Experimental Characterization of Vertically Split Distribution Wet- Cooling Media Used in the Direct Evaporative Cooling of Data Centers

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ABSTRACT

When operating in direct evaporative cooling (DEC) mode, the amount of moisture added to a system can be controlled by frequently modulating water supply to the wet cooling media. Though many challenges arise due to geographical and site conditions, this concept can be applied to data centers to serve as a cost-effective alternative for maintaining the operating temperature of the facility at any weather condition. However, this method results in scale and mineral build up on the media because of an irregular water distribution. To prevent the scale formation, the operators allow the water supply continuously on the cooling media ultimately leading towards the high consumption of facility water and significantly deteriorating the Wet cooling media life. This challenge has been addressed for the first time by experimentally characterizing the vertically split distribution wet cooling media. These systems allow some section of the media to be wetted while other sections remain dry. Various configuration of vertically staged media may be achieved by dividing the full width of the media into two, three, four or more number of equal and unequal sections and providing individually controlled water distribution headers. To increase the number of stages and provide smooth transition from one stage to the other, a MATLAB code is written to find width of DEC media sections for known total width of the media and number of sections. Here, an experimental design to characterize the performance characteristics of a vertically split wet cooling media which has separate water distribution setup has been presented. Apart from relative humidity and temperature, other parameters of interests like pressure drop across the media and saturation efficiency of the rigid media are presented. In the unequal configuration, the media was tested for 0%, 33%, 66%, and 100%. This research provides a potential solution towards the limitation of direct evaporative cooling in terms of energy savings, facility water, reliability and contaminants.

KEY WORDS: humidity control, direct evaporative cooling, power and water consumption.

NOMENCLATURE

DEC	Direct evaporative cooling
RH	Relative humidity
FPM	Foot per minute
GPM	Gallon per minute
TDB	Dry Bulb Temperature (F)
$\dot{M}$	Mass flow rate (kg/s)
h	specific enthalpy (kJ/kg)

Greek symbols

ω	humidity ratio (kg water vapor/kg dry air).
$\dot{V}$	volume flow rate (m^3/min).
ν	Specific volume (m^3/kg dry air).

INTRODUCTION

Evaporative cooling process remains one of the least expensive techniques which provides an optimum cooling with minimum energy usage [1, 2] especially, in data centers, where the information technology (IT) equipment such as servers and network switches are housed. All these equipment and other necessary electronic units consume large electricity power and dissipates heat energy at the same time [1, 3]. In data center, cooling requirement changes according to the IT load and outside environment (e.g. diurnal and seasonal changes). Also, IT and electronic components must be maintained at certain temperature and humidity so that they operate reliably for their expected lifetime.

Data center equipment are surrounded by air that contains a combination of gasses which include nitrogen (78%), oxygen (21%), carbon dioxide (0.3%), and water vapor. The water vapor in air is known as humidity, and this water vapor needs to be maintained in a proper amount in the air surrounding IT equipment so that the IT equipment can be protected from dangerous static electrical discharge. Also, too much or too little amount of vapor can be harmful to the internal electronic components and lead to failure and downtime [4]. To overcome the challenge of excess humidification, the technique called as staging of DEC media has been proposed through this research, where the DEC media is divided into multiple vertical sections or staking two or more sections together by providing separate water distribution headers to control each section. This staging of DEC media provides incremental control over humidity and temperature and enables reduction of electricity and water consumption [5]. In this experimental study, the wet cooling media has been given a vertical split into two unequal sections and tested for 0%, 33.3%, 66.7% and 100% wetting stages at any given time. These types of wetting stages have been tested and investigated for incremental effect on relative humidity (RH) as well as temperature of discharge air.

Experimental Setup

The experimental set up consists of an airflow bench, Variable Exhaust System (Blower), and the test duct for the evaporative cooling test (Figure 1). Air-flow bench is a device which can be used for testing the thermal resistance of the test sample, testing for fan performance curve and to calculate the airflow rate. It consists of a blast-gate that controls the opening and closing of the chamber for air entry, flow straighteners to channelize the air flow path and nozzles with different diameter sizes to achieve the desired flow rate (Figure 2).

Figure 1: The air-flow bench and the Air Blower

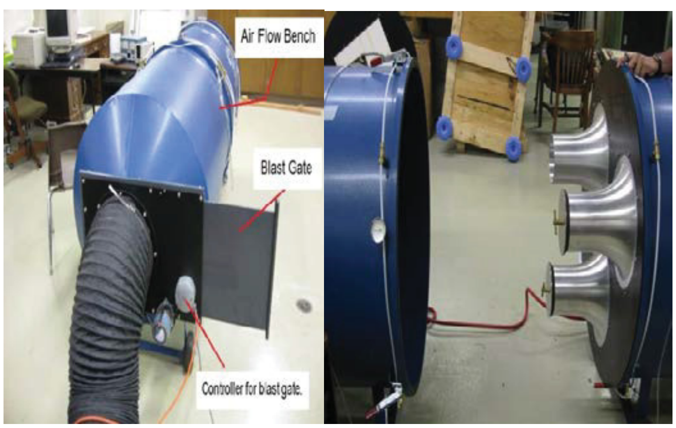

Figure 2: Blast gate and Nozzle plate

The DEC pad is sitting inside the middle zone of the test duct. The duct was initially modeled in modeling software, PRO-E and then fabricated for the experimental testing. The three duct segments were 0.6m X 0.6m in dimensions and 1.8m long. It was attached to the downstream end of the air-flow bench with the cooling pad fitted approximately 0.7m away from the downstream [1].

Eight Dwyer A-302F-A pressure taps were fitted on the upstream and downstream ends of the duct to measure the static pressure across the DEC media. Eighteen RF Code R155 humidity-temperature tags were mounted such that one tag covers one-ninth of the cross-sectional area of the duct on two plastic egg crates light diffusers where the sensors were placed at 24 inches before and after the wet cooling media to measure the RH and Temperature for the inlet and outlet (Figure 3).

Figure 3: RF code R155 Humidity-temperature sensors

The middle section of the duct is shown in figure 5 where the DEC media, water reservoir, water pump, water, distribution header, and water level regulator are placed (Figure 4)

Figure 4: Water level regulators, water pump, and the sump downstream of the duct

The manufacturer of the DEC media recommends distributing 1.5 gpm per square foot of top surface area of the media [6]. Since we have two un-equal sections of the DEC media 33.3% (8 in) and 66.6% (16 in) which means 1 ft. x 1ft and 1 ft. x 2 ft., the water flow rate from the water pump is adjusted to about 1 gpm for the 33% and 2gpm for the 66%. Digital water flow meter is used to measure and calibrate the water flow rate for each section. To control the relative humidity of the room during the wet media tests, three dehumidifiers were used to keep the humidity with desired limits (Figure 5).

Figure 5: Digital water flow meter on each Water supply and Fantech Dehumidifier

Figure 6: Separate water distribution headers

To prevent the air and water leaks during the test, duct tapes and water-resistant foams (R-Matte-rigid insulating water-resistant material) were used (Figure 6).

Test Procedure and Results

KUUL 12 inch cellulose DEC media was partitioned into two un-equal sections 33.3% and 66.6% and tested for four wetting stages. Figure 7 and Table 1 show the splitting and the water pumping state of the staging of the DEC media.

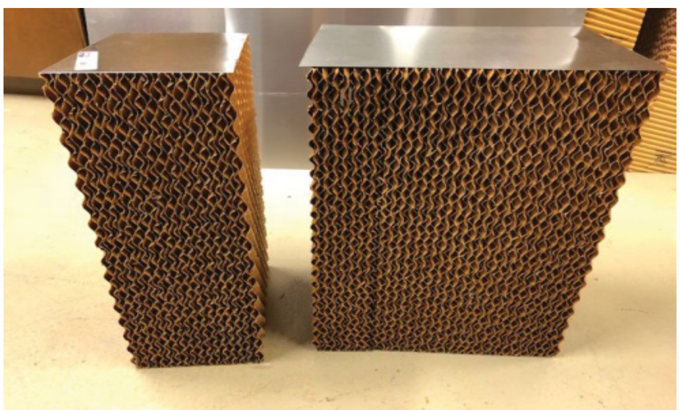

Figure 7: The un-equal splitting of DEC media

Stage	Section width (1 = on & 0=OFF)		% of media that's wet
	8 inch	16 inch	
1	0	0	0
2	1	0	33.3
3	0	1	66.7
4	1	1	100

Table 1: Two sectioned media showing pump on/off state [3]

The two sections of the DEC media were tightly kept inside the middle segment of the duct with water distribution taps on the top of each section and was split by aluminum metal sheet to prevent the water crossing from the wet section to the dry section during the test. The two sections of the DEC media were supplied water by separate water distribution headers and all possible gaps were tightly sealed (Figure 9).

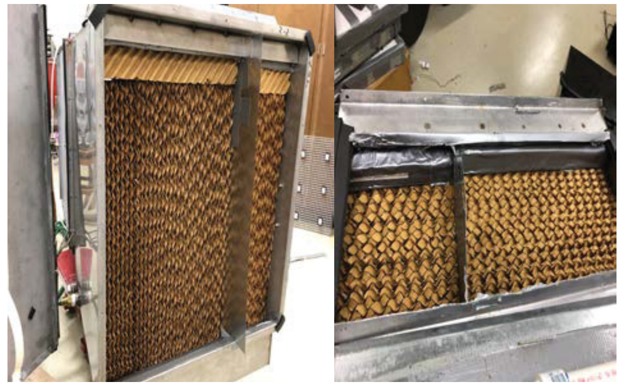

Figure 9: Side and top view of the DEC pad fitted inside the middle duct.

Stage one of the test: In the stage the DEC media was tested with 0% wet which is a dry test, the test was conducted under room temperature 73 F and varying air velocity starting from 613 FPM to 233 FPM to calculate the pressure drop across the DEC media. It has been observed that at 613 FPM the pressure drop across the DEC media was about 0.25 Inch of H_2O. Comparing with the manufacturer data for the same FPM air velocity, the pressure drop was found about 0.24 in of H_2O. This proves that the results are in good agreement with the manufacturer data [1]. (Figure 10)

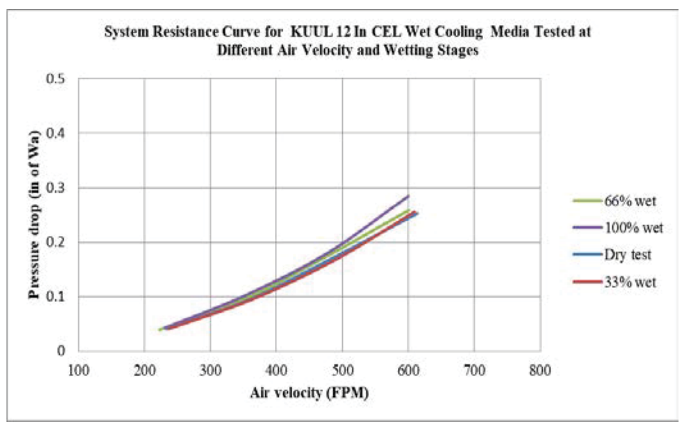

Figure 10: Pressure drop curve for KUUL 12in cellulose at different Air velocity, Temperature and Wetting stages.

Stage two of the test: The second stage of the test was for 33% wet DEC media; the test was conducted at higher inlet temperature (Figure 11). To achieve the high upstream air temperature, two ProFusion Heat Industrial Fan-Forced Heaters (Model HA22-48M) (Figure 12) were placed at the inlet of the airflow bench blower. And the water flow rate was kept constant during the test (1gpm).

Figure 12 shows 33% cooling media under Test

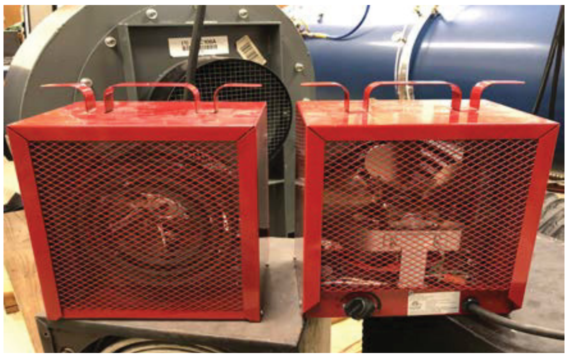

Figure 12: ProFusion Heaters

In this wetting stage, the variation of RH, temperature and Pressure drop across the DEC media were tested. Pressure drop was found about 0.2554 inH_2O at 609 FPM and 91° F. (Figure 10).

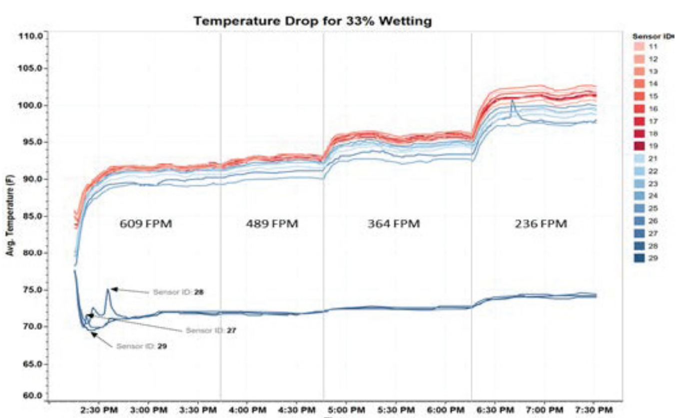

Figure 13: Upstream and downstream temperature during 33% wetting for different face velocities of inlet air

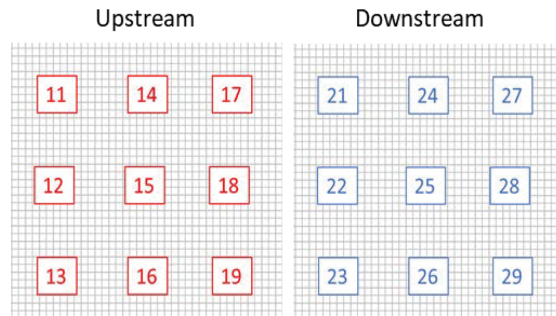

Figure 14: Location of upstream and downstream temperature and relative humidity sensors with respective sensor ID numbers

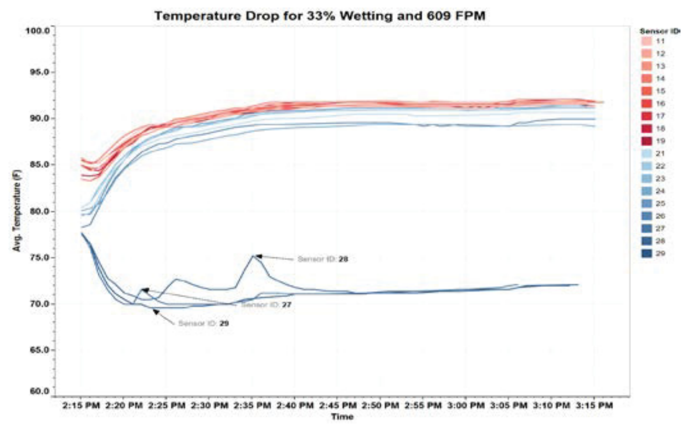

Figure 15: Temperature drop across the 33% wet media pad with 609 FPM inlet air face velocity

Figure 13 shows the temperature variations of the RF code sensors upstream and downstream with different Air velocity start from 609 FPM till 236 FPM for 33% wet media test to calculate the pressure drop across the wet cooling media. Figure 15 shows the readings of each sensors during 609 FPM, It was observed that the downstream temperature sensors readings for the wet side (27, 28, and 29) were decreased all way till 68°F from 77 °F and it took about 30 minutes until reached the steady stated of 72 F° as shown in the red oval in Fig.13. While the other 6 sensors for the downstream dry side (21, 22,23,24,25, and 26) went all way up with the upstream sensors. The upstream temperature rose all way up to 92°F from 84°F.

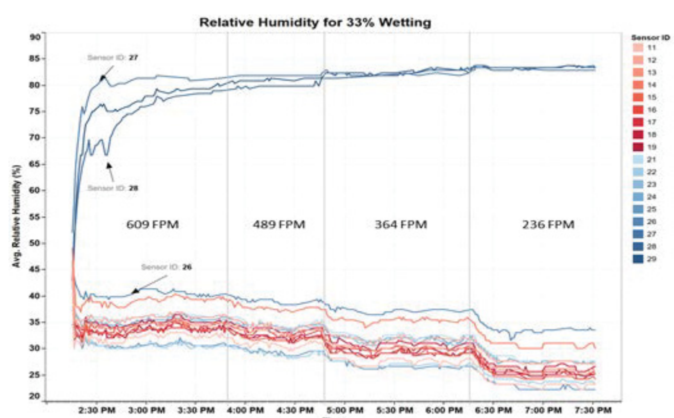

Figure 16: Upstream and downstream RH during 33% wetting for different face velocities of inlet air

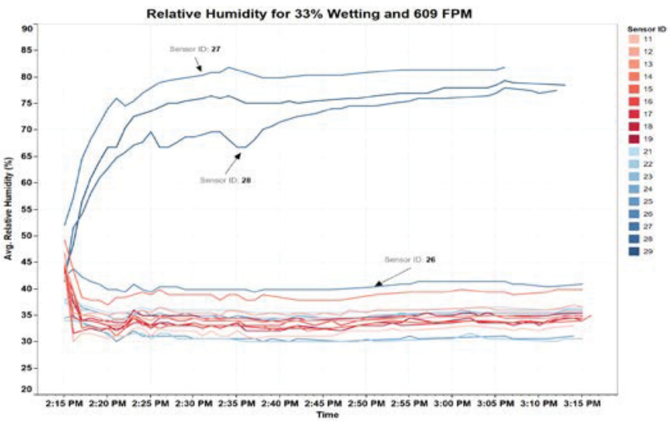

Figure 17: Relative Humidity variation across the 33% wet media pad with 609 FPM inlet air face velocity

Figure 16 shows the variation in RH between downstream and upstream with different air velocity. While figure 17 shows the RH readings of each sensors during 609 FPM, It was observed that the RH for the downstream wet side sensors went all way up to 82 % from 42 %, and the sensors for the dry side were decreased with upstream sensors to 30% - 40% during a constant air velocity of 609 FPM.

Third stage of the test: the third stage was for 66% wet of DEC media, where the 33% part kept fully dry and the 66% part was fully wet.

Figure 18 shows 66% DEC cooling media under test

The test was carried out at higher inlet air temperature 90°F by operating both the heater with varying air velocity from 601 FPM to 222 FPM to calculate the pressure drop during the wetting test. The pressure drop was found about 0.258 inch of H_2O at 601 FPM. (Figure 10).

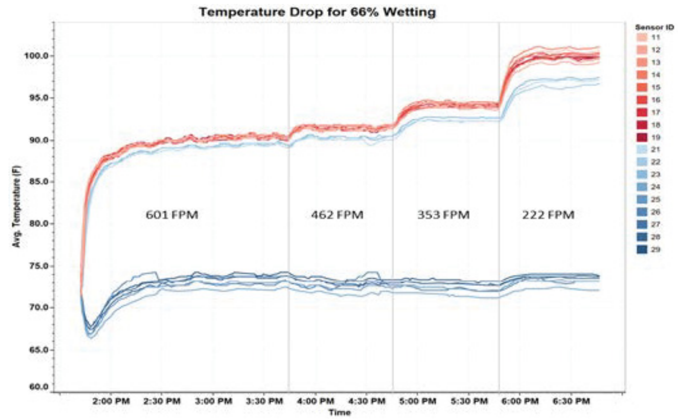

Figure 19: Upstream and downstream temperature during 66% wetting for different face velocities of inlet air

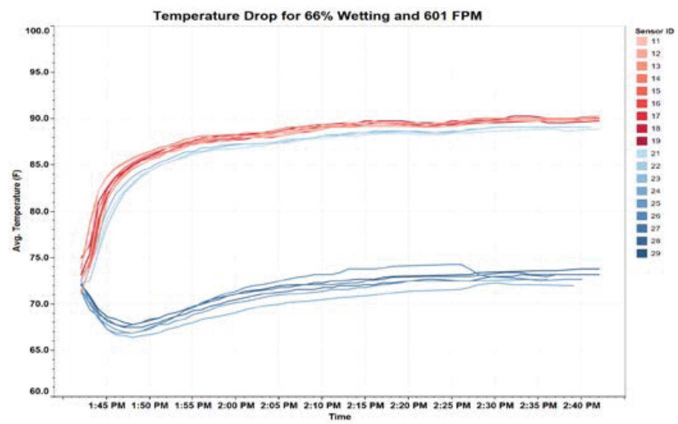

Figure 20 Temperature drop across the 66 % wet media pad with 601 FPM inlet air face velocity.

Figure 19 shows the temperature variation during the test. It was observed that the upstream temperature rose all way up to 100 °F from 72 °F while the downstream temperature increased from 65 °F and remain about 70 °F during different air velocity. Figure 20 shows the tempreture readings of each sensors during 601 FPM. It was observed that the downstream temperature sensors readings for the wet side (24, 45, 26, 27, 28, and 29) were decreased all way till 66°F from 72 °F and it took about 50 minutes until reached the steady stated of 72 F° as shown in the red oval in Fig.13. While the other 3 sensors for the downstream dry side (21, 22, 23, and 24) went all way up with the upstream sensors. The upstream temperature rose all way up to 90°F from 75°F.

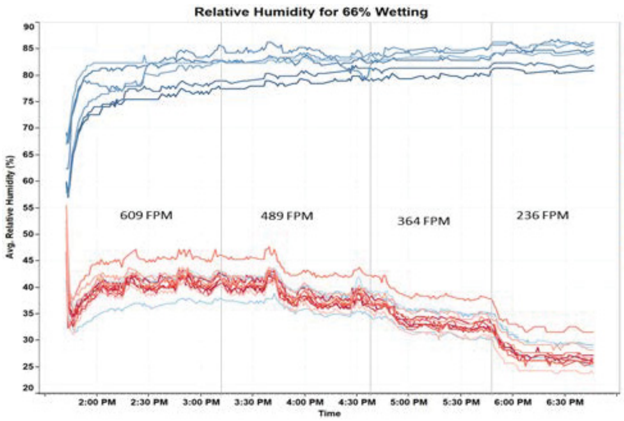

Figure 21: Upstream and downstream RH during 66% wetting for different face velocities of inlet air

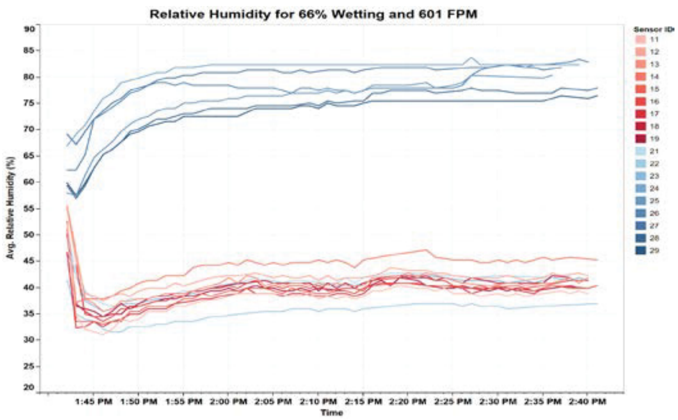

Figure 22 Relative Humidity variation across the 66 % wet media pad with 601 FPM inlet air face velocity.

Figure 21 shows the variation in the RH between Downstream and upstream during different air velocity. In figure 22 shows the RH readings of each sensors during 601 FPM, it was observed that the RF code sensors for RH of the wet side downstream went all way up between 74% – 84% from 58%, while the sensors on the dry side downstream remain below 40%. The upstream RH rose from 35 % and remains about 42% during the initial air velocity 601FPM as shown in figure 22.

Fourth stage of the test: In this stage, both sections of the DEC media tested as 100% wet.

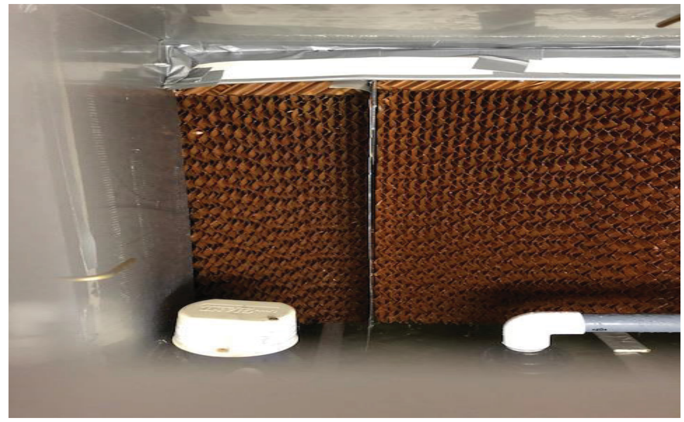

Figure 23 shows 100% wet DEC media under test.

The test was carried out with both heaters on to achieve the higher inlet temperature and varying air velocity start from 600 FPM to 231 FPM to calculate the pressure drop for the wet DEC media. The pressure drop was found 0.28 in of H_2O (Figure 10).

Figure 20 shows the temperature variations of the RF code sensors upstream and downstream with different air velocity. It was observed that the upstream temperature rose all the way up to 102°F from 73°F. The downstream temperature readings decreased from 78°F to 70 and it took about 30 minutes to reach the steady state of 73 and remains constant during with different air velocity.

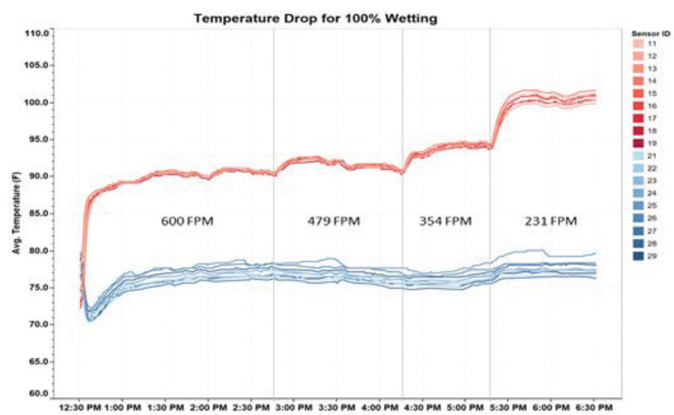

Figure 24: Upstream and downstream temperature during 100% wetting for different face velocities of inlet air

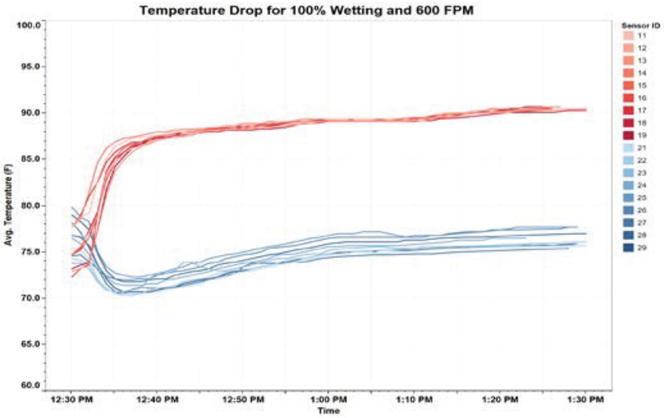

Figure 25 20 Temperature drop across the 100 % wet media pad with 600 FPM inlet air face velocity.

The below figure shows the humidity variations of the RF code sensors upstream and downstream during the 100% wet media testing. It was observed that the downstream humidity went all way up between 70% - 82% from 55%. The upstream humidity readings increased from 40% to 48 % during the wetting phase (constant air velocity) and then decreased back to 30% for the varying air velocity test.

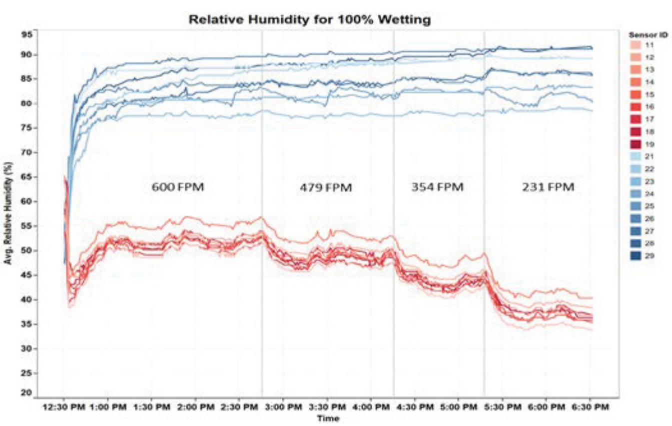

Figure 26: Upstream and downstream RH during 100% wetting for different face velocities of inlet air

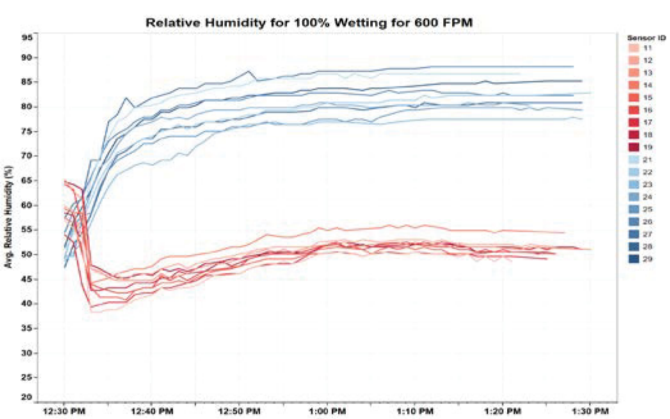

Figure 27 Relative Humidity variation across the 100 % wet media pad with 600 FPM inlet air face velocity

Theoretical analysis: Adiabatic Mixing of Air Stream

The staging of DEC media has a simple configuration (Fig.28a and 28b) where downstream air leaving the staged DEC media has different temperature and humidity (Saturated air and Dry air). At adiabatic saturation conditions [7], the saturated air leaving the wet section can be mixed adiabatically with the dry air that leaving the dry section.
The properties such as (h, ω and ν) of each section can be determined from the psychometric chart depending on the experimental results of the downstream temperature and relative humidity of each section.
As we know, this is a steady- flow mixing, so the mass flow rate ($\dot{m}$) in each stream are:

$$\dot{m}_1 = \dot{V}_1 / \nu_1 \qquad (1)$$

$$\dot{m}_2 = \dot{V}_2 / \nu_2 \qquad (2)$$

Energy and Mass conservation:

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2)\, h_3 \qquad (3)$$

$$\dot{m}_1\, \omega_1 + \dot{m}_2\, \omega_2 = (\dot{m}_1 + \dot{m}_2)\, \omega_3 \qquad (4)$$

($\dot{V}_1$, $\dot{V}_2$) are known in the experiment as flow rate (FPM).
And
(ν_1,ν_2) are a Specific volume (m^3/ kg dry air). From the psychometric chart.

The enthalpy and the specific humidity of the mixture can be determined from below Eq. (3, 4)

Now from these two properties, we can determine the temperature and relative humidity of the mixed air from the psychometric chart (See figure 29).

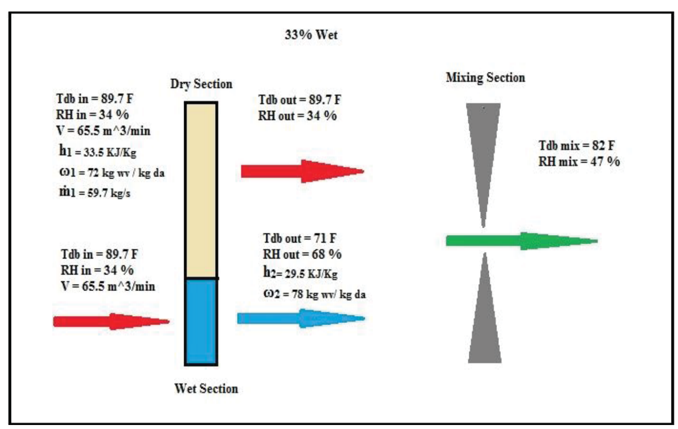

Figure 28a: 33% wet section of the DEC media

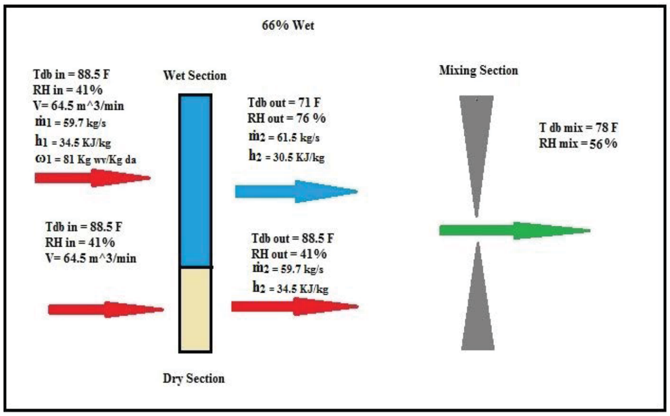

Figure 28b: 66% wet section of the DEC media

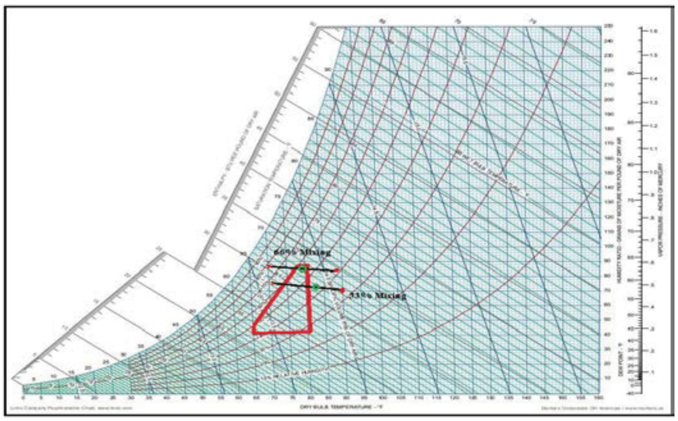

Figure 29: psychometric chart shows the mixing results of 33% and 66% wet.

Conclusion

The vertically staging of DEC media has been successfully tested experimentally. The change in relative humidity and the temperature drop has been carefully reviewed and interesting results are found experimentally and theoretically by using the psychometric chart and adiabatic saturation equations. While operating the two unequal stage with similar assumed conditions these two stages can be turned on /off with mixing both the streams of air and bringing the mixed air inside the ASHRAE recommended and allowable envelops for both 66% and 33% wet running stages. The comparison of two configurations showed the un-equal configuration has better control on relative humidity than the single stage configuration. This clearly shows when the vertical split configuration is implemented for any number of staging, it would be beneficial, if the sections are un-equal.

This control on relative humidity and temperature greatly helps the data center environment to be run inside the ASHRAE's allowable range of relative humidity and temperature upon implementing the vertical split distribution system. This ultimately increases the reliability of the IT equipment and minimizes the cost associated with it. It also helps saving water utilization and power consumption.

Acknowledgement

This work is supported by NSF IUCRC Award No. IIP-1738811.

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