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Improve Mixing of Stratified Airflows

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ABSTRACT

In this paper, baffles were used as a solution to the stratification problem. Computational fluid dynamics (CFD) has been used to simulate a specific air handling unit with outside air passing straight through the mixing chamber and the outdoor air entering the mixing chamber perpendicular to the outside air. Mixing characteristics such as thermal statistic and range mixing effectiveness of two baffles have been investigated. The influence of the baffle size and angle on these characteristics was studied and compared to the results of a case with no baffle.
The results show that when both the Outside Air Baffle and the Return Air Baffle are used results show no progress in mixing characteristics when the angle of the baffles equal 0°. However, increasing the angles of the return and outside air baffles resulted in an improvement in the mixing characteristics.
The relationship between the pressure drop and mixing effectiveness was plotted for all cases in order to determine the best case that leads to good mixing characteristics with a small pressure drop.

KEY WORDS: Air Stream- Baffles- Stratification- Air Handling Unit- Mixing Effectiveness- Mixing Chamber Computational Fluid Dynamics

1. INTRODUCTION

The major purpose of heating, ventilating and air-conditioning (HVAC) systems is to maintain a comfortable indoor environment and good air quality for occupants under all predictable conditions with low operational cost and high reliability. In a typical HVAC system as shown in Figure (1), the air is provided by a supply fan to air handling unit (AHU) which consists of mixing plenum, filter, reheat coil, preheat coil, and humidifier. This unit receives air from outside (OA) the building and return air (RA) from the indoor space. The outside and return air are then mixed in the mixing plenum, filtered, heated or cooled, and delivered to occupied areas through ducts. These ducts discharge the air into the space, usually through supply air diffusers located on the drop ceiling. A flow chart of this process is depicted in Figure (2). The briefly described HVAC system has many problems which may increase operational costs. But before discussing these problems, it is necessary to first understand both the specifics of the design and the intended functionality of these systems. The basic HVAC system, as shown in Figure (1). consists of:

- Outdoor air intake: the outdoor air intake is the portion of the system that brings outdoor air from the exterior of the building to the air handling unit. For some systems this section is simply a screen and an outdoor air damper incorporated into the unit housing. For other systems the outdoor air intake can be more extensive including Louvers which are typically found in HVAC systems at the point where air enters and exits the air handling equipment. The primary functions of the louvers are to minimize the entry of water into the air handling system and to act as the first stage of very rough filtration for the air handling equipment.

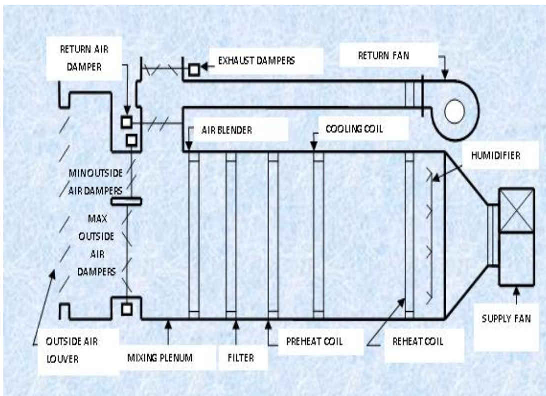

Fig. (1): Schematic of Typical HVAC System

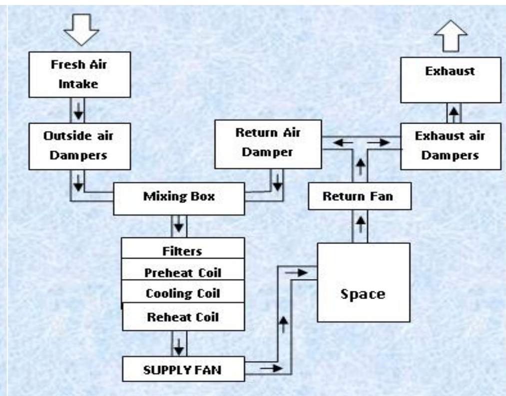

Fig. (2): Flow Chart of HVAC System Process

•**Mixing plenum:** the mixing plenum is the part of the AHU where the outdoor air and the return air are mixed and is often called the mixing box. The mixed air is then passed to the pre-heat or heat coil.

•**Pre-heat coil:** the pre-heat is the first element in the air stream following the mixing plenum. This unit protects the rest of the system from freezing. Air preheat applications are typically found on 100% outdoor air systems and on systems with high outdoor air fractions relative to their total supply flow. Most air handling systems seldom require pre-heat if their minimum outside air percentage is 20-30% of the supply flow rate and good mixing is achieved.

•**Air filters:** Air filters are used to remove dirt upstream air. The outside and return air has dust in it which must be removed before the air goes through the coils. If not, dust will accumulate in the coils and clog them.

• **Cooling-heating coils:** in order to provide thermal conditioning in a building, the HVAC equipment either adds heat to or removes heat from the supply air stream. This can be accomplished with either one coil, which is changed between cooling and heating depending on the building demand, or multiple coils which are dedicated to either heating or cooling. The coils used in HVAC are chilled water, brine, glycol, or various types of refrigerant as the cooling medium.

• **Supply and Return Air Fans:** the air fan is the heart of the air handling system since it is one of the most significant energy users in a building. After the air stream is passed through the coil section where heat is either added or extracted, air then moves through the supply fan chamber and the distribution system. The supply air fan provides the driving force to move the air through the distribution system. There can be just supply air fan or a combination of supply air fan and return air fan in the HVAC system. Return air fan prevents excess ambient pressure in the conditioned space when economizer cycle introduces more than the minimum quantity of outside air. It is also reduces the static pressure the supply fan has to work against. As mentioned before the HVAC system has many problems one of which is the lack of sufficient mixing in the mixing plenum. This problem is known as air stratification and will be discussed in the following section.

AIR STRATIFICATION

Stratification of return air and outside air streams occur when the two streams have poor mixing. This problem results partly because the momentum and turbulence that promote mixing drop off significantly as the velocities in the mixing box drop. Unfortunately, when incoming air becomes stratified, or separated into layers having different temperatures, many problems will take place in HVAC systems.

- Coil freeze-up. As mentioned before stratification results from inadequate mixing of the return air and outside air. If the outside air temperature is below freezing and the outside air and return air remain separate for long distance through AHU equipment, localized freezing in heating and cooling coil will accrue which known as coil freeze-up. This problem reduces the effective heating or cooling capacity of the coil and in many cases cause tube rupture.
- Nuisance freeze-stat trips. A freeze-stat is a temperature sensing device for HVAC system that monitors a heat exchanger to prevent its coils from freezing. The operating range for many freeze-stats is typically between 35°F and 38°F. If any portion of the device is exposed to a temperature below the set point, the freeze-stat will trip, shutting down the air handler. A typical response to freeze-stat problems is to shut off the outdoor air supply to eliminate cold air in the mixing plenum. Unfortunately, this solution does not allow the proper amount of ventilation air into the building, thereby compromising the indoor air quality.
- Sensor error. Since the return air and outside air are physically separated, a single sensor may not detect the true average temperature of the mixed air. An inaccurate information received from the sensor makes the system changed the position of dampers, which may be unnecessary, to maintain the desired supply air temperature.

THE FLOW PROBLEM AND ASSOCIATED PARAMETER RANGE

The mixing chamber under consideration is shown in Figure (3). As seen, two air streams representing the outside and return flows enter the mixing chamber perpendicular to each other with uniform velocities and temperatures (V_{OA}, T_{OA}) and (V_{RA}, T_{RA}), respectively. The outside and return air inlets are equipped with a set of flow dampers that consist of four blades. The angle of each set of blades can adjust in a range between 0° (fully closed dampers) and 90° (fully opened dampers). Two baffles are incorporated near the outdoor and return flow inlets. These baffles are named the outside air baffle (OAB) and return air baffle (RAB) as depicted in Figure (4). The Angle between +x-axis and outside baffle named as outside baffle's angle (Θ_{OAB}) and the angle between –y-axis and return baffle named as return baffle's angle (Θ_{RAB}). The interactions of the two airstreams and subsequent flow developments and mixing downstream in the mixing chamber are influenced by a large parameter space. This space can be divided into two categories: flow parameters and geometry parameters.

- Flow parameters: these are identified based on the property of the flow that would be passing through the mixing chamber. These parameters are
  - Return air velocity, V_{RA}
  - Outside air velocity, V_{OA}
  - Return air pressure, P_{RA}

- Outside air pressure, P_{OA}
- Return air temperature, T_{RA}
- Outside air temperature, T_{OA}

• Geometry parameters: these are identified based on the configuration of the mixing chamber and these parameters are

- Return duct area, A_{RA}
- outside duct area, A_{OA}
- outlet duct area, A_{MA}
- length of mixing chamber, L
- outside air inlet dampers angle, Θ_{OA}
- return air inlet dampers angle, Θ_{RA}
- baffle length, h
- baffle angle, Θ

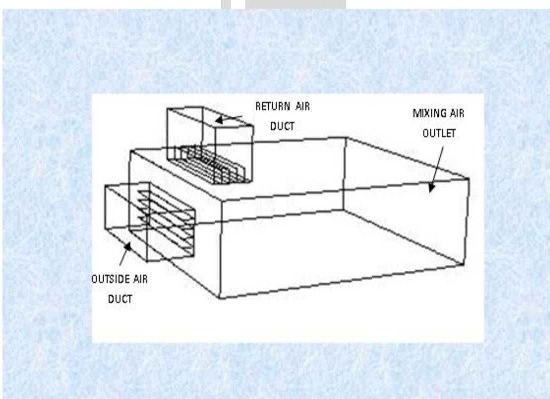

Fig (3) the Mixing Chamber-3D View

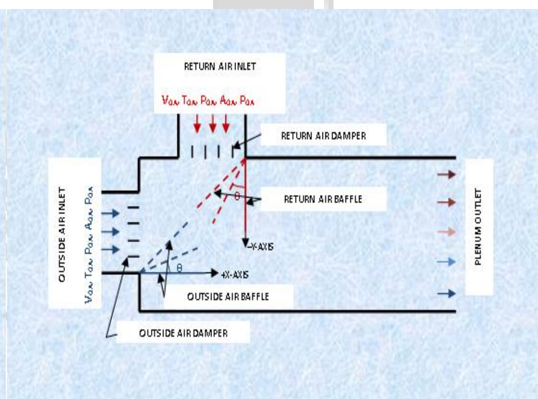

Fig (4) Side View of the Mixing Chamber Showing the Baffles Location

Due to a wide range of parameters that may influence mixing performance, a limited parameter range was considered. From the above parameters, variability of baffles length and angle are studied in this paper and the other parameters are kept constant. Table (1) shows the schedule of parameter values for the Parametric Study, whereCase 1 referred to reference case (no baffles). Cases 2 through 36 represent variation of RAB size for each of OAB size for $\Theta_{RAB}$and Θ_{OAB} =0°, 15°, 30°, and 45°.

Table (1) Test Plan for the Parametric Study

Test Conditions													
Case No.	RA						OA						
	Velocity (Fpm)	Temp (°F)	Flow Rate (CFM)	RA %	Baffle		Velocity (Fpm)	Temp. (°F)	Flow Rate (CFM)	RA %	Baffle	
					H/H	Θ(°)					L/H	Θ(°)
1	1500	110	12,110	50	-	-	1500	70	12,110	50	-	-

4. COMPUTATIONAL FLUID DYNAMICS (CFD) SOFTWARE

- The software used for this paper is Fluent, which is a computational fluid dynamics (CFD) package to simulate fluid flow problems. It uses the finite-volume method to solve the above governing equations for a fluid. A solution of a fluid flow problem can be obtained by following these steps in the software package:

- Create Geometry in GAMBIT
- Mesh Geometry in GAMBIT
- Set Boundary Types in GAMBIT
- Set Up Problem in FLUENT
- Solve!
- Analyze Results

5. MIXING EFFECTIVENESS

Mixing effectiveness is a method to express how well a mixing device mixes two air streams. This effectiveness can be determined by identifying the range mixing effectiveness and the statistical mixing effectiveness [4]. This helps the designer to predict when the temperature spread will exceed some critical value also allows for selectionof what type of mixing equipment is required for each particular system.

- **Thermal Range Mixing Effectiveness ERT.** Based on the assumption that the return air and outside air in the mixing plenum are uniform, a modified effectiveness rating was done in order to quantify the degree to which two streams mix with respect to temperature. The equation for this relationship is

$$E_{RT} = \left[1 - \frac{\Delta T_{DS}}{\Delta T_{US}}\right] \times 100\% \quad (1)$$

Where $\Delta T_{DS} = T_{max} - T_{min}$ **and** $\Delta T_{US} = T_{RA} - T_{OA}$. **Note that** T_{max} **and** T_{min} **are** measured at a station downstream of the mixing process; and T_{RA} and T_{OA} are measured at upstream of the mixing process. Equation (1) has a range between 0% which represents no mixing to 100% which represents perfect mixing. The Thermal Range Mixing Effectiveness is useful when the actual reduction in temperature is important such as avoiding coil freeze.

- **Thermal Statistical Mixing Effectiveness** E_{ST}**.** The definition for thermal statistical mixing effectiveness is

$$E_{ST} = \left[1 - \frac{\sigma_{DS}}{\sigma_{US}}\right] \times 100\% \tag{2}$$

Where σ_{DS} and σ_{US} are the downstream and upstream temperature standard deviation, respectively. The equation of standard deviation is:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{i=n}(T_i - T_m)^2} \tag{3}$$

Where n is the number of measurements, T_i measured value of temperature and T_m average value of measured temperature. Equation (3) also has a value between 0% and 100% representing no mixing and ideal mixing, respectively. Note that the E_{ST} measure was found more stable then E_{RT} because it was less affected by single reading temperature but it was more difficult to use [4, 9]. The range effectiveness can be used when the extremes of a mix are of prime importance, such as in coil freeze-up. The statistical effectiveness can be used when the uniformity is of prime importance, such as in control response.

6. COMPUTATION OF FLOW AND TEMPERATURE FIELDS IN A BASIC MIXING CHAMBER

The mixing chamber geometry, shown in Figure (4), without baffles is used as a reference case. The operating conditions for this chamber were as follows: The chamber's dampers are fully open, the air flow enters the RA duct, with VRA =1500 fpm, TRA =70°F and OA duct with VRA =1500 fpm and TRA =110°F. The flow developments and temperature distributions were computed throughout the mixing chamber. Employing the computed temperature distributions and Equations (1) and (2), the thermal mixing effectiveness were computed at 28 stations in the mixing chamber and presented in Figure (5). As seen, the thermal statistical and range mixing effectiveness are plotted versus the ratio (X/L). As expected, the mixing effectiveness of the two streams increases almost linearly throughout the mixing chamber as the distance downstream from the return air inlet increases. As seen, the maximum range and statistical mixing effectiveness attained at the exit of the mixing chamber was approximately 28% and 70%, respectively.

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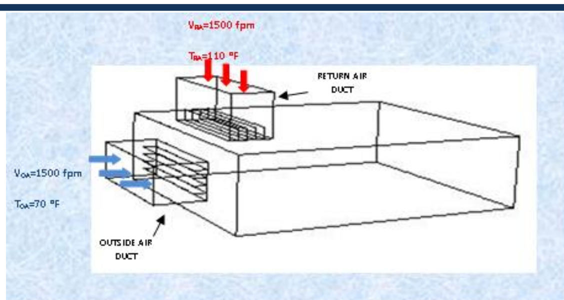

Fig (4): Basic Mixing Chamber

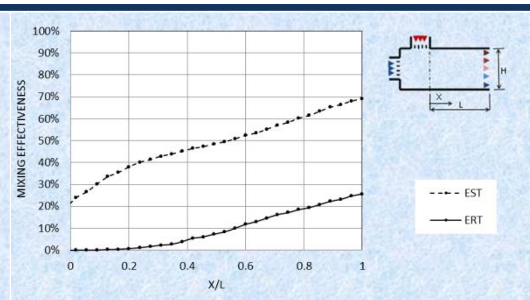

Fig (5): Range and Statistical Thermal Mixing Effectiveness for the Reference Case

To visualize the temperature distribution and corresponding flow velocity fields, the temperature and velocity vectors were plotted at five stations (stations 1 through 5 depicted in the schematic of figure (6). As seen in figures (7), these plots provide a useful insight on the flow and temperature fields as the two air streams flow and mix through the chamber. As shown in figure (8), the temperature distribution for station 1 shows a core region with high temperature (shown in red) and a region with low temperature near the bottom wall of the mixing chamber (shown in blue). These two regions have maximum and minimum temperature of 110°F and 70°F, respectively. As the flow moves to station 2, the core region of high temperature and low temperature area become less pronounced which indicates that the maximum temperature difference is reduce to increased mixing between the two flows. As the flow move towards Station 5, the hot core region has almost disappeared. However, two warm spots are still visible with colder layer at the bottom of the mixing chamber. The corresponding visualizations of the velocity vectors reveal the formation of circulation regions at the top and the bottom of the mixing chamber. At the top of the chamber, the flow is dominated by two large vortices on each side. Meanwhile, two smaller vortices are formed at the bottom. As the distance downstream increases (Stations 2 and 3) the smaller vortices merge with the larger vortex to form a stronger vortex at each side of the mixing chamber. Due to the temperature difference of the small and large vortices, the merging process produce mixing enhancement of the two streams as they flow and interact downstream. As expected, these results suggest that a long mixing chamber is needed to achieve improvement of flow mixing. However, short mixing lengths are usually required due to limited available space. To explore the possibility of improving the mixing of the two air streams in shorter distance, baffles were incorporated into the mixing chamber. The subsequent sections present computational study of the influence of baffles on temperature, flow fields, and overall flow mixing.

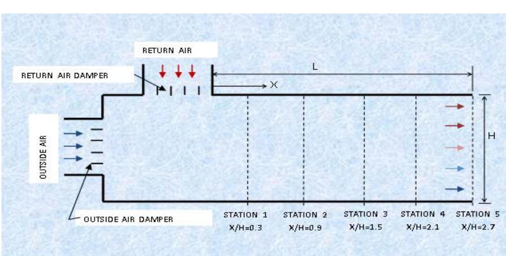

Figure (6) Side View of the Mixing Chamber Showing Station Locations

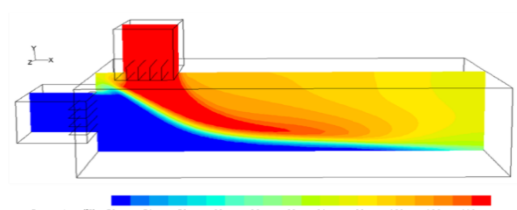

Fig (7) Temperature Distribution along Mixing Chamber Longitudinal Centerline for the Reference Case

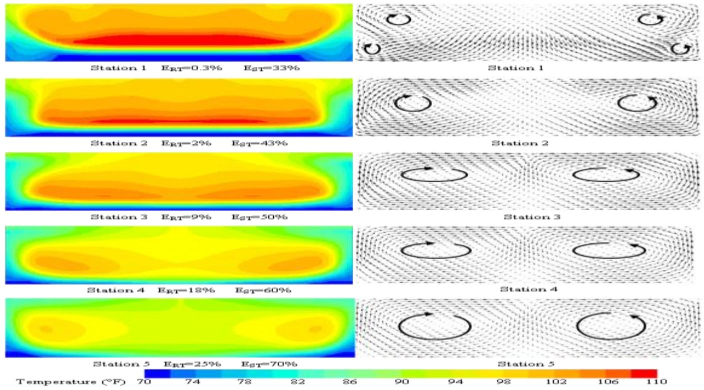

Fig (8) Temperature Distribution and Velocity Vectors at Downstream Stations for the Reference Case

7.Influence ofTwo Baffles On The Flow Mixing.

-The Position of The Return Air and The Outside Air Baffles in The Basic Mixing Chamber and The Properties of Inlet Flows Are Shown inFigure (9). The Influence of Two Baffles in The Statistical Mixing Effectiveness Is Presented inFigures (11). These Figures Show That When ϴ=0°, RAB Size H/H=0.15 And OAB Size Has Values Of 0.0, 0.15, 0.35 And 0.55 (Charts A), A Small Decrease in Mixing Characteristics (E_{RT}, E_{ST}) Observed as The Length ofOAB Is Increased. With ϴ=15° For Same Baffle Size, A Small Increase Was Noticed. Increasing ϴ=30° And 45°, A Major Increased in Mixing Characteristics Is Observed As H//H ofOAB Is Increased. For Charts (B) In the Same Figures, RAB Has Fixed Value Of H/H=0.35 And OAB Has H/H Values Of 0.0, 0.15, 0.35 And 0.55. In This Case, when ϴ=0° And H/H ofOAB Is Increased in The Range From 0.0 To 0.55 A Small Decreased in Mixing Characteristics Took Placed After X/L=0.6. When ϴ=15°, However A Small Increased inE_{RT}Occurred withOAB Size H/H Of 0.15, 0.35. Note That There Was About 15% Increase in Mixing Characteristic When H/H=0.55. Also Charts B Show A Growing in The Mixing Characteristics With ϴ=30° And 45°. Charts (C) Has RAB Size Of H/H=0.55 And OAB of H/H=0.0, 0.15, 0.35, 0.55 Show the Same Trend as Charts A andB. Consequently, Added Outside Air Baffle to A Mixing Chamber Which Has Return Air Baffle Did Not Make A Good Progress in Mixing Characteristics When the Angle of The Baffles Equal 0° Butas The Angle of The Return and Outside Air Baffles Are Increased, Improvement of The Mixing Characteristics Occurred. The Temperature and The Velocity Contours for This Case Are Shown inFigures (10). Based on The Above Observations, One May Conclude That in This Paper, Many Cases Was Studied in Order to Improve Mixing in The Mixing Chamber and The Results of This Study Show That Added Baffles to The Mixing Chamber Improves Mixingin Several Cases, But the Question Is Which Case Is theBest?In General Designers Are Looking for A Good Mixing in A Short Space with A Small Pressure Drop. The Following Section Will Present the Relation Between the Pressure Drop and The Mixing Effectiveness for All Studied Cases.

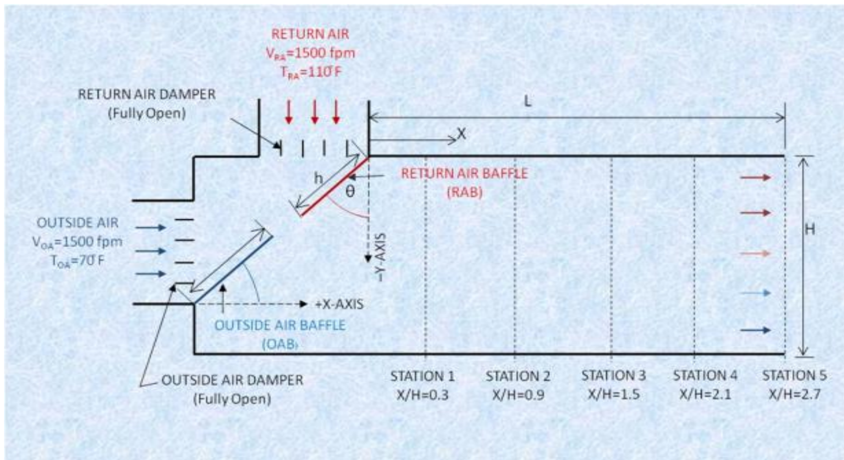

Fig 9. Side View of the Mixing Chamber Showing Location of Outside Air Baffle and Return Air Baffle

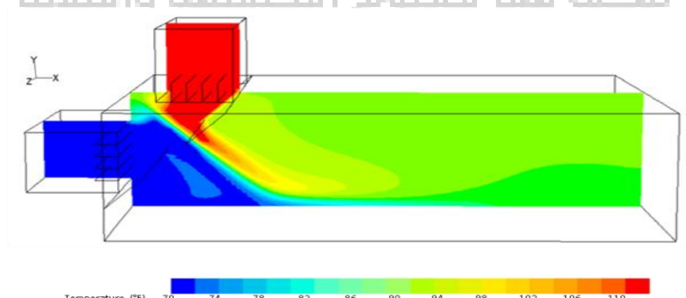

Fig (10) Temperature Distribution Along Mixing Chamber Longitudinal Centerline for Case (H/H $_{(RAB, OAB)}$ =0.35, Θ $_{(RAB, OAB)}$ = 45°)

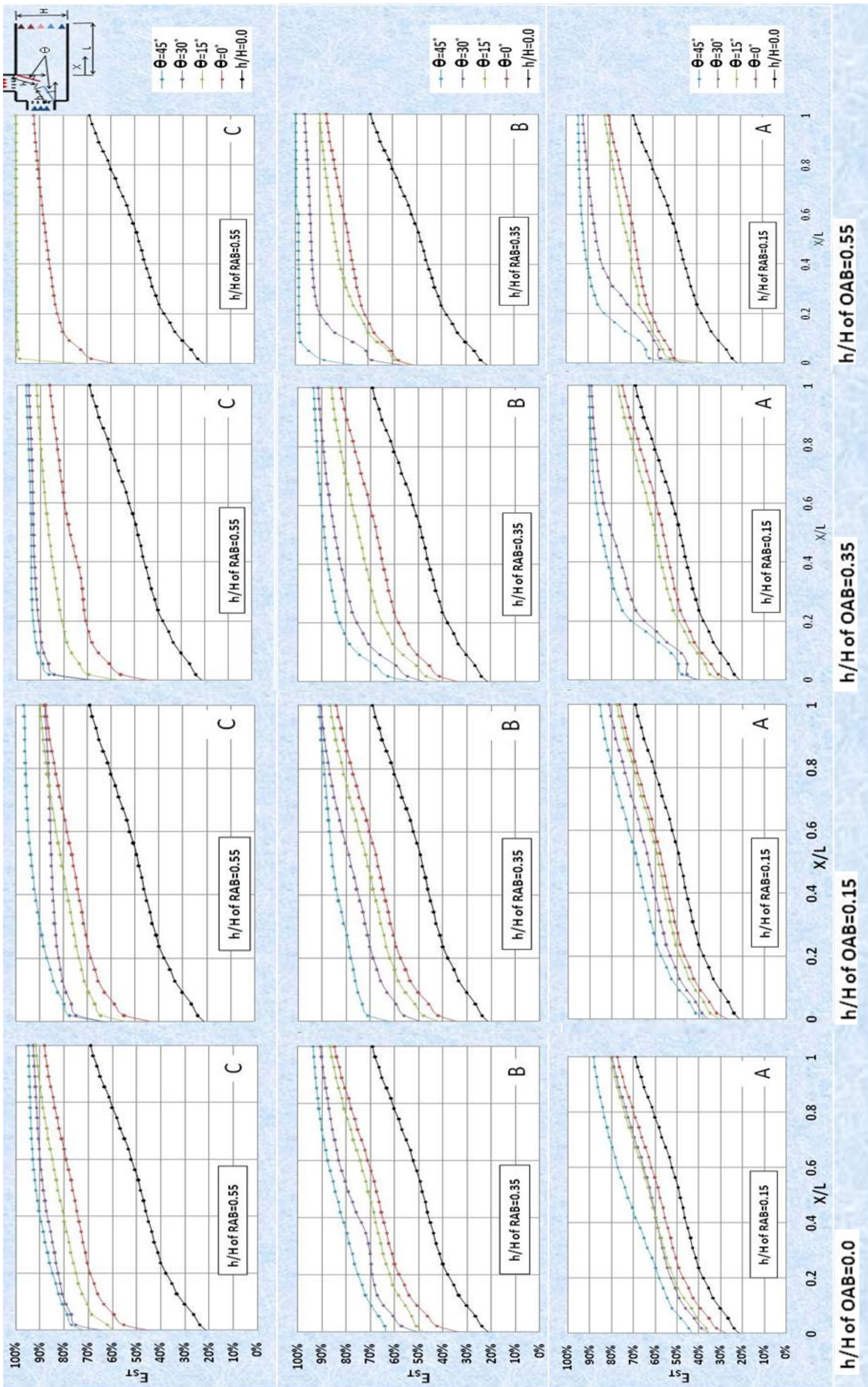

Fig (11) Influence of The Return and Outside Air Baffle Angle on Statistical Mixing Effectiveness Taking the Return and Outside Air Baffle Size as A Fixed Parameter

8. Influence Of Baffles On The Pressure Drop

A very important factor towards a system design is the pressure drop required to be overcome by the fan. Design modifications directed towards increasing the mixing effectiveness often involve a penalty paid in the form of larger fans to compensate for the additional pressure drop generated. The introduction of the baffle in the mixing chamber increases the overall pressure drop within the system. The pressure drop was computed by subtracting the average of total pressures (static plus dynamic) between the inlet and outlet of mixing chamber

$$\Delta P = \bar{P}_{t_{US}} - \bar{P}_{t_{DS}} \quad (4)$$

where $\bar{P}_{t_{US}}$ **and** $\bar{P}_{t_{DS}}$ are an average total pressure at stations upstream and downstream of the mixing chamber, respectively.

$$\text{Total Pressure} = P_{Static} + \frac{1}{2}\rho V^2 \quad (5)$$

Figures (12) show the pressure drop for all cases under study verses the range and statistical mixing effectiveness of these cases, respectively.

The x-axis of this figure is a ratio of the pressure drop of each case divided by the pressure drop for reference case and the y-axis is a ratio of the range mixing effectiveness at station 5 for each case divided by the value of the range mixing effectiveness for reference case at the same station. Green dot of this figure represented the reference case. Red and blue dots represented cases where the return and outside air baffle was installed in mixing chamber, respectively. Black dots represented cases where both the return and outside air baffles were installed in mixing chamber. From these figures, depend on how much mixing characteristics needed at X/L=1.0, a case with minimum pressure drop should be a best case to choose.

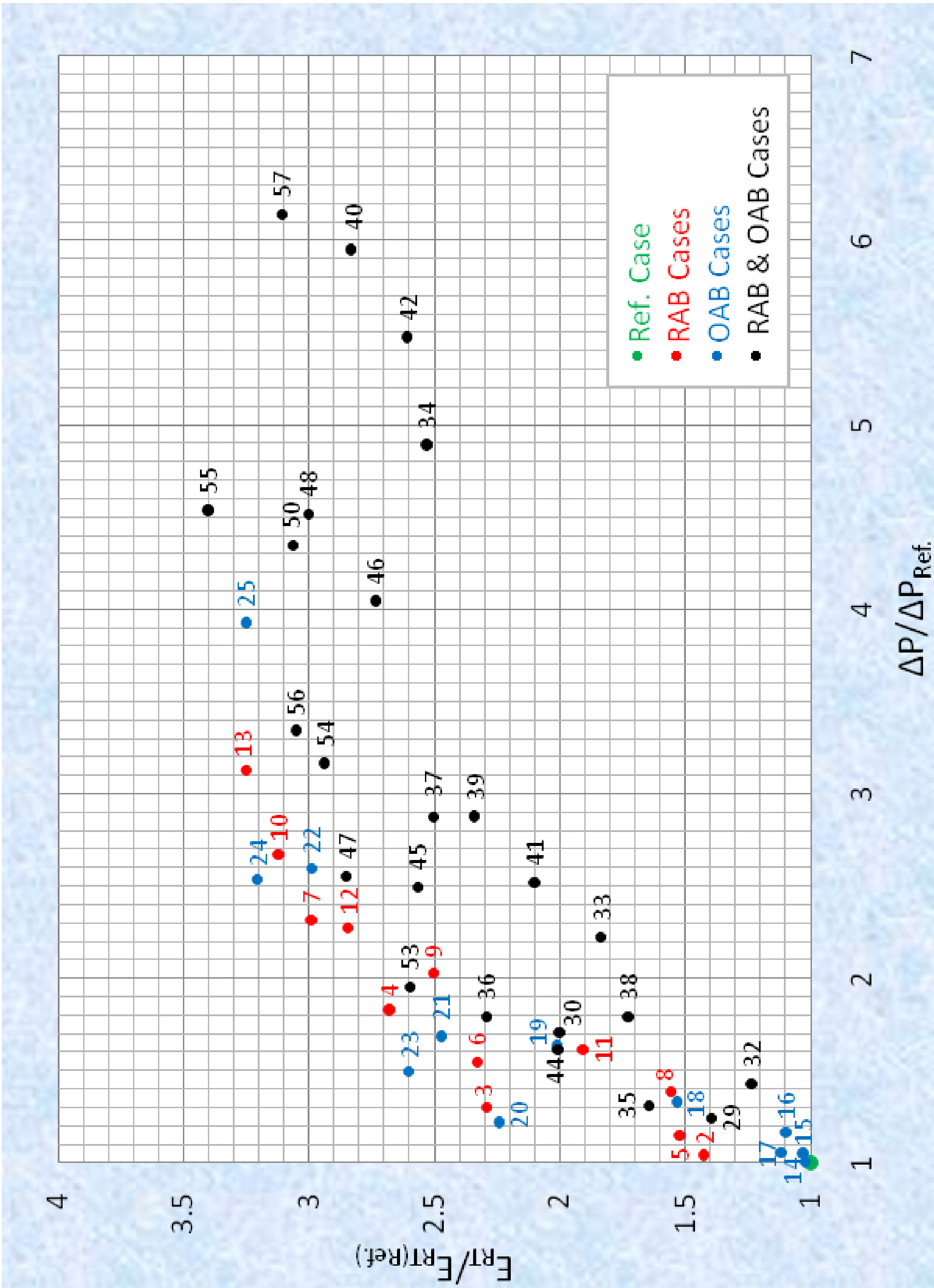

Fig (12) Pressure Drop Ratio Verses Thermal Range Mixing Electiveness Ratio

9. Conclusions

The objective of this paper was to investigate the influence of baffles on mixing of two air streams with dissimilar temperature by installing two baffles in a mixing chamber. A parametric study that focuses on the influence of a variation in the angle and size of these baffles on flow mixing is conducted. The following is a summary of the results and observations obtained from this paper.

1. For a basic case (no Baffle) in which the return air enters the mixing chamber directly while the outside air enters perpendicularly, the range and statistical mixing effectiveness increase as the distance downstream of a mixer is increased. The temperature distributions at stations along the mixing chamber show hot and cold regions that have high and low temperatures. These regions get smaller as the distance of the mixing chamber increases but when a limited space is available the cold region can cause series problems in the winter weather.
2. Adding an outside air baffle to the mixing chamber which has return air baffle did not alter the mixing effectiveness in a significant way when the angle of the baffles equal 0°, but as the angle of the baffles is increased, enhance of the mixing effectiveness occurred.
3. The introduction of the baffle in the mixing chamber increases the overall pressure drop within the system. Therefore, depending on how much mixing effectiveness is needed in a short distance, the case that has minimum pressure drop should be the best case.

10.NOMENCLATURE

Symbol	Description
HVAC	Heating, Ventilating, and Air Conditioning
AHU	Air Handling Unit
OA	outside Air
RA	Return Air
VAV	Variable Air Volume
CFD	Computational Fluid Dynamic
V_{OA}	Outside Air Inlet Velocity
V_{RA}	Return Air Inlet Velocity
T_{OA}	Outside Air Inlet Temperature
T_{RA}	Return Air Inlet Temperature
OAB	outside Air Baffle
RAB	Return Air Baffle
Θ_{OAB}	outside Air Baffle Angle
Θ_{RAB}	Return Air Baffle Angle
E_{RT}	Thermal Range Mixing Effectiveness
E_{ST}	Thermal Statistical Mixing Effectiveness
ΔT_{DS}	Downstream Temperature Difference
ΔT_{US}	Upstream Temperature Difference
σ_{DS}	Standard Deviation of Downstream Temperature Measurements
σ_{US}	Standard Deviation of Upstream Temperature Measurements
σ	Standard Deviation
h	Baffle Height
H	Mixing Chamber Height
W	Mixing Chamber width

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