EXPERIMENTAL CHARACTERIZATION OF VERTICALLY SPLIT DISTRIBUTION WET-COOLING MEDIA USED IN DIRECT EVAPORATIVE COOLING OF DATA CENTER

by

AHMED AL KHAZRAJI

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April 12, 2018

Abstract

EXPERIMENTAL CHARACTERIZATION OF VERTICALLY SPLIT DISTRIBUTION WET-COOLING MEDIA USED IN DIRECT EVAPORATIVE COOLING OF DATA CENTER

Ahmed AL Khazraji, MS

The University of Texas at Arlington, 2016

Supervising Professor: Dereje Agonafer

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.

Table of Contents

List of Figures

LIST OF TABLES

Nomenclature

GPM	Gallons per minute
DEC	Direct evaporative coolers
DBT	Dry-bulb temperature
WBT	Wet-bulb temperature
RH	Relative humidity
WBD	Wet-bulb depression

Chapter 1

INTRODUCTION

Evaporative cooling process remains one of the least expensive techniques which provide 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].

Figure 1-1 Facebook Data Center [9]

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.

1.1 Types of Evaporative Cooling Used in Data Centers

a) Indirect Evaporative Cooling (IEC)

With an Indirect Evaporative Cooling system the supply air is passively cooled before it enters the space by passing over a medium that has been directly evaporatively cooled on an adjacent but isolated side. Thus no moisture is added to the supply air stream.

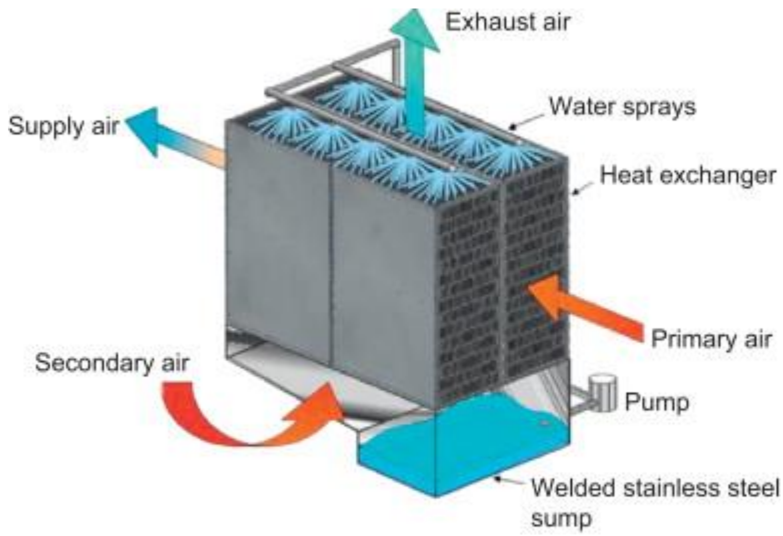

Figure 1-2 Indirect Evaporative Cooling [10]

In this process, the secondary air is cooled by water flowing over the heat exchenger coils. The primary air will pass through the heat exchanger colis and the heat transfer between the secondary air and water will provide the necessary cooling effect to reduce the inlet temperature of the primary air. This type of cooling is usedful for the humid climate, because both the dry-bulb and the wet-bulb temperatures will decrease and there is no moisture will be add to the supply air.

b) Direct evaporative cooling (DEC)

DEC is a process of cooling warm air through direct contact of air and cold water. When warm air is contacted to the cold water, the warm air gives up its energy to evaporate the water in the form of latent heat and then reducing the air temperature and increacing its humidity content.

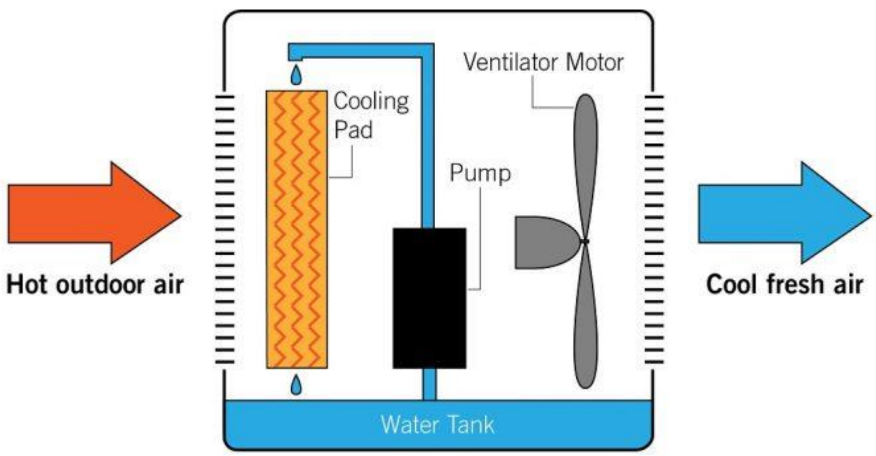

Figure 1-3 Direct Evaporative Cooling [11]

- Advantage of direct evaporative cooling.
- Consumes minimal energy for cooling
- Increases the cooling effect by addition of moisture to dry air
- Best suited for hot climates
- Disadvantages of direct evaporative cooling.
- Water consumption
- Maintenance required for replacing pads
- High relative humidity

1.2 Evaporative Cooling Pads

Evaporative Cooling Pads is a rigid media pads used in direct evaporative cooling system and play a significant role in air-water interaction to increase the cooling performance.

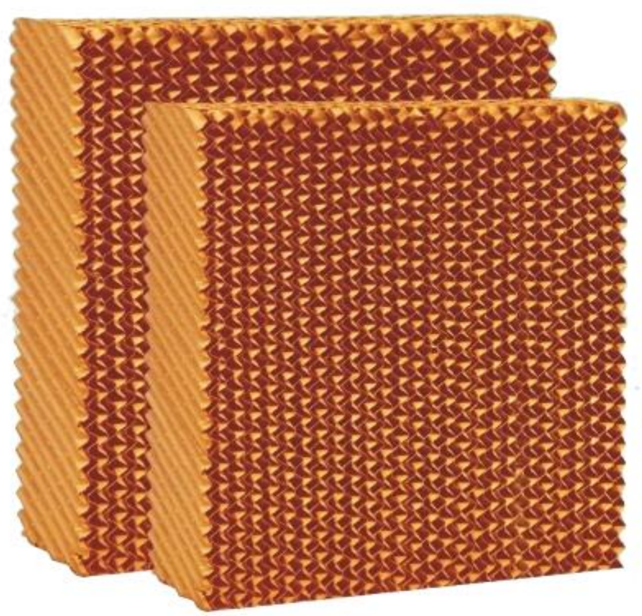

Figure 1-4 Evaporative Cooling Pads. [12]

There are many different types of DEC pads in the market fiber glass, cellulose, Aspen fiber, Plastic, et cetera. B. Gebrehiwot [3] discussed and classified all the types of DEC media used in direct evaporative cooling system. Cooling efficiency in DEC pads is depending on an important parameters which are:

i. Thickness of the media

ii. Flute angle

iii. Material of the media

iv. Surface area of the media

Other two key performance factors taken in to consideration are

i. Static pressure drop

ii. Saturation efficiency

Pressure drop is the difference between the average static pressure at the inlet and outlet of the duct.

Saturation efficiency is calculated using the correlation,

$$\eta = 100\ x\ \frac{t\,1 - t2}{t1 - ts}$$

Where,

η – Saturation Efficiency, %

$t1$ – Entering Air Temperature, °F

$t2$ – Leaving Temperature, °F

ts – Saturation Temperature, °F

1.3 Staging of wet cooling media

In DEC systems the amount of moisture added to a system can be controlled by frequently modulating the water supply to the wet cooling media. However, this method results in scale and mineral build up on the media. To work around this problem, staged systems can be used.

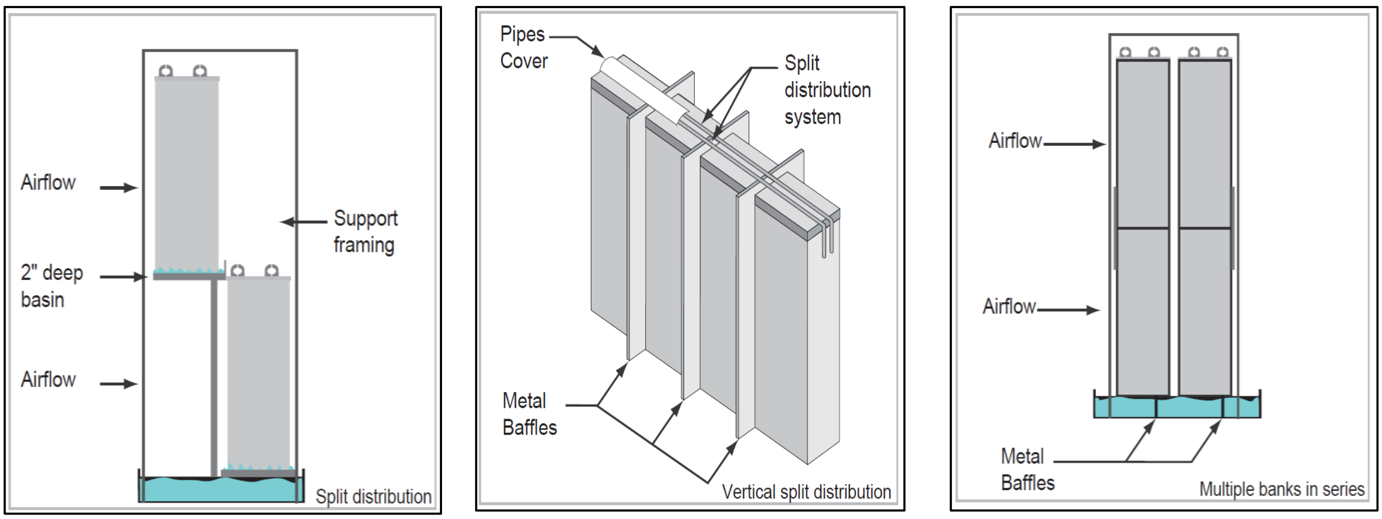

Figure 1-5 Types of staging of wet cooling media [13]

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. Increasing the number of stages while maintaining same number of sections allows more precise control of humidity and temperature.

Chapter 2 Research Objective

2.1 Vertically Split Distribution

This experimental study is focus on the vertically split distribution of wet DEC media to see the control over the relative humidity and the temperature drop across the DEC media. The DEC media will splitted vertically into two un-equal section and provided individually controlled water distribution headers. Apart from relative humidity and temperature, other parameter of interests like pressure drop across the rigid media is presented.

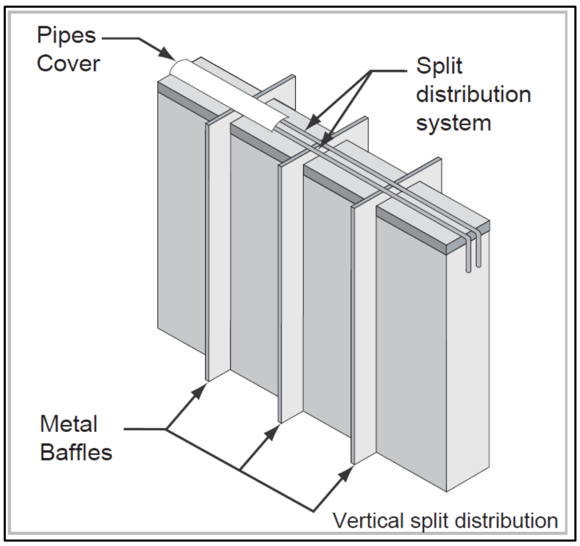

Figure 2-1 vertically split distribution

Advantage of staging of wet cooling media

- Precise control over humidity and temperature.
- It can reduce total water and electricity consumption of the system.
- Life of cooling media can be increased by using staging. (Staging reduces scale build up on DEC media)

2.2 EXPERIMENTAL SETUP

The experimental set up is consisted of airflow Bench, Variable Exhaust System (Blower), and the test duct for the evaporative cooling test (see figure 2-2, 2-3). Air-flow bench is a device 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.

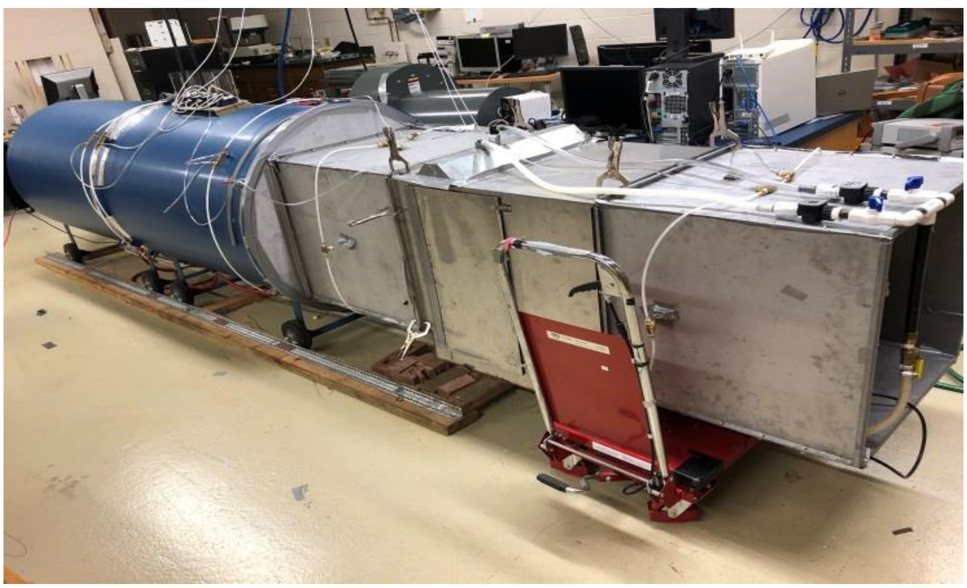

Figure 2-2 Air-Flow Bench and the Test Duct

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 sitting inside the middle zone and fitted approximately 0.7m away from the downstream [1].

Figure 2-3 Air Blower

The above figure shows the blower and counter blower provisions for air flow bench with variable air velocity. Depending upon the requirement the flexible host (black pipe in picture) is connected to the inlet port of the Air- Flow Bench to push the air through the system.

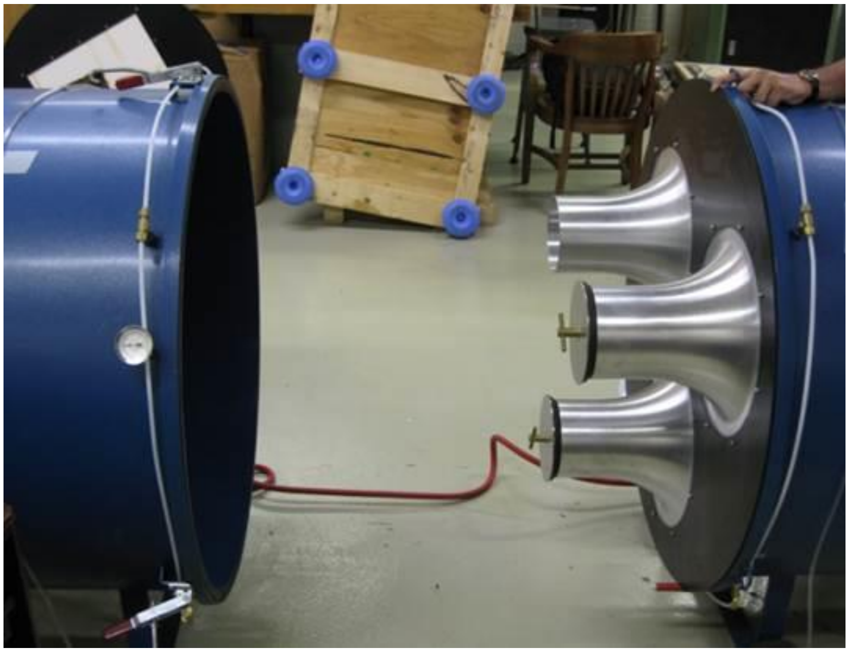

Figure 2-4 Nozzle Plate

Figure 2-4 shows the Nozzles plate it can be placed at the center of the air flow bench chambers, the nozzles are positioned on the plate so that they may be used in parallel to achieve higher flow ranges.

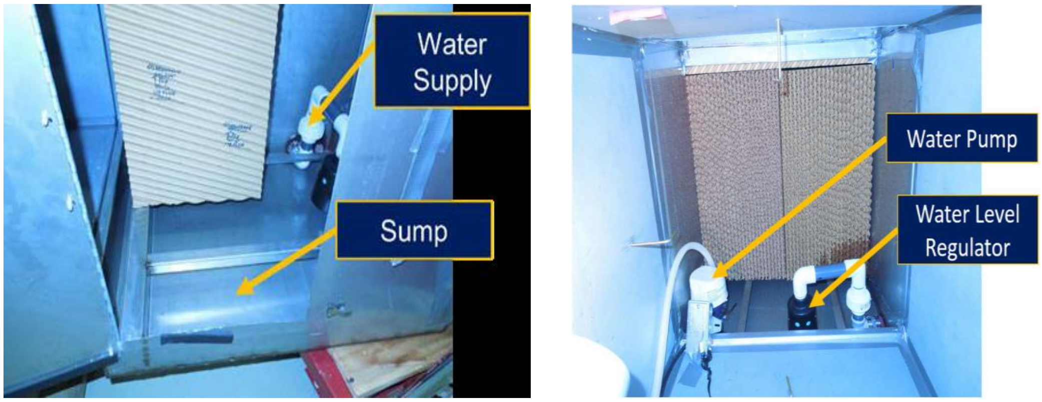

Figure 2-5 Side and front view of the middle duct

Figure 2-5 shows the middle section of the duct where the DEC media, water reservoir, water pump, water, distribution header, and water level regulator are placed.

Based on the manufacturer of the DEC media recommends to distributed (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 (see figure 2-6). To control the relative humidity of the room during the wet media tests, three of dehumidifiers were used to keep the humidity with desired limits (see figure 2-7).

Figure 2-6 shows Digital water flow meter on each water supply and Separate water distribution headers

Figure 2-7 shows Fantech Dehumidifier

Eight Dwyer A-302F-A pressure taps were used and 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 sensors were mounted such that one sensor covers one-ninth of the cross sectional area of the duct on two plastic egg crate 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 2-8 Plastic egg crate light diffusers, RF Code R155 Sensor and Dwyer A-302F-A pressure taps

Chapter 3

TEST PROCEDURE AND RESULTS

The test was conducted in lab 109 at the University of Texas at Arlington. KUUL 12 x 24 inch cellulose media was splitted into two un-equal section 33.3% and 66.6% and tested for four wetting stages. Figure [3-1] and Table [1.1] shows the splitting and the water pumping state of the staging of the DEC media.

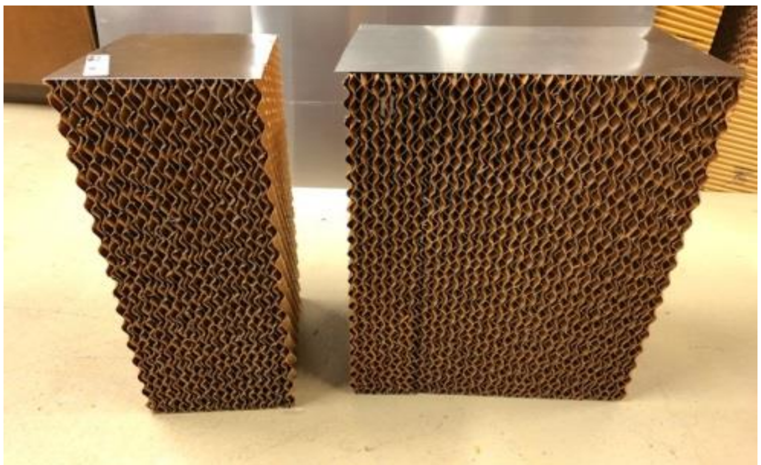

Figure 3-1 shows the un-equal splitting of DEC media.

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 1.1 Two section media showing pump on/off state. [3]

The two un-equal section of the DEC media were tightly sits inside the middle segment of the duct with water distribution try on the top of each section and splitted 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 by 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 in this experiment.

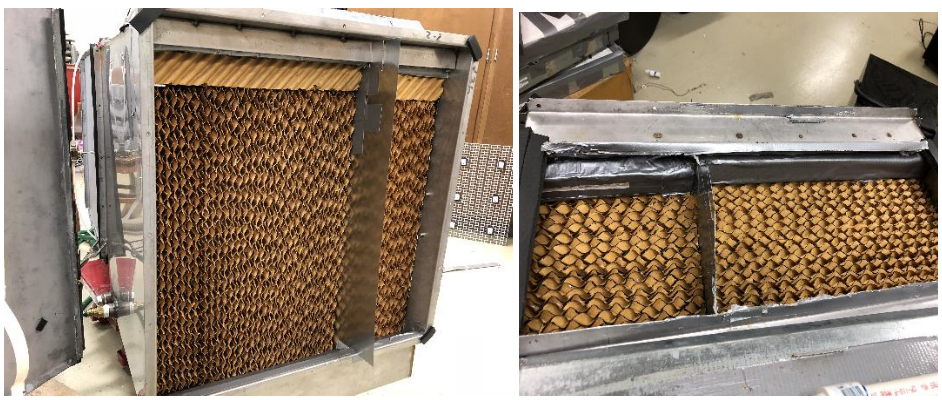

Figure 3-2 shows Side and top view of the DEC pad fitted inside the middle duct.

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 ^{o} 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 3-3)

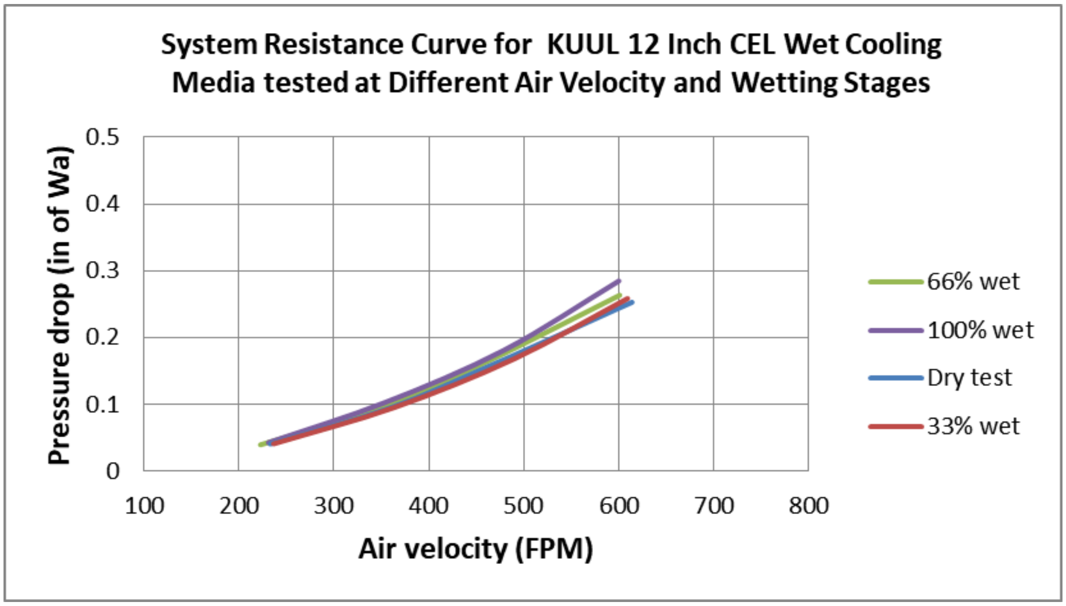

Figure 3-3 System Resistance Curve for KUUL 12in cellulose at different Air velocity, Temperature and Wetting stages.

Stage two of the test: The second stage of the test was for 33% wet of DEC media; the test was conducted at higher inlet temperature (Figure 3-4). To achieve the high upstream air temperature, two ProFusion Heat Industrial Fan-Forced Heaters (Model HA22-48M) (Figure 3-5) were placed at the inlet of the airflow bench blower. And the water flow rate was kept constant during the test (1gpm).

Figure 3-4 shows 33% cooling media under Test

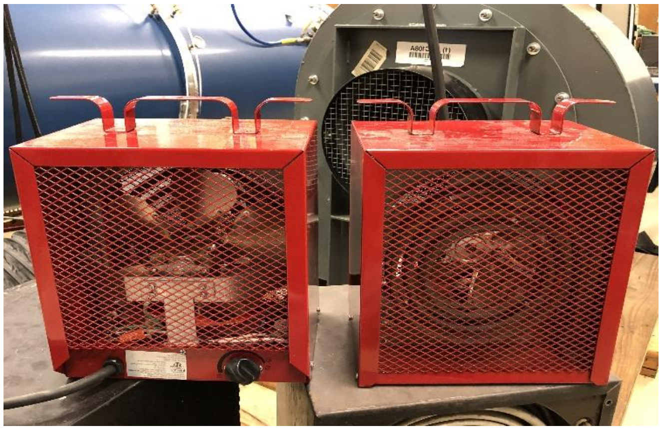

Figure 3-5 ProFusion Heaters.

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 inch H_2O at 609 FPM and 91ºF. (See Figure 3-3).

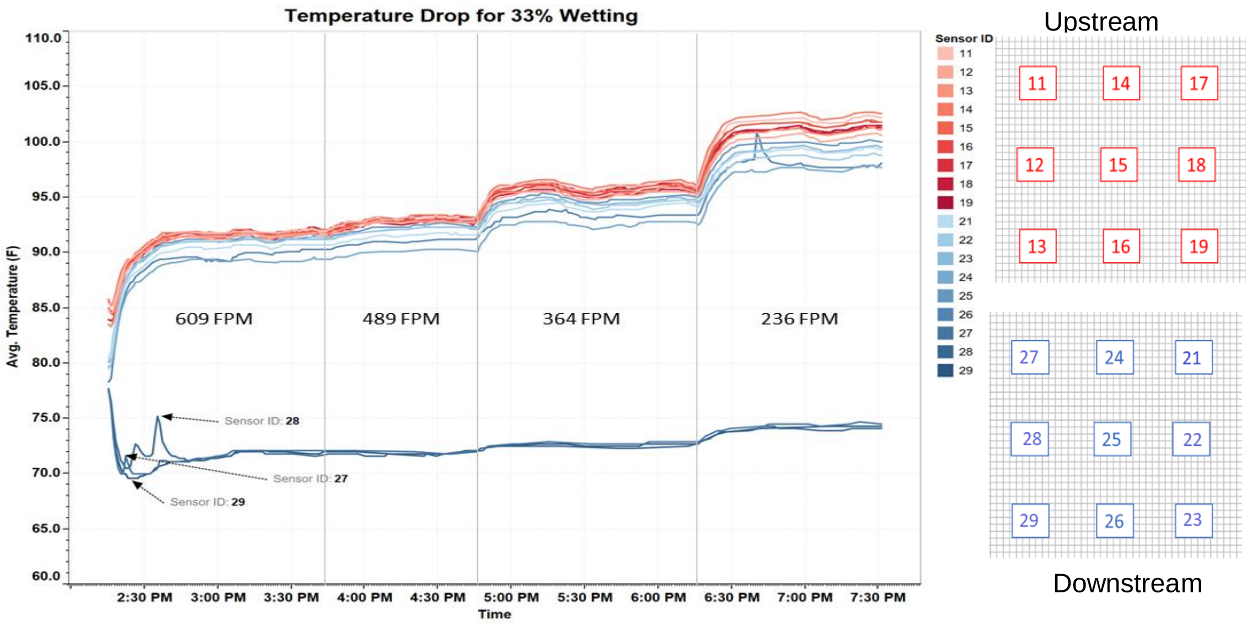

Figure 3-6 RF Code sensors readings for the temperature during 33% wetting for different face velocities of inlet air

Figure 3-6 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 Fig.3-6. 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.

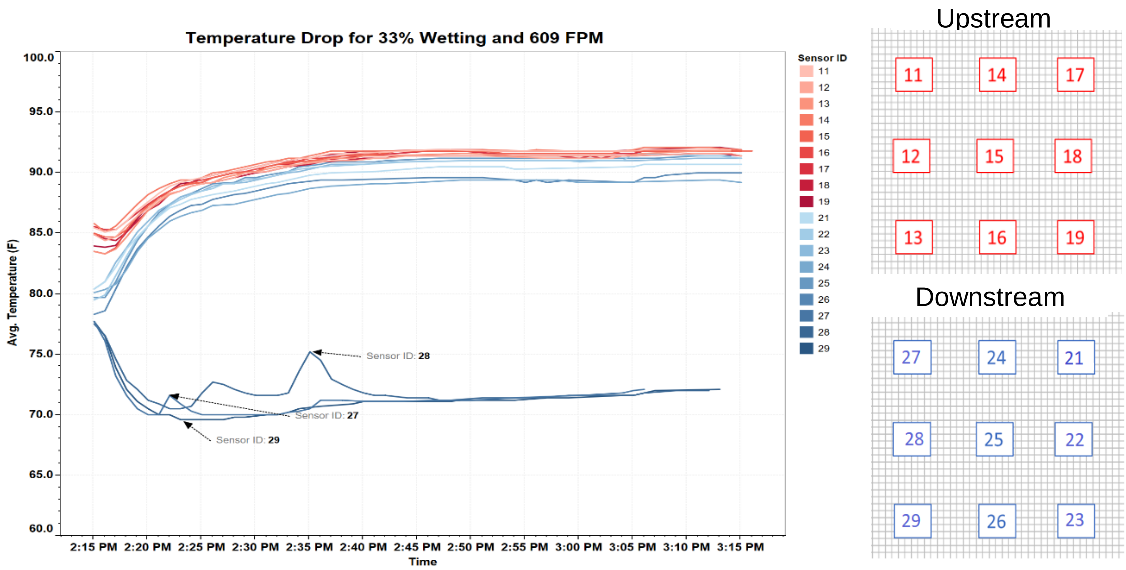

Figure 3-7 Temperature drop across the 33% wet media pad with 609 FPM inlet air face velocity

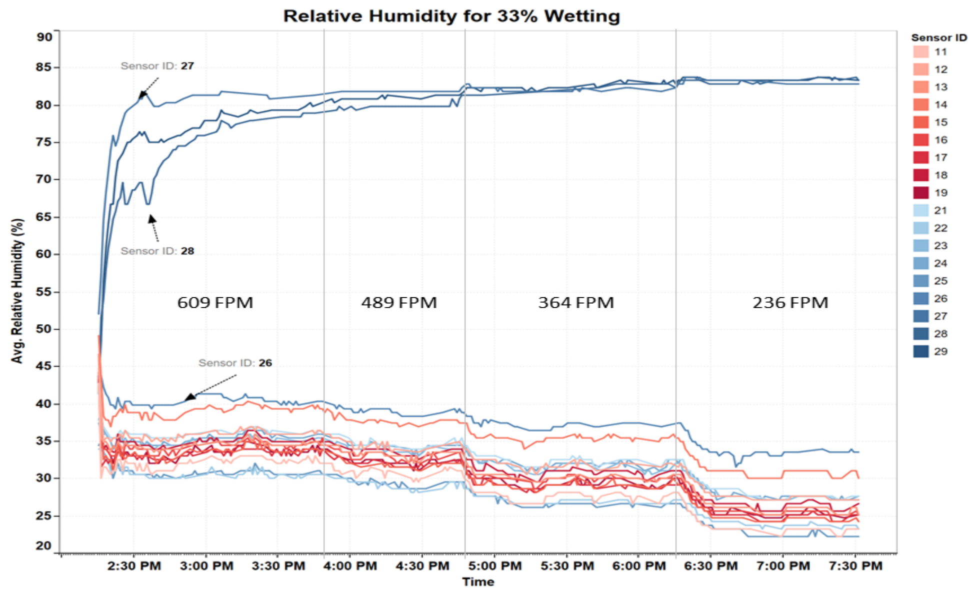

Figure 3-8 Upstream and downstream RH during 33% wetting for different face velocities of inlet air

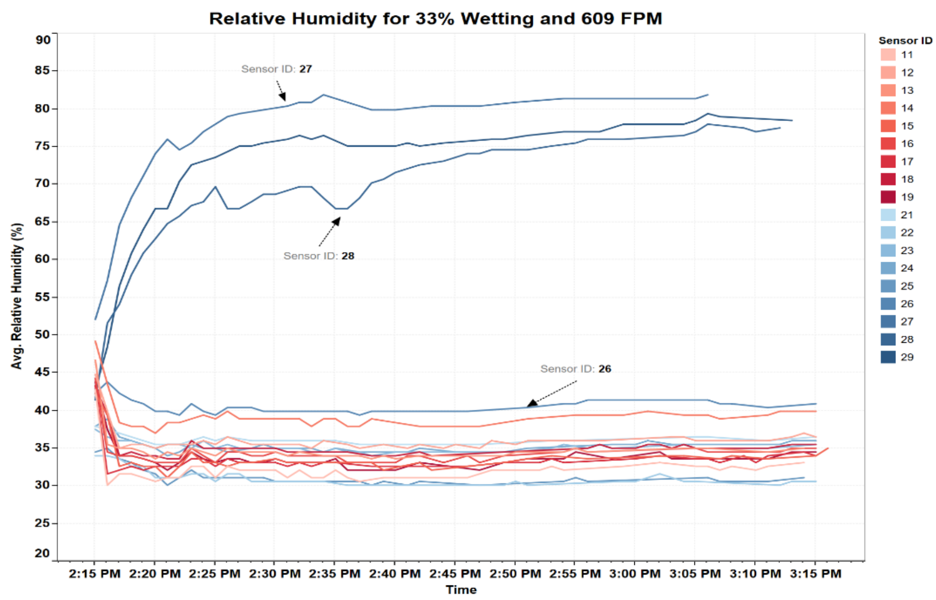

Figure 3-9 Relative Humidity variation across the 33% wet media pad with 609 FPM inlet air face velocity

Figure 3-8 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, were the 33% part kept fully dry and the 66% part was fully wet.

Figure 3-10 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 3-3).

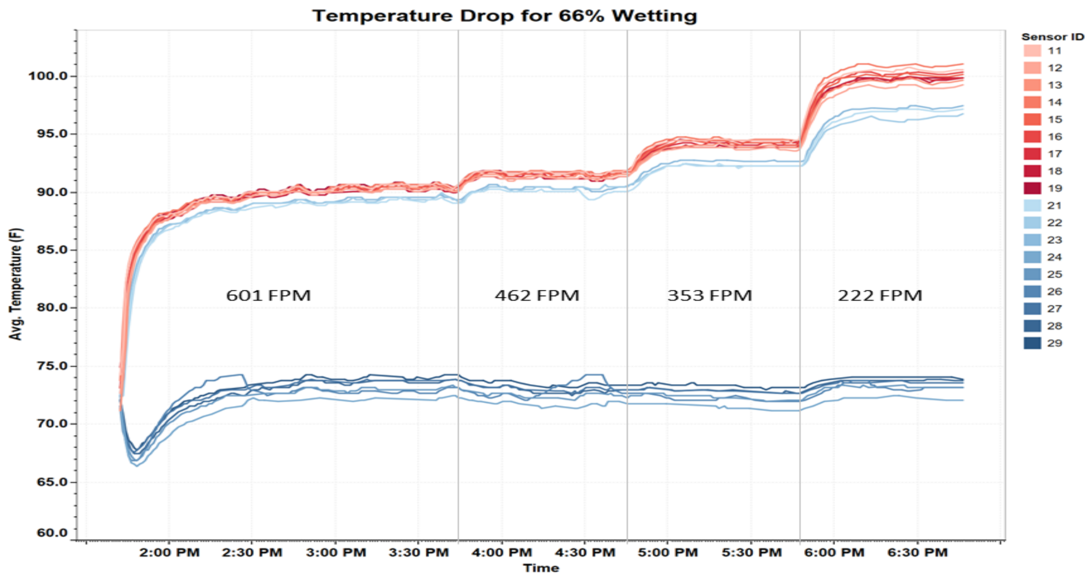

Figure 3-11 Upstream and downstream temperature during 66% wetting for different face velocities of inlet air

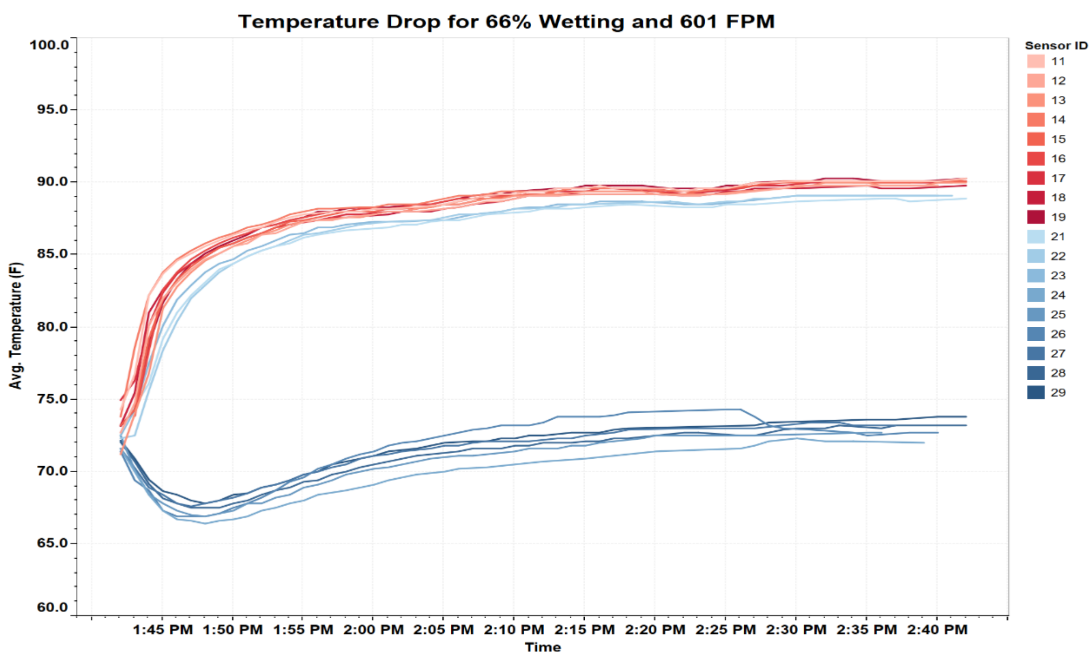

Figure 3-12 shows the Temperature readings of each sensors during 601 FPM

Figure 3-11 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 3-12 shows the temperature 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.3-11. 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.

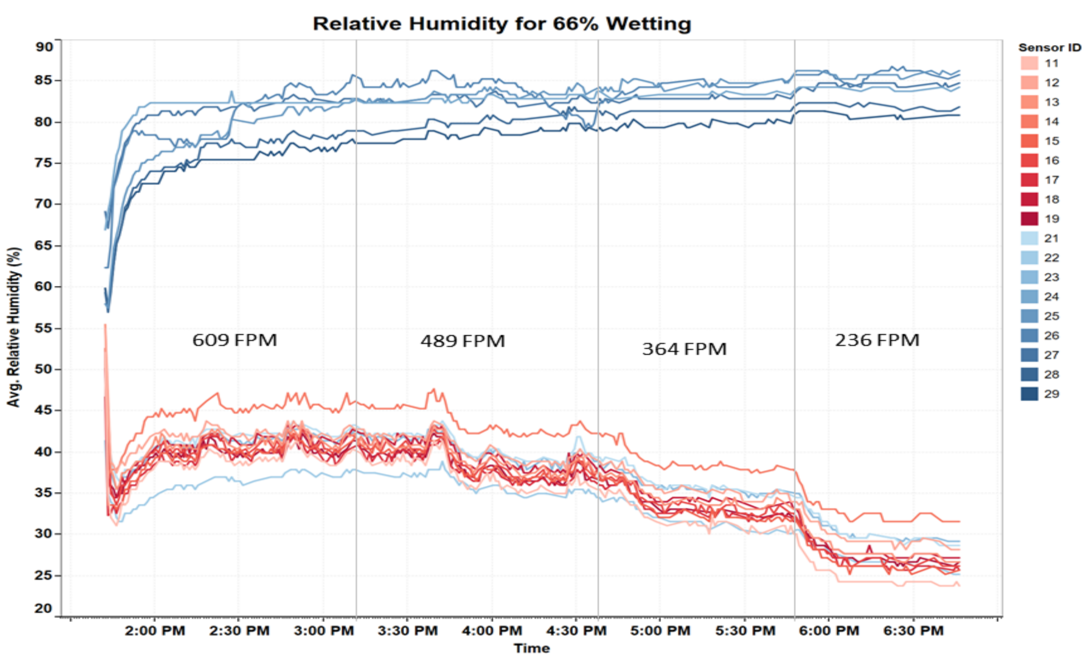

Figure 3-13 RH variations of RF Code sensors with time (66% wet)

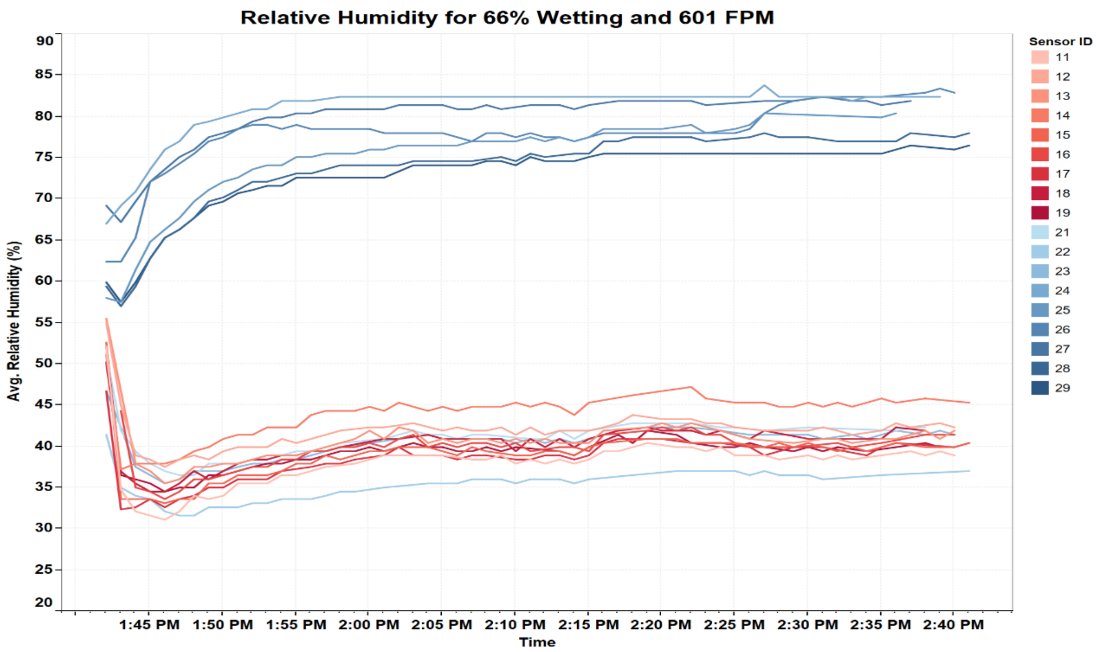

Figure 3-14 shows the RH readings of each sensors during 601 FPM.

Figure 3-13 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 3-14.

Fourth stage of the test: In this stage, both sections of the DEC media tested as 100% wet**.** 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 H2O (Figure 3-3).

Figure 3-15 shows 100% wet DEC media under test.

Figure 3-16 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.

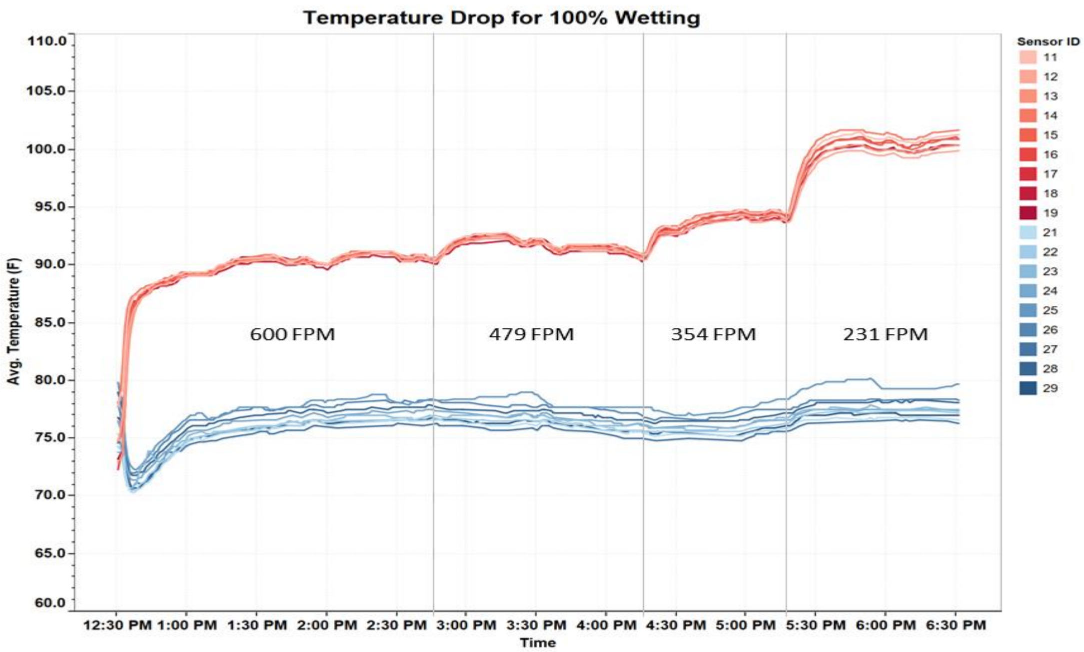

Figure 3-16 Temperature variation for 100% wet media of RF Code sensors with time.

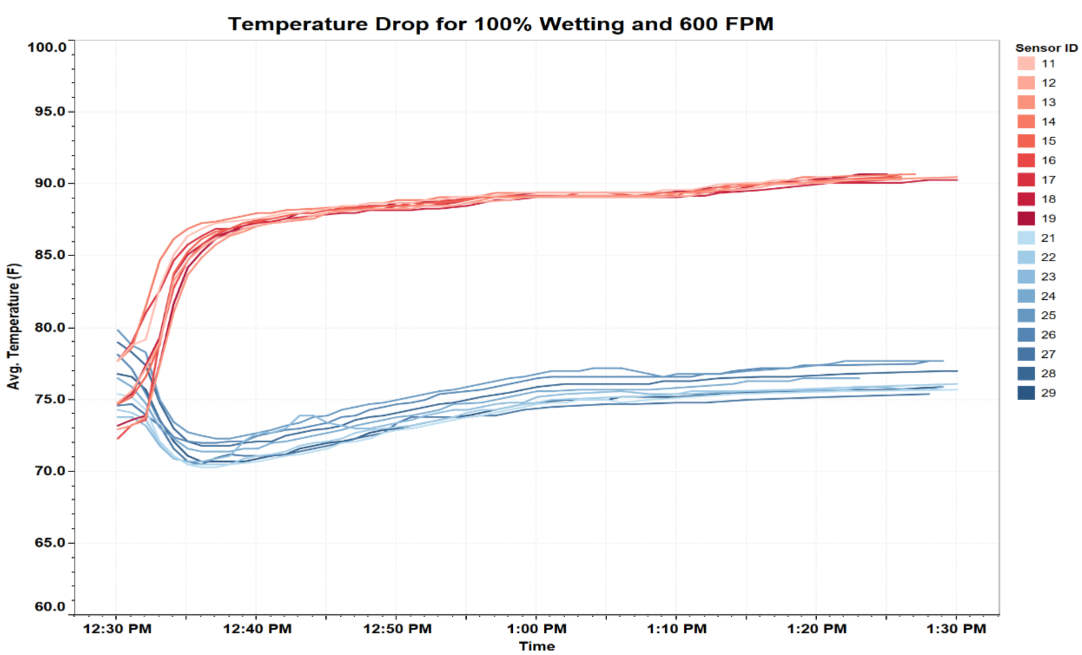

Figure 3-17 shows the Tempreture readings of each sensors during 600 FPM.

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.

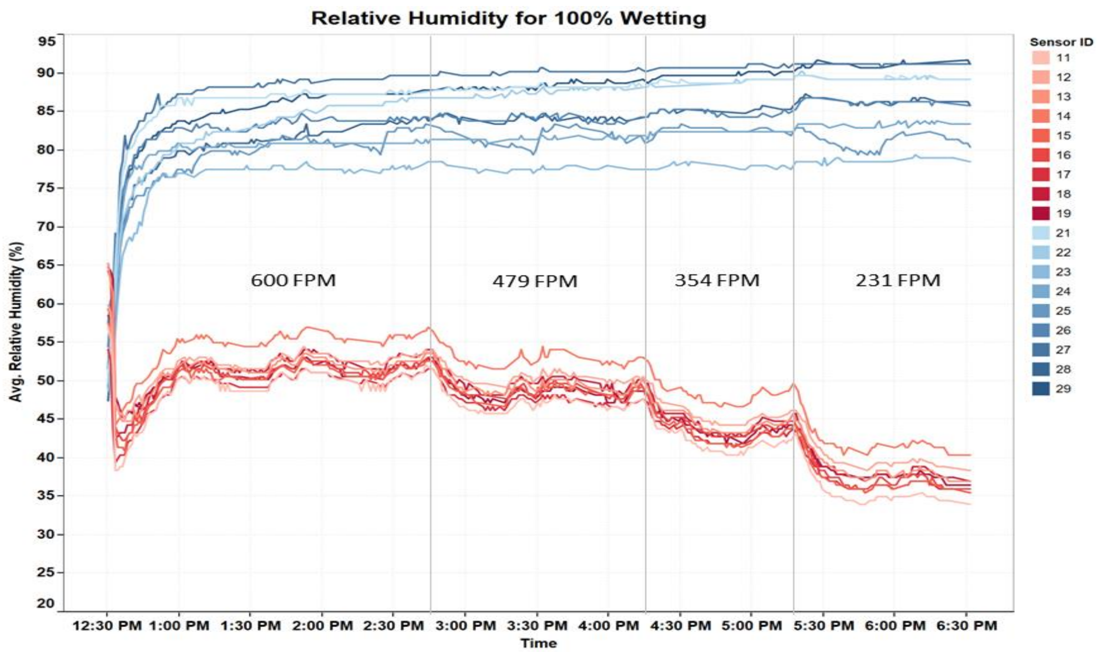

Figure 3-18 RH variation for 100% wet media of RF Code sensors with time and different air velocity

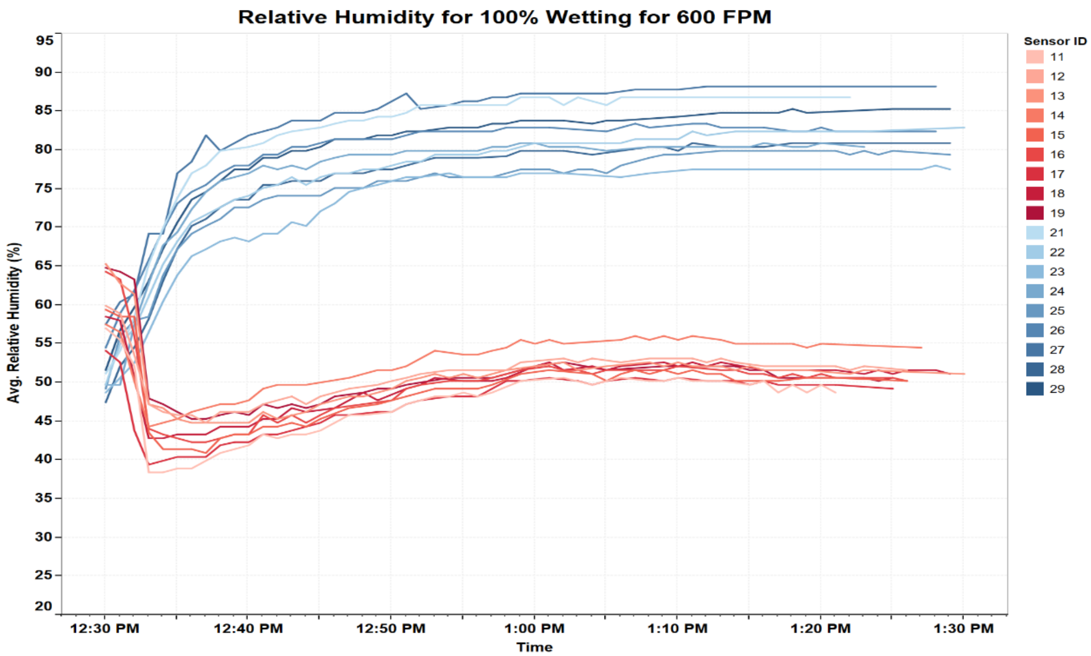

Figure 3-19 shows the RH readings of each sensors during 600 FPM.

Chapter 4

Theoretical analysis: Adiabatic Mixing of Air Stream

The staging of DEC media has a simple configuration (Fig.4-1 and 4-2) 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 v) 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:

$\dot{m}_1 = \dot{V}_1 / v_1$ (1)

$\dot{m}_2 = \dot{V}_2 / v_2$ (2)

Energy and Mass conservation:

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

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

($\dot{V}_1$, $\dot{V}_2$) are known in the experiment as flow rate (FPM). And (v_1, v_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 4-3).

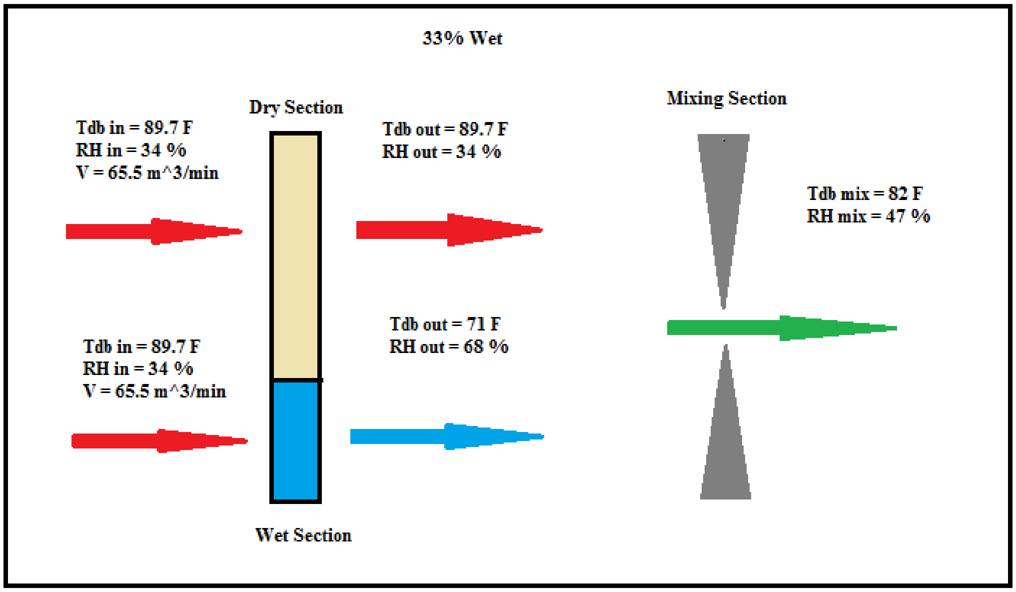

Figure 4-1 33% wet section of the DEC media

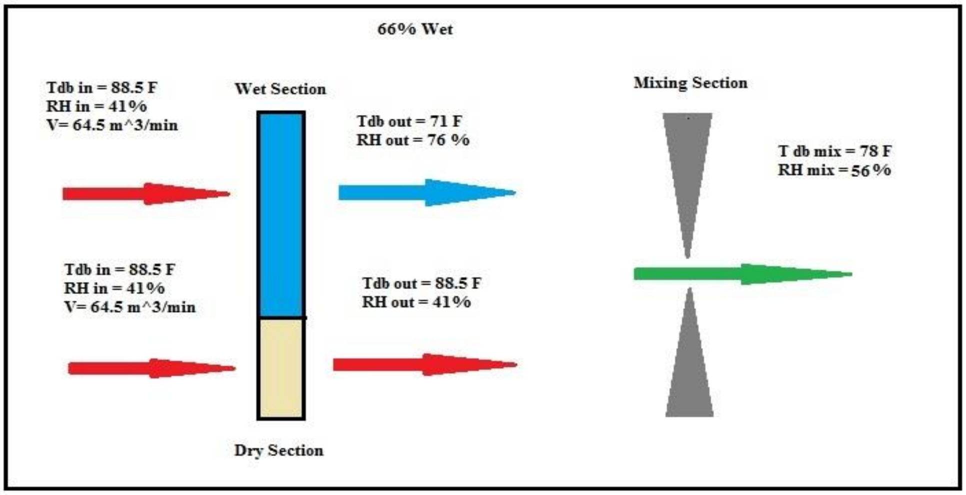

Figure 4-2 66% wet section of the DEC media

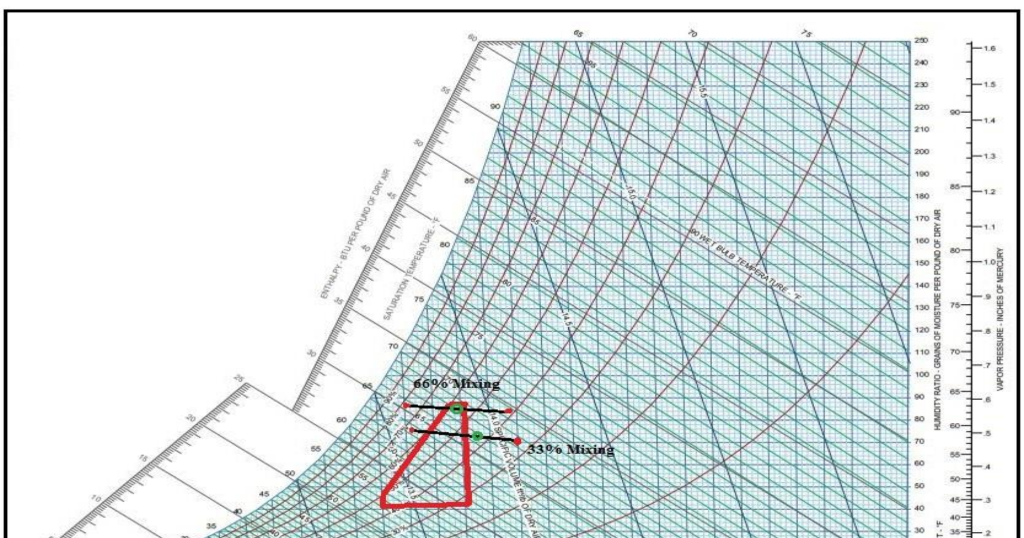

Figure 4-3 psychometric chart shows the mixing results of 33% and 66% wet.

Chapter 5
Discussion and 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.

Future work

- Mixing of the downstream air to be investigated experimentally or through CFD modeling.
- Experimentally testing the horizontally split of Cooling Media. Record and compare the vertically split with experimental results

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Biographical Information

Ahmed Al Khazraji (May, 13th, 1984) is from Iraq, he completed his Bachelors in Mechanical Engineering from University of Technology in Baghdad, Iraq at 2007. Ahmed worked as a Quality Assurance and Maintenance Engineer with the USA Army in Iraq from 2008-2011. He came to the united stated in April 2012 as a US permanent resident, he joined The University of Texas at Arlington in August 2015 for Master of Science program in Mechanical Engineering. Ahmed worked as Graduate Research Assistant for EMNSPC in 2017 under supervision of Professor Agonafer with project 4 (Direct / indirect evaporative cooling systems used in data center cooling). Ahmed graduated from The University of Texas at Arlington on May 12, 2018.