol. 54(1), pp 24-29 , 2012