EXPERIMENTAL STUDY OF CENTRIFUGAL HUMIDIFIER FITTED IN AN INDUSTRIAL SHED LOCATED IN TROPICAL CLIMATES

by

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An evaporative cooling system based on centrifugal humidification technique is proposed for large industrial spaces. In this system, the evaporation rate is improved by splitting the water into fine micronisers by impinging it on the stationery strips. The various parameters influencing the rate of evaporation are identified. The effect of mass flow rate of water, disc speed, and mass flow rate of air on space cooling and humidifier efficiency is studied experimentally and plotted with respect to time. The studies indicate that medium mass flow rate of water, higher disc speed and medium mass flow rate of air are preferable in reducing the dry bulb temperature of room and for increasing humidifier efficiency.

Key words: *centrifugal humidifier, rectangular pin, evaporative cooler, humidification*

1. Introduction

Evaporative air cooling is an easily available method of achieving a comfortable indoor climate, especially in the arid regions of the world. It is economical, energy efficient, and pollution free [1]. Brown [2] showed drastic reduction in the total energy cost in the air conditioning system by proper selection and combination of the evaporative cooling units. Supple *et al.* [3] suggested various configurations to achieve the indoor comfort for the office space. Giabaklou *et al.* [4] studied passive evaporative cooling, which makes use of natural draft for air movement rather than the use of motor driven fans. Vollebregt *et al.* [5] designed a unit applied to lower temperature and humidity of air in green houses. Hunn *et al.* [6] studied the effect of the building type and location on performance of indirect evaporative cooler. Scofield *et al.* [7] studied characteristics of direct and indirect evaporative cooling units, which utilize plate type air-to-air heat exchanger. Al-Juwayhel *et al.* [8] studied the performance of an indirect/direct evaporative cooling system and the effect of coupling the system with a cooling tower.

The most familiar evaporative cooler is the cabinet cooler. Here, a convenient cabinet is usually surrounded by wetted pads. When the water passes over these wetted pads,

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the water evaporates by taking the heat from the incoming air thereby reduces the dry bulb temperature of the air, with the corresponding increase in air humidity [9]. Some evaporative coolers, also called curtain coolers, have a sheet of canvas or strong adsorbent cloth used as the evaporating surface [10]. The upper end of the sheet may be raised or lowered, while its bottom is dipped in a trough of water. Through a wick type action, water is transported continuously from this end to the upper surface where it is evaporated, thus cooling the space around it. Most of present day coolers are wetted pad type, where the volume of air cooled is proportional to the wetted pad surface area. Hence pad type coolers are limited to cooling of smaller air space as pad area cannot be increased beyond certain level. In a country like India, there are large number of industrial sheds. To cool such industrial sheds, larger air volumes are to be handled. The present work attempts to develop a centrifugal type air cooler. Such coolers are best suited for cooling large air volumes, suitable for cooling industrial sheds.

Experimental facility

The humidification technique proposed in this work uses a centrifugal humidification technique, wherein the evaporation surface area of the water is increased by means of atomization process. By atomization, the water particles are split into fine mist and thereby ease the evaporation.

An experimental facility, shown in fig.1, has been developed. It consists of a blower, centrifugal humidification unit, evaporation chamber, droplet eliminator, and the test space to be cooled.

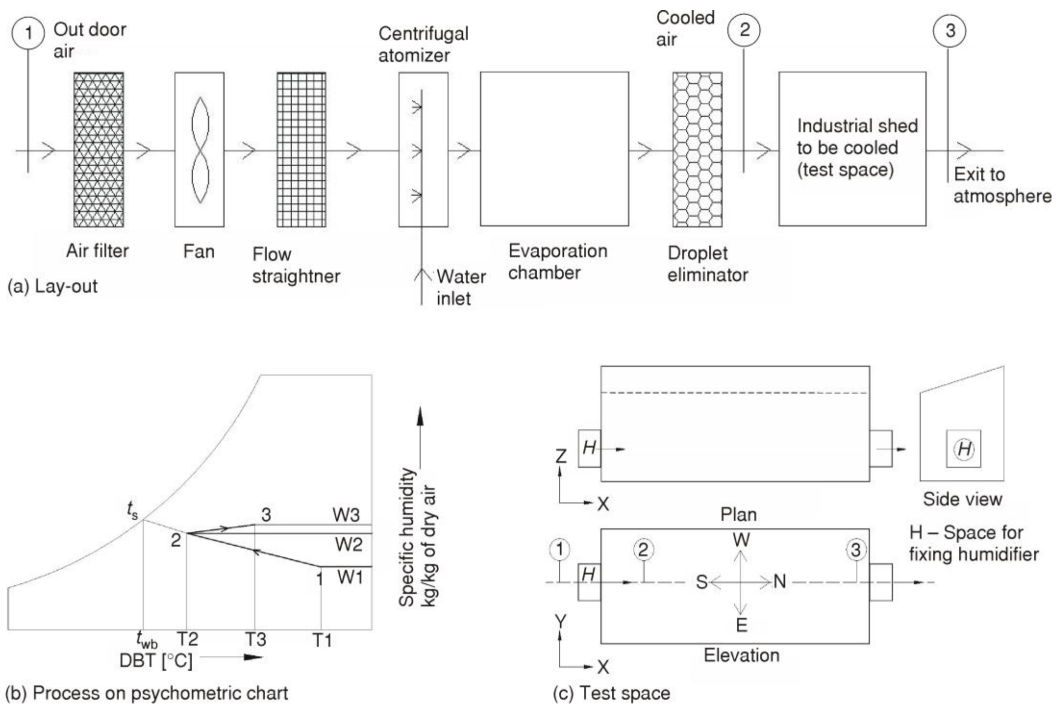

Figure 1. Experimental facility

Nylon mesh filters conventionally used in air-conditioning units are used as the filter. Blower is of axial flow type, having diameter of 0.340 m, driven by 360 W motor running at 3000 rpm. A speed control arrangement has been made to vary the blower speed in order to vary the air flow rate. In order to reduce the flow swirling effects, normally present at the blower exit, an air straightener is added after the blower.

The centrifugal humidifier has a 760 W motor, a spinning disc and a stationery ring fitted with breaker strips. The motor rotates the disc at 1000 rpm to 3000 rpm. Arrangements have been made to inject water at the centre of the disc at a specified rate. The breaker strips are rectangular in shape having 1.0 mm thickness, 5.0 mm width and 15 mm height. The strips are screwed on the face of the stationery ring at 4.0 mm pitch and aligned such that the water leaving the disc strikes at the middle of the strip. A gap of 5.0 mm is provided between the disc and strips to avoid physical contact.

The evaporation chamber is a box made of acrylic transparent sheet with dimensions 0.335 m × 0.335 m × 1.2 m length. A mixture of air and a mist of water particle enter the chamber. While traveling through the chamber, the water particles evaporate and become water vapour. Water should not enter in the user space as water droplets; hence a droplet eliminator section has been added between the evaporation chamber and the test space. The droplet eliminators have two layers of nylon mesh with 5.0 mm and 3.0 mm square holes. The air when pass through this mesh, water droplet if any present in the air will be eliminated.

The cooled and humidified air then enters in the test space. The test space is an unoccupied industrial shed having masonry brick wall (0.23 m thick) on the four sides and tilted asbestos roof. The shed is 10.0 m long in the north-south direction and 3.0 m wide in the east-west direction. A window at the south side wall is used to fit the evaporative cooler. The window is 1.83 m wide and 1.5 m height. The cooler of 0.335 m × 0.335 m is fitted at the middle of the window and the gap between the cooler and the wall is tightly closed using wooden sheet.

The test space lies at the middle of a continuous shed and is located at Coimbatore city (11º 0' N, 77º 10' E), Tamilnadu state, India. The east and west walls are the interior walls. The south wall has a 6 feet shade. The only wall which is exposed to Sun is north wall. The roof is covered by asbestos fiber reinforced cement sheets of 5 mm thick. For rain water drainage, the sheets are laid in an inclined way. Thus the west wall is of 4.3 m high and the east wall is 3.4 m high. The window in the north wall is also covered by wood and opening of 0.335 m × 0.335 m is kept the middle for exit of air from the test space.

Measurement and instrumentation

Experiments have been carried out between 10th and 30th May, 2009, and were conducted all these days. This period corresponds to dry hot summer season. Solar radiation intensity falling on the roof surface and outside air dry bulb temperature (DBT) and wet bulb temperature (WBT) have been measured at one hour interval over the day. The readings of the days where in the daily average value of these three parameters agree with in ±5% are taken for calculations. DBT and WBT of air at outside, at the room entry, with in the room at the specified locations and at the room exit are measured. Within the room DBT and WBT are measured at 27 locations. These locations lie at the intersections, along the length of 1 m, 5 m, and 9 m from the inlet, along the width of 0.5 m, 1.5 m, and 2.5 m from wall and along the height 0.5 m, 1.5 m, and 2.5 m from the floor. A sling psychrometer having an accuracy of 0.5 ºC is used for measure DBT and WBT. Air velocity has been measured using propeller type hand held anemometer, having the range of 0-12,000 rpm with an accuracy of ±10% full scale reading. Air velocity has been measured at room inlet and room exit. Both at inlet and exit area air velocity has been measured at 9 locations and spatial average has been reported. As the inlet and exit areas are equal, the measured velocities agreed within ±5% in all cases. Flow rate of water impinging on the disc centre has been measured by volume-time method. Water has been made to flow without switching on the blower and the spinning disc. For collecting one liter of water, the time taken has been noted using a stop watch with 0.01 seconds accuracy. Then the blower and disc are switched-on conduct experiments.

The water that drains off from the system is also collected over a specified time and the discharge rate is estimated. From these two quantities, the net water evaporated is estimated. From the measured air flow rate, DBT and WBT at the outside air and at the room inlet, the mass of water vapour added has been estimated. These two quantities agreed within ±8% in all the cases.

Results and discussion

Experiments are carried out to study the effect of mass flow rate of air, mass flow rate of water and disc speed. Air flow rate is varied from 0.465 kg/s to 0.809 kg/s, and the water flow rate varied from 0.0035 kg/s to 0.0109 kg/s. The disc speed is varied from 1000 to 3000 rpm, with each setting. The experiments are carried out from 6.00 a. m. to 6.00 p. m. and the readings taken at one hour interval.

Spatial variation of DBT, WBT, and relative humidity

At disc speed N_s of 3000 rpm, water flow rate of 0.0081 kg/s, air flow rate of 0.547 kg/s, and time of the day 13 hours, the variation of DBT, WBT and relative humidity (RH) along the X-direction is shown in figs. 2 and that along Y-direction is shown in figs. 3. The direction along the length, width, and height are referred as X, Y, and Z, respectively.

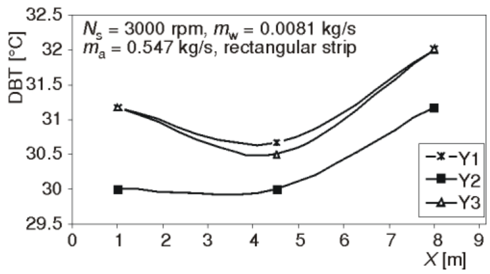

Figure 2(a). DBT variation along X-direction

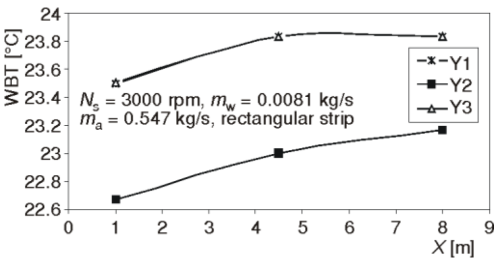

Figure 2(b). WBT variation along X-direction

In the X-direction, up to the middle of the room, DBT decreases, WBT increases, and RH increases. It is possible only if the water particle evaporates by taking heat from the room air. It indicates that all the water particles created by the centrifugal humidification section did not evaporate in the evaporation chamber. Few minute particles are carried over in the room that evaporates in the room. From the middle of the room to the exit, DBT increases, WBT increases, and RH decreases. It is due to the addition of heat to the room air from the building roof and building walls.

Considering the variation along the room width (Y-direction), DBT, WBT and RH near to the surfaces are slightly higher than that at the middle. Similarly, DBT, WBT and RH near the roof are larger than that at the bottom and middle. These are due to addition of heat from the building surfaces to the room air.

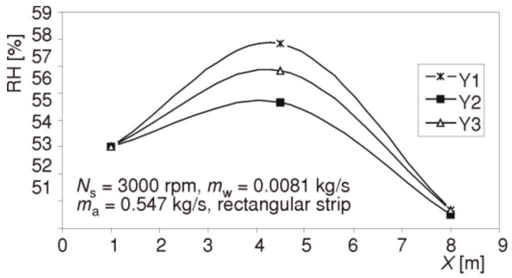

Figure 2(c). RH variation along X-direction

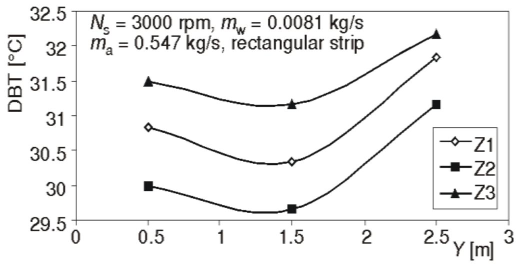

Figure 3(a). DBT variation along Y-direction

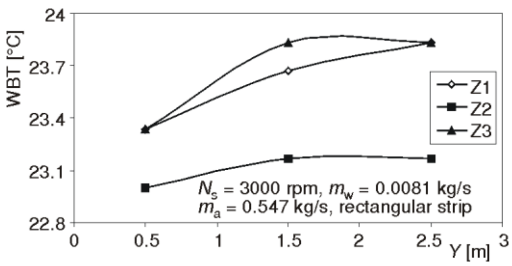

Figure 3(b). WBT variation along Y-direction

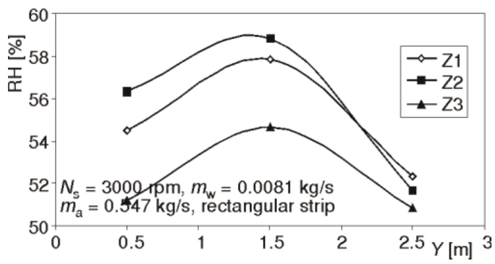

Figure 3(c). RH variation along Y-direction

Variations of DBT, WBT, and RH over a day

The variation of various parameters over a typical test day is shown in figs. 4 to 6. Both DBT and WBT of outside air are low at the morning increase to a peak value around 13 hours and then drop. Despite larger variation in outside air DBT over the day, the DBT room air remains almost constant over the day, thus ensures more comfort. In line with relative position of DBT curves, the WBT curves also follow. The relative position of WBT curves from lower to higher are WBT_1, WBT_2, WBT_{RA}, and WBT_3. The RH curves shown in fig. 6 point out that outside RH are very low (about 15-25%) which are not good for human comfort. Use of such evaporative cooling system will ensure RH in the range of 35-55% which is much better.

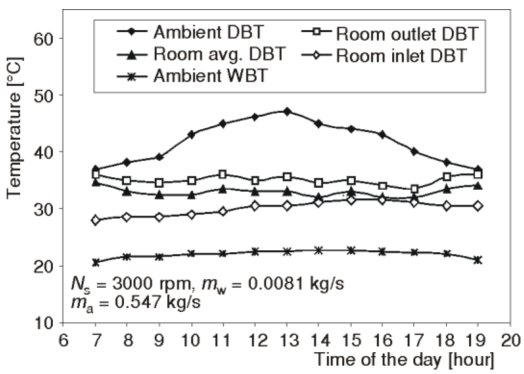

Figure 4. DBT variation over a day

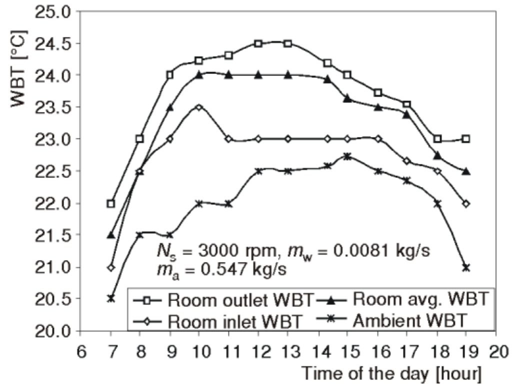

Figure 5. WBT variation over a day

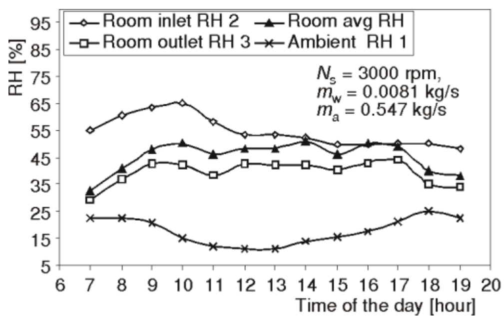

Figure 6. RH variation over a day

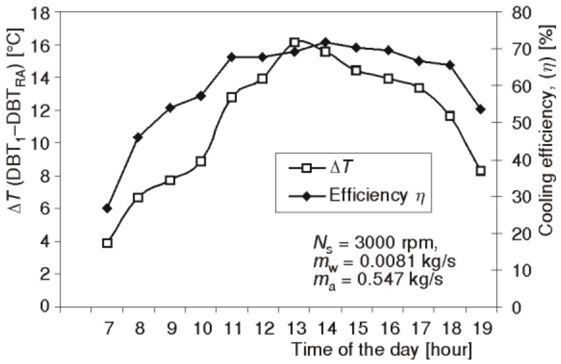

Figure 7. Drop in temperature difference and cooling efficiency across the cooler over a day

The ultimate use of using such evaporative cooling system can be visibly seen in fig. 7. It shows the temperature reduction (DBT_1 – DBT_{RA}) with in the room by the use of the evaporative cooling system. It ranges from 4-12 ºC. Higher temperature drops are noticed around the noon where the outside DBT are very high. The figure also shows efficiency of the evaporative cooler, $\eta = (DBT_1 - DBT_2)/(DBT_1 - WBT_1)$. The efficiency values obtained are 20-70%. The efficiencies are higher when outside DBT are higher. In general, the proposed evaporative cooling system is able to provide considerable cooling for the large industrial space having higher solar roof load under tropical climate compared to air conditioning, the power consumption towards such cooling will be lower.

Effect of mass flow rate of air

The effect of varying the mass flow rate of air has been studied, the temperature difference (DBT_1-DBT_{RA}) obtained and the evaporative cooler efficiency is shown in fig. 8 and fig. 9, respectively. The air flow rates are varied as 0.809 kg/s, 0.5749 kg/s, and 0.465 kg/s. The disc speed of 3000 rpm and water flow rate 0.0081 kg/s are kept constant during the study, the values are obtained with rectangular strip.

At lower air flow rate, the room cooling obtained are lower and at the medium air flow rate, the cooling is higher. At higher air flow rate, the cooling obtained is moderate. It may be because of the balance among the quantity of heat entering the room, time available for the water particles to evaporate and the air flow rate. Lower air flow rate may not be sufficient enough to remove the external heat entering the room. Larger air flow rate may also bring in high temperature outside air in the room and higher air velocities may provide less residential time for the air. Low residential time may not be sufficient for the evaporation of water particles. Thus there exist an optimum airflow rate for a given building and climate conditions. For the present case, the optimum air flow rate is 0.5749 kg/s. The cooling efficiency curves shown in fig. 9 also show that highest efficiency over the most part of the day is obtained with the air flow rate of 0.5749 kg/s.

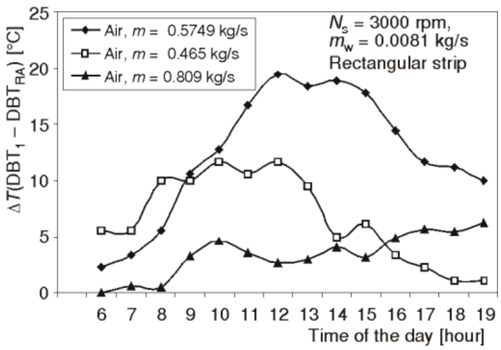

Figure 8. Effect of mass flow rate of air in the temperature difference of humidifier

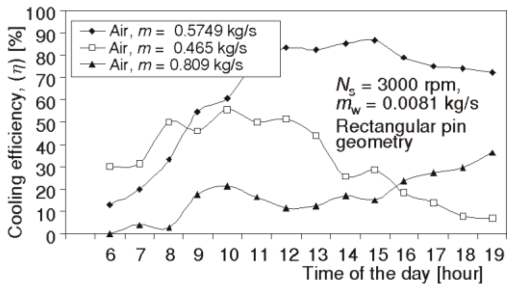

Figure 9. Effect of mass flow rate of air on the efficiency of humidifier

Effect of water flow rate

The effect of varying the water flow rate for the system performance is shown in fig. 10 and fig. 11. The moderate flow rate is found to give better performance. Lower flow rate do not load the entire disc, thus insufficient water particles are produced. Larger water flow rate floods the breaker strips, thus the water mist produced is found to be less. Thus an optimum flow rate yields better performance. For the present case, the optimum water flow rate is 0.00808 kg/s.

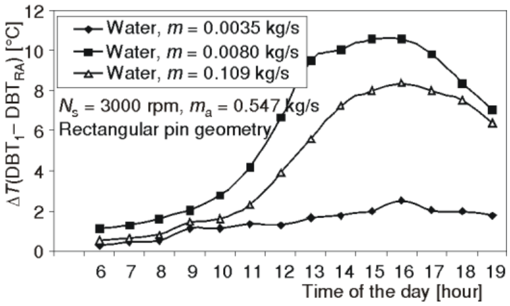

Figure 10. Effect of mass flow rate of water in the temperature difference of humidifier

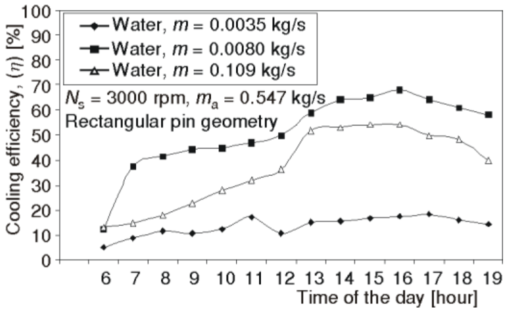

Figure 11. Effect of mass flow rate of water on the efficiency of humidifier

Effect of disc speed

Effect of varying the spinning disc speed on system performance is plotted in fig. 12 and fig. 13. In general, it is found that higher the disc speed, larger is the centrifugal force, better is the performance. Higher speed imparts higher centrifugal forces to the water supplied to disc at the middle. Thus water leaves the disc with higher velocities. It improves the mist formation and hence higher performance is noticed with the higher disc speed.

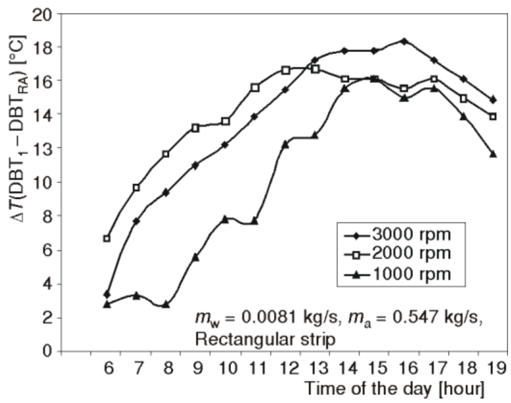

Figure 12. Effect of disc speed in the temperature difference of humidifier

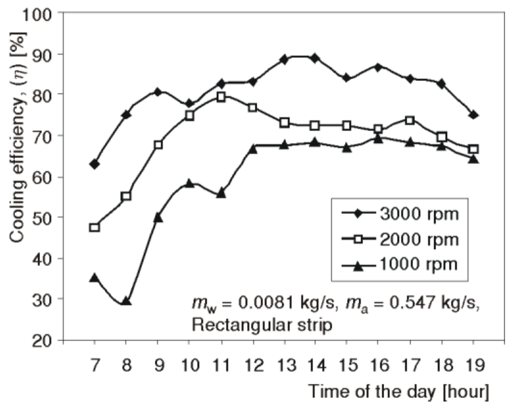

Figure 13. Effect of disc speed on the efficiency of humidifier

Conclusions

A centrifugal humidifier based evaporative cooling system is tested experimentally in an industrial building having masonry wall and asbestos cement sheet roof. This study has yielded the following conclusions.

- The system is found to reduce the interior temperature by 4-12 ºC. Higher cooling is observed when the outside ambient temperatures are higher.
- The proposed system is found to cool larger air volumes and is suitable for larger industrial sheds.
- For a given building and climatic condition, there exists an optimum air flow rate and an optimum water flow rate.
- Larger the spinning disc speed, better is the performance.

Nomenclature

DBT – dry bulb temperature, [°C]
DBT_1 – dry bulb temperature in ambient, [°C]
DBT_2 – dry bulb temperature at room inlet, [°C]
DBT_{RA} – room average dry bulb temperature, [°C]
m – mass flow rate, [kgs^{-1}]
N_S – disc speed, [rpm]
RH – relative humidity, [%]
ΔT – temperature difference, [°C]
WBT – wet bulb temperature, [°C]
WBT_1 – wet bulb temperature in ambient, [°C]
WBT_2 – wet bulb temperature at room inlet, [°C]
WBT_3 – wet bulb temperature at room exit, [°C]
WBT_{RA} – room average wet bulb temperature, [°C]

Greek symbol

η – cooling efficiency, [%]

Subscript

a – air
RA – room average
w – water
1 – ambient air
2 – condition at cooler exit/test space inlet
3 – condition at test space exit

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