

Characterization of parallel and opposed control dampers to observe the effect on thermal mixing of air streams in an air-cooling unit

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Abstract

Cold Aisle in data centers have characteristic operating conditions as per ASHRAE standards. Temperature and humidity must be maintained within a specified range for normal operation. Air cooled data centers need several methods of cooling to condition the air before reaching the IT equipment. Direct evaporative cooling, as the name infers, the hot air comes in direct contact with the chilled water as a result the temperature drops and humidity increases. Similarly, Indirect Evaporative cooling involves reducing the dry bulb temperature of the hot air. Sometimes both the methods are used when the air is dry and hot. To improve the efficiency in cooling, Air-side Economization or free cooling is used in areas where the weather is cold. The outside air and the return air from the datacenter mixes in a dedicated space to achieve a target operating temperature & humidity and sent to the cold aisle. This dedicated space is known as mixing chamber. The return air and the outside air is mixed in such a ratio using a set of dampers at the entrance of the mixing chamber. These dampers are of two types, parallel plate and opposed blade. These two types of dampers not only mix the air but also influences the mixing effectiveness of the air downstream. The objective of this paper is to study the various effects of thermal stratification, mixing effectiveness and pressure drop that occurs at the mixing chamber based on the two types of dampers at various positions/angles. Also, the underlying mechanics of mixing the air at different conditions is discussed. It is observed that opposed blade dampers are more effective in terms of mixing than parallel blade dampers based on the numerical study. Also, the mixing and thermal stratification is more effective when the dampers face the wall of the mixing chamber when they are operated.

Keywords

Air Side Economization, Control Dampers, Parallel damper, opposed damper, straight line law, mixing chamber, air handling unit, datacenter air cooling

Nomenclature

Air flowrate – CFM
Air Temperature – deg. C
Damper angle – deg.
Pressure – Pascal (Pa)

1. Introduction

Between 2010 and 2018, the amount of computing done in data centers more than quintupled, resulting in around 205 terawatt-hours of power consumed, or nearly 1% of all electricity consumed that year globally [1]. Therefore, energy

consumption is a major concern when operating a datacenter with air cooled systems. Air side economization is an arrangement of duct, damper and automatic control system which together allow introducing outside air to reduce the mechanical cooling during mild or cold weather thereby decreasing the energy consumption [2]. The American society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommended a few thermal guidelines for the safe operations of IT equipment in data centers. Prior to these guidelines, recommendations were provided by the IT manufacturer on the operation of their product in the data center environment, which were not accurate due to multiplicity of usage of equipment in a data center.

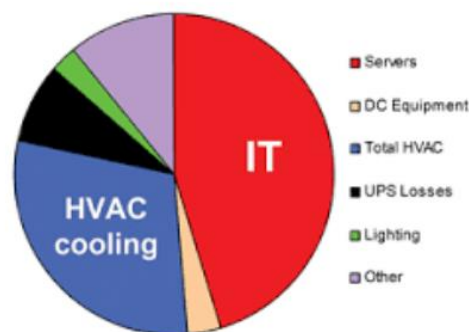


Figure 1 Energy consumption Breakdown in Datacenters [1]

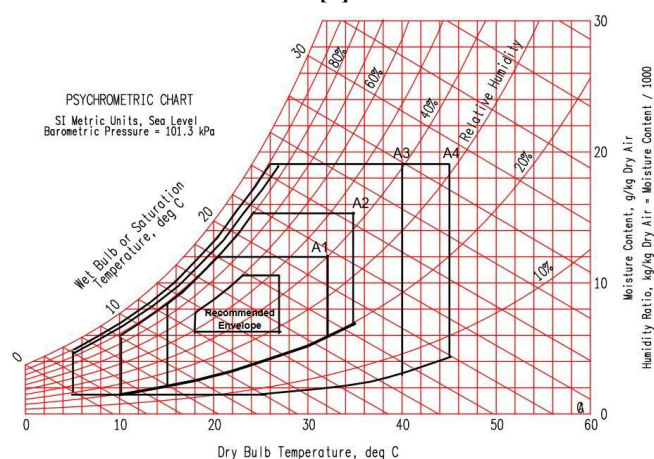


Figure 2 Psychrometric chart showing various ASHRAE Zones [3]

The outside ambient air and heated return air from the information technology (IT) pod is mixed inside a dedicated space to achieve a target cold aisle operating temperature and thereby increase economization. Major constrain faced by the

design engineers while designing the Mixing Chamber/Plenum is the stratification of air stream due to the Temperature gradient in the mixed air stream and this stratification can be attributed to the short span of time and space that is available for the air streams to interact with each other. Thermal stratification can lead to coil freeze-ups, nuisance freeze-stat trips, energy wastage due to sensing error and poor indoor air quality and increases the cooling power. So, objective was to understand the fundamental physical phenomenon which causes mixing of any two fluids and thereby apply the knowledge to our test scenario.

When external conditions are favorable for cooling, the economizer with the help of control system adjust the position of dampers which allows fresh air into facility as a primary source of cooling.

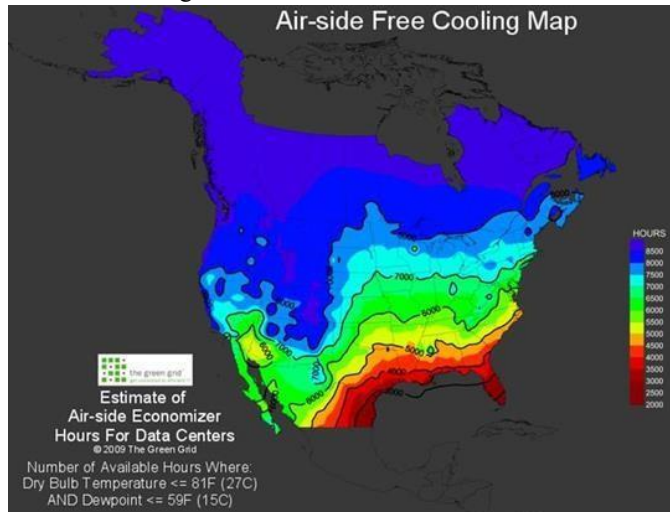


Figure 3 Hours with Ideal conditions for an air-side economizer operation [4]

Filters are used to get rid of dust and contaminants, this filtered air is then introduced into the cold aisle of the data center. Exhaust ventilation is provided to take out the exhaust air [5]. An exhaust air damper maintains pressure so that if an excess amount of air present in system, it 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 a return air damper a portion of return air is mixed, which results in a reduction of use of air conditioning units and chilled water systems. In our case AHU at Mestex Inc. was used for modeling. Computational Fluid Dynamic analysis is carried out to report the proof of concept and thereby report the changes in the effectiveness of the mixing process at upstream of heating coil and downstream of cooling pad.

2. Computational model

The AHU was modeled based on MESTEX Aztec ASC 30 unit. This unit has a total evaporative face area of 4320 in². The volumetric flow rate for this unit is 15000 CFM. This unit was chosen to provide cooling for the standalone IT pod that was designed after the standard models from the open compute project. This CFD model was created in software called 6SigmaRoom from Future Facilities.

Geometrical Specification

- AHU Chamber size – 72.5 * 92 * 204 inches

- Supply air vent Size – 70 * 20 inches
- Return air vent size – 53.5 * 32.5 inches
- Outdoor air vent size – 36.5 * 60 inches
- Damper size – 0.5 * 10 * 36.5 inches

Fan Specification

- Fan Diameter – 18.2 inches
- Fan Flow rate – 6250 CFM
- Number of Fans – 9

Air inlet conditions

- Outside air Temperature – 68° F
- Return air Temperature – 115° F

The flow rate through the cooling pad is 0.134 CFM of water at a temperature of 60F. In 6Sigma Room, the media pad object is modeled and simulated using Darcy equation which has two coefficients viscous and inertial resistance coefficient of the media pad. From previous studies a standard media pad has viscous resistance coefficient of 3 which is multiplied to the total flowrate and inertial resistance coefficient of 30 which is multiplied to the square of the total flowrate to obtain the overall resistance. The evaporative efficiency of the pad was set to 90%.

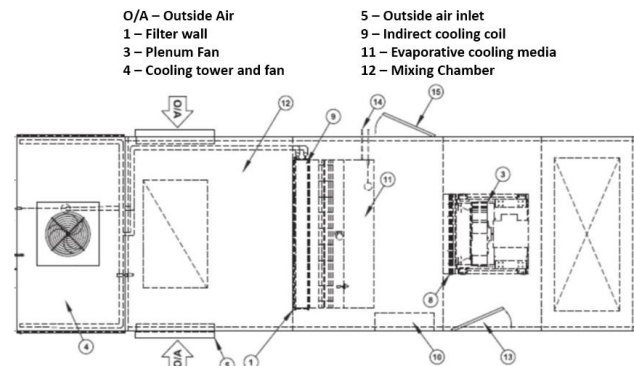


Figure 4 Air Handling Unit at Mestex Inc. [6]

A damper is a valve/flaps that regulates the flow of air through the inlet/outlet of the air handling unit. There are two types of dampers commercially available for regulating the air flow. This study includes parallel and opposed blade dampers.

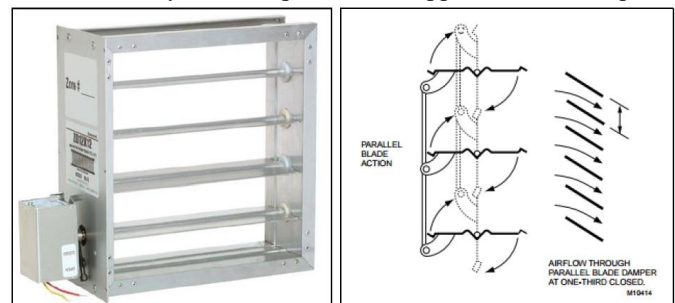


Figure 5 Parallel Blade Damper

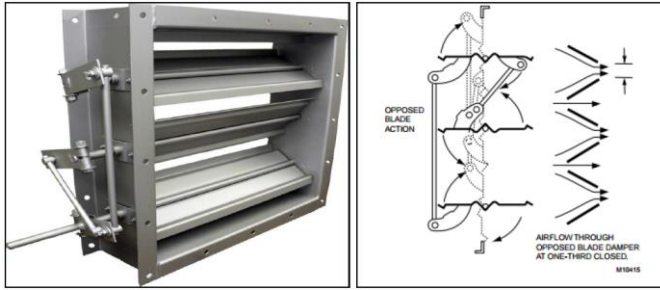


Figure 6 Opposed blade Damper

In an attempt for good mixing one of the important factors to consider is the damper angles. For dampers 0° is completely closed while 90° is completely open. When outside air conditions are favorable to the data center environment, OA dampers are opened at higher angles and when the outside air is too cold and humid, RA dampers are opened at higher angles to maintain the suitable data center conditions. RA dampers allow the return air from the data center (hot and dry) to mix with the outside air in the mixing chamber eliminating the need for heaters and dehumidifiers in the AHU. Following Simulations are performed to compare the parallel and opposed dampers.

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

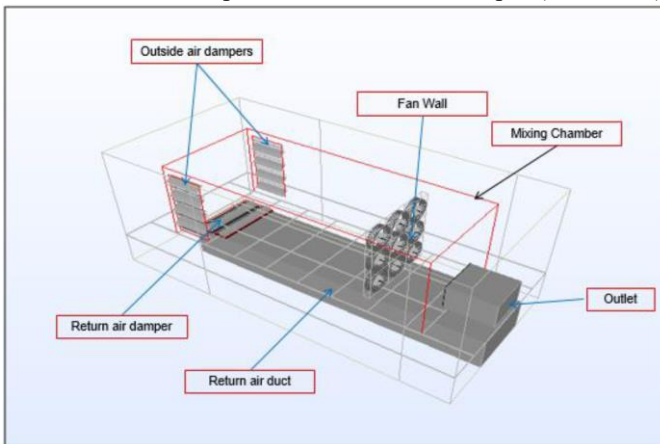


Figure 7 Computational model of the Aztec AHU unit with dampers at outside air inlet and return air inlet

The extreme angles for Outside air damper have not been selected because usually there will not 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.

3. Numerical/Computational study

3.1. OA Damper- 30° : RA Damper (10° to 90°)

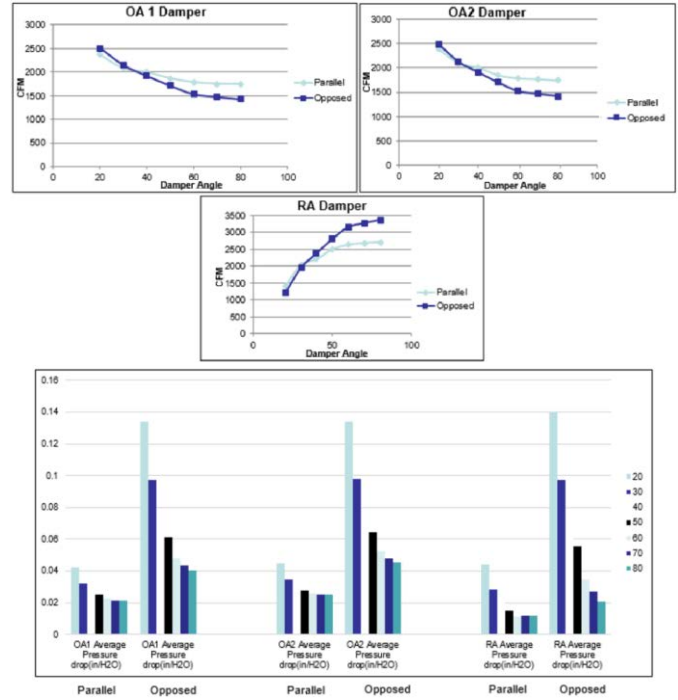


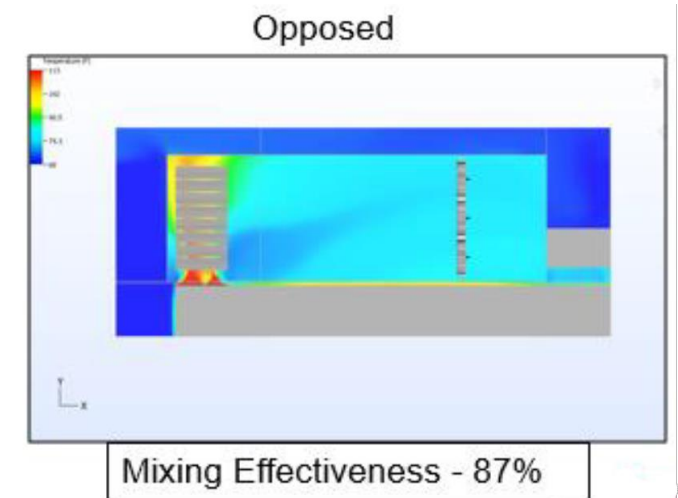
Figure 8 (a) Damper Angle vs Air flowrates (b) Damper Angle vs Pressure Drop

For outside air dampers flow rate for opposed blade decreases while compared to parallel blade dampers and in case of return air dampers, as the angle increases opposed blade will give more flowrate comparing to parallel blade as shown in Fig. 3 (a). 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. Opposed blade dampers rotate towards each other they offer more resistance to the flow hence the pressure is more across the opposed blade dampers.

Mixing effectiveness is calculated based on the following formula for all the cases studied

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

Where, T_{Max} and T_{Min} are maximum and minimum temperature of the mixed air stream respectively, T_{RA} and T_{OA} are the return and outside air temperatures respectively.



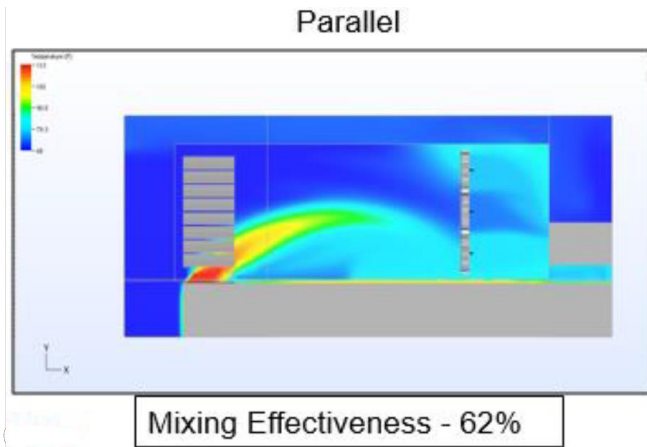


Figure 9 Temperature Contours for (a) opposed blade (b) parallel blade dampers

From the contour (exactly at center 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.

3.2. OA Damper- 50°: RA Damper (10° to 90°)

Similarly, for outside damper at 50° position, similar trends in the results are observed as shown in Fig. 5 (a) and Fig. 5 (b).

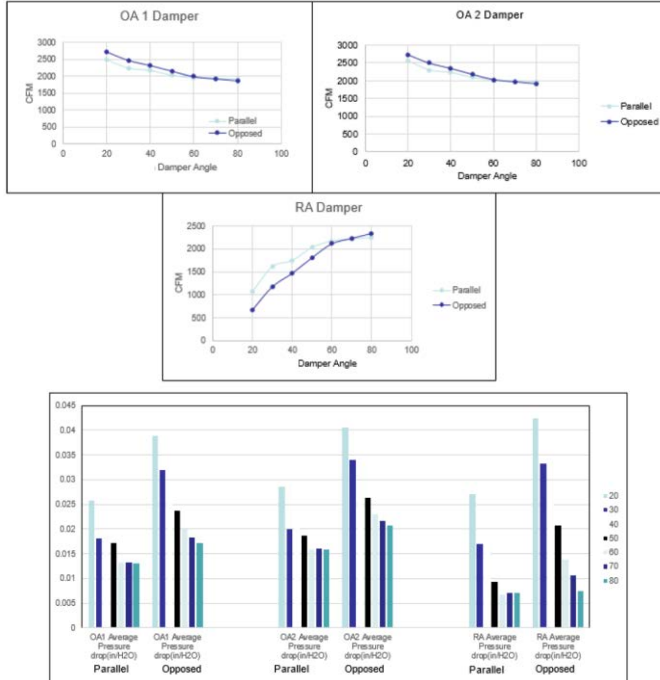


Figure 10 (a) Damper Angle vs Air flowrate (b) Damper angle vs Pressure Drop

Temperature contour and percentage of mixing effectiveness is calculated and shown in Fig. 11. It can be observed that when the outside dampers open, the mixing effectiveness reduces while using opposed blade dampers rather than parallel blade dampers.

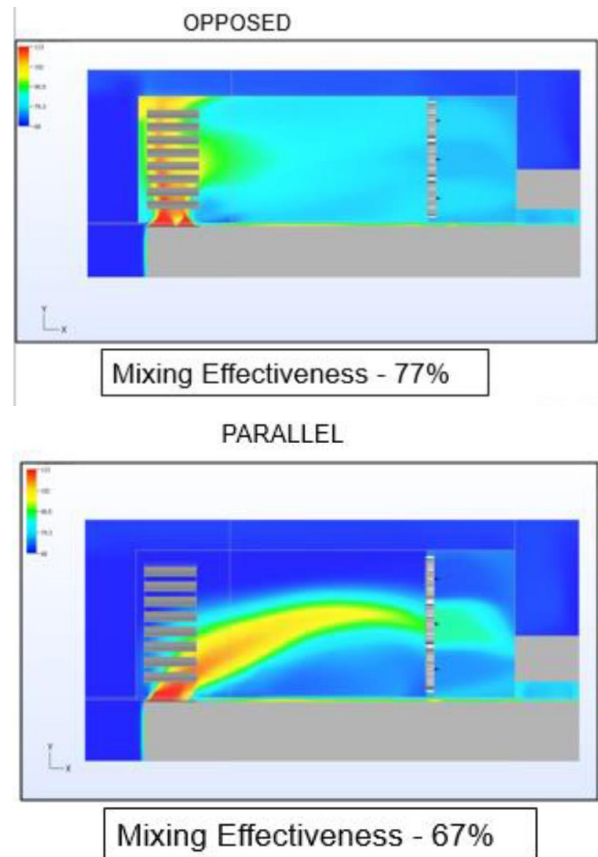


Figure 11 Temperature Contours for (a) opposed blade (b) parallel blade dampers

3.3. OA Damper- 80°: RA Damper (10° to 90°)

Similarly, for outside damper at 80° position, similar trends in the results are observed as shown in Fig. 12 (a).

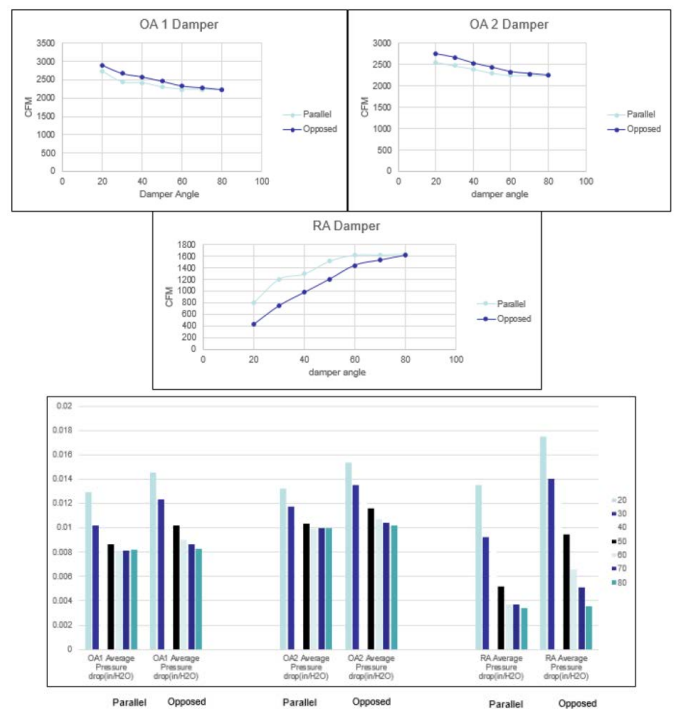


Figure 12 (a) Damper Angle vs Air flowrates (b) Damper Angle vs Pressure Drop

Temperature contour and percentage of mixing effectiveness is calculated and shown in Fig. 13. It can be observed that when the outside dampers open more, the mixing effectiveness while using opposed blade dampers is almost equal to parallel blade dampers. To achieve a desired final temperature of the air after mixing, the procedure should follow the straight-line law of the psychrometric chart.

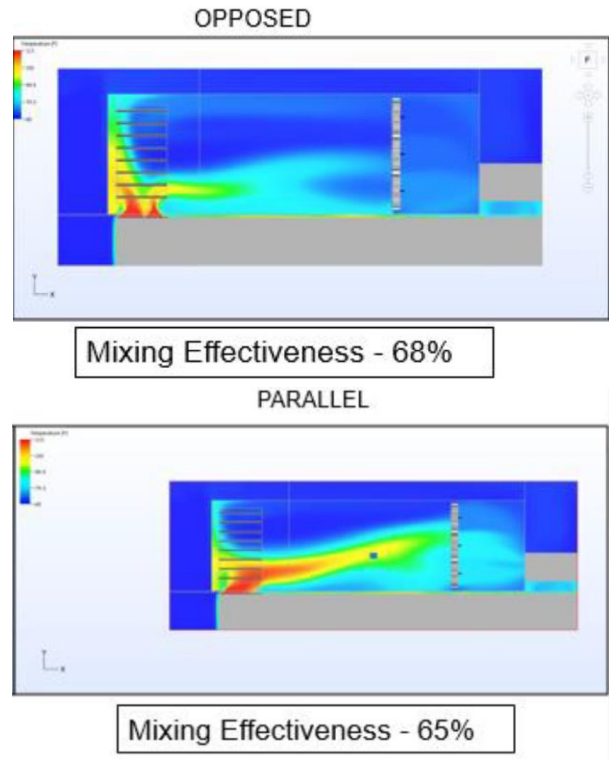
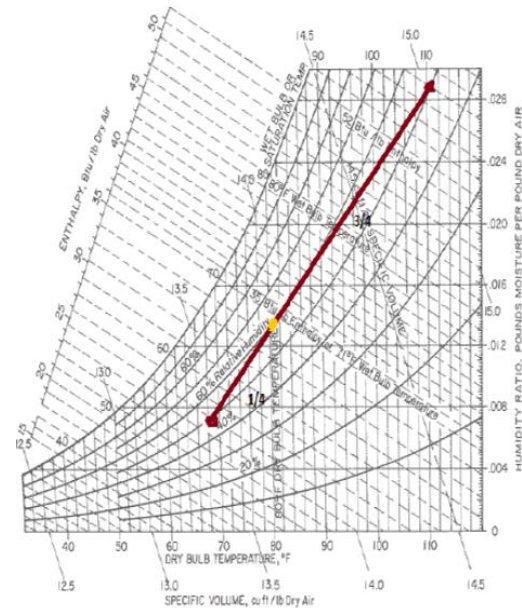


Figure 13 Temperature Contours for (a) opposed blade (b) parallel blade dampers

Calculating the volume of outside air to be mixed with return air

For a target, mixed air temperature of 80°F, given outside air is 68°F and return air is 113°F, the return air needs to be ¼ of the total volume (using straight line law) discharge flow rate of 6250 cfm. Based on the study we could see that certain number of configurations (Fig. 15) for parallel and opposed blade dampers would be helpful in achieving the mixing efficiency. Controlling the dampers based on the correlation depends on where the dampers were positioned initially.



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

Figure 15 Possible damper combination positions

4. CONCLUSION

The purpose of this study is to quantify and observe the characteristics of opposed blade and parallel blade dampers under various operating angles for a constant air flowrate and temperature. It was found that opposed Blades provide better mixing as compared to parallel blades in most cases where the dampers are not completely opened.

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