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# "CFD Analysis to Determine Toxic Level in Underground Car Parking and Applying Jet Fans to Remove Hazardous Gases For Basement-1"

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***Abstract —*** *The risks that carbon monoxide pose to health have been well documented and car exhaust fumes are a rich source of this gas. This requires that all enclosed car parks are monitored for hazardous gas concentrations and the control of the carbon monoxide levels within permissible limits by proper ventilation fans. The CFD analysis of Basement-1 of car park lead to a conclusion that CO level are below 35ppm and within permissible limit, which is the maximum exposure limit as per ASHRAE handbook 2007. Still two jets were installed to ensure quick exit of smoke in case of fire .*

***Keywords-*** *Flow rates, Ventilation ,Thermal comfort, Air changes rate, CFD*

## I.INTRODUCTION

Over the past few years, BRE(BRE is a world leading multi-disciplinary building science centre with a mission to improve the built environment through research and knowledge generation) has seen a rise in the number of underground car park designs it has been asked to assess for ventilation performance. The assessments were carried out because Building Control Officers required assurance that CO levels would be within safety limits. This case study underlines the value of such checks and demonstrates how they can point the way to a solution when design modifications are required.

## AIR CHANGES PER HOUR (ACH)

The volume of fresh air (make up air) required for proper ventilation is determined of the size and use of the space.


Air changes per hour

The fresh air supply to a room can be calculated as

$q = n V$ (1)

*where*

$q$ = *fresh air supply* ($ft^3/h$, $m^3/h$)

$n$ = *air change rate* ($h^{-1}$)

$V$ = *volume of room* ($ft^3$, $m^3$)

The Table below indicates recommended air change rates (air changes per hour) in some common types of rooms and buildings:

| **Building / Room** | **Air Change Rates - *n* - *(1/h, $h^{-1}$)*** |
|---|---|
| Assembly halls | 4 – 6 |
| Auditoriums | 8 – 15 |
| Bakeries | 20 – 30 |
| Banks | 4 – 10 |
| Boiler rooms | 15 – 20 |
| Cafeterias | 12 – 15 |
| Classrooms | 6 – 20 |
| Computer Rooms | 15 – 20 |
| Libraries, public | 4 |
| Malls | 6 – 10 |
| Photo dark rooms | 10 – 15 |
| Precision Manufacturing | 10 – 50 |
| Pump rooms | 5 |
| Residences | 1 – 2 |
| Restaurants | 8 – 12 |
| Shopping Centers | 6 – 10 |
| Theatres | 8 – 15 |

| **Building / Room** | **Air Change Rates - *n* - *(1/h, $h^{-1}$)*** |
|---|---|
| Transformer rooms | 10 – 30 |
| Turbine rooms, electric | 5 – 10 |
| Warehouses | 2 |
| Waiting rooms, public | 4 |
| Warehouses | 6 – 30 |

**Car Park Ventilation**

Car park ventilation systems have to control the exhaust gases emitted by vehicles but must also take into account possible fuel spillages and the venting of smoke in the event of a fire.

Air flow:

The principle factor that influences the pattern of air flow is the distribution of air inlets. The strength of the mixing effect will depend upon the speed of the incoming air and the size of the inlet opening. With natural ventilation, the speed increases proportionally with the square root of the applied pressure difference. Air extract points have a much lower effect on air movement but their location relative to inlets may be important. Other factors to take into account include the geometry of the space, convective flows and intermittent turbulent flows.

**Natural ventilation**

Natural ventilation with at least 3 Air Changes Per Hour (ACH). The provision of well distributed permanent natural ventilation e.g. openings at each car parking level with an aggregate equivalent area equal to at least 1/20th of floor area at that level of which at least 25% should on each of the two opposing walls.

The performance of natural ventilation depends on many factors including site layout and orientation, size and sitting of air vents, height and proximity of neighboring buildings, and local wind conditions. When these are favorable, natural ventilation will provide both a mean level of air change and be able to cope with peak conditions. Where conditions are not ideal there will be periods when it is unable to cope with heavy loads and ventilation rates will fall below a desirable level. In these circumstances it is necessary to understand just how low those rates could fall and what impact this would have on air quality and the health and safety of users. The effect of extended periods of low wind speed, and thus low ventilation rate, on CO levels is of particular interest.

As well as the overall ventilation rate, it is necessary to consider the distribution of pollutant concentrations within the car park. The assumption that the air is 'well mixed', i.e. the concentrations are uniform, is often used when predicting concentrations. However, it is important to examine the factors that may contribute to non-uniform mixing and to determine the sensitivity of the predicted concentrations to assumptions about the degree of mixing. The two interacting factors that contribute to the degree of mixing are (a) the air flow pattern within the space and (b) the location of the pollutant sources.

**Mechanical ventilation**

For basement car parks provision of mechanical ventilation systems capable of at least 6 ACH .for exits and ramps, where cars queue inside the buildings with engines running, provision to be made to ensure local ventilation rate of at least 10 ACH.

This project Derives its standards From ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers.) for CO levels and BRE for minimum ACH required inside Car Park.

**Co poisoning effects**

Many studies of air quality have focused on Carbon Monoxide (CO) because it is generally considered to have Carbon monoxide severe impact colourless, odourless, and highly toxic gas, emitted as a product of incomplete combustion of hydrocarbon-based fuels. When CO is inhaled, it combines preferentially with haemoglobin. (Hb), the oxygen carrier of

the blood, to produce carboxy haemoglobin(COHb), displacing oxygen and reducing system arterial oxygen content. Its toxicity is due to the fact that it binds reversibly to haemoglobin with an affinity 200-250 times that of oxygen.
This makes CO dangerous even at low concentrations. The level of CO concentration is measured in parts per million (ppm). For example, 100 ppm CO means that for every 1,000,000 molecules of air, 100 of those molecules are CO.

| **CO Level** | **Condition & Health Effects** | Institute |
|---|---|---|
| 0 ppm | Normal, fresh air | |
| 9 ppm | Maximum allowable short-term exposure | ASHRAE |
| 10-24 ppm | Possible health effects with long-term exposure | |
| 25 ppm | Max TWA exposure for 8 hour work-day | ACGIH |
| 50 ppm | Maximum permissible exposure in workplace | OSHA |
| 100 ppm | Slight headache after 1-2 hours | |
| 200 ppm | Dizziness, nausea, fatigue, headache after 2-3 hours of exposure | |
| 400 ppm | Headache and nausea after 1-2 hours of exposure / Life threatening in 3 hours | |
| 800 ppm | Headache, nausea, and dizziness after 45 minutes / Collapse and unconsciousness after 1 hour of exposure / Death within 2-3 hours | |
| 1,600 ppm | Headache, nausea, and dizziness after 20 minutes of exposure / Death within 1-2 Hours | |
| 3,200 ppm | Headache, nausea, and dizziness after 5-10 minutes / Collapse and unconsciousness after 30 minutes of exposure / Death within 1 hour | |
| 6,400 ppm | Death within 30 minutes | |
| 12,800 ppm | Immediate physiological effects, unconsciousness / Death within 1-3 minutes of Exposure | |

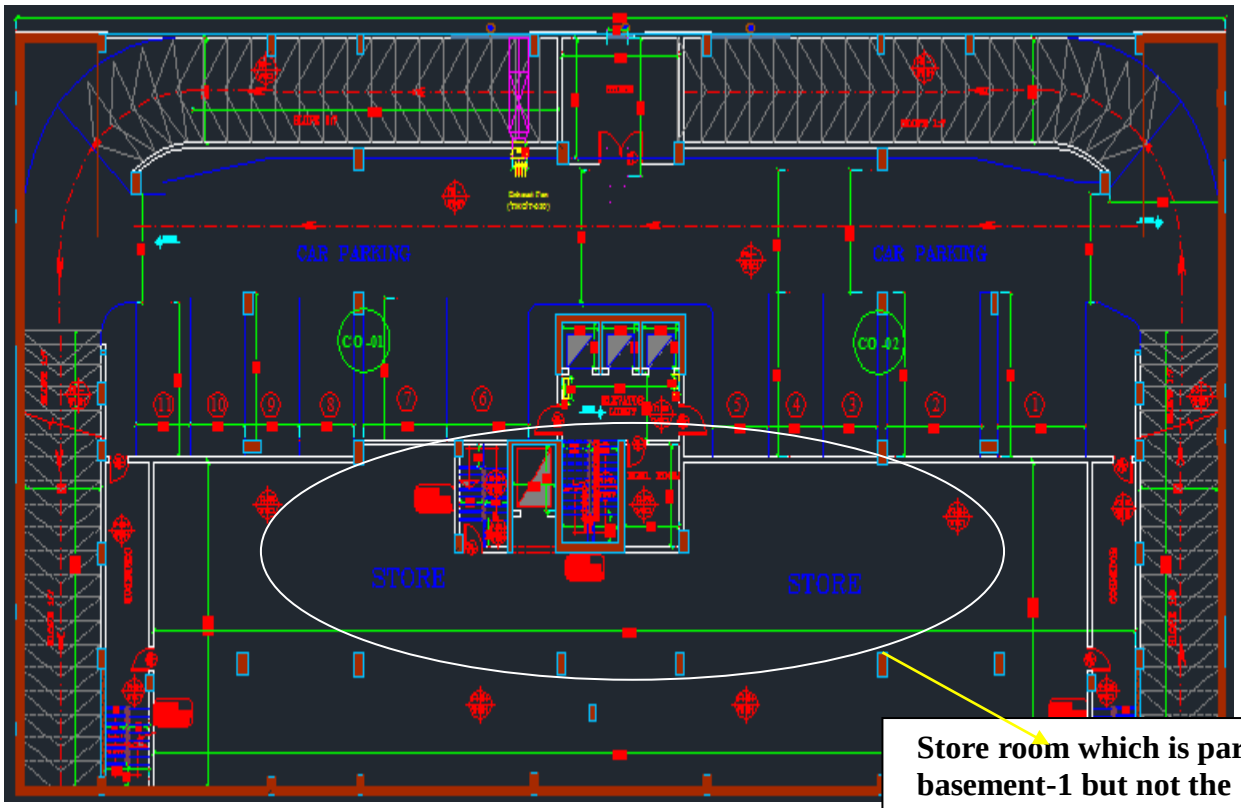
Carbon Monoxide (CO), one of the most toxic components of vehicle exhaust, is a significant safety concerns in parking structures. Gas-powered vehicles make use of these structures on a regular basis and emit CO.

**"II.CFD"**

Computational Fluid Dynamics (CFD) is the use of computer-based simulation to analyze systems involving fluid flow, heat transfer and associated phenomena such as chemical reaction. A numerical model is first constructed using a set of mathematical equations that describe the flow. These equations are then solved using a computer program in order to obtain the flow variables throughout the flow domain. Since the advent of the digital computer, CFD has received extensive attention and has been widely used to study various aspects of fluid dynamics. The development and application of CFD have undergone considerable growth, and as a result it has become a powerful tool in the design and analysis of engineering and other processes. In the early 1980s, computers became sufficiently powerful for general-purpose CFD software to become available. CFD deals with 4 basic steps modeling, meshing, solver and post processing.

**"III.MODELING AND MESHING"**

We know that CFD deals with 4 basic steps modeling, meshing, solver and post processing. The detailed plan view of auto-cad model is as shown in the figure below which gives the location of all ramps and their extract opening.



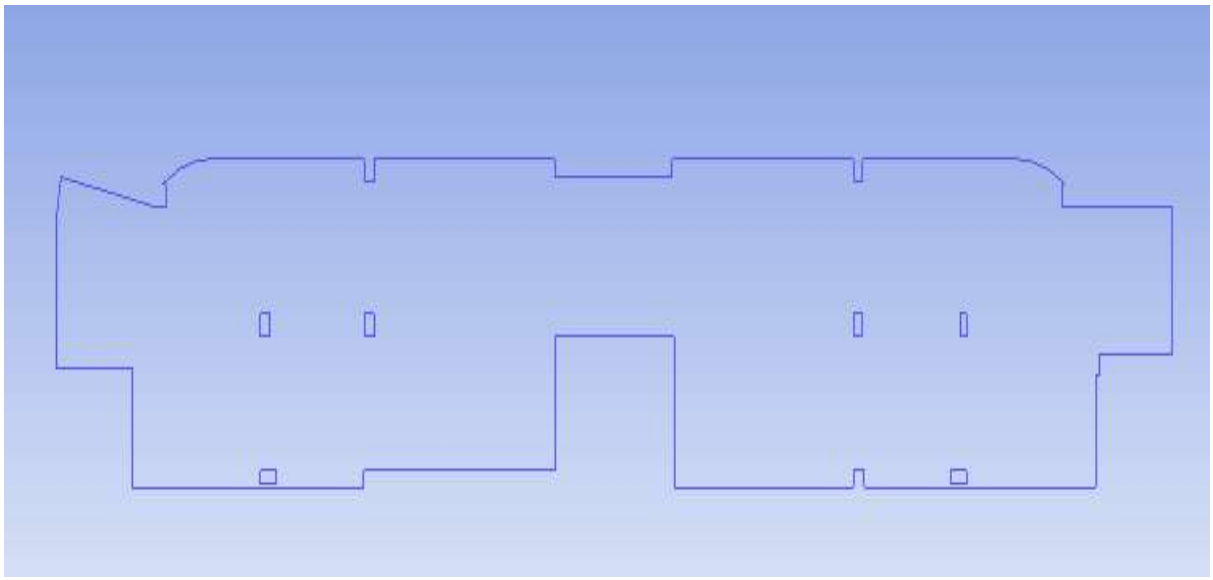

plan view of basement-1

The above figure show plan view of basement-1 which has two ramp openings entering from ground floor to lower level that is basement-1. It has one exhaust Fan with variable flow rates as per the requirement.

The main Aim of the project is to estimate the CO (carbon monoxide) levels in basement-1.

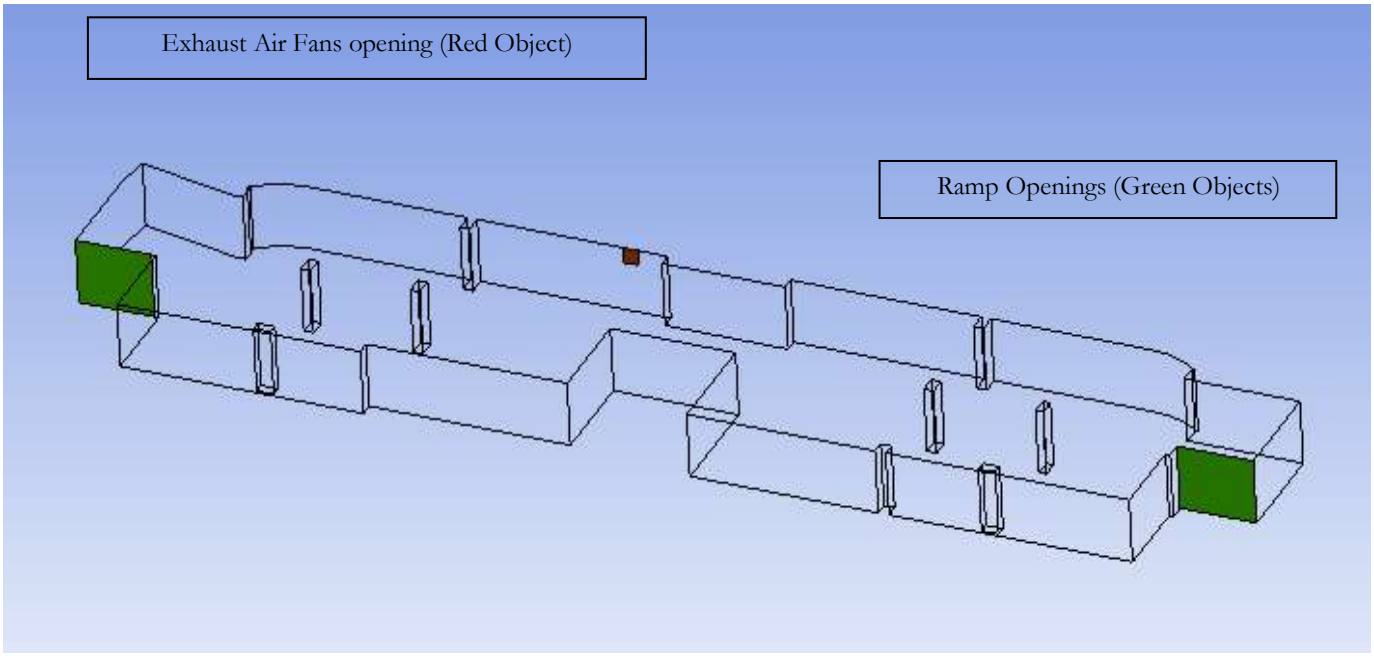
The model from AutoCAD was imported by selecting required zone in ACIS (sat) form and used in gambit software to complete the remaining portion of modeling.

**Two Dimensional View Of Basement-1 In Gambit Software**



2d layout of basement-1

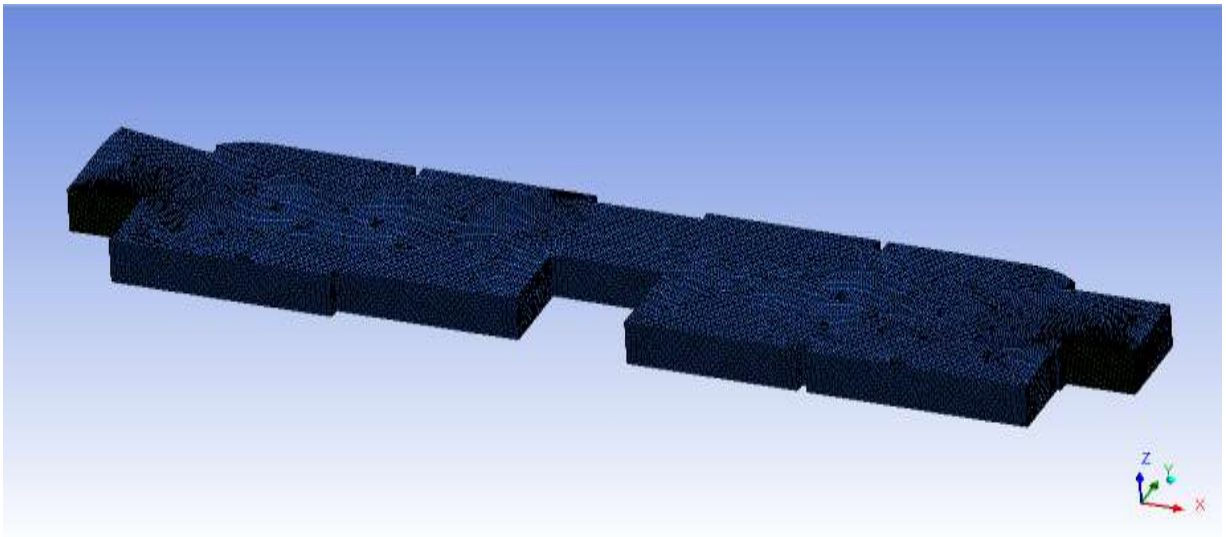
**Three Dimensional View Of Basement-1 In Gambit Software**




Position of Exhaust Air Fans Opening and Ramp Openings in (Basement-1)

**Mesh Generation Of Basement-1 In Gambit Software**

Mesh size of around 3.6 lakh nodes was created using tetrahedral scheme (unstructured).mesh and model images are shown in images below.



Mesh of basement-1

**BOUNDARY CONDITION**

Ramp dimensions and exhaust fan dimensions with their boundary conditions are shown in tables below. The usage of exhaust fan was limited by amount of co concentration present in the domain. The logic set by the client is also shown below. If CO is less than 30PPM(parts per million) then the fans will run at 30% speed and if it is between 30-50 PPM it will run at 60% speed and above 50PPM it will run at full speed.

Even with 30% of exhaust ACH(air changes per hour) was around 3, which is the minimum requirement for Basements with (Ramps) natural openings. So it satisfies the required flow rate conditions as per the standards.

| SUPPLY AIR | Ramp-1 | Ramp-2 |
|---|---|---|
| opening Length (m) | 3.525 | 3.575 |
| opening Height (m) | 3.000 | 3.000 |
| Actual area of supply ($m^2$) | 10.575 | 10.725 |
| Perimeter of opening | 13.05 | 13.15 |
| Hydraulic Diameter | 3.24 | 3.26 |

Boundary condition of supply air for ramp-1 and 2

| Exhaust Fans | Ex-left | |
|---|---|---|
| fan opening Length (m) | 0.71 | |
| Fan opening Height (m) | 0.720 | |
| Actual area of Exhaust Fan ($m^2$) | 0.5112 | |
| Perimeter of fan opening | 2.86 | |
| Hydraulic Diameter | 0.71 | |
| Each fan flow rate in m^3/h | 4710.0 | 30 percent |
| velocity | 2.559 | |
| Each fan flow rate in m^3/s | 1.308 | |

Boundary condition of Exhaust fan for ramp-1 and 2

Exhaust Fan Speed used initially was 30% of total flow rate available and if results are below 30PPM then it will be used and only in case of fire it will run at 100% speed.

| SR. No | Exhaust Fan Details | Flow Rate in CMS ( Each Fan) |
|---|---|---|
| 1 | Exhaust Fan-1 (30 % speed) | 1.308 |

The acceptance contaminant level criterion for parking garages is recommended in *ASHRAE 2007 Handbook*. According to ASHRAE, the main criterion is for car parks are the carbon monoxide levels are to remain below a designated peak value. At present the regulation is that *'Parking garages ventilation rate designed to maintain a CO level of 40mg/$m^3$ (35 ppm)for 1 Hour exposure, with a maximum of 130 mg/$m^3$ (120 ppm) for 15 minute exposure.*

The input to the project was the data and information provided by the client in form of 2-D Layout drawing of car parking of "Residential & Commercial Building (Base-1)"

The mathematical modeling for the analysis involves a few simplifying assumptions and care has been taken to be sufficiently conservative with the assumptions to meet the safety requirements. At first the analysis was done without placing any Jet Fans. This provides an indication of stagnant areas in the car park. The second analysis is done with Jet Fans operating at Normal Mode speed, placed & optimized so as to remove the stagnant areas and to reduce the concentrations of CO in the car park.

Pollution mode Simulation was done according to the following inputs and assumptions:

| **Parameter** | **Formula Used** | **Value** |
|---|---|---|
| Surface area of a horizontal plane in concerned geometry (**A**) | Input by client | 526.2$m^2$ |
| Height of the roof (**H**) | Input by client | 3.0m |
| Total Volume to be concerned (**V**) | **A**X **H** | 1578.6 $m^3$ |
| Per vehicle CO emitted (**CE**) (**$C_E$**) | (31.5+61)/2* | 46.25mg/sec |
| Total no. of vehicles in concerned geometry(**N**) | Input by client | 11cars |
| Total CO emitted (**$C_T$**) (8%) | **N**X **$C_E$** X10%** | 40.7mg/sec |
| Total CO concentration in concerned geometry(**$C_C$**) | **$C_T$** (Kg/sec)/**V** | 0.000000026 Kg/$m^3$-sec |

A vehicle emits CO in two conditions. When vehicle is being started (Cold Emission), it emits 61 mg/sec (3.66 g/min). In running state (Hot Emission), vehicle emits 31.5 mg/sec (1.89 g/min). We take average of both conditions. Refer to "2007 ASHRAE Handbook-HVAC Applications (SI)-Chapter 13".

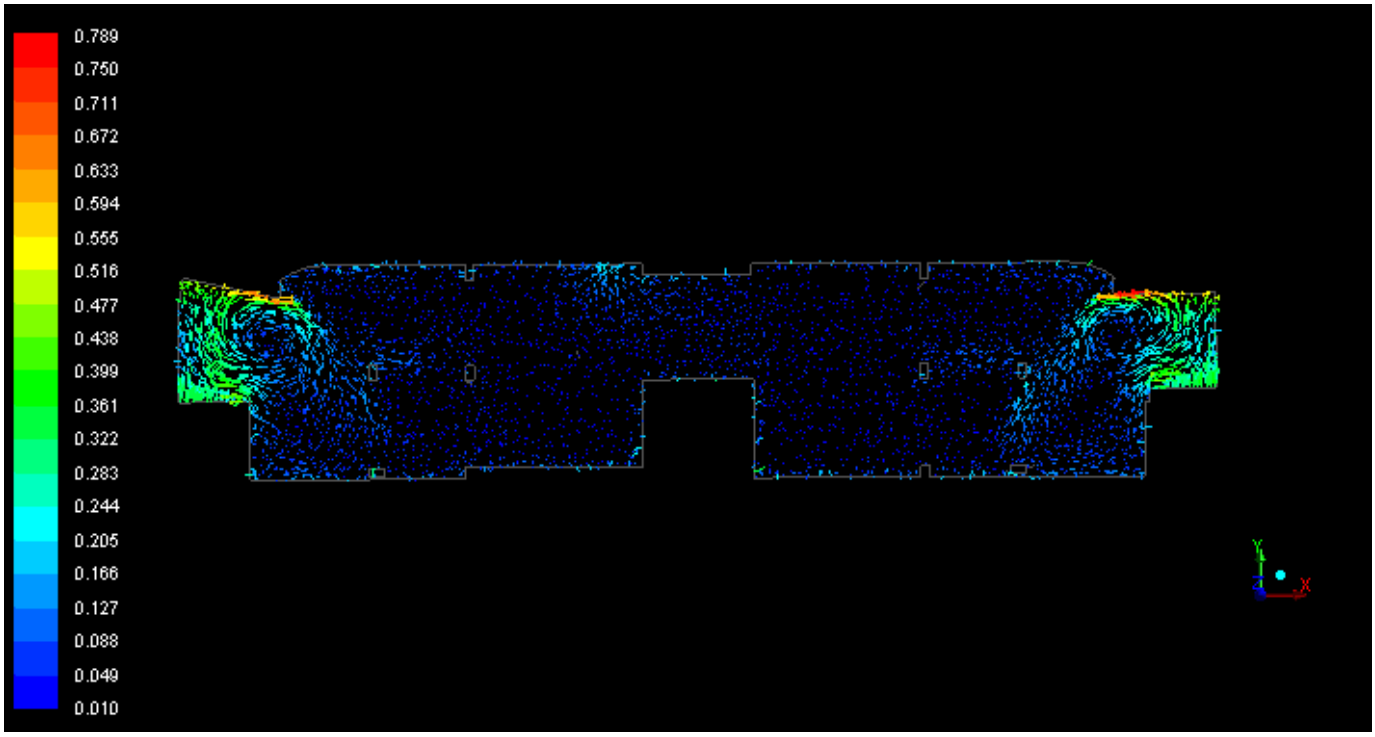
As per ASHRAE standard for apartment building type underground parking's, we have taken 10% of total vehicle have been considered in running conditions for simulation. Refer to "2007 ASHRAE Handbook-HVAC Applications (SI)-Chapter 13".

The boundary conditions applied were as follows

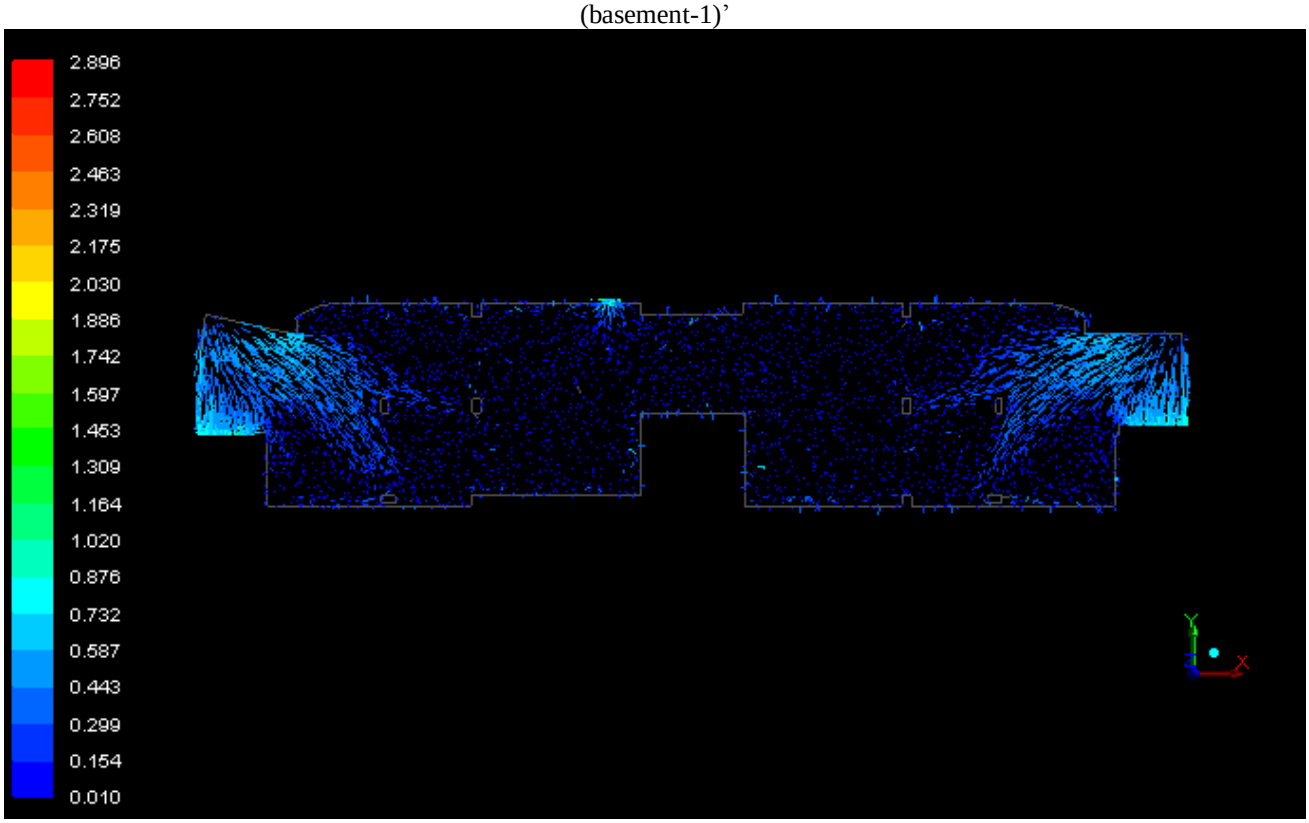
| Sr.no | Name | Boundary condition | Magnitude |
|---|---|---|---|
| 1 | Ramp | Pressure inlet | --- |
| 2 | Exhaust (@30% of total flow rate) | Velocity inlet | -2.6m/s |

**"IV. RESULT AND ANALYSIS"**

The Following results were obtained at average human height (z=1.5m) and jet fan height which is 0.3 below the celling level.



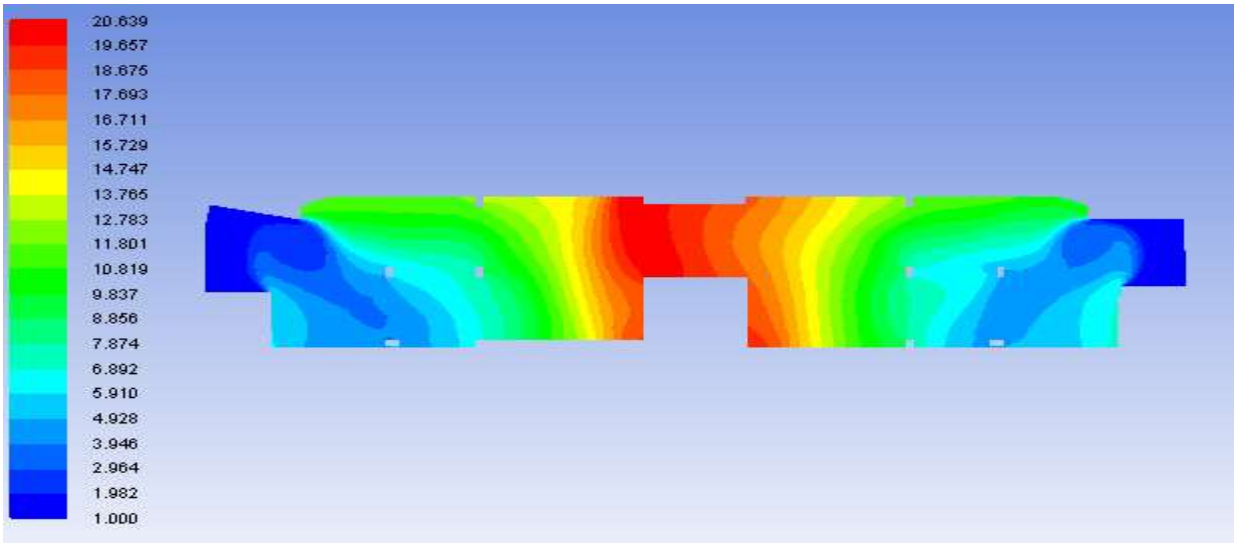

Vector plot of velocity magnitude (without jet fans) at 1.5 m from ground of 'residential & commercial building (basement-1)'




Vector plot of velocity magnitude (without jet fans) at jet fan height from ground of 'residential & commercial building (basement-1)'

Figure shows velocity contours at human height with max magnitude of 0.78 m/s and at jet 2.6m/s near the exhaust. Following figure shows the contours of CO concentration of the air without Jet Fans

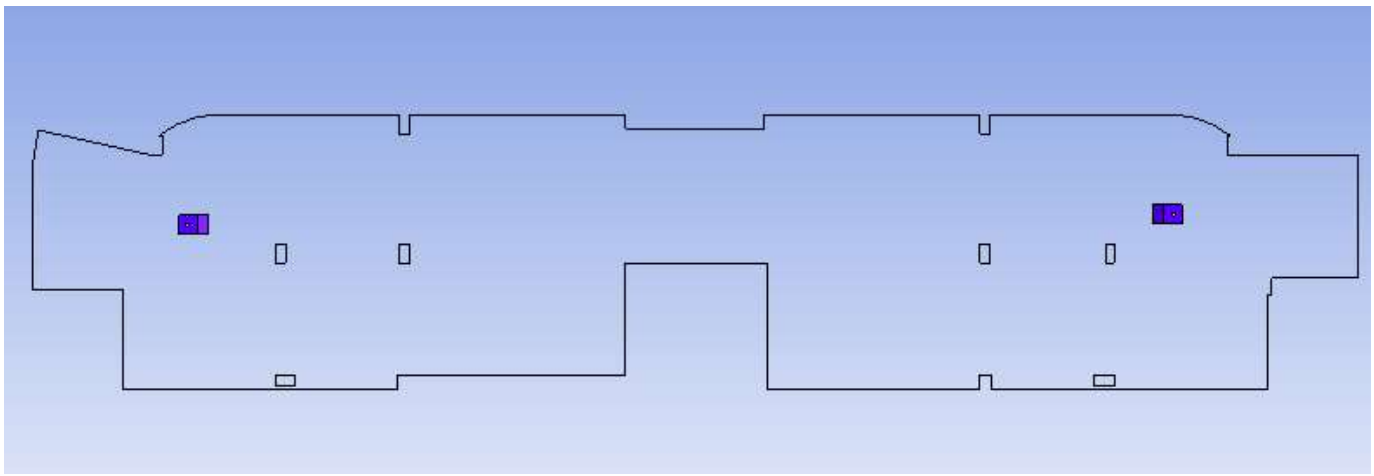
Highest is 21ppm, which is within the safe CO level for human for 1 hour exposure



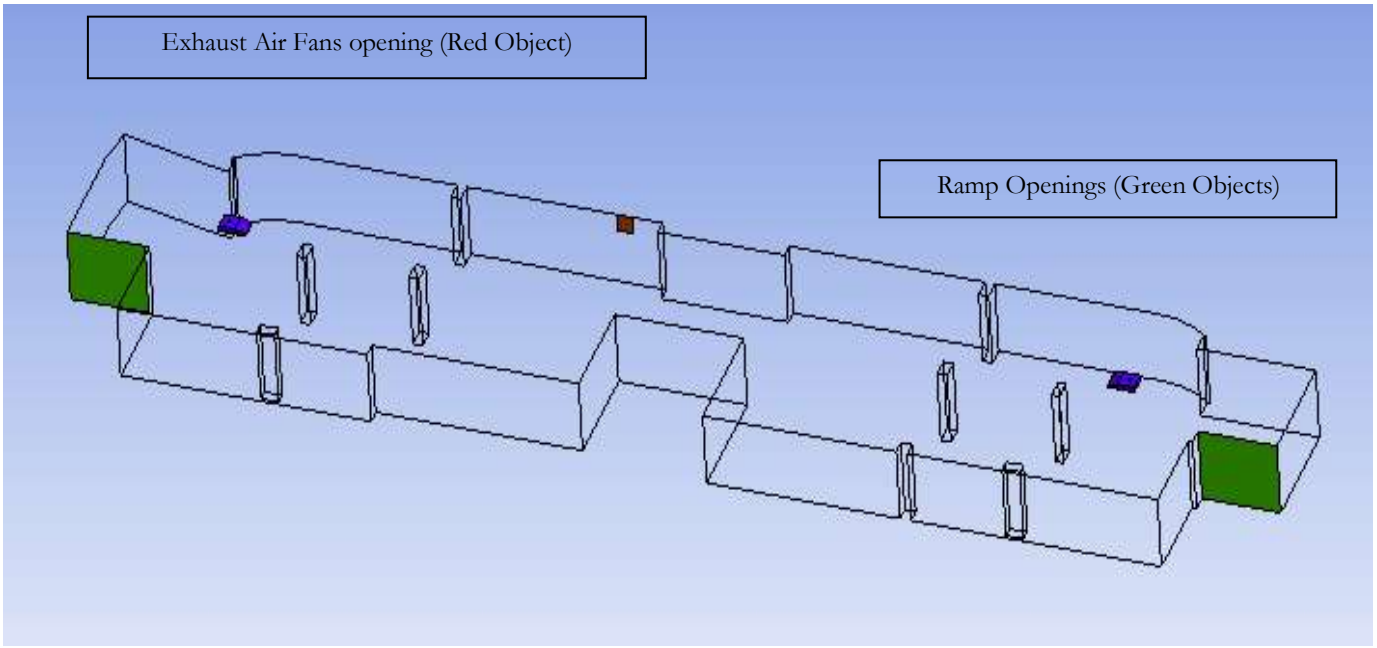

**[Mass fraction; ppm]**

Contour plot of mass fraction of co (without jet fans) at 1.5m from ground of 'residential & commercial building (basement-1)

- Now while we putting two jet fans in Basement-1 following results are derived.
- The model was added with 2 induction jet fans as per client's specification. Basically two types of jet fan models are available in market one Simple Impulse jet fans and other Induction fans. Impulse fans suck air from behind and throw out in forward direction , while Induction fans suck from bottom and throws out in forward direction.
- Then meshing was done in Gambit software. Mesh of around 4 lakh elements was generated. The model and its views are as shown in figures to follow.



2d layout of "residential & commercial building (basement-1) with induction fans"




position of exhaust air fans opening and ramp openings in "residential & commercial building (basement-1) with induction fans"

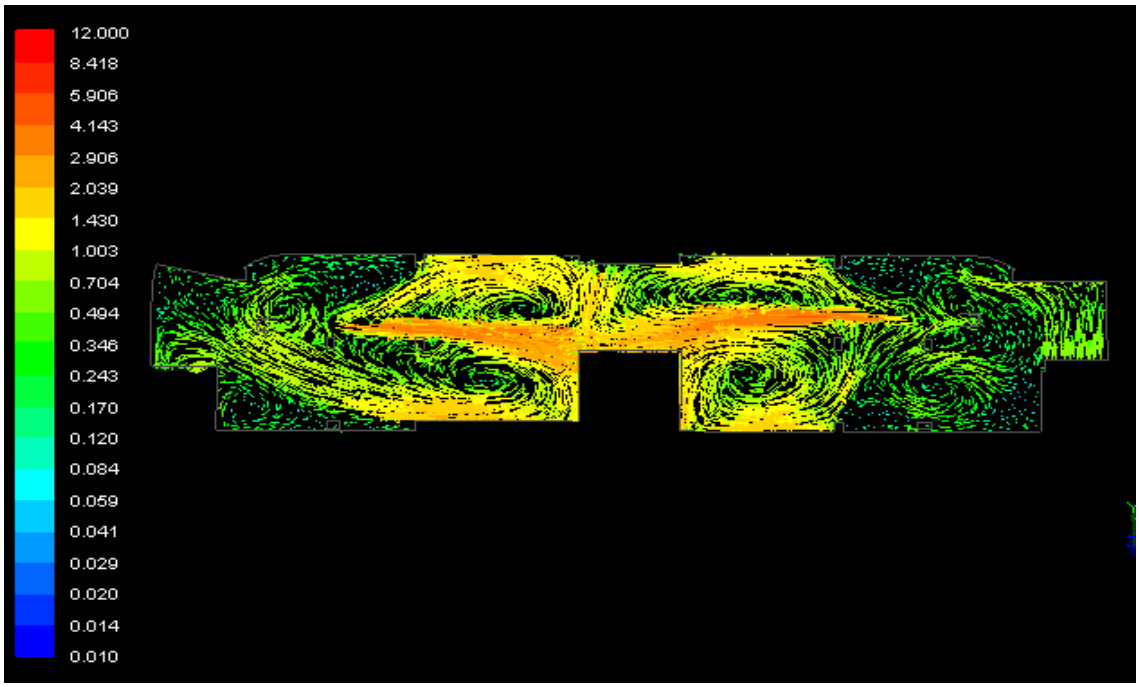
| Jet Fan Specifications | | | |
|---|---|---|---|
| **Type** | **No. in final configuration** | **Flow Rate in CMH (Each Fan)** | |
| IFHT 4/8-50N-C | 2(OFF) | Low Speed | High Speed |
| | | 3100 | 6138 |

jet fan specification

Above table shows jet fan specification with its flow rate. This jet will be switched of as CO level without jet are within permissible limits and this will be used only under circumstances of Fire. The remaining boundary conditions for exhaust fans will remain same.

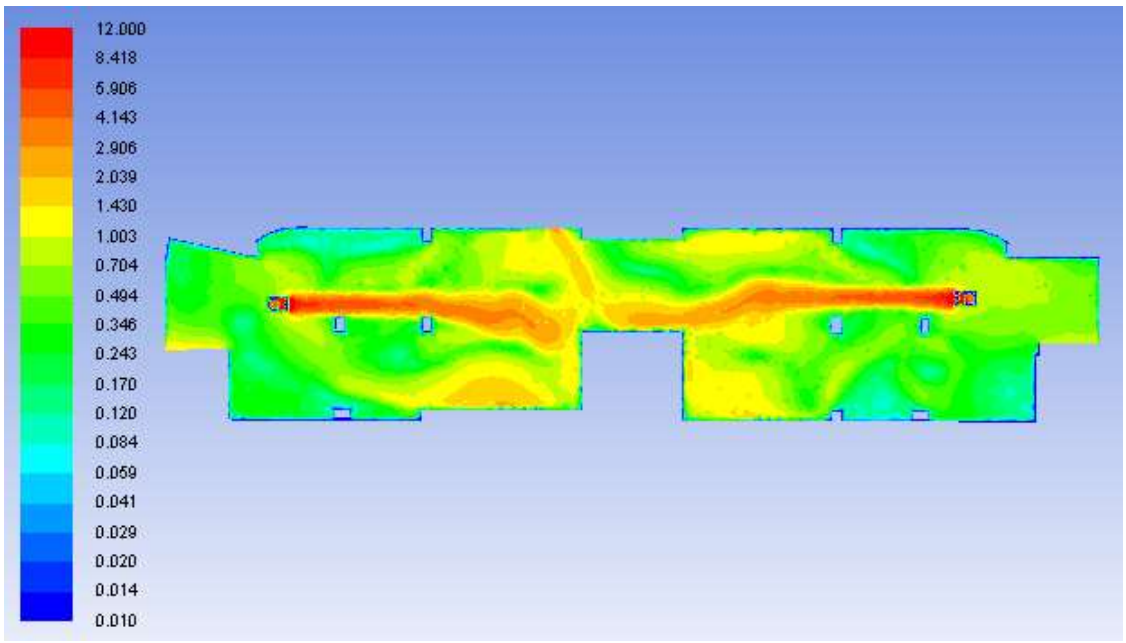
## CO Simulation Results with Jet Fans:

**Following figures shows the Velocity Vectors of the air with Jet Fans**

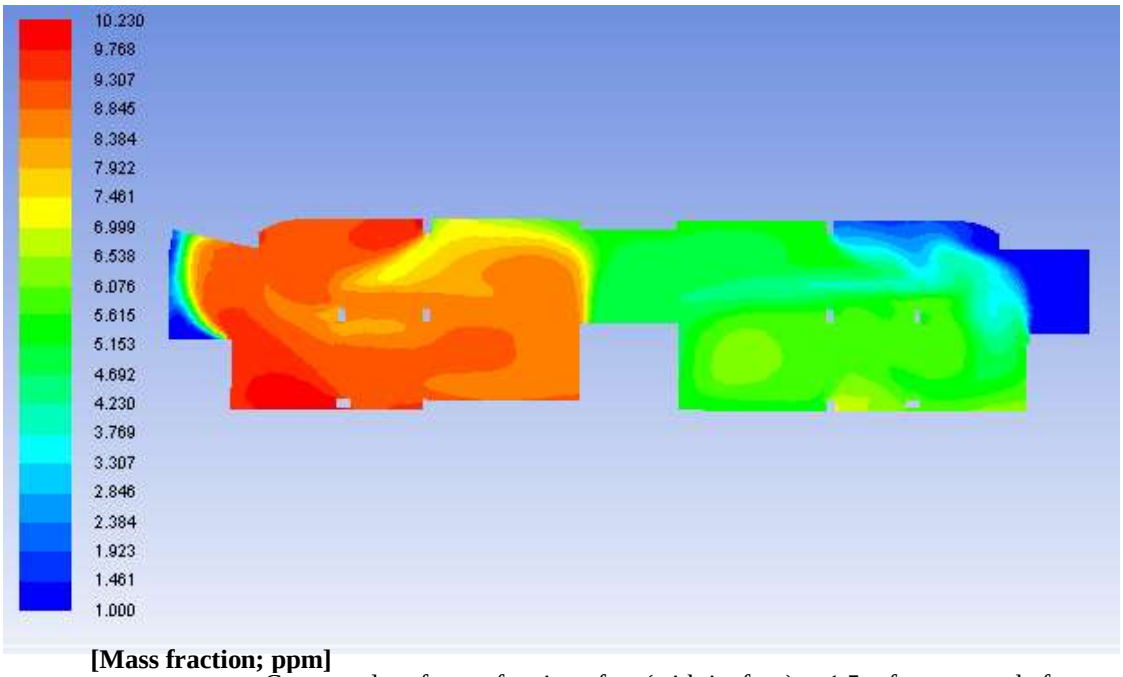



vector plot of velocity magnitude (with jet fans) at 1.5 m from ground of 'residential & commercial building (basement-1)

**Following figures shows the contours of Velocity of the air with Jet Fans**




Contour plot of velocity magnitude (with jet fans) at jet fan height from ground of 'residential & commercial building (basement-1)'




**[Mass fraction; ppm]**

Contour plot of mass fraction of co (with jet fans) at 1.5m from ground of 'residential & commercial building (base-1)'

**COMPARISON OF RESULTS IN TABULAR FORM WITHOUT AND WITH JET FANS**

| | **Without Jet Fans** | **With Jet Fans** |
|---|---|---|
| **No. of Exhaust Fans in Normal mode** | 01 | 01 |
| **No. of Induction Jet Fans** | N.A. | 02 |
| **Type of Jet fans** | N.A. | IFHT 4/8-50N-C |
| **Positions of the Jet fans** | N.A. | As shown in Fig 6.1 and 6.2 |
| **Air change rate in CO mode (at 30% exhaust speed) (ACH = Volume flow rate/ volume)** | 15700*0.3/1578.6=**3 ACH** | |
| **Highest CO concentration in PPM** | 21 | 10.3 |
| **Mode of Fresh Air Supply** | Natural | |
| **Mode of Exhaust Outlet** | Mechanical | |

**CONCLUSIONS:**

- The following conclusions can be drawn from the CFD simulations of Jet Fan Ventilation system for "Residential & Commercial Building (Basement-1)"as:
- Ventilation System in the car park area has been designed to reduce the CO level within the acceptable limits. This has been done with the help of CFD tool.
- All assumptions have been taken according to the client requirements and safety Standards.
- The CO concentrations from the CFD simulations, without using Jet Fans has been obtained as 21 ppm which is within the safest CO limit for human beings for 1 hour exposure.
- After conducting CFD analysis with placing and optimizing the two Induction Fans in car park area, maximum CO level found to be 10.3, which also with in permissible limits.
- As without using jet fans we are getting CO levels within permissible limits, Induction fans may be kept turned off. Induction fans will be used only when fire occurs .

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