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Computational Study of Indoor Pollutant Dispersion of an Apartment

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Abstract

Objectives: Indoor Air Quality (IAQ) is very important for the health of human beings. Proper ventilation of apartment can improve IAQ. The objective of the study is to analyse the pollutant dispersion behaviour inside the fluid domain at fixed boundary conditions. **Methods/Statistical Analysis**: A 2BHK apartment has been taken for study. The fluid domain of apartment has been simulated in the Computational Fluid Dynamics (CFD) software "ANSYS Fluent 16.2". Four inlet doors, four inlet windows, one outlet door, one outlet window and two ventilations from toilets were taken in the apartment. Seven inlet pollutant sources at the middle of the bottom of each enclosed area i.e. drawing/dining room, master bedroom, bedroom 1, kitchen, toilet 1 and toilet 2 have been considered. The methane gas is selected as the pollutant in the study. The k-epsilon (2 equations) model has been used and methane-air mixture has been taken for species transport. **Findings**: The methane mass fraction has been studied at different planes and at different locations of the domain. It was observed that the pollutant dispersion phenomena were varying at different locations and with this the highest methane mass fraction zone have been discussed. **Application/Improvements:** Simulated model can be useful in urban management and planning to find the best geometrical configurations of infrastructure, especially residential, to achieve proper and effective ventilations. Present model can also be more effective with environmental wind tunnel validations.

Keywords: Air Pollution Modelling, CFD, Environmental Modelling, Indoor Air Quality, Pollutant Dispersion, Turbulence Model

1. Introduction

IAQ (i.e. Indoor Air Quality) is a major concern for commercial, builder, residential and public buildings nowadays. Poor quality of indoor air may cause severe damage to the health, comfort, wellbeing and productivity of the building occupants. Mixing of unhealthy external particles known as pollutant with air creates a poor IAQ. Pollutant control can be obtained by proper ventilation to dilute the pollutant concentration. As we know, pollutant concentrations are inversely proportional to the ventilation rates. There are number of parameters that affect the pollutant dispersion such as geometrical configuration, pollutant sources, pollutant emission rate, air circulation etc. Therefore, it is imperative to conduct a proper scientific investigation to find out the effects of these parameters. However, the experimental studies are very costly due to initial setup cost and variation in the type of problems. Computational Fluid Dynamics (CFD) makes it possible to simulate with precision the airflow, heat flow and pollutant dispersion at much lesser cost. This work attempts to develop a CFD-based model for general IAQ studies adopting conservative contaminant emissions factors.

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Numerical simulations and modelling of Air Velocity and Ammonia Distribution in High-Rise Hog Building conducted by using Gambit and Fluent CFD software[1]. Experimental tests were conducted in a room and in a kitchen of an experimental house[2]. Then the numerical simulation of this problem was performed by considering experimental data as boundary conditions, apart from air leakage from wall being considered in numerical simulations. Computational simulation performed by using CFD Fluent commercial software, with k-epsilon turbulent models and studied the expiratory diseases[3]. VOC's and formaldehyde considered as pollutants and wooden material as the pollution sources[4]. For the simulation study, the CFD code PHONEICS was used[4]. Indoor radon concentrations studied which was dependent on radon production rate, ventilation specification and indoor conditions. For this simulation study, CFD software Fluent had been used[5]. Simulation study was conducted on SOLIDWORKS was used to define and model the geometry. Commercial CFD software Fluent was used. K-epsilon eddy model was used to study thermal conditions and airflow characteristics of the library[6]. Experimental measurements were done and CFD Fluent 6.2 had been used for validation of experimental results. Computer was considered as the pollutant source and heat generated by computer as pollutants[7]. Printer has been considered in the lab as heat source and pollution source[8]. A roof exhaust system was studies, combined roof exhaust and displacement ventilation systems. ANSYS Fluent 2009 had been used for studies. Numerical simulation was done by using CFD software Fluent. Indoor Air Quality Computer models (IAQ computer models) have been developed and increasingly used for predicting indoor air pollutant concentrations[9]. Dispersion phenomena have been discussed by many researchers[10–14].

For this project, a 2BHK+2T apartment has been selected. By Literature Review, VOCs (Volatile Organic Compounds), Radon, Formaldehyde Carbon di-oxide, Carbon-mono oxide etc. are some of the possible indoor air pollutants. For modelling the geometry of apartment (i.e. pre-processing), CFD software ANSYS Fluent 16.2 had been used. Dimensions had taken from the selected floor plan. For meshing, tetrahedral-mesh has been used. Appropriate boundary conditions had been taken.

2. Numerical Setup

A 2BHK+2T apartment has been considered as indoor fluid domain for pollutant dispersion study of apartment. In Figure 1 shows the top view of the floor plan of apartment. Figure 2 shows the isometric view of the selected apartment. In this apartment, there are two bedrooms, one drawing room, one dining room, one kitchen and two toilets. Master bedroom is having one inlet door and one window in north direction and an outlet window in its eastern wall. At this eastern wall, an internal door is connecting toilet-1 to master bedroom. Second bedroom, next to master bedroom have one inlet door and window in north direction. On the south wall of this room, an internal door is connecting the room with drawing room. Master bedroom is also connecting with an internal door to drawing room. Drawing room has outlet door at south-western wall. Dining room is connected with drawing room and has inlet door and window on the north side. Kitchen is connected to dining and drawing room through an internal door. Kitchen has one inlet door and one window in its north direction.

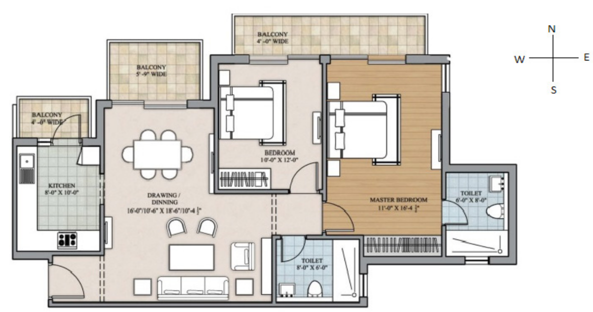


Figure 1. Top view of floor plan of the apartment[10].

Figure 2. Isometric view of the apartment[10].

The indoor fluid domain of the apartment has been made using ANSYS geometrical tool. Appropriate dimensions have been considered in the geometrical modelling. 3-dimensional fluid domain has been made on 1:1 scale of original dimensions. Figure 3 shows the top view of the modelled apartment. Four inlet doors, four inlet windows, one outlet door, one outlet window and two outlet ventilations have been modelled. Seven inlets for pollutant dispersion source have been modelled at appropriate locations.

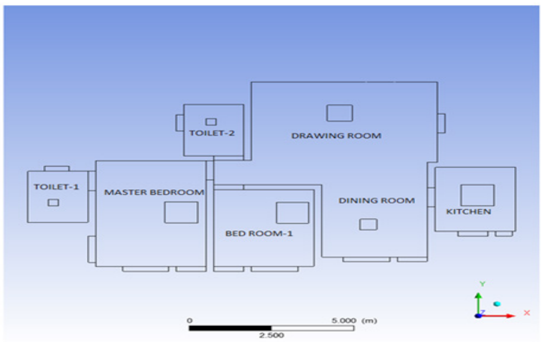


Figure 3. Wireframe top view of apartment.

Mesh has been created using Meshing tool of ANSYS software as shown in Figure 4. Tetrahedron meshing method has been applied. Fine meshing has been made for the quality simulation. Statistics shows that the number of nodes and total number of elements are 20271 and 99668 respectively. Four doors and four windows in the north direction have been named as inlet boundaries as shown in Figure 5. One outlet door, one outlet window and two ventilations from toilets have been considered as outlets of apartment modelled as shown in Figure 6. Seven sources of pollutants have been considered in each of the room, drawing room, dining room, kitchen and two toilets as shown in Figure 7. Remaining planes have been considered as walls.

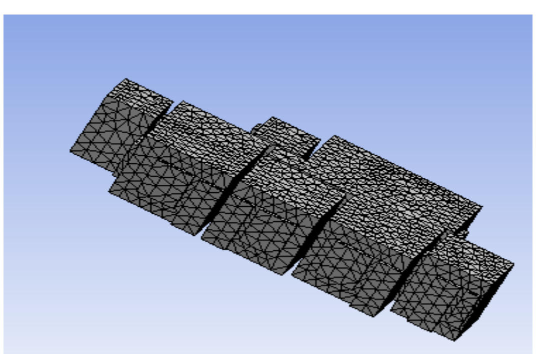


Figure 4. Tetrahedron meshing of apartment.

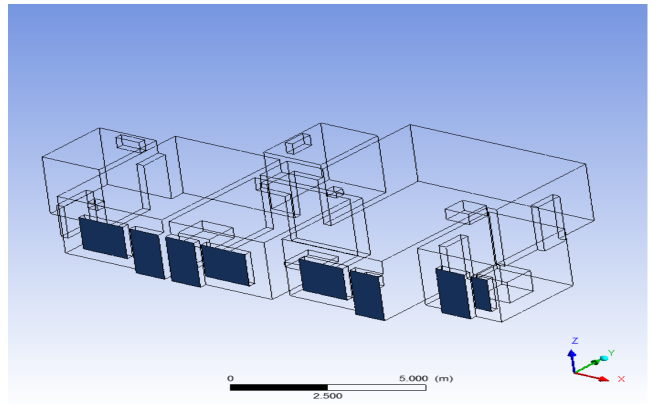


Figure 5. Air inlets of apartment.

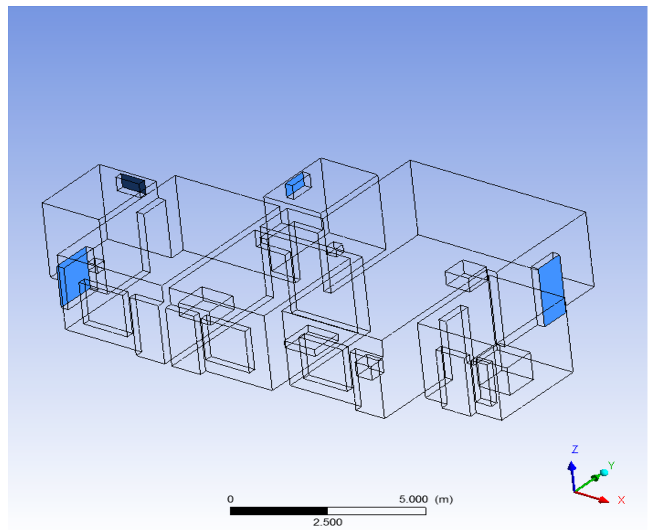


Figure 6. Pollutant mixed air outlet of apartment.

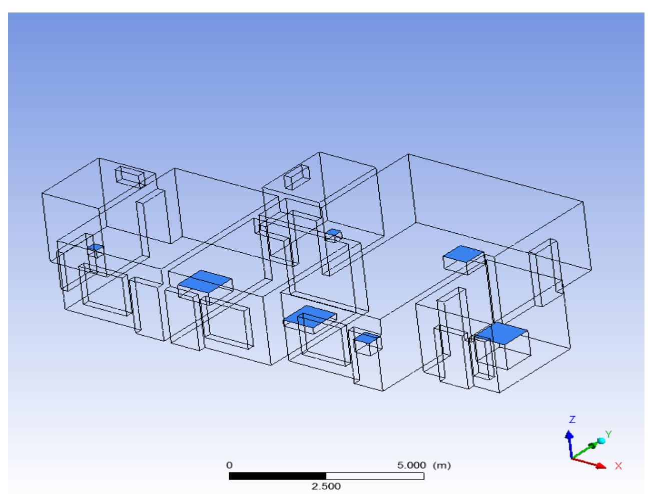


Figure 7. Pollutant inlet sources inside apartment.

The pollution dispersion simulation inside fluid domain has been done. The mesh of apartment's fluid domain has been imported in fluent software for numerical setup. In species transport model, methane-air mixture has been taken. K-epsilon (2 equation) turbulent model has been applied for pollutant dispersion study. For all the air inlets, 0.1 m/s velocity magnitude has been taken and air has taken as material. For all pollutant inlets, 0.05 m/s velocity magnitude has been taken. Mixture of the species material has been taken as 0.95 i.e. 95% methane and rest 0.05 i.e. 5% air. Outlets have been considered as pressure outlets. For numerical solution, gradient has taken as least square cell based, pressure as second order and momentum as second order upwind, turbulent kinetic energy as first order upwind and turbulent dissipation rate as first order upwind. The problem has given run of 1000 iterations and the curve is converging around 985 iterations. Result of flow streamline, velocity vector, pollutant contour and pollutant plots have been discussed.

3. Result Discussion

In this apartment, there are four inlet doors, four inlet windows, one outlet door and window and two ventilations. There are seven sources of pollutants as depicted earlier. Due to intermixing of pollutants and air, streamline flow is being created, which is under study. Air enters through door 1 and window 1 and mixes with pollutants and goes out through outlet window in master bedroom. For bedroom 1, air enters through inlet door 2 and window 2 and mixes with pollutants inside bedroom 1 and goes out through ventilation 1 of toilet 1, ventilation 2 of toilet 2 and outlet window of master bedroom. For dining/drawing room, air enters through inlet door 3 and window 3 and mixes with pollutants and goes out through the outlet door. From door 4 and window 4 of kitchen, air enters and mixes with pollutants and moves out through outlet door. These all streamline flows have been shown in Figure 8.

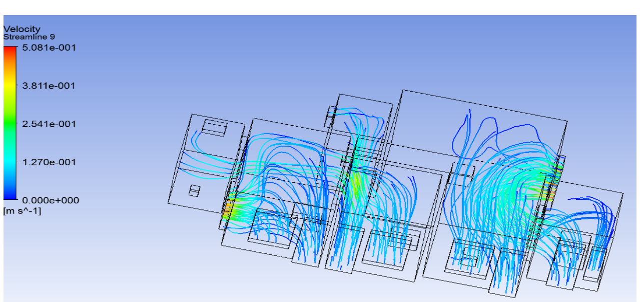


Figure 8. Streamline pattern of the apartment.

Contour of pollutants have been taken at four equidistant planes in z-direction, which has been taken along the height of the apartment. Figure 9 shows the contours of methane at 0.54864 m. in Figure 10 representing the contours of methane at 1.09728 m. in Figure 11 at 1.64592 m and Figure 12 at 2.19456 m in z-direction. Pollutant concentration in master bedroom is high near the internal door of hall and is increasing up to middle plane, subsequently decreasing near the next upper plane. In bedroom 1, pollutant concentration is higher near the south wall right corner of the room. In this area, pollutant pocket has been created and is not moving out of the room properly. In the dining/drawing room, most of the pollutants are concentrated in the middle of the drawing room. In the kitchen, mostly the pollutants are concentrated in the middle location but are not accumulating. Both the toilets are equipped with ventilation, so very less methane mass fraction has been observed here and are almost constant.

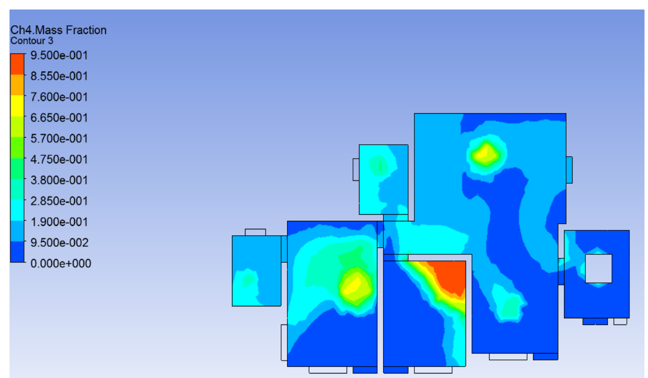


Figure 9. Contours of methane mass fraction at plane z = 0.54864 m from ground of apartment.

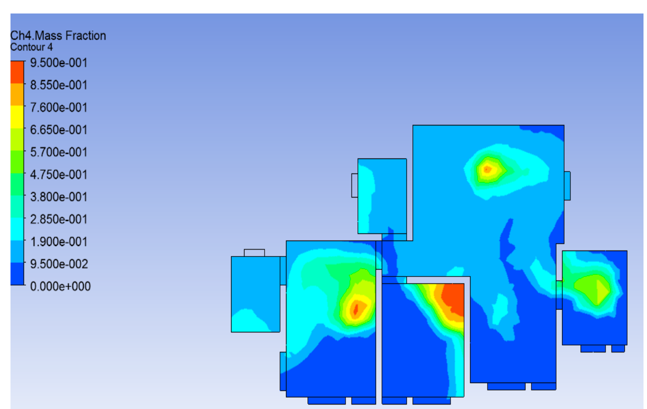


Figure 10. Contour of methane mass fraction at plane z = 1.09728 m from ground of the apartment.

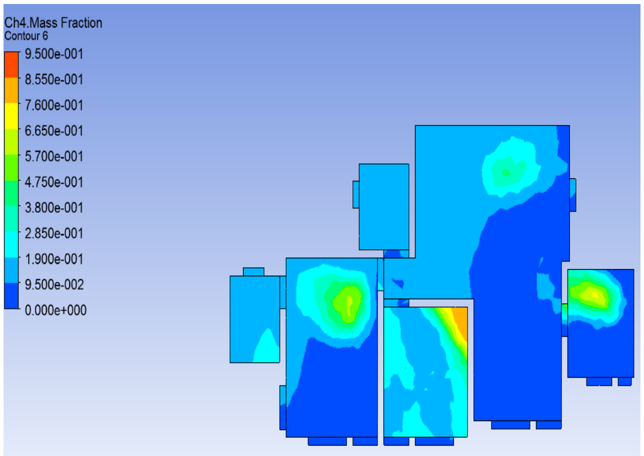


Figure 11. Contour of methane mass fraction at plane z = 1.64592 m from ground of the apartment.

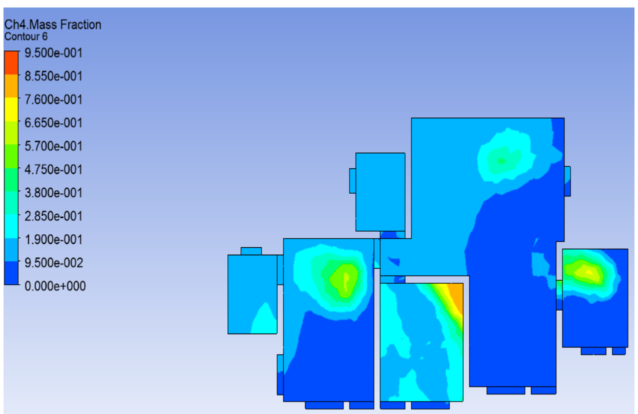


Figure 12. Contour of methane mass fraction at plane z = 2.19456 m from ground of the apartment.

Plots of the methane (pollutant) mass fraction have been drawn at different locations of the apartment. For toilet 1, it has been taken at line T1L1 and T1L2 and similarly for toilet 2 pollutants have been plotted at line T2L1 and T2L2. For master bedroom, methane mass fraction has been plotted at four lines MBL1, MBL2, MBL3 and MBL4. For bedroom 1, methane has been plotted at four lines i.e. BL1, BL2, BL3 and BL4. For drawing/dining room it has been plotted at four lines at HL1, HL2, HL3 and HL4. For kitchen methane mass fraction has been plotted at four lines i.e. KL1, KL2, KL3 and KL4. In Figures 13 and 14 represents all of these lines locations.

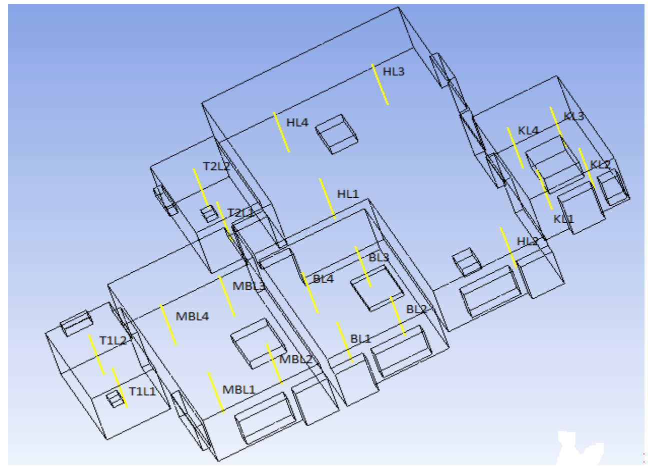
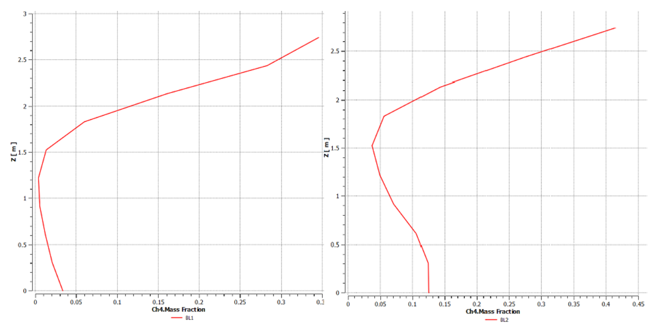


Figure 13. Location of twenty lines where methane mass fraction has been plotted.



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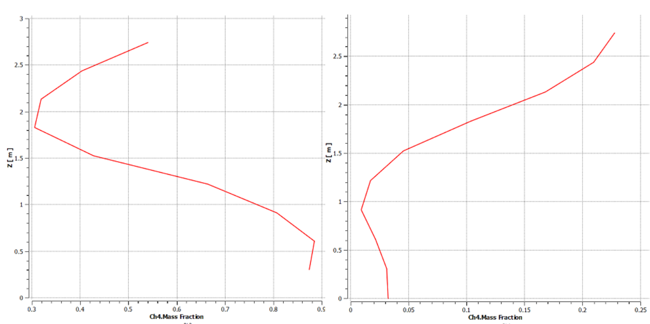
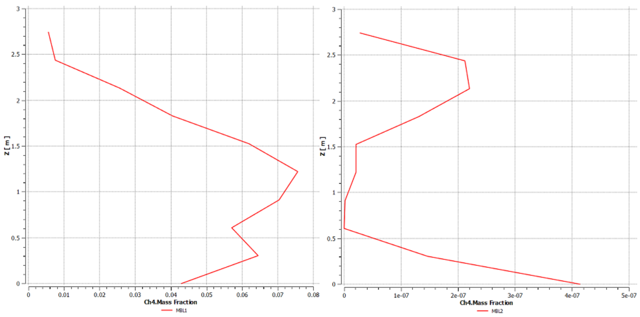


(b)

Figure 14. Methane mass fraction vs. height at lines (a) BL1 and BL2 (b) BL3 and BL4.

In bedroom-1, methane mass fraction is highest near the roof of the apartment. at line BL1, BL2 and BL4. At BL3, it is maximum at 0.6 meter from bottom to Z-direction in shows Figure 15.



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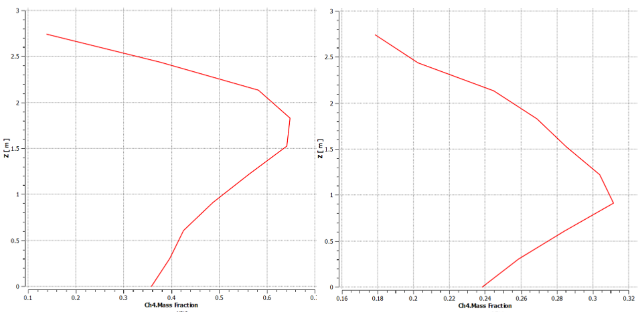
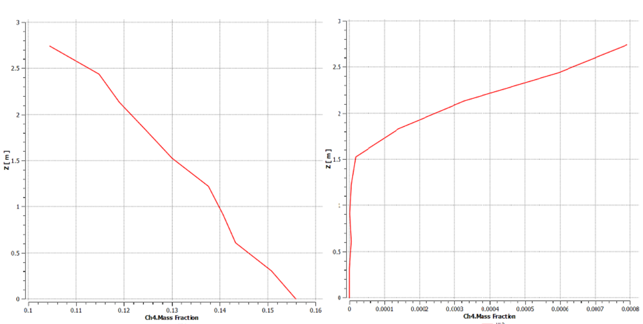


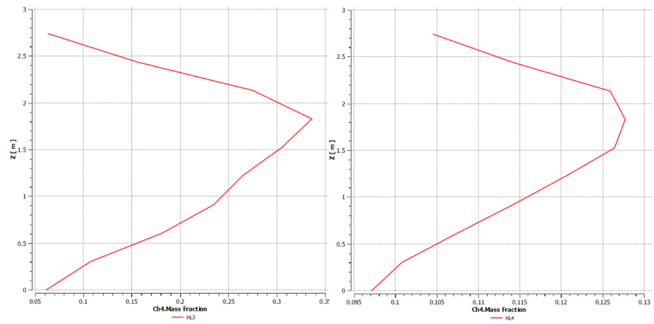
(b)

Figure 15. Methane mass fraction vs. height at line (a) MBL1 and MBL2 (b) MBL3 and MBL4**.**

In master bedroom, methane mass fraction has been noticed maximum at 1.25 meter from bottom. At line MBL2, it is noticed maximum at bottom and is decreasing up to height 0.6 meter. Post that, it is almost constant up to 1.55 meter. It is then slightly increasing between 2.2 meters to 2.4 meters. It then decreases gradually up to entire height. At line MBL3, it is noticed maximum at 1.8 meter from bottom and at MBL4; it is maximum at 0.85 meter is shown in Figure 16.



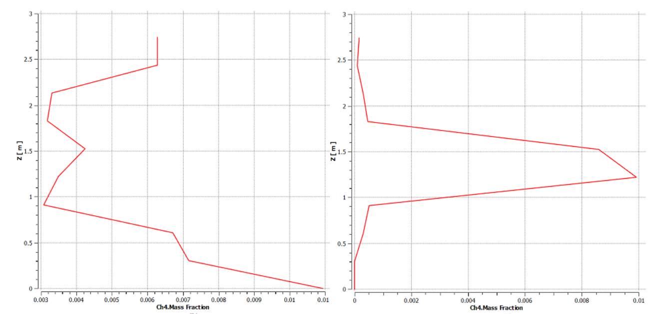
(a)



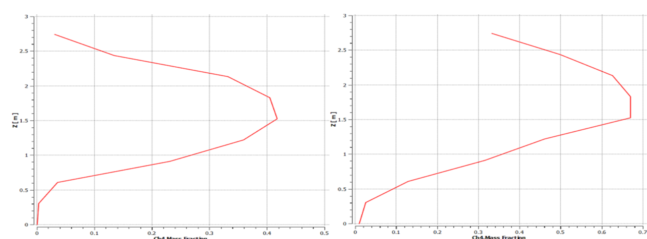
(b)

Figure 16. Methane mass fraction vs. height at line (a) HL1 and HL2 (b) HL3 and HL4.

In drawing/dining room at line HL1, methane mass fraction is maximum at bottom. At line HL2, this is maximum at the roof. At HL3, it is maximum at 1.8 meter from bottom. At HL4, it is maximum at 1.8 meter from bottom in shows Figure 17.



(a)



(b)

Figure 17. Methane mass fraction vs. height at line (a) KL1 and KL2 (b) KL3 and KL4.

In kitchen at line KL1, methane mass fraction is maximum at bottom. At line KL2, it is maximum at 1.2 meter from bottom. At line KL3, it is maximum at 1.5 meter. At line KL4, it is maximum and constant between 1.5 meter to 1.8 meter in Z-direction in shows Figure 18.

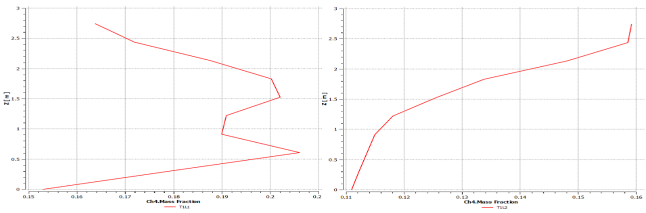


Figure 18. Methane mass fraction vs. height at line T1L1 and T1L2.

In toilet 1, at line T1L1, methane mass fraction is maximum at 0.6 meter from bottom and line T1L2, it is observed maximum near the roof in shows Figure 19.

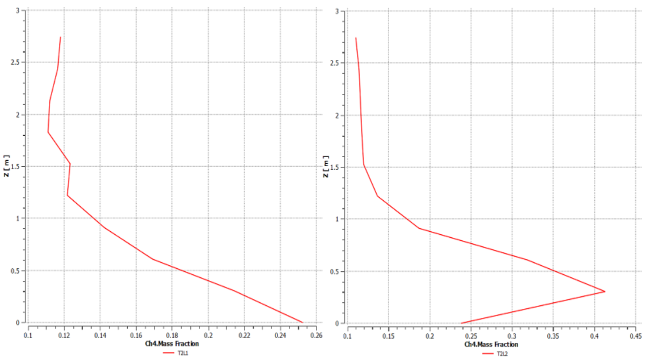


Figure 19. Methane mass fraction vs. height at line T2L1 and T2L2.

In toilet 2, at line T2L1, methane mass fraction is observed maximum at bottom and at line T2L2, it is maximum at 0.3 meter from bottom.

4. Conclusion

The pollutant dispersion inside an apartment has been studied to find out the zone with most pollutant accumulation inside an apartment with the given inlet and outlet conditions and pollutants. For this study, CFD software ANSYS Fluent 16.2 has been used. The pollutant dispersion has been studied through the contours of pollutant mass fraction at different plane locations and plots of methane mass fraction vs. height at different locations of line in the apartment. Through these observations, it has been found out that mostly all the pollutants are completely washing out from apartment but the south western corner of bedroom 1 is having the pollutant zone that are not washing out fully. By this type of study, it is easy to find out the pollutant dispersion inside apartment at given boundary conditions and helps in finding out the ventilation is proper or not. If ventilation is not proper, then design and geometry can be changed for getting the proper pollutant dispersion inside an apartment with the same boundary conditions. In future different type of pollutants can be studied in the apartment with different pollutant sources.

5. References

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