

# DESIGN & PROPORTIONAL COMPUTATIONAL ASSESSMENT BETWEEN A CONVENTIONAL AND CIRCULAR DUCT SYSTEM

*An industrial air conditioning – A Case Study*

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**Abstract :** The successful operation of any air-conditioning system is dependent upon the sufficient circulation of air in the air-conditioned space. The careful estimation of the pressure losses is necessary for the selection of proper duct size. The duct cost in air conditioning system is 20 to 30 % of the total cost of the equipment's requirement and power required by the fan contributes the substantial part of the running cost. It is, therefore, necessary to design an air duct system for least capital cost & lowest running cost of the fan. Duct design is the design of pipes which convey conditioned air and then distribute it to different spaces according to the requirement. The advantages of well designed and constructed interior duct systems are numerous. Among these advantages are improved energy efficiency through the elimination of duct leakage to outside and the elimination of conductive heat gains/losses. This paper focuses on a study of design and modifications air cooling duct using Computational Fluid Dynamics (CFD) analysis considering all air flow features relating to the duct system efficiency. The need for optimizing duct design especially to provide improved flow conditions. It combines theoretical and software-enabled tools to provide a detailed comparative analysis of the costs and benefits involved in selecting a particular shape (rectangular or circular) of duct for a prescribed situation. The focus of this paper will be on using CFD software tools to study velocity distribution of air in the duct at various sections, pressure difference at various outlets and distribution of air flow for different load conditions.

**IndexTerms - Duct system, Duct design, Duct installation, Heating, Ventilation, Air conditioning, Dynamic pressure distribution, Velocity profile, Turbulence, CFD**

## I. INTRODUCTION

An air conditioning duct is a type of pipe or tunnel that is used to distribute air throughout a structure. Systems of ducts, known as ductwork, are a central component of a building's Heating, Ventilation and Air Conditioning (HVAC) system. In most systems, only one set of ductwork is present, which is used to transport cool air in the summer and heated air in the winter, along with as air required for general ventilation needs [1]. Air conditioning duct is used only with central air units and is not required for homes that rely on split systems or ductless air conditioning. The purpose of air conditioning ductwork is to deliver air from the fan to the diffusers which distribute the air to the room. Air moves through the ductwork in response to a pressure difference created by the fan [2].

A system of intake grilles or louvres pulls fresh air from outside into the central air unit. The air is cooled, blown into an air conditioning duct system, where it is distributed to various rooms. The cool air enters the rooms through air terminal units installed at the end of each duct line, which generally take the form of diffusers or grilles. This network of ducts that transport cool air from the unit to each room is called the supply ductwork [3].

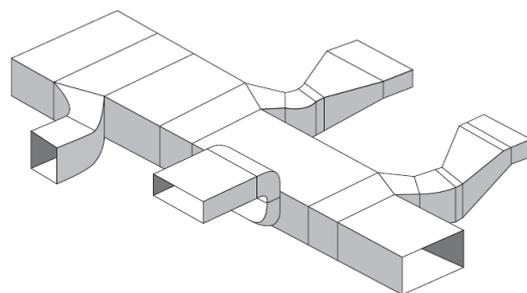


Fig. 1: Simple duct layout [2]

## II. DESIGN APPROACH

It consists of embroidery machines, which can be considered as factory. This design is mainly based on maintaining the temperature of the room so aesthetic and noise considerations are of most importance in duct design. For this purpose, the aim is to design effective duct layout which can ensure human comfort besides sufficient air distribution, lower power consumption with the minimum noise level [4].

The objectives of good duct design are occupant comfort, proper air distribution, economical heating and cooling system operation and duct installation. The outcome of the duct design process will be a duct system (supply and return plenums, ducts, fittings, boots, grilles, and registers) that provides following functions [6].

- (1) It provides conditioned air to meet all room heating and cooling loads.
- (2) It is properly sized so that the pressure drop across the air handler is within manufacturer and design specifications.
- (3) It is sealed to provide proper air flow and to prevent air from entering the house or duct system from polluted zones.
- (4) It has balanced supply and return air flows to maintain a neutral pressure in the house.
- (5) It minimizes duct air temperature gains or losses between the air handler and supply outlets, and between the return register and air handler.

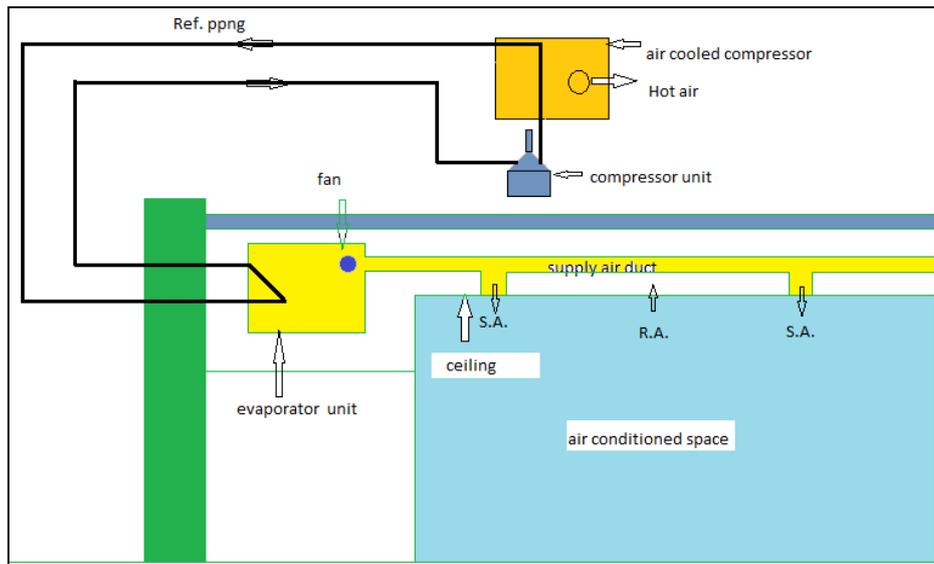


Fig. 2: Working principle of HVAC

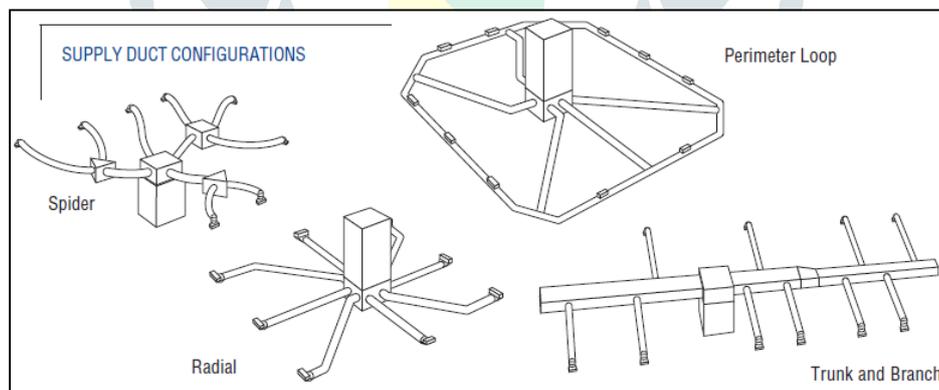


Fig. 3: Types of supply duct system [3]

In this research article, cooling load calculation and completed the design of air condition duct for one site using HEAT LOAD software and CAD software is discussed [7]. Load calculation and design of Radhe Krishna Diamond factory, Surat, Gujarat, India site is discussed in below sections.

There are three different methods of duct design:

- Velocity Reduction Method
- Equal Friction Method
- Static Regain Method

Duct design is done using velocity reduction method. Velocity method is one of the simplest ways of designing the duct system for both supplies and return air. However, the application of this method requires selection of suitable velocities in different duct runs, which requires experience. Wrong selection of velocities can lead to very large ducts, which, occupy large building

space and increases the cost or very small ducts lead to large pressure drop and hence necessitates the selection of a large fan leading to higher fan cost and running cost.

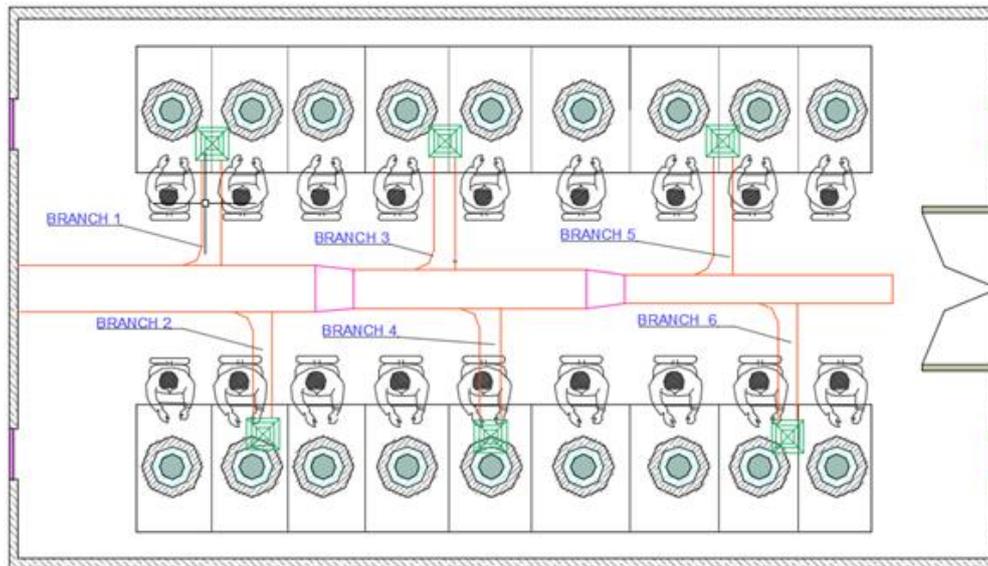


Fig. 4: Layout of Radhe Krishna Diamond factory, Surat, Gujarat, India

**2.1 Calculation of duct cross-section area [5]:**

- Aspect Ratio: It is a ratio of two sides of rectangular duct shape. Aspect ratio= $a/b$  (Where  $a$  = width,  $b$  = height)

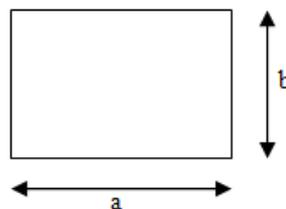


Fig. 5: Rectangular duct shape geometry

- CFM (Cubic Feet per Minute): It is a unit of air flow rate generally used in air conditioner system. Area= $cfm/velocity$
- Equivalent diameter (D): The equivalent diameter is the diameter of a circular duct or pipe that gives the same pressure loss as an equivalent rectangular duct or pipe. Where,  $D=2ab/(a+b)$

The factors for the dust design are: Area of the room, Occupancy, Cooling load

Table 2.1: Velocity for different applications

Type of area	Velocity(ft/min)	Remark
Bedroom	900	Silent
Living room	1000-1100	Somewhat noisy
Factory/Industry	1400	Noisy

**2.2 Calculation of cooling load using Heat Load Software [10]:**

A Layout of Radhekrishna Diamond factory is shown in above figure 4. Here different parameters include dimensions of the site (length, width, height) and wall thickness are discussed by observing site properly. By entering these parameters into HEAT LOAD software cooling load is calculated.

**2.3 Selection of Air Conditioner Unit :**

The Total cooling load required for an industrial site is 44520 Watt. The required corresponding air flow rate is 8228 cubic feet per minute. With respect to the requirement of power and air flow rate, the AC unit have been selected from the catalogue of DAIKIN AIR CONDITIONER. The unit having model No: RXYQ16PRY6/PAY6 is selected from the catalogue.

**2.4 Calculation of Duct cross-section Area:**

The selected velocity between the living room and factory which is 1200 ft/min.

Dimension for main duct:

Duct Area= $cfm/velocity = 8228/1200 = 6.86 \text{ ft}^2 = 0.64 \text{ m}^2$

In order to make rectangular duct c/s, taken Aspect Ratio= $a/b=2$

Area =  $a \times b = 0.64 \text{ m}^2 = 2 \times b^2 = 0.64 \text{ m}^2$ ,  $b = 0.56 \text{ m}$ ,  $a = 1.13 \text{ m}$   
 Likewise all the calculations for the main duct are tabulated as follows:

Table 2.2: Dimensions for main duct for Industrial site

Reduction No.	CFM	Velocity (ft/min)	Area (m <sup>2</sup> )	Aspect ratio	a (m)	b (m)	Equivalent diameter (m)
1 <sup>st</sup>	5484	1150	0.44	2.0	0.94	0.47	0.63
2 <sup>nd</sup>	2740	1100	0.23	2.0	0.68	0.34	0.45

Equivalent diameter of main duct is 0.75 m.

Dimensions for branches from the main duct:

Table 2.3: Dimensions for sub-branches for Industrial site

Branch No.	CFM	Velocity (ft/min)	Area (m <sup>2</sup> )	Aspect ratio	a (m)	b (m)	Equivalent diameter (m)																
1	1372	1100	0.11	2.0	0.46	0.23	0.31																
2	1372	1100	0.11	2.0	0.46	0.23	0.31																
3	1372	1000	0.12	2.0	0.50	0.25	0.33																
4	1372	1000	0.12	2.0	0.50	0.25	0.33 </tr <tr> <td>5</td> <td>1372</td> <td>900</td> <td>0.14</td> <td>2.0</td> <td>0.52</td> <td>0.26</td> <td>0.35</td> </tr> <tr> <td>6</td> <td>1372</td> <td>900</td> <td>0.14</td> <td>2.0</td> <td>0.52</td> <td>0.26</td> <td>0.35</td> </tr>	5	1372	900	0.14	2.0	0.52	0.26	0.35	6	1372	900	0.14	2.0	0.52	0.26	0.35
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6	1372	900	0.14	2.0	0.52	0.26	0.35																

### III. SIMULATION-BASED APPROACH

The paper included the analysis of two shapes viz. circular and rectangular cross-section ducts and selection of one which encounters minimum distribution losses. The principle of Computational Fluid Dynamics was applied for fluid flow analysis, by using the following tool:-

Fluent – A commercial software package used to simulate the pressure drop inside the duct. The following sequence of steps were followed to obtain the desired results while performing the software analysis: Creating geometry in ANSYS > Meshing in ANSYS with Tool > Setting boundary types in ANSYS > Setting up a problem in FLUENT > Solving and obtaining solutions in FLUENT. Duct design is done using velocity reduction method. This CFD tool can be used for a whole building to analyze air pressure and velocity fluctuation for the duct [11, 12].

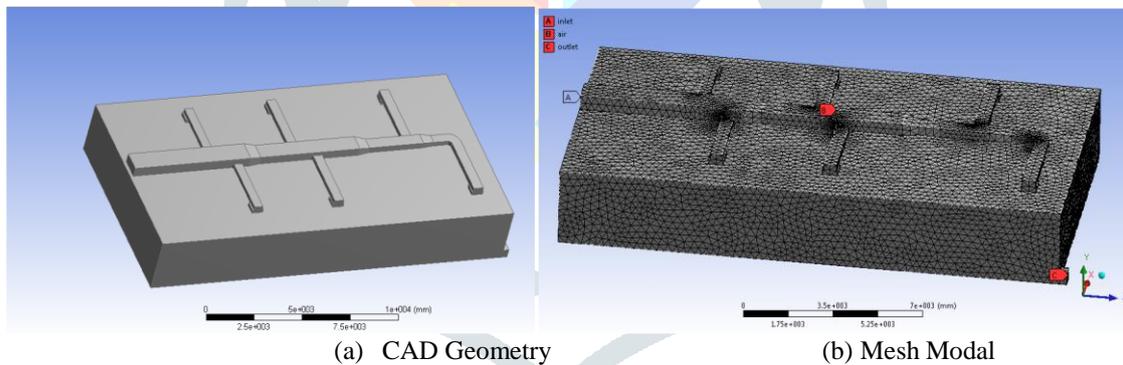
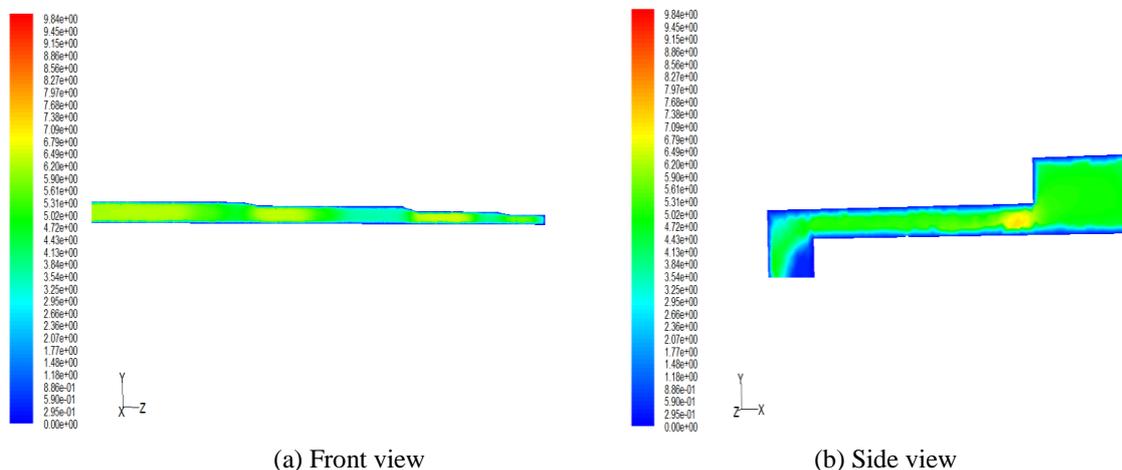
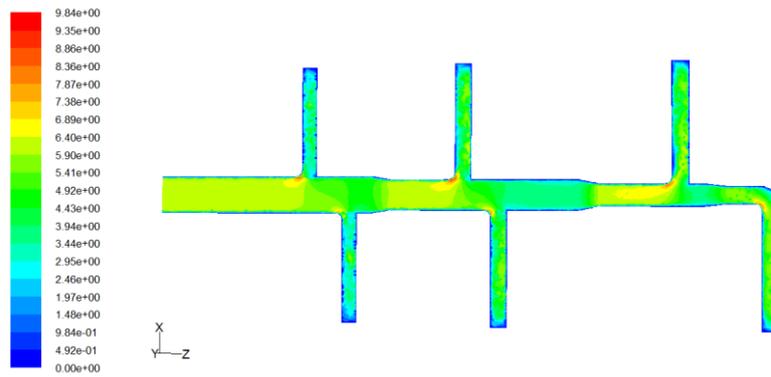


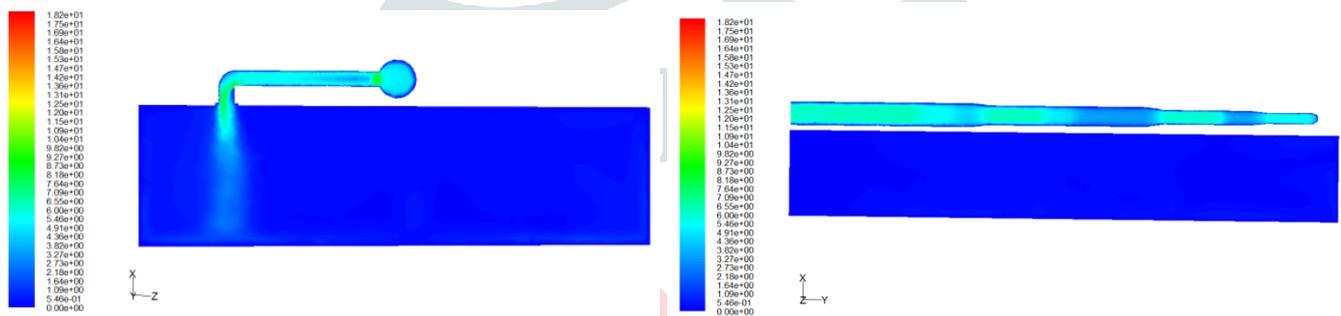
Fig.6: Conceptual design of duct system





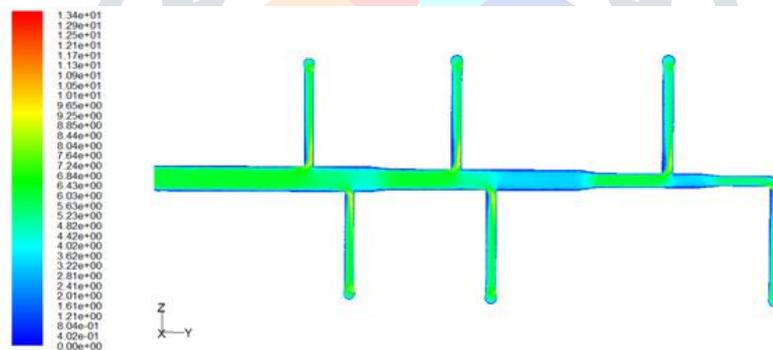
(c) Top view

Fig. 7: Velocity distribution in the rectangular duct for Industrial site



(a) Side view

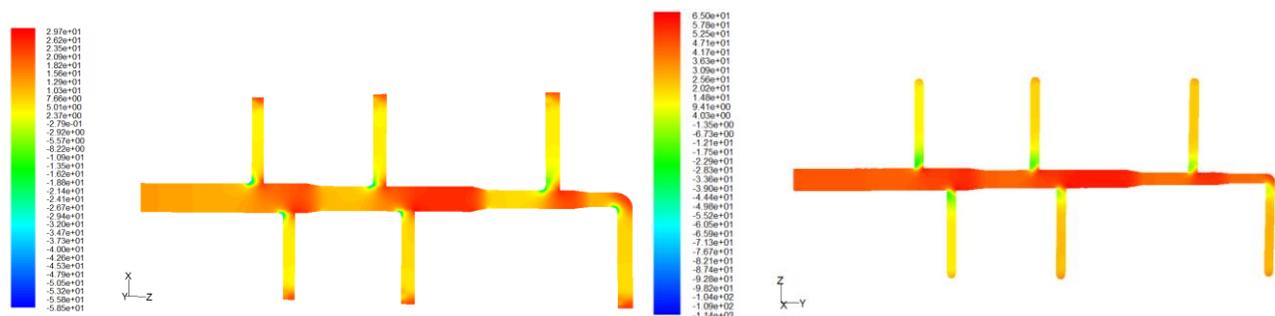
(b) Front view



(c) Top view

Fig. 8: Velocity distribution in the circular duct for Industrial site

The comparison of the velocity of air flowing through the rectangular duct and circular duct is shown in Fig. 7 & 8. Inlet velocity of 6 m/s is selected in both cases [10]. In rectangular duct maximum velocity is 9.84 m/s and in circular duct maximum velocity is 13.4 m/s. Here, maximum velocity in both cases occurs at bends. It is difficult to manufacture circular bend. So the provision of a straight duct is done at a branch. Due to this maximum velocity occurs at a bend in the circular duct [13].



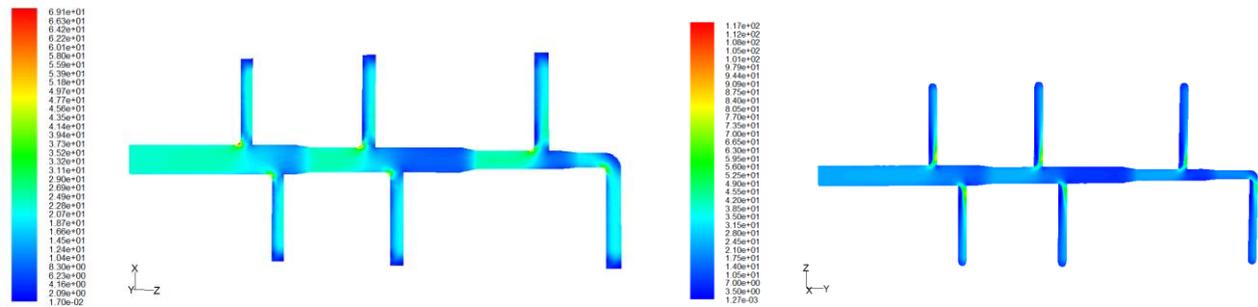
(a) Rectangular Duct

(b) Circular Duct

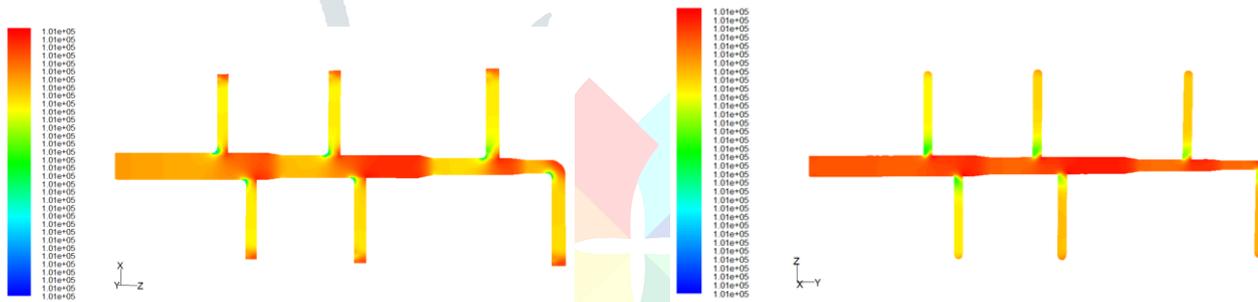
Fig. 9: Static Pressure distribution for Industrial site

There are mainly four types of pressure as follows [8]:

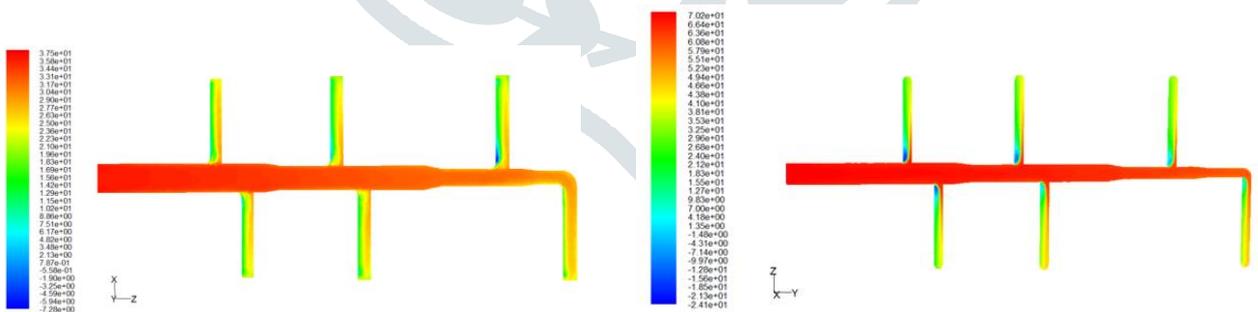
- Static pressure: It is potential pressure exerted in all direction by air at rest. In a duct, static pressure tends to expand or contract duct, depending upon static pressure is positive or negative. If static pressure is higher than atmospheric pressure, it is positive and if lower than atmospheric pressure, it is negative.
- Dynamic pressure (Velocity pressure): It is the pressure caused by the velocity of air moving in the direction of flow. It is always positive. It is kinematic pressure and it exists only when the air is in motion.
- Total pressure: Pressure creating an air movement is called Total Pressure. Total pressure has two components: Static Pressure and Dynamic Pressure. Air handling systems are designed with a specific Total Pressure so the fan can be sized properly.
- Absolute pressure: It is zero-referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure.



(a) Rectangular Duct (b) Circular Duct  
 Fig. 10: Dynamic Pressure distribution for Industrial site



(a) Rectangular Duct (b) Circular Duct  
 Fig. 11: Absolute Pressure distribution for Industrial site



(a) Rectangular Duct (b) Circular Duct  
 Fig. 12: Total Pressure distribution for Industrial site

Table 3.1: comparisons of all four pressures in rectangular and circular duct for Industrial site

Maximum Pressure (Pascal)	Rectangular	Circular
Static pressure	29.1	65
Dynamic pressure	69.1	117
Absolute pressure	1.01 x 10 <sup>5</sup>	1.01 x 10 <sup>5</sup>
Total pressure	37.5	70.1

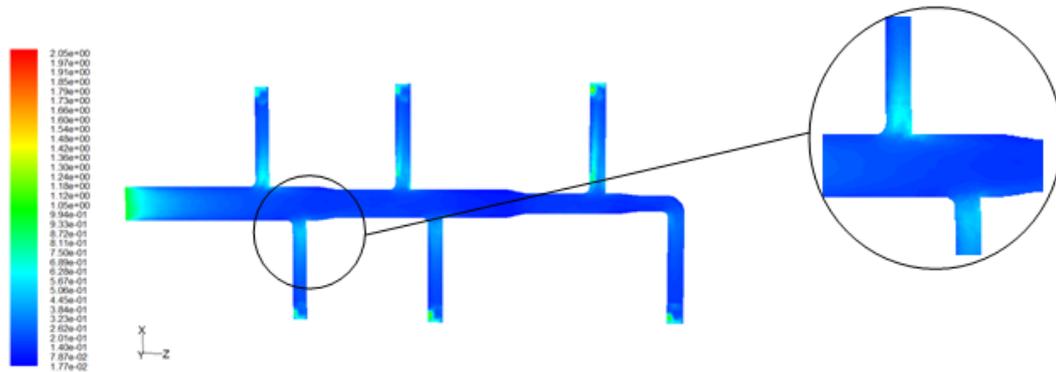


Fig. 13: Turbulence in the rectangular duct for Industrial site

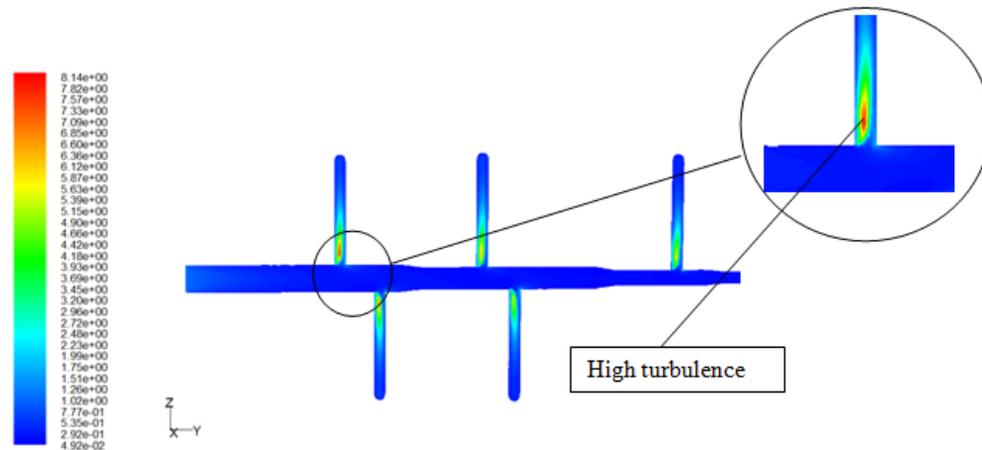


Fig.14: Turbulence in the circular duct for Industrial site

Here in case of a circular duct, more turbulence is created at the branch as bend are not provided. So, from noise generation point of view rectangular ducts are preferable as it is possible to provide bends at a branch.

#### IV. RESULT & DISCUSSION

The experimental and computational investigation provided a satisfactory tool to capture the complex airflow pattern of a number of industrial ducts. CFD analysis provides the ability to quantify flow improvement and to quickly predict the behaviour of the several design proposals at low cost. The CFD analysis has offered a comprehensive range of output including velocity distribution, pressure profile and turbulence levels. Subsequent testing of the modified duct system has validated the approach using CFD analysis tools.

The following various conclusions summarize the present paper:

- The cooling load calculation of an industrial site is done, applying various methods and duct design is carried out by velocity method. All results are comparable with existing plant by authors.
- Due to less value, duct diameter is increased but a loss in static pressure, velocity pressure can be avoided. The Smaller diameter of the duct would increase the noise level. So the requirement of sound attenuating devices may need. Also, the probability of dampers is decreased with increasing diameter. But the first cost is increased with increasing duct diameter.
- Due to proper branching (with elbow) of ducts, a loss is minimized in this design. But in existing plant, there is straight branching in so many locations, which may increase the pressure loss.
- Pressure loss in duct fitting is kept minimum by using elbow with proper shape considering very less pressure loss coefficient.
- CFD software is used to analyze the airflow in the straight duct and an elbow. Eddies are observed due to an incorrect shape of the elbow. So proper shape of an elbow and correct velocity are estimated to minimize eddies as well as pressure loss.
- CFD can be used to study pressure and velocity fluctuation for a whole building. So it is a better tool which can be used in HVAC system to save time and cost.

In this case study, it is concluded that if a proper cross-section of the duct and duct layout is designed then it can ensure proper air distribution for human comfort. From a comparison of three duct design method named Velocity Reduction, Equal Friction and Static Regain based on various parameters such as a total surface area of the duct, pressure losses, identify the best method for duct design for a particular site. Pressure losses are also less in case of the circular duct. Due to improper shape and velocity, eddies are observed in the elbow with CFD analysis. So by proper shape, eddies are minimized analysis of all ducting.

## V. ACKNOWLEDGMENT

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