# A PARAMETRIC STUDY ON THERMAL MIXING OF AMBIENT AIR AND RETURN AIR STREAMS IN A MIXING CHAMBER OF A DATA CENTER COOLING

By

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May16, 2017

# ABSTRACT

## A PARAMETRIC STUDY ON THERMAL MIXING OF AMBIENT AIR AND RETURN AIR STREAMS IN A MIXING CHAMBER OF A DATA CENTER COOLING

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Air side economization is an arrangement of duct, damper and automatic control system which together allow introducing outside air to reduce or eliminate the mechanical cooling during mild or cold weather. In this process, ambient air is drawn inside from environment, passed through filter to get rid of contaminants and then is introduced to the cold aisle of data center. Per ASHRAE, use of air side economization is mandatory when outside air conditions are favorable to reduce data center energy consumption. To maximize economizer hours, direct evaporative cooling, indirect evaporative cooling, two stage direct/indirect evaporative cooling & compressor less cooling can be considered. The outside ambient air and heated return air upon process cooling is mixed to achieve a target cold aisle operating temperature and increases economizer hours. The dedicated space where these two air streams mix is called a mixing chamber. Mixing chamber accommodates mixing of two air streams in a short span of time. Two types of dampers are considered in this study: parallel blade dampers that rotate together in same direction and opposite blade dampers that have alternating open and shut directions. Damper blade angles have major impact on flow rate, directionality and overall mixing effectiveness. Damper blade angles for ambient air and return air inlets are varied in increments and their effect on mixed air temperature is investigated.

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# LIST OF ILLUSTRATIONS

# NOMENCLATURE

| | |
|---|---|
| P | Density (kg/m3) |
| k | Thermal Conductivity (W/m-K) |
| ε | Kinematic Rate of Dissipation (m2/s3) |
| v | Velocity (m/s) |
| μ | Viscosity (N/m2 s) |
| m | Mass flow rate (kg/s) |
| q | Heat load (W) |
| P | Power (W) |
| v | Volumetric Flow Rate (cfm) |
| IT | Information Technology |
| ASHRAE | American Society of Heating, Refrigeration and Air Conditioning Engineers |
| Re | Reynolds number |
| Cp | Specific Heat capacity (J/kg K) |
| p | Pressure (in of H2O) |
| DEC | Direct Evaporative Cooling Unit |
| IEC | Indirect Evaporative Cooling Unit |
| OA | Outside air damper |
| RA | Return air damper |

# CHAPTER 1

# INTRODUCITON TO MODULAR DATA CENTERS

## 1.1 Data Centers

Data Center is a large group of networked computer servers typically used by organizations for the remote storage, processing, or distribution of large amounts of data. The functions of data centers are processing, manage, storage and interchange of data and information. The increasing need for networking and internet usage for basic activities such as payment of utility bills, shopping, etc. lead to the data centers to be seemingly global. However, it is observed that the usage of telecommunications, banking, stock markets, social networks, educational institutions, search engines the need for data centers is increasing day by day.

Figure 1 Facebook data center [1]

The heat dissipated by the IT equipment increases as the work load increases. In these data centers, complex power distribution is employed along with expensive cooling systems to cool the IT equipment.

### *1.1.2 Power trends in Data centers*

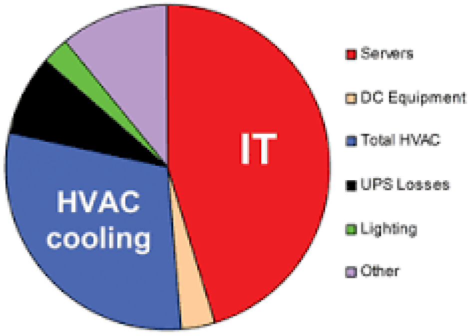


Figure 2 Energy Break down in a Data center [2]

It is estimated that about 12 million computer servers in almost 3 million data centers carry all U.S online activities. Roughly the data centers consume enough electricity to power whole of New York households for about 2 years. [1].

The above figure illustrates the energy break down within a data center. Almost 50% of the total power is consumed by the IT equipment and another 40% of the total power goes in for cooling this equipment. This trend is likely to increase every year; hence it is a necessary to design energy efficient data centers

## 1.2 ASHRAE Recommendations

The American society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommended few thermal guidelines for the safe operations of IT equipment in data centers. Prior to these guidelines, recommendations provided by the IT manufacturer on the operation of their product in data center environment, which were not accurate due to multiplicity of usage of equipment in a data center [1].

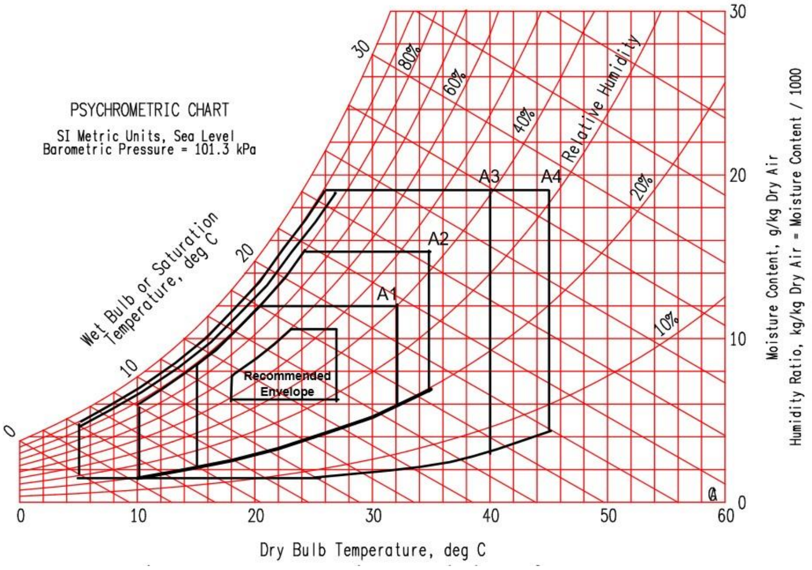


Figure 3 Psychometric chart displaying various zones recommended by ASHRAE [5]

The TC 9.9 expanded the environmental range to allow data center operators to operate in the most energy efficient mode and achieve the required reliability for the IT equipment.

ASHRAE class A3 gives allowable window for temperature range to 41 to 113 while moisture range is from 8% RH and 10.4 dew point temperature to 90% RH.

ASHRAE class A4 gives the allowable temperature range from 41 to 113 while the moisture range is from 8% RH and 10.4 dew point temperature to 90 % RH.

The recommended class is 64.4 to 80.6 for dry bulb temperatures, with humidity range from 41.9 dew point to 60 % RH and 59 dew point temperature [6]

# CHAPTER 2

# INTRODUCTION TO FREE COOLING AND EVAPORATIVE COOLING

## 2.1 Air Side Economization

Air side economization is a mechanism which is used to regulate the use of outside air for cooling. It is the most commonly used cooling systems. Air side economizers are used to supply the cold air from environment to the data center through ducts. The outside and inside temperature conditions are measured with the help of sensors. When external conditions are favorable for cooling, the economizer with the help of control system adjust the position of dampers which allows fresh air in to facility as a primary source of cooling Filters are used to get rid of dust and contaminants, this filtered air is then introduced into the hot aisle of the data center. Exhaust vent is provided to take out the exhaust air. Exhaust air damper maintains pressure so that if excess amount of air present in system has a provision to go out and maintain the balance in the system. If environment temperature is cooler than required, then with the help of return air damper a portion of return air is mixed, which results in reduce of use of air conditioning units and chilled water systems.

Ambient air conditions are very important for air side economization. Humidification and de- humidification is needed depending on air dryness.

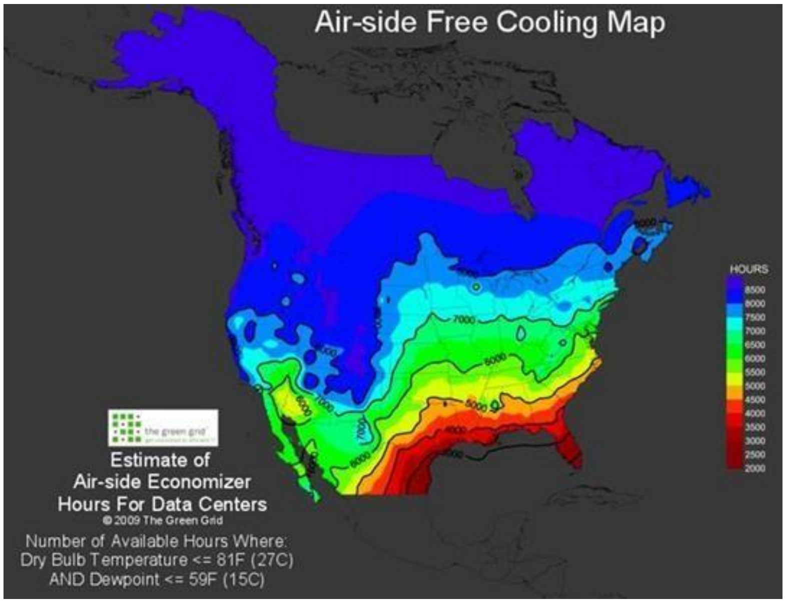


Figure 4 Hours with Ideal conditions for an air-side economizer operation [7]

### 2.1.1 Introduction to Evaporative Cooling

Cooling through evaporation is a natural process. The principle behind phase change cooling is that the use of warmth to vary from liquid to vapor. Thus, heat is absorbed from the water remaining in liquid state creating it a cooler liquid [7]

Conventional cooling systems come at a high initial and operating cost and operate on refrigeration cycle. Evaporative cooling techniques can be used where traditional cooling system can be avoided. Mist cooling, spray cooling are the other names for evaporative cooling.

## 2.2Types of Evaporative Cooling

There are two types of evaporative cooling systems, direct evaporative cooling and indirect evaporative cooling.

### 2.2.1 Direct Evaporative Cooling

In direct evaporative cooling (DEC), the air from outside is introduced into water saturated medium and is cooled through evaporation. With the help of blower air is circulated inside the unit. DEC adds moisture to the air up to its saturation point. Dry bulb temperature is reduced keeping the wet bulb temperature constant. Most of the time these systems are used in home and industries. DEC is economical comparing it to vapor compression system also it consumes less energy.

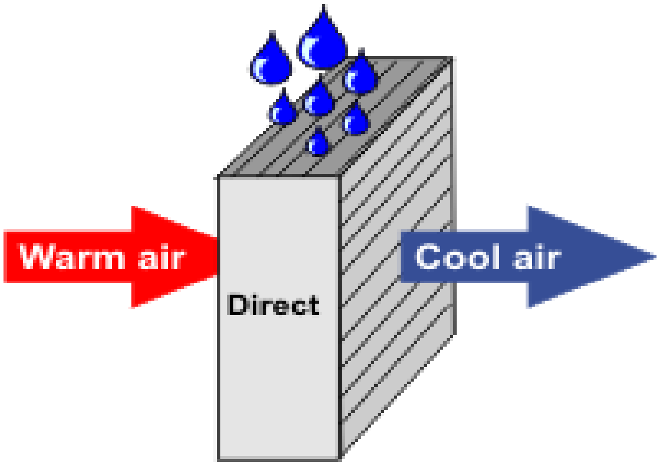


Fig 5 Direct Evaporative Cooling [2]

### 2.2.2 Indirect Evaporative Cooling

In indirect evaporative cooling (IEC), a secondary air stream is cooled using water and is passed through a heat exchanger where it cools the primary air stream from the direct evaporative cooling method. This cooled air is circulated into system using blower. In this method moisture is not added to the primary air stream. Dry bulb and wet bulb temperatures are reduced

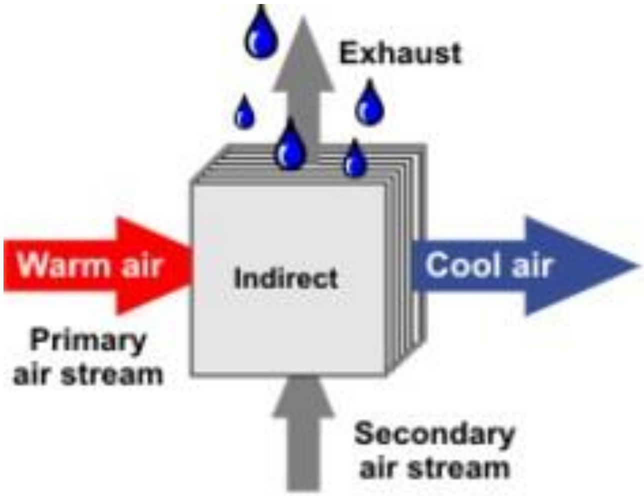


Fig 6 Indirect Evaporative Cooling [2]

### 2.2.3 Direct/Indirect evaporative cooling

In this combination both direct and indirect evaporative cooling techniques are used. The primary air stream is cooled using indirect evaporative cooling and then it is passed into direct evaporative cooling unit where it is further cooled.

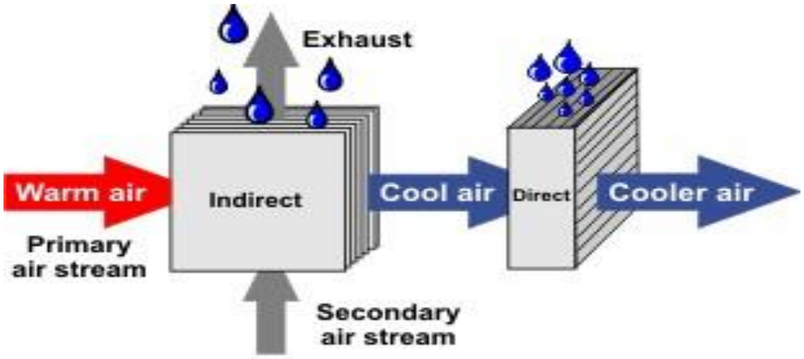


Fig 7 Combiner Evaporative Cooling [2]

# CHAPTER 3

# AIR HANDLING UNIT AND DAMPERS

## 3.1 INTRODUCTION TO AIR HANDLING UNITS

An air handler, or air handling unit (AHU), is a device which regulates and circulates air as part of a heating, ventilating, and air-conditioning (HVAC) system. The air handler is a large metal box connected to a duct, ventilation system that distributes the conditioned air throughout the building and returns to AHU. The return duct from the IT pod forms as supply duct to the AHU and the supply duct to the IT pod acts as the AHU output. There are various components of AHU from the return duct, through the unit, to the supply duct.

The components include

1. Filters,
2. Heating or cooling element,
3. Humidifiers,
4. Mixing chambers
5. Blower fans and
6. Dampers.

Air from the cooling unit is effective only when we use this cooled air properly through proper orientation of Inlet Dampers

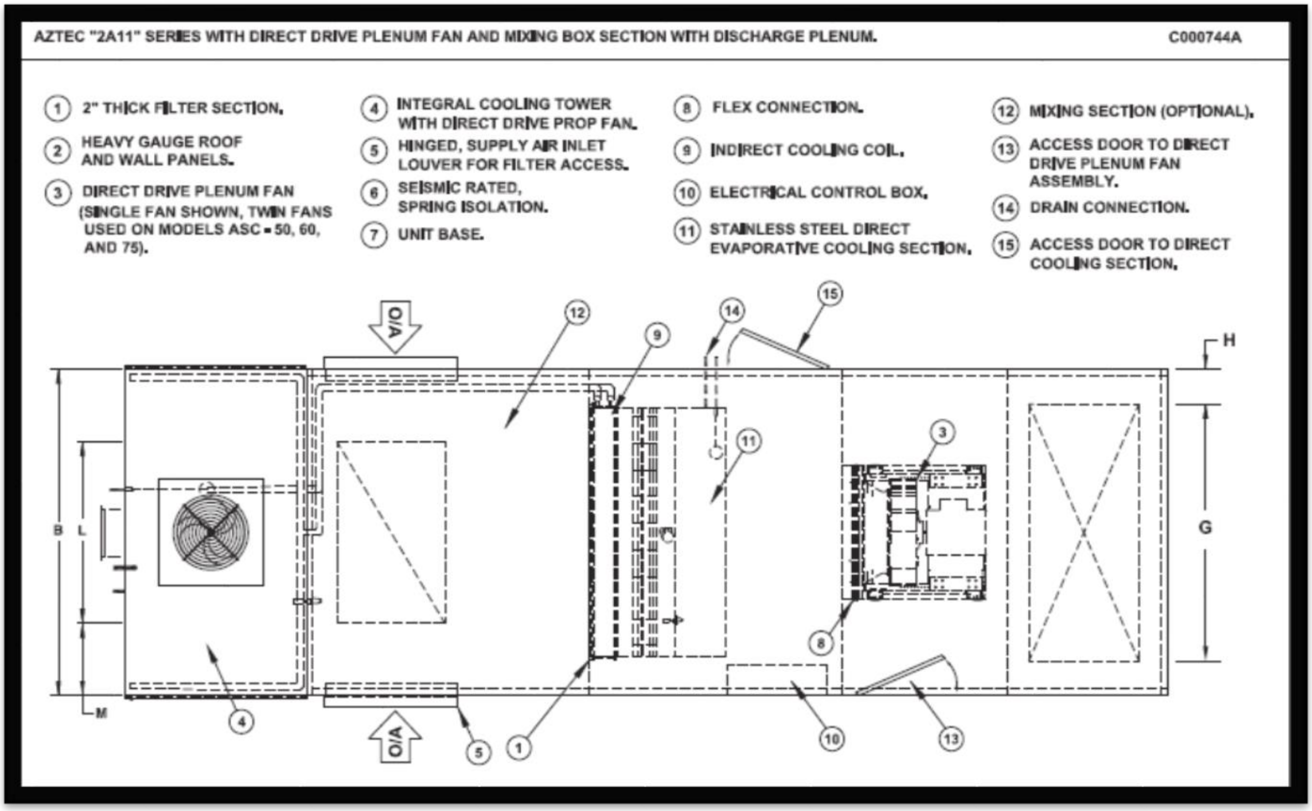


Figure 8 Air handling unit [10]

## 3.2 INTRODUCTION TO DAMPERS

A damper is a valve or plate that stops or regulates the flow of air inside a mixing chamber. The primary supply of air to mixing chamber is from the different sides of mixing chamber. Dampers are the flaps, operated from the control system, which regulate the flow of air through the mixing chamber. Damper controls that varying airflow through an air outlet, inlet, or duct. A damper position may be immovable, manually adjustable or part of an automated control system.

There are two types of damper considered for this application

### 2.2.3.1 Parallel Blade

### 2.2.3.2 Opposed Blade

## PARALLEL BLADE DAMPERS

Parallel blades rotate so they are always parallel to each other; therefore, at any partially open position, they tend to redirect airflow and increase turbulence and mixing within the downstream duct work or plenum. This characteristic makes them good candidates for return and outside air intake into a mixing chamber. The two dampers are often linked together (one opens and one closes) to coordinate control.

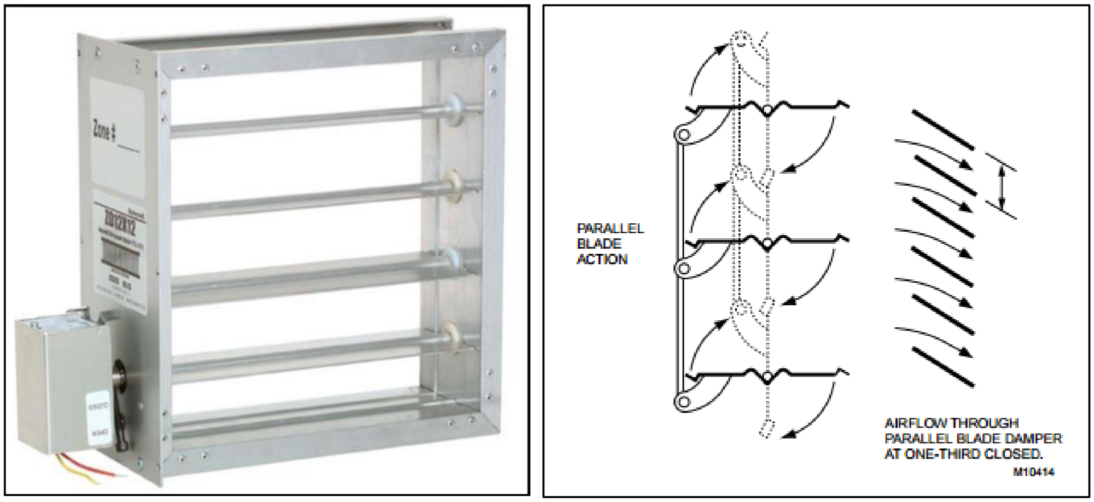


Figure 9 Parallel Blade Damper

## OPPOSED BLADE DAMPERS

Opposed blades rotate opposite each other in adjacent pairs. Air discharge through this type of damper is straighter and a bit quieter under partial-flow conditions. Opposed blade dampers are often specified where air direction control is important relative to other factors, such as within final volume control devices. The flow characteristics of parallel and opposed dampers are different; an opposed blade damper must be opened further (creating a higher modulating pressure drop) to provide the same percentage of total air volume as a parallel damper (creating a lower modulating pressure drop). When they are wide open, the pressure drop is the same for both types.

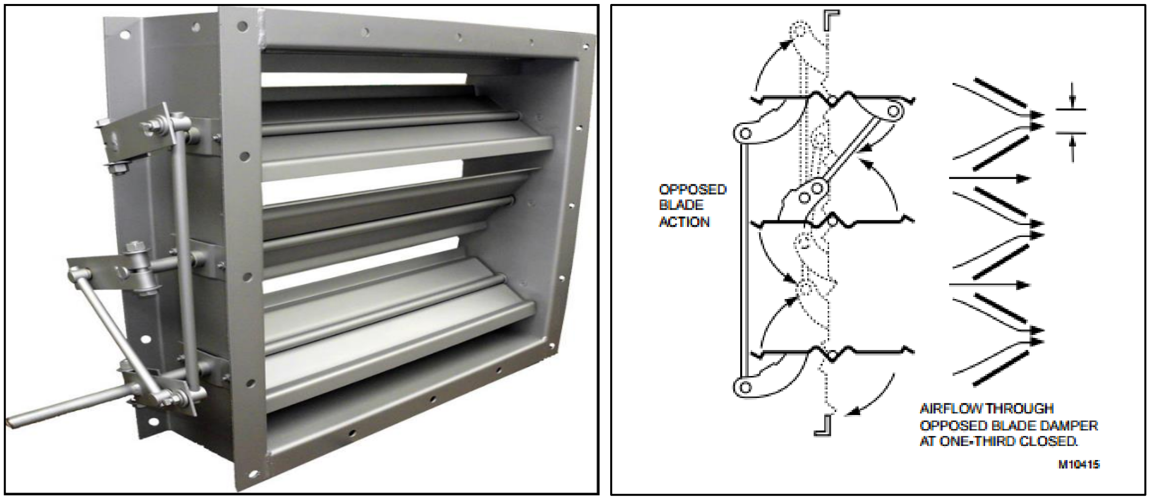


Figure 10 Opposed Blade Damper

## 3.3 DAMPER SIZING

Dampers are typically chosen based on duct size and convenience of location. Proper selection and sizing of dampers provides the following benefits: —

- Lower installation cost because damper sizes are smaller. In addition, smaller actuators or a fewer number of them are required. —
- Reduced energy costs because smaller damper size allows less overall leakage. —
- Improved control characteristics (rangeability) because the ratio of total damper flow to minimum controllable flow is increased.
- Improved operating characteristics (linearity).

When selecting a damper, one of the important factor to consider is the operating characteristics and capacities so the desired system control is achieved.

# CHAPTER 4

# MIXING CHAMBER & CFD MODELLING

A mixing chamber/plenum is the region upstream in a cooling unit where the outside ambient air and return air are introduced. A relatively short length of mixing plenum makes complete mixing quite difficult.

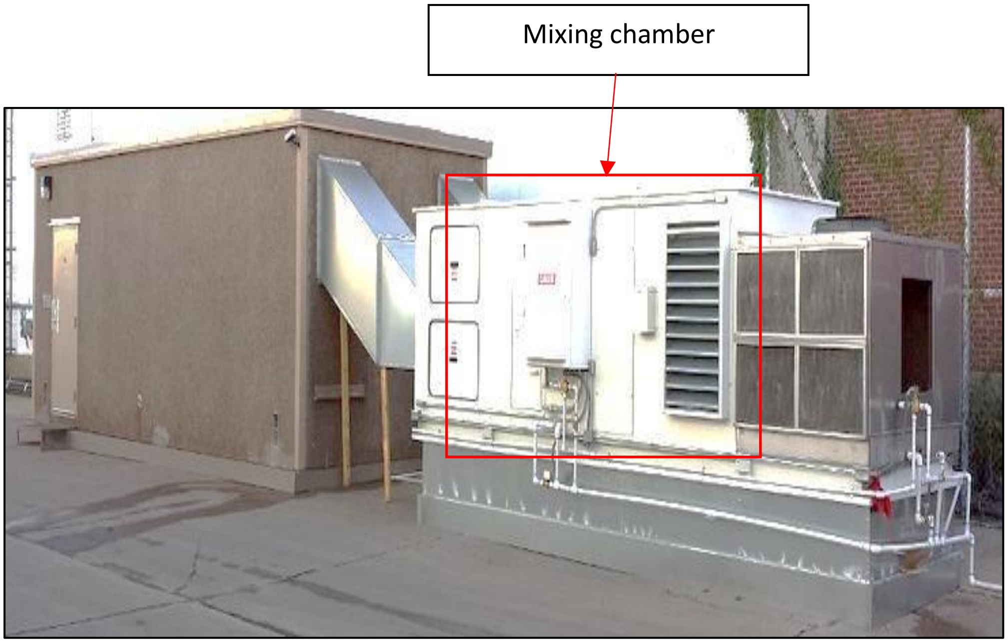


Figure11 Data center facility at Mestex

The above figure shows the actual modular data center facility at Mestex. It consists of the IT pod attached with cooling unit with the help of air handling units. The highlighted area in red shows the mixing chamber.

## 4.1 CFD modelling

An idealized mixing chamber configuration is modelled for computational fluid dynamics (CFD) analysis using 6SigmaRoom CFD tool by Future Facilities. The Aztec 15 model from Mestex is considered for the CFD modelling.

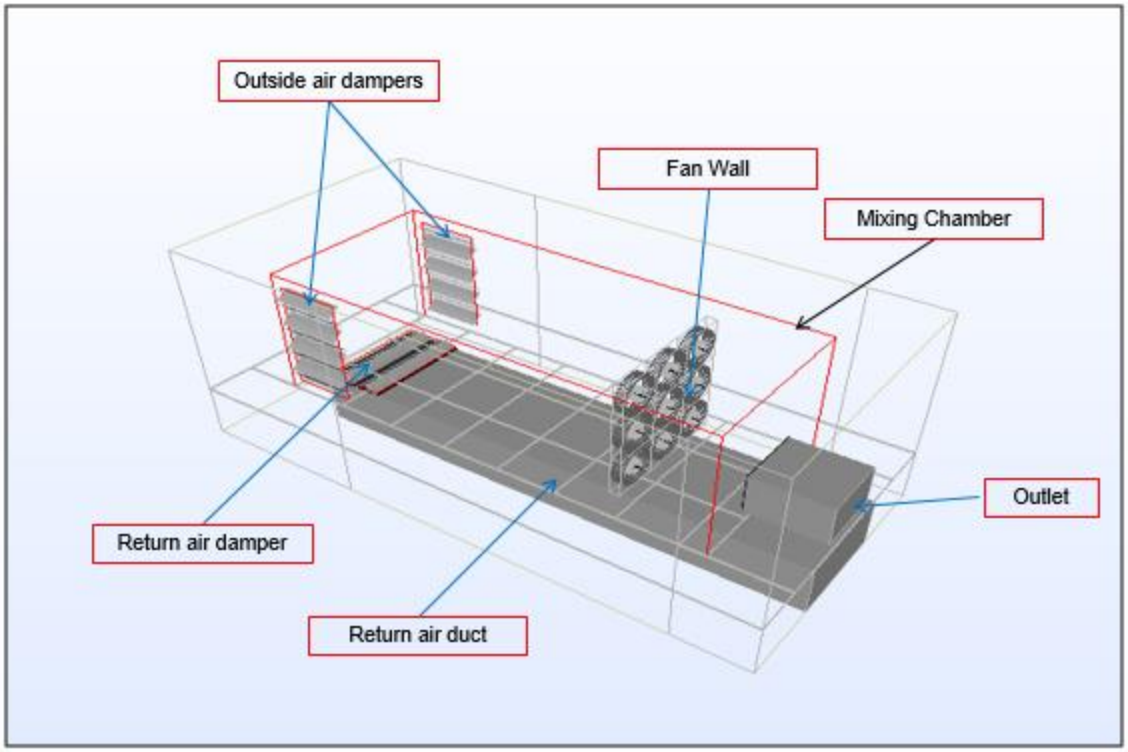


Figure12 CFD model for Mixing Chamber

## 4.2 MODEL SPECIFICATIONS

- MIXING CHAMBER
  - Chamber size- 58.5*175*71 (inches)
  - Vent- 24*48 (inches)
  - Supply vent - 27*18.3 (inches)
  - Bade- 6*0.5*44 (inches)

- FAN SPECIFICATIONS:
    - Diameter- 16 inches
    - Flow rate- 694 CFM
    - No. of fans- 9
- MODEL SPECIFICATIONS:
    - Model- Standard k Epsilon is suggested by Future Facilities for data center applications.
    - Number of cells- 2 million

Note: Mixing chamber dimensions are replicated from Aztec 15 unit

## 4.3 GRID INDEPENDENCE

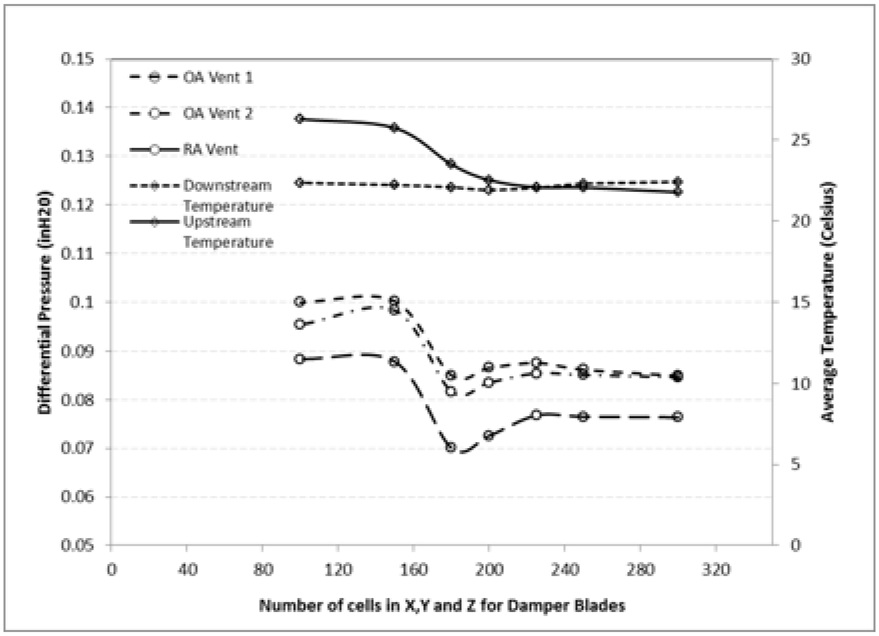


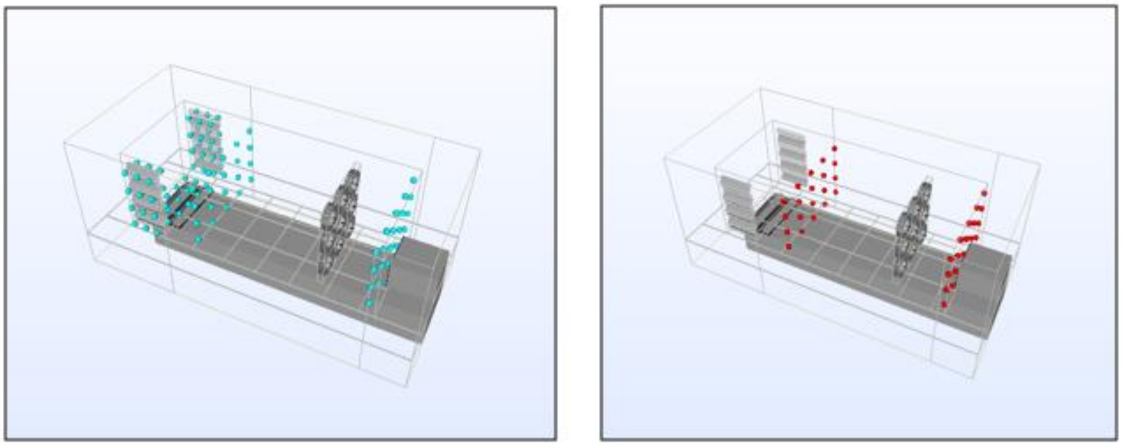
Figure 13 Grid Independence

- As most of the geometry happens to be open and plain, grid sensitivity is done on dampers and space between the dampers to capture air flow.
- Grid Independence is achieved at 180 cells for the blades.
- Overall cell count is 2 million but varies as angle of damper changes due unstructured grid

## 4.4 BOUNDARY CONDITIONS

- Outside Air Temperature:68ºF
- Return Air Temperature:113ºF
- Maximum Design Flow rate – 6250 CFM
- Fixed Flow rate for a fan is 694 CFM
- Number of fans -9

## 4.4 PRESSURE AND TEMPERATURE SENSORS.



Pressure Sensors

Temperature Sensors

Figure14 Sensor placement in CFD model for Mixing Chamber

PRESSURE SENSORS:

There are 24 sensors in together across each damper & 50 sensor across the downstream of mixing chamber to calculate the overall pressure difference across the mixing chamber.

TEMPERATURE SENSORS:

25 sensors at upstream and 25 sensors at downstream to measure the mixing of air streams.

## 4.5 MIXING EFFECTIVENESS

$$\mathbf{Mixing\ Effectiveness} = \left(\mathbf{1} - \frac{\mathbf{T_{Max} - T_{Min}}}{\mathbf{|\ T_{RA} - T_{OA}\ |}}\right) * 100\%$$

Where,

$T_{max}$&$T_{min}$ – Maximum and minimum Temperature of Mixed Flow.

$T_{ra}$ – Return air temperature.

$T_{oa}$- Outside air temperature

## CHAPTER 5

## CFD SIMULATIONS & RESULTS

In an attempt for good mixing one of the important factor to consider is the damper angles. For dampers 0° is completely closed while 90° is completely open. As it is clearly visible there will be large number of damper angles which can be used with various combinations to check the mixing. Ideally when outside air conditions are suitable outside air dampers are opened at higher angles and when outside air conditions are too cold that time return air damper angle is kept at higher number.

Using the logic mentioned above certain angle combination have been picked for simulation to check mixing for parallel blade and opposed blade and comparing the results.

### 5.1 CFD Simulations

Following Simulations are performed to compare the parallel and opposed dampers.

- Outside Air Damper- 30º: Return Air Damper (10º to 90º)
- Outside Air Damper- 50º: Return Air Damper (10º to 90º)
- Outside Air Damper- 80º: Return Air Damper (10º to 90º)

The extreme angles for Outside air damper have not been selected because usually there won't be a case where 100% outside air or 100% return air will be used. Hence 80° provides maximum outside air while 30° provides less amount of outside air.

## 5.2 RESULTS

### 5.2.1 Outside Air Damper- 30º: Return Air Damper (10º to 90º)

#### TEMPERATURE

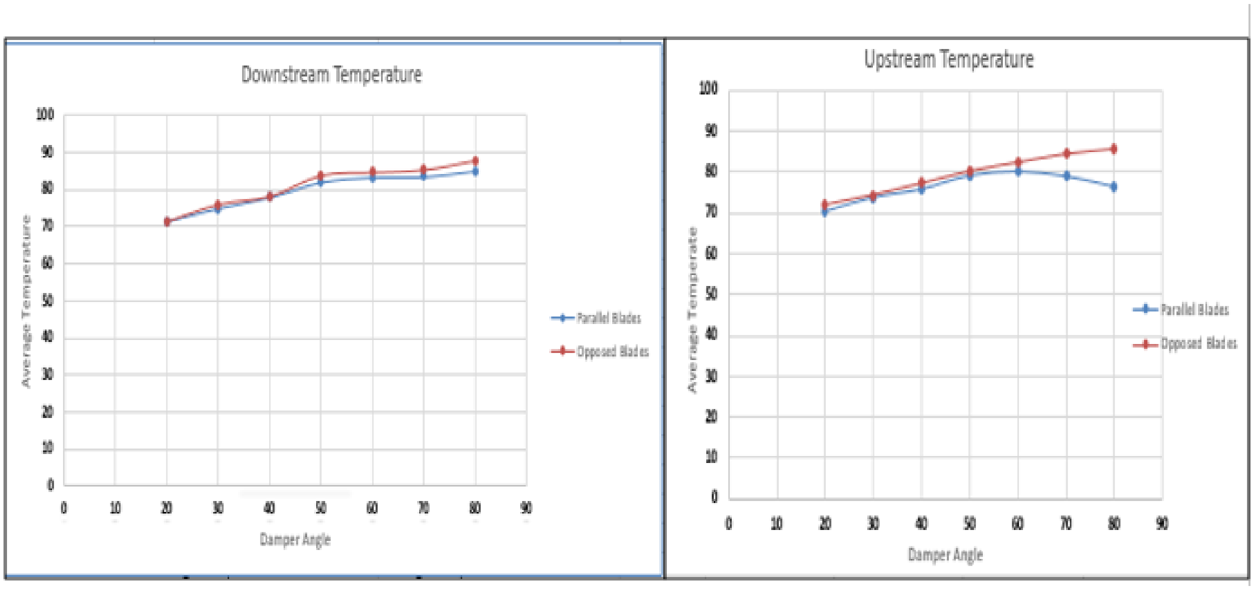


Figure 15 Upstream and Downstream temperature plot

In the above plot, X axis gives damper angle while Y axis give the temperature. Red line represents opposed blade while blue represents parallel blade.

For both upstream and downstream temperature, its clearly visible as the angle increase opposed blade will give more average temperature in other words opposed blade dampers give good mixing.

# FLOWRATES

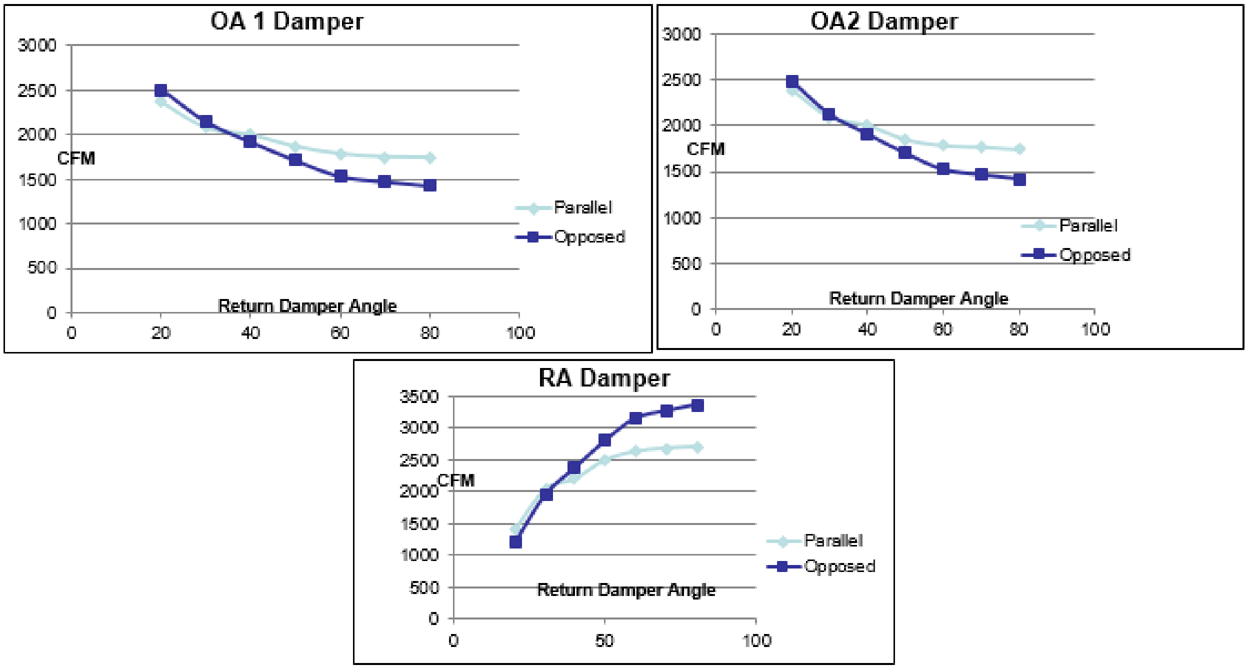


Figure 16 Flowrate plot for all vents

- In the above shown graph X axis gives return damper angles while Y axis gives CFM. Blue represents Opposed blade while cyan represents parallel blade.
- For outside air dampers as the angle increases flow rate for opposed blade decreases while compared to parallel blade dampers.
- In case of return air dampers as the angle increases opposed blade will give more flowrate comparing to parallel blade.

PRESSURE DROP

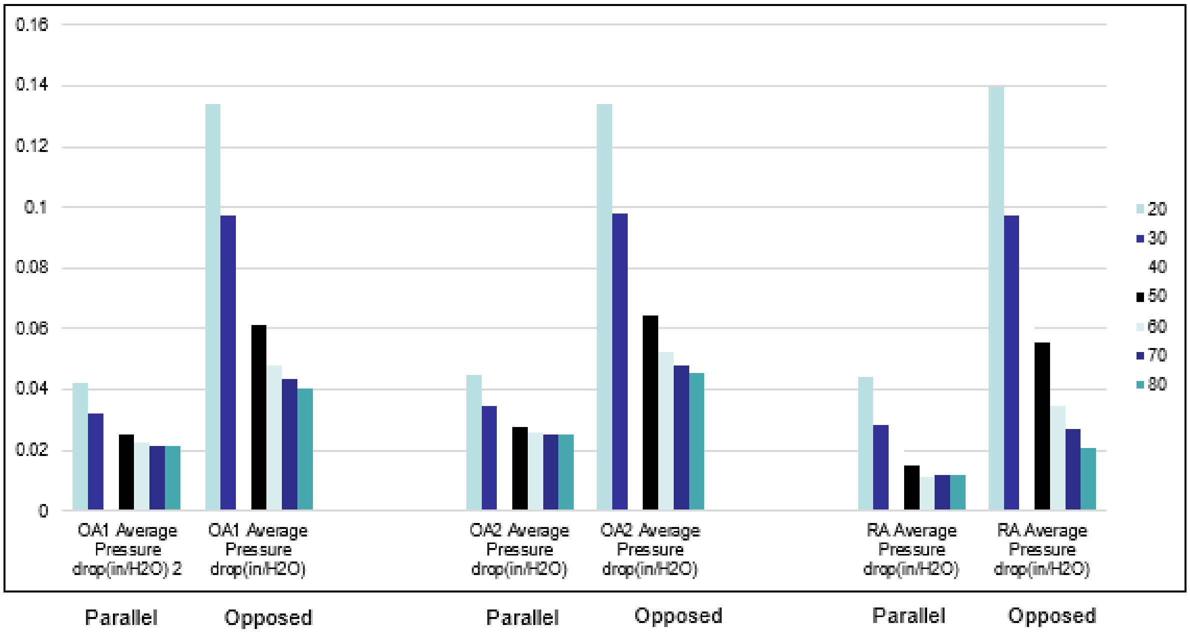


Figure 17 Pressure drop plot

When you compare two identical color bars of adjacent (parallel, opposed) graphs it is clearly visible that pressure drop across opposed blade is more as compared to parallel blade. The reason for this is, as opposed blade dampers rotate towards each other they offer more resistance to the flow hence the pressure is more across the dampers.

## TEMPERATURE CONTOUR & MIXING EFFECTIVENESS

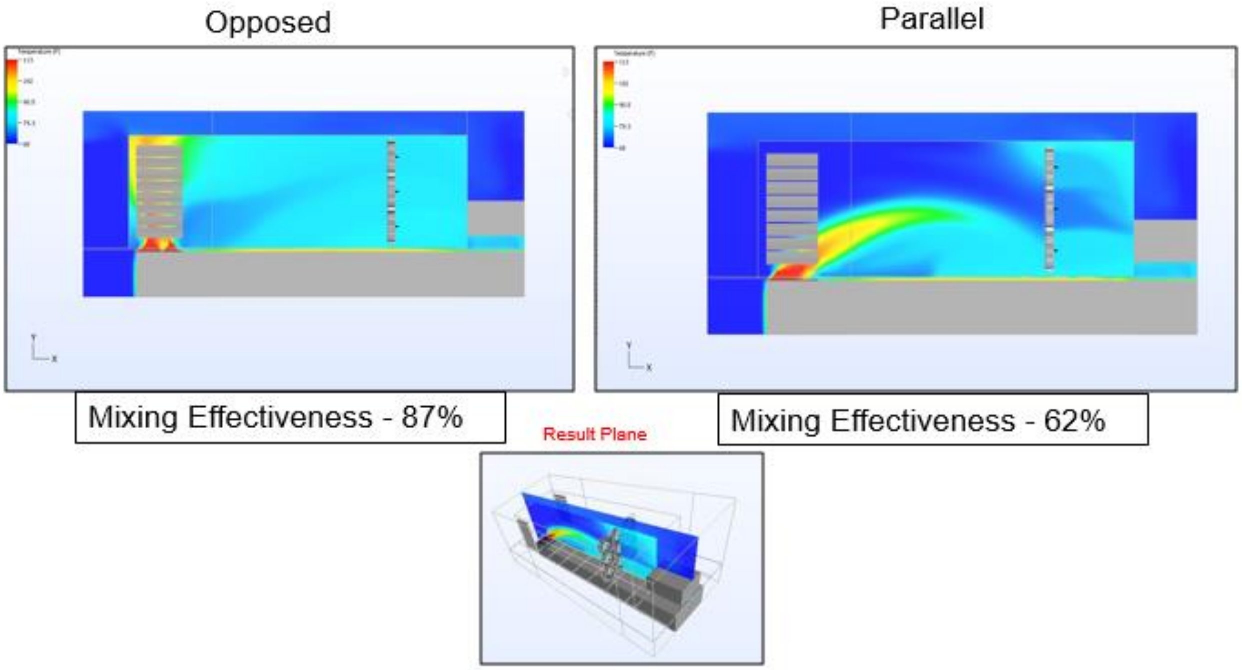


Figure 18 Temperature contour

From the contour (exactly at centre of mixing chamber along the length) and the percentage of mixing effectiveness it’s clear that opposed blade provides good mixing as compared to parallel. The uniformity through the chamber is seen when opposed blades are used while thermal layers are present for parallel which is usually not recommended.

## 5.2.2 OUTSIDE AIR DAMPER- 50º: RETURN AIR DAMPER (10º TO 90º)

### TEMPERATURE

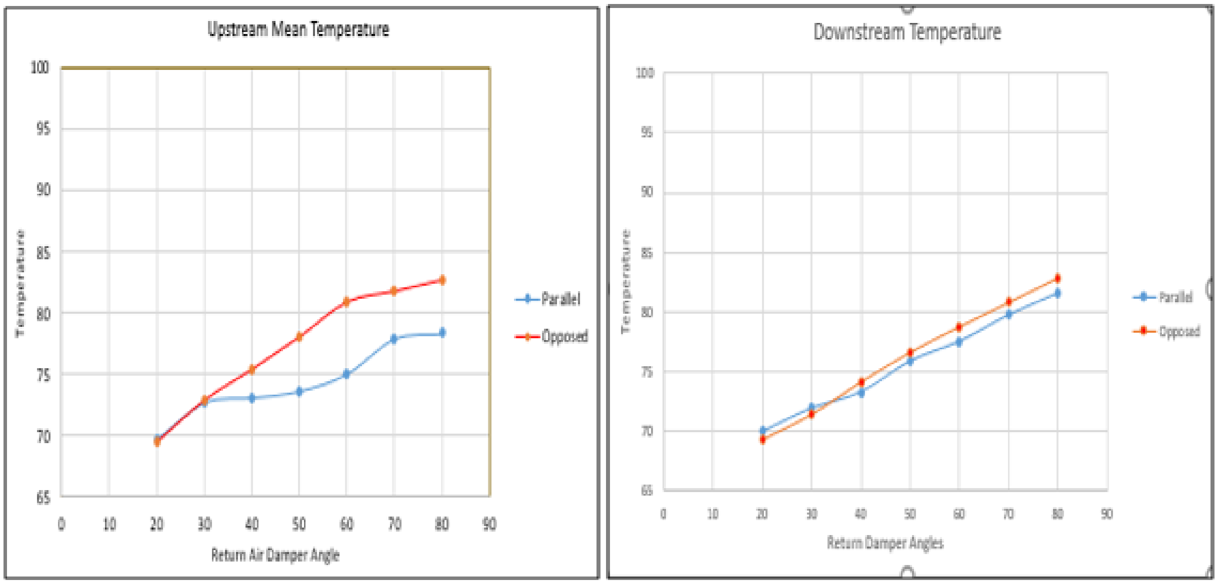


Figure 19 Upstream and Downstream temperature plot

- In the above plot, X axis gives damper angle while Y axis give the temperature. Red line represents opposed blade while blue represents parallel blade.
- For both upstream and downstream temperature, its clearly visible as the angle increase opposed blade will give more average temperature in other words opposed blade dampers give good mixing.

# FLOWRATES

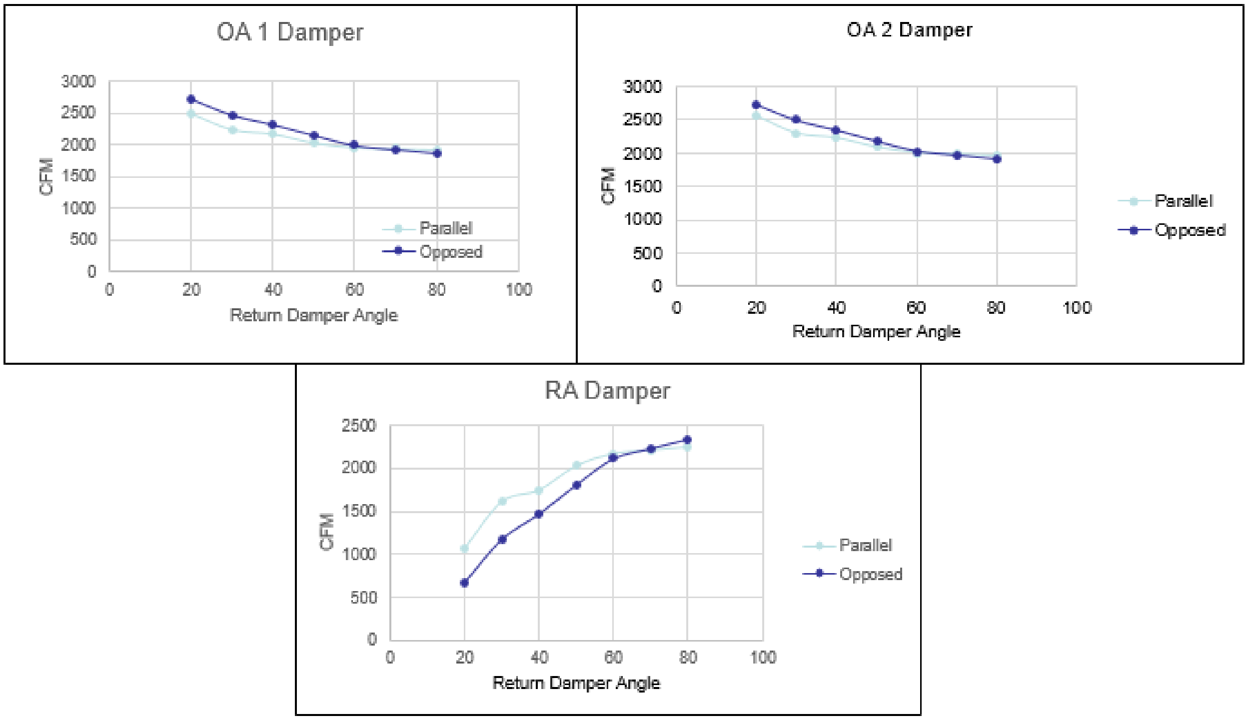


Figure 20 Flowrate plot for all vents

- In the above shown graph X axis gives return damper angles while Y axis gives CFM. Blue represents Opposed blade while cyan represents parallel blade.
- For outside air dampers as the angle increases flow rate for opposed blade decreases while compared to parallel blade dampers.
- In case of return air dampers as the angle increases opposed blade will give more flowrate comparing to parallel blade

## PRESSURE DROP

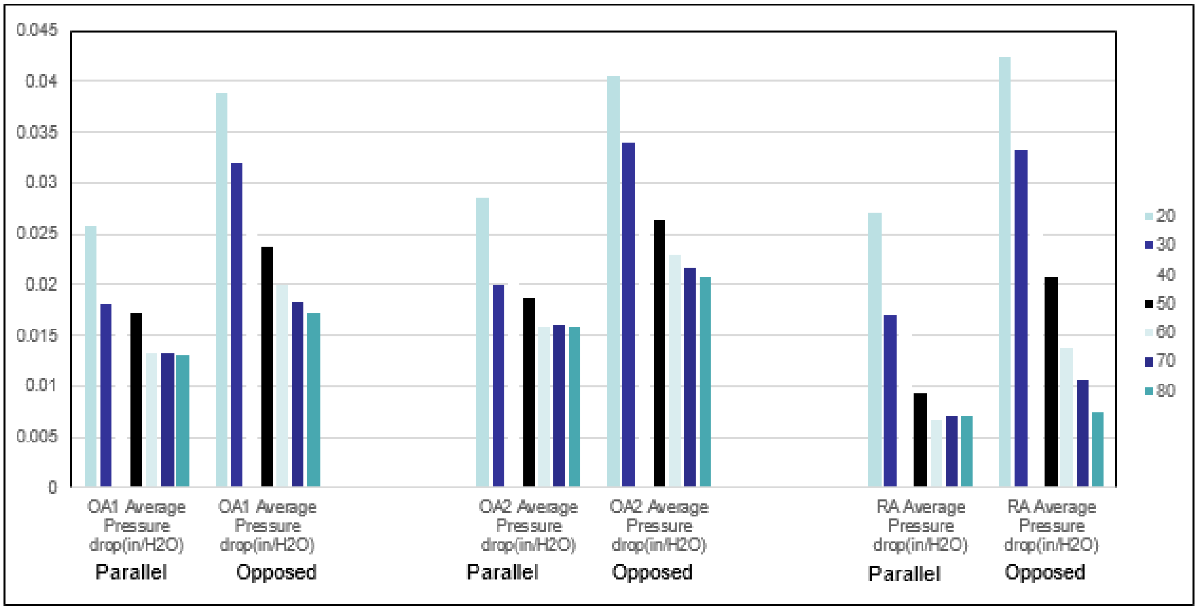


Figure 21 Pressure drop plot

When you compare two identical color bars of adjacent (parallel, opposed) graphs it is clearly visible that pressure drop across opposed blade is more as compared to parallel blade. The reason for this is, as opposed blade dampers rotate towards each other they offer more resistance to the flow hence the pressure is more across the dampers.

## TEMPERATURE CONTOUR AND MIXING EFFECTIVENESS

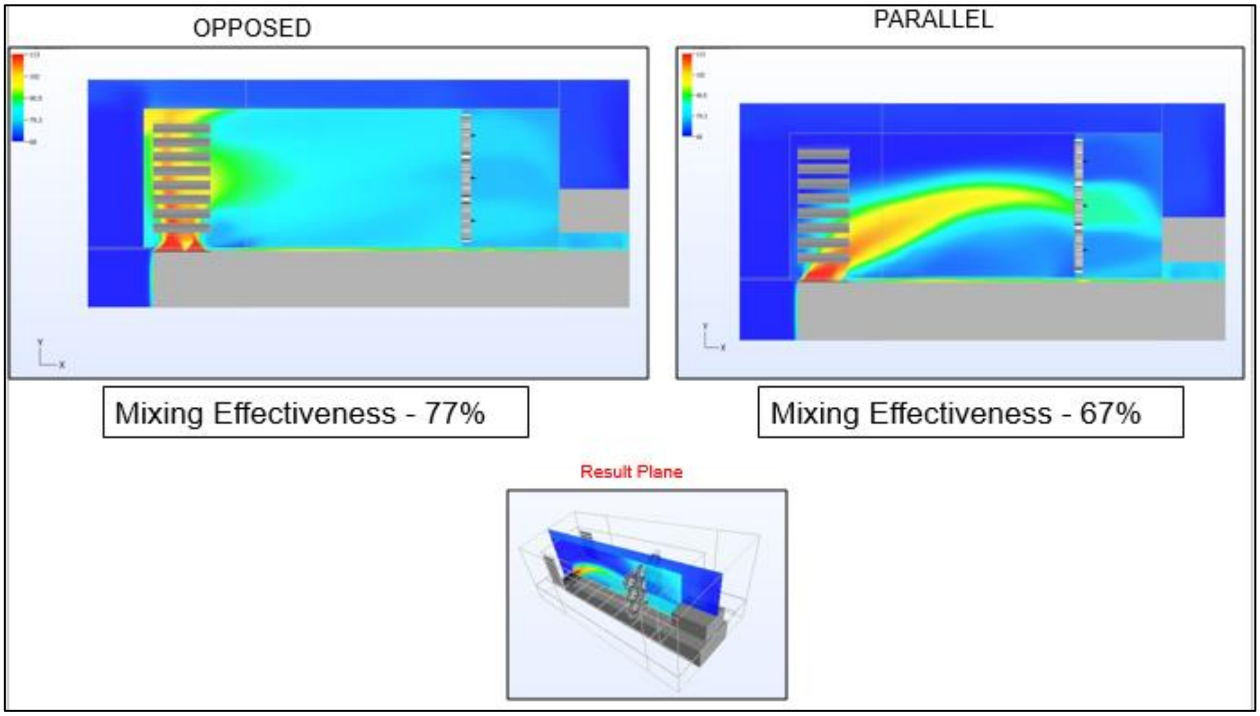


Figure 22 Temperature contour

From the contour (exactly at centre of mixing chamber along the length) and the percentage of mixing effectiveness it’s clear that opposed blade provides good mixing as compared to parallel. The uniformity through the chamber is seen when opposed blades are used while thermal layers are present for parallel which is usually not recommended.

### 5.2.3 OUTSIDE AIR DAMPER- 80º: RETURN AIR DAMPER (10º TO 90º)

#### TEMPERATURE

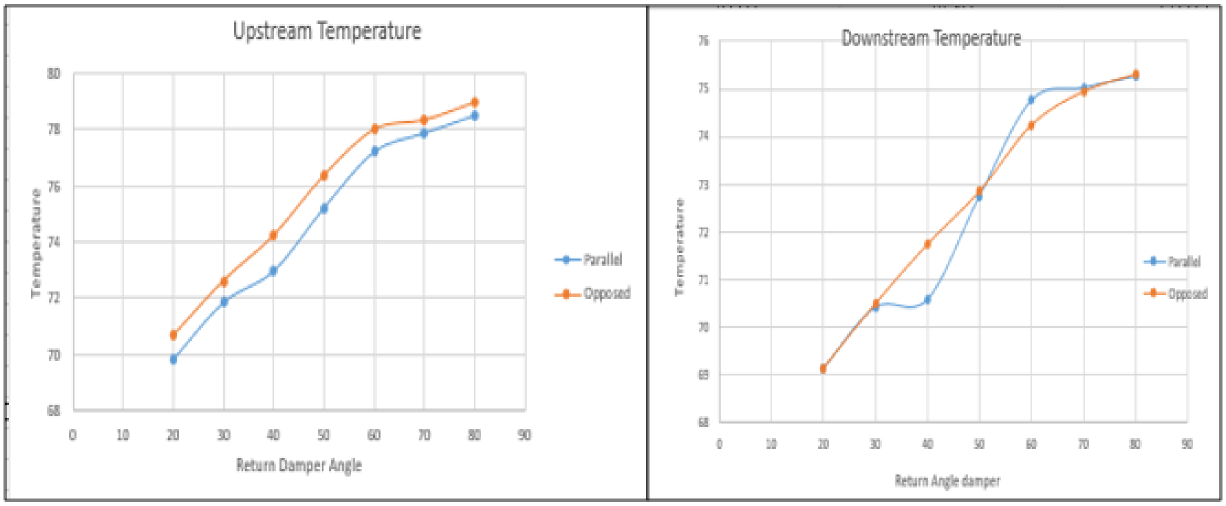


Figure 23 Upstream and Downstream temperature plot

For 80° outside air damper angle it is clearly noticeable that both dampers show equally same average temperature and amount of mixing. The reason for this when dampers are opened at 80° percentage opening for both dampers is same. Hence for higher angles both the dampers give similar results.

# FLOWRATES

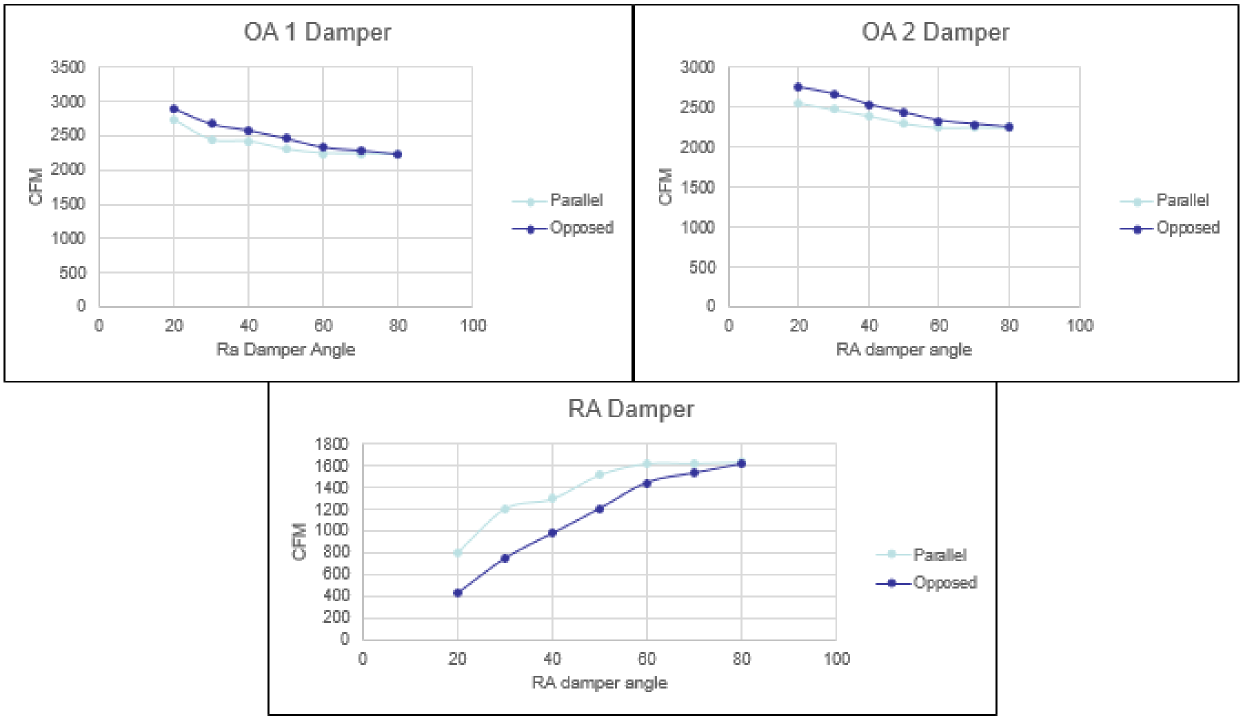


Figure 24 Flowrate plot for all vents

In case of flowrates the pattern remains the same. Parallel blade and opposed blade tend to move along almost among the same path. As mentioned earlier the reason is same as the angle is higher the percentage opening is almost same hence the amount of air taken in the mixing chamber is almost same.

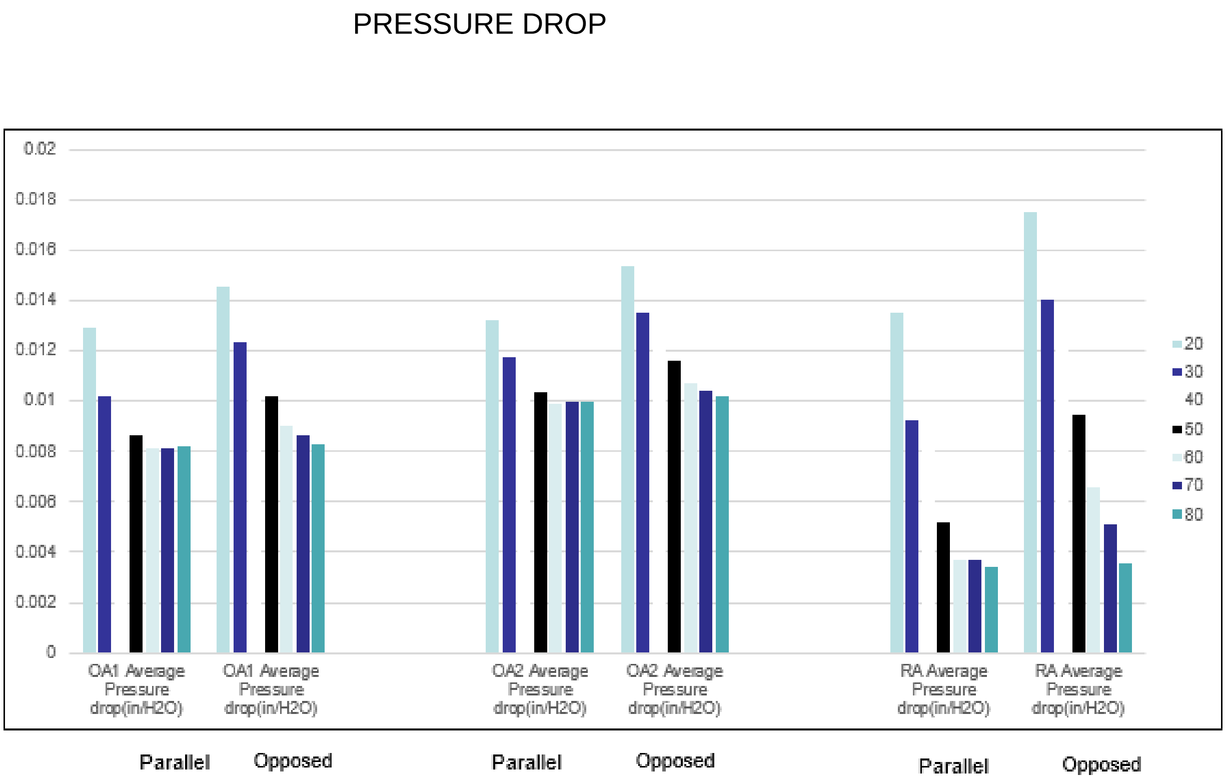


Figure 25 Pressure drop plot

As the percentage opening is almost same pressure across the damper remains almost same. When compared from the above graphs it shows pressure is more for opposed but as compared to lower angle this difference is certainly a lot less, hence we can conclude for higher angle temperature, flowrate, pressure drop doesn’t change much be it parallel or opposed bade damper.

## TEMPERATURE CONTOUR AND MIXING EFFECTIVENESS

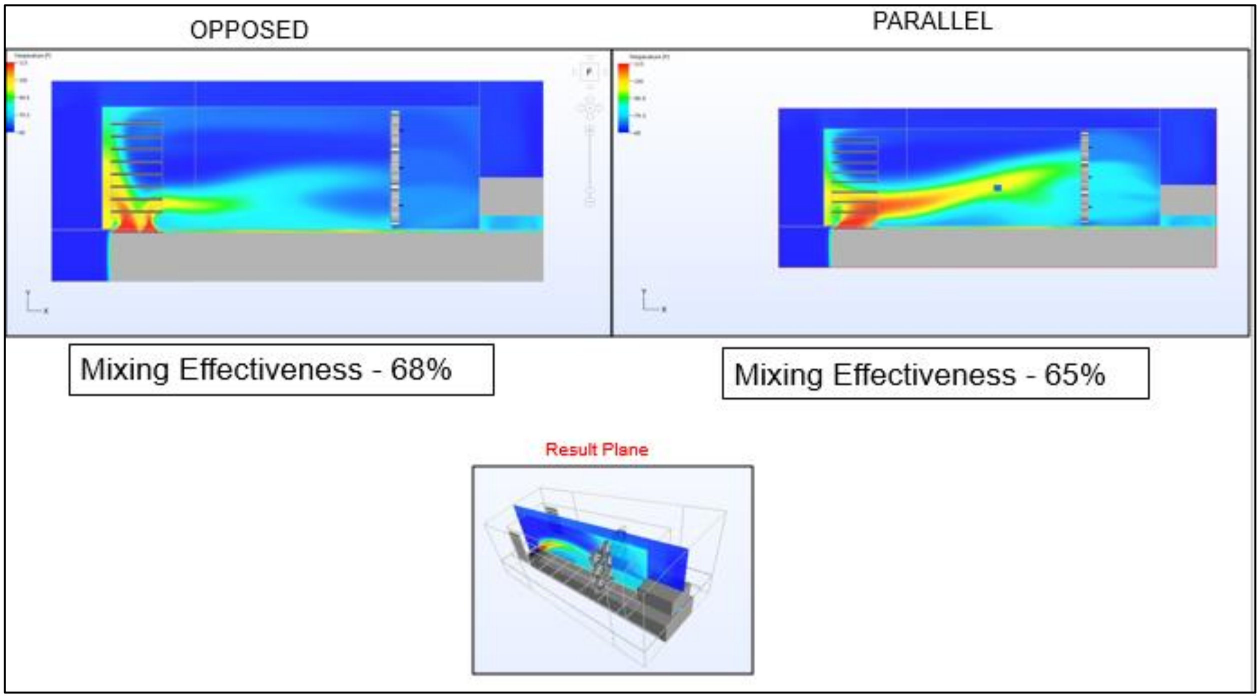
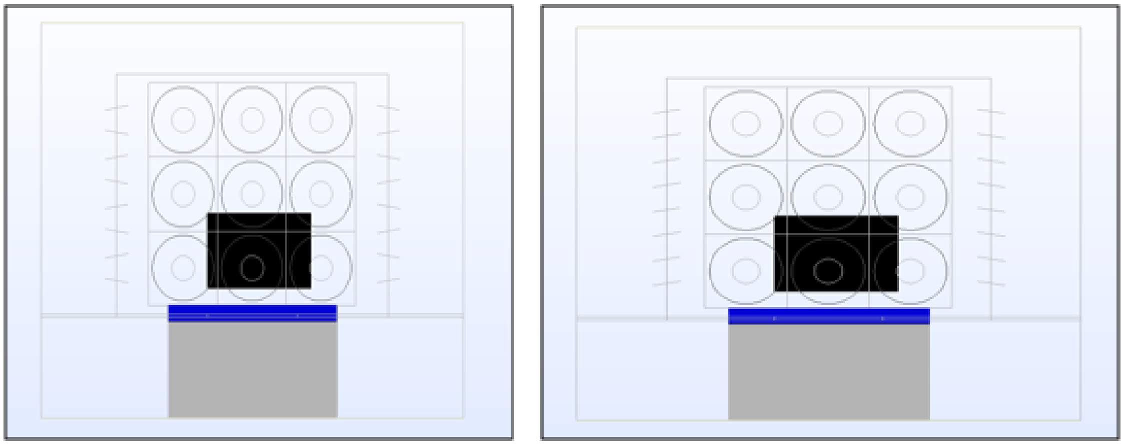


Figure 26 Temperature contour

As mentioned during the earlier results above contour and mixing effectiveness value shows that there not much of a difference. Also, the pattern in mixing chamber show somewhat of similarities if not completely.

## 5.3 DAMPER PROFILE

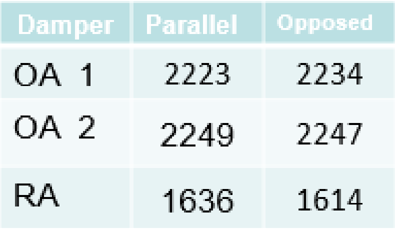
Dampers with 80° outside air damper.



Opposed Dampers

Parallel Dampers

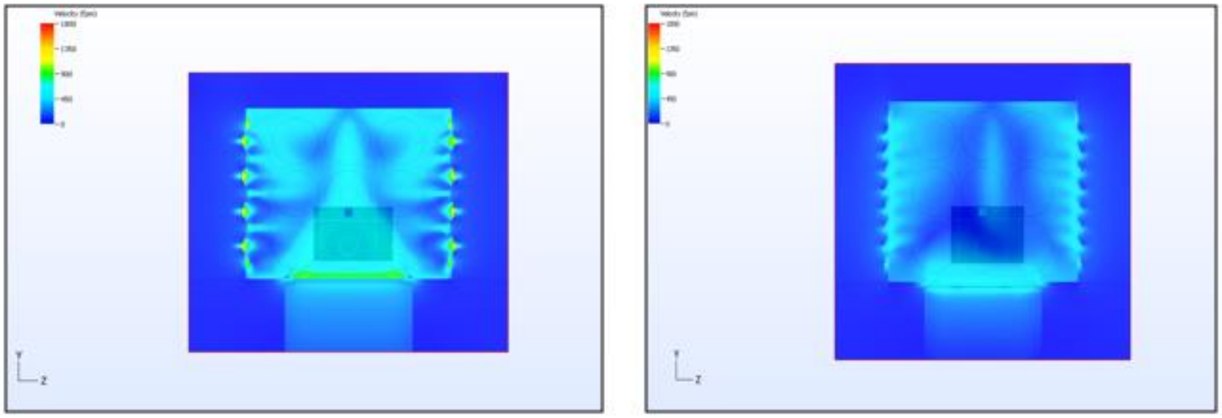
Flowrate



| Damper | Parallel | Opposed |
|---|---|---|
| OA 1 | 2223 | 2234 |
| OA 2 | 2249 | 2247 |
| RA | 1636 | 1614 |

Like mentioned earlier you can see the opening schematic for both dampers. It is visible that the opening percentage is almost similar and hence the above shown results do not show much noteworthy change.

## FLOW THROUGH DAMPERS



Opposed

Min Velocity- 3.247fpm
Max Velocity- 1423 fpm

Parallel

Min Velocity- 1.017fpm
Max Velocity- 865 fpm

Above image shows velocity profile for both the blades. It is visible that the velocity is more for opposed blade damper. As the opposed blade rotate opposite to each other area available to the flow is small as compared to parallel hence the velocity is more for opposed blade damper which is one the reason for better mixing.

## 5.4 DESIRED MIXED AIR TEMPERATURE

### 6 Straight Line Law for Psychometric Chart

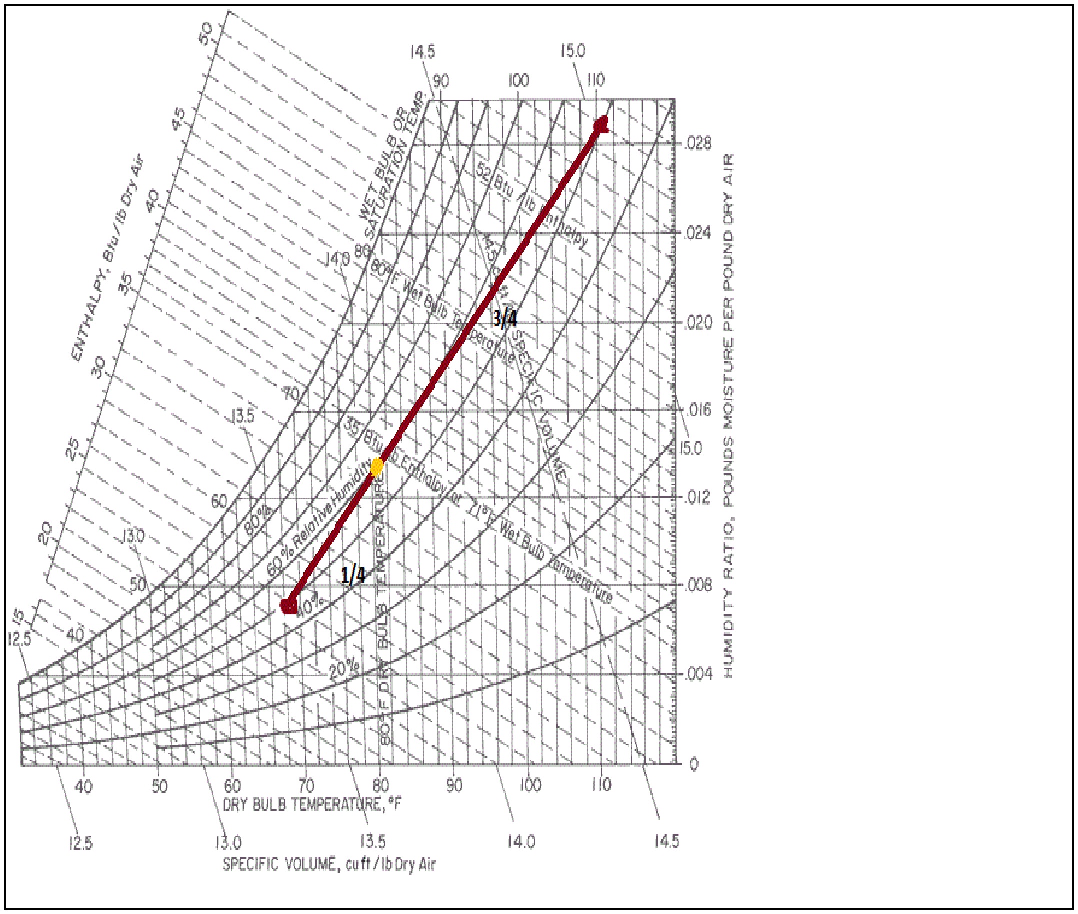
$$\left.\begin{aligned} m_{a1}h_1+m_{a2}h_2 &= (m_{a1}+m_{a2})h_3 \\ m_{a1}w_1+m_{a2}w_2 &= (m_{a1}+m_{a2})w_3 \end{aligned}\right\}$$

Energy and mass conservation

Rearraigning,

$$\frac{h2-h3}{h3-h1}=\frac{w2-w3}{w3-w1}=\frac{Ma1}{Ma2}$$

## 5.4.1 ANGLE NARROWING AT 68°F

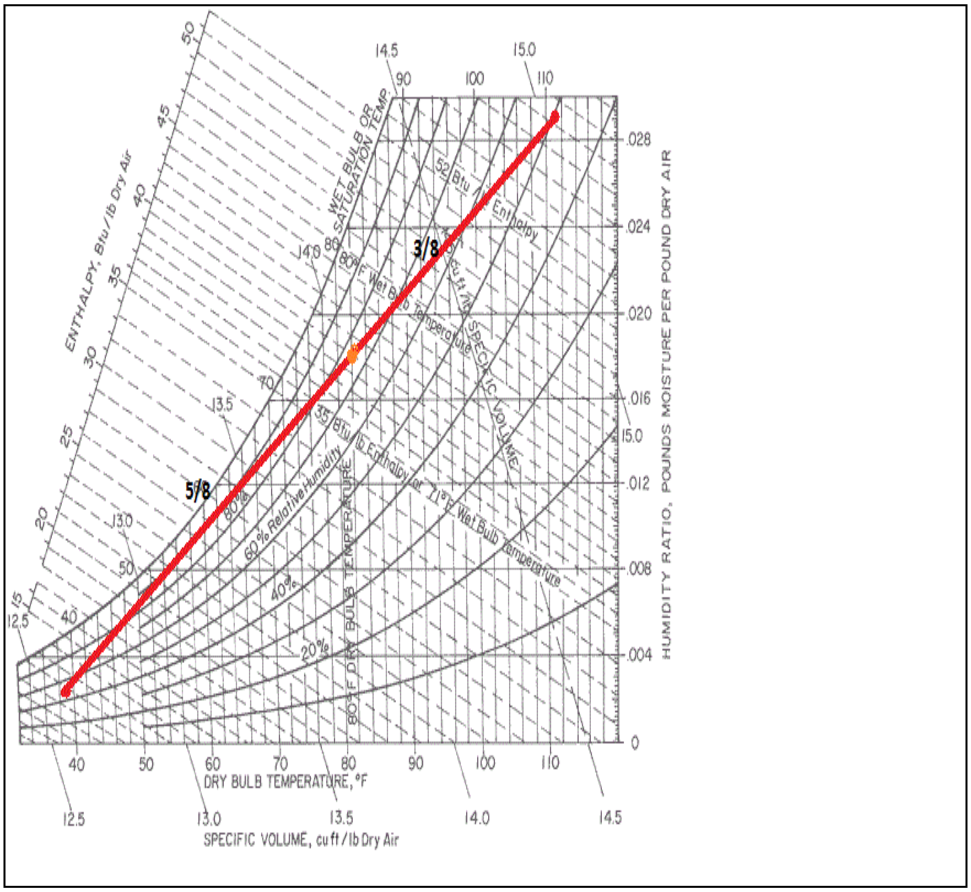


- For a target, mixed air temperature of 80ºF, given outside air is 68 and return air is 113ºF, the return air needs to be ¼ of the total volume (using straight line law) discharge flow rate of 6250 cfm.

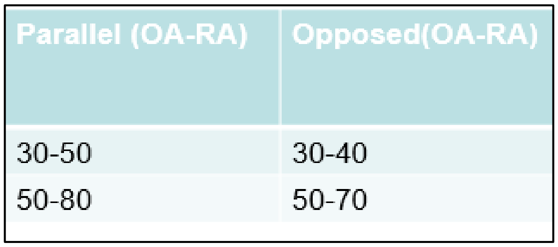
- Possible Damper Angles for mixed air of 68ºF

| Parallel (OA-RA) | Opposed(OA-RA) |
|---|---|
| 30-20 | 30-30 |
| 50-30 | 50-40 |
| 80-60 | 80-80 |

## 5.4.2 ANGLE NARROWING AT 37°F

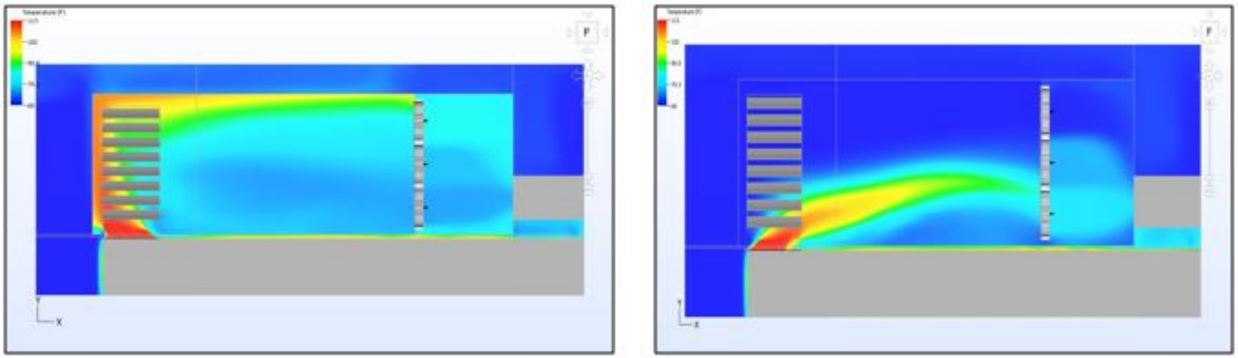


- For a target, mixed air temperature of 80ºF, given outside air is 37ºF and return air is 113ºF, the return air needs to be 5/8 of the total volume discharge flow rate of 6250 cfm
- Possible Damper Angles for mixed air of 68ºF.



| Parallel (OA-RA) | Opposed(OA-RA) |
|---|---|
| 30-50 | 30-40 |
| 50-80 | 50-70 |

## 5.5 RETURN AIR VENT FACING WALL Vs RETURN AIR VENT FACING FANS



Mixing Effectiveness - 74%

Mixing Effectiveness - 69%

Return Air Vent facing wall

Return air Vent facing Fans

Figure 27 Temperature contour for parallel blades with different orientation

In the Aztec 15 model of Mestex the return air damper open towards the fan. So, in this thesis there is one additional simulation to check the results when return air dampers are rotated toward the wall and not fan.

When this reverse technique is used, there is good amount of mixing. One of important factor on improper mixing is less time for mixing. So, when orientation is reversed for parallel blade dampers present in the Aztec 15 unit there will good amount of mixing as compared to the current orientation.

# CHAPTER 6

# CONCLUSION AND FUTURE WORK

## 6.1 CONCLUSION:

- Opposed Blades provide good mixing as compared to parallel blades.
- In Aztec 15 model present at Mestex, if RA damper blades are open towards wall and not fan, then the present unit can provide better mixing.

## 6.2 FUTURE WORK:

- Add the shape detail to the opposed blade because one can imagine that the shape of the blades will add turbulence and consequently increase mixing
- Various other vent positions can be taken into consideration.
- Vertical Dampers may be compared with the horizontal one
- A combination of parallel and opposed may also be considered.
- Experimental Work to compare with the CFD data.

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# Biographical Information

Pavan Vijaykumar Kaulgud (Oct 1st, 1989) is from Sangli, India. He completed his Bachelors in Mechanical Engineering from Shivaji university in June 2012. Pavan has worked as a CAE Analyst at Finite 4 Technologies from March 2013 to May 2014 He joined The University of Texas at Arlington in Fall 2015 for Master of Science program in Mechanical Engineering. He joined EMNSPC team in Fall 2015 and started working on various projects.

His primary research includes Mixing of air streams for data center cooling where he has worked on steady state analysis. Pavan has been involved a number of projects in UTA with the industry especially with Direct and Indirect Evaporative Cooling for IT Pod (Phase II).

Pavan graduated from The University of Texas at Arlington on May 16, 2017.