FOSSEE, IIT Bombay
OpenFOAM Case Study
Project 16 April, 2024

Impact of Air Conditioning on Airflow in the Nuclear Laboratory at IIT Bombay

Rohan Sheth

Indian Institute of Technology, Bombay

April 2024

Abstract

This case study explores the effects of air conditioning on airflow dynamics within a nuclear laboratory at the Indian Institute of Technology Bombay (IIT Bombay). The primary objective is to evaluate how air conditioning and the position of an extra window influence factors such as ventilation rates and the duration air remains within the lab environment. Through analyzing the current ventilation setups and integrating air conditioning systems, the study aims to enhance environmental conditions critical for nuclear research and ensure adherence to safety protocols, with a particular emphasis on minimizing air residence time.

1. Introduction

Nuclear laboratories require precise environmental management to safeguard the health and safety of workers and to preserve the accuracy of experiments. Effective ventilation is essential in these settings for sustaining good air quality and efficiently eliminating hazardous substances, particularly when handling radioactive materials. The implementation of air conditioning (AC) systems could potentially modify the dynamics of existing ventilation systems, possibly shortening the time air spends circulating within the lab. This case study is designed to explore the influence of AC on air residence time in a nuclear laboratory environment, assessing whether these changes enhance or compromise the laboratory's safety and operational standards.

Figure 1 (a) Front view of wall at backside

Figure 2 (b) Front view of wall with door

2. Problem Statement

The figure above presents views of the Nuclear Lab. The images show that the nuclear laboratory at IIT Bombay is outfitted with state-of-the-art facilities for research in nuclear physics and materials science. The lab's ventilation systems are carefully designed to manage air circulation, eliminate pollutants, and restrict the dispersal of radioactive materials. Although the existing ventilation is effective, there is increasing interest in adding air conditioning (AC) systems to enhance the comfort levels of staff. Nonetheless, the effects of AC on air residence time and the overall effectiveness of the ventilation system require further study. In the first image, a window is visible, while a door can be seen in the second. A Computational Fluid Dynamics (CFD) analysis using Ansys 2024 R1 was conducted to evaluate this setup with the AC turned on, comparing air residence times with and without the AC system in operation.

3. Governing Equations

SimpleFoam Solver :

The Navier-Stokes equations serve as the fundamental principles for modeling single-phase fluid dynamics, and when addressing turbulence, the k-epsilon model is commonly employed. Here are the primary equations governing each:

$$\frac{\partial(\rho\mathbf{v})}{\partial t} + \nabla\cdot(\rho\mathbf{v}\mathbf{v}) = -\nabla p + \nabla\cdot\tau + \rho\mathbf{g}$$

Where:
P is the Pressure.
τ is the stress tensor
g is the gravitational acceleration vector

The necessary equations used for calculating the turbulence model are:

$$\boldsymbol{k} = \frac{\mathbf{3}}{\mathbf{2}}(\boldsymbol{U}_{\infty}\boldsymbol{I})^{\mathbf{2}}$$

$$\boldsymbol{I} = \mathbf{0.16}(\boldsymbol{Re})^{-\frac{\mathbf{1}}{\mathbf{8}}}$$

$$\boldsymbol{\epsilon} = \frac{\mathbf{0.0164}\cdot(\boldsymbol{k})^{\mathbf{1.5}}}{\mathbf{0.007}\cdot\boldsymbol{L}}$$

Where:

k is turbulent kinetic energy,
I is the turbulent intensity
$\boldsymbol{\varepsilon}$ Turbulent dissipation rate
L is the inlet length
$\boldsymbol{U}\infty$ is a characteristic velocity scale

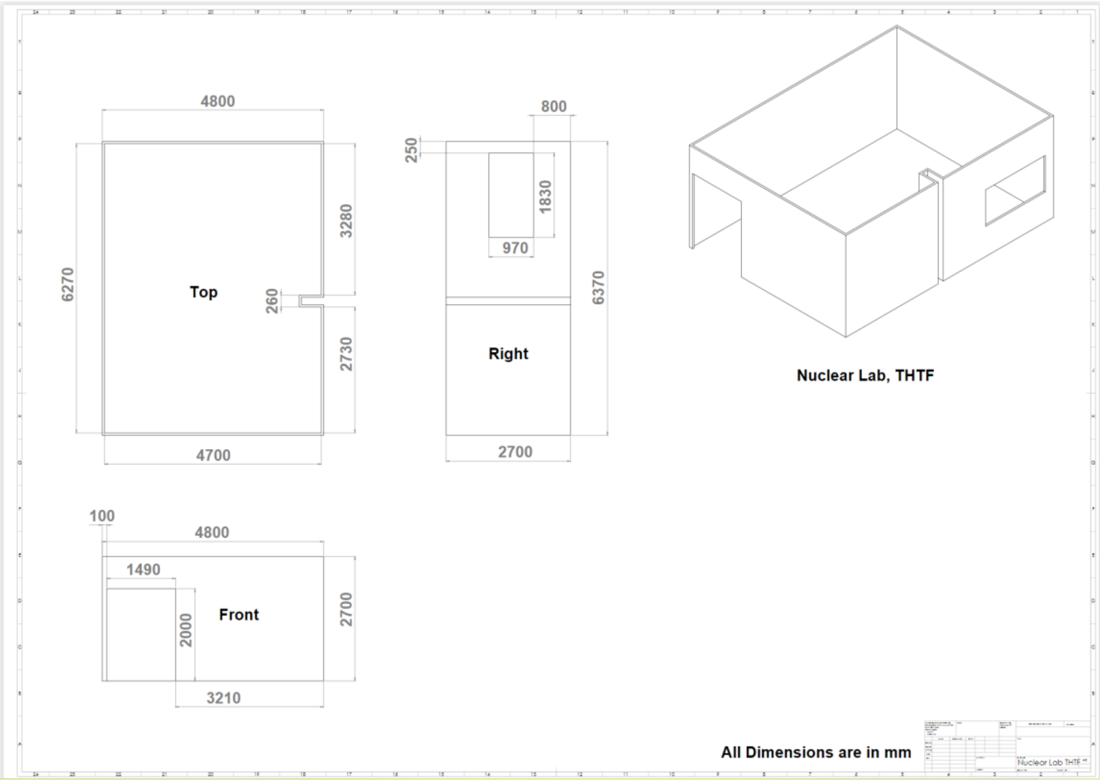
ArtFoam solver :

$$\frac{\partial S}{\partial t} + \nabla \cdot (\mathbf{S}) - \nabla^2 (S) = \text{Source}$$

Where S = air residence time.

4. Simulation Procedure

4.1. Geometry and Mesh



The geometry for the study was developed using SpaceClaim modeling software. To evaluate the impact of an air conditioner on room airflow, two different geometries were created: one featuring a single window, and another incorporating two windows and one air conditioner.

The mesh for these geometries was generated using Ansys Fluent 2024. A Cartesian meshing method was employed, with an element size set at 0.085 meters. This configuration resulted in a mesh comprising 124,465 control volumes and 132,602 nodes within the geometry.

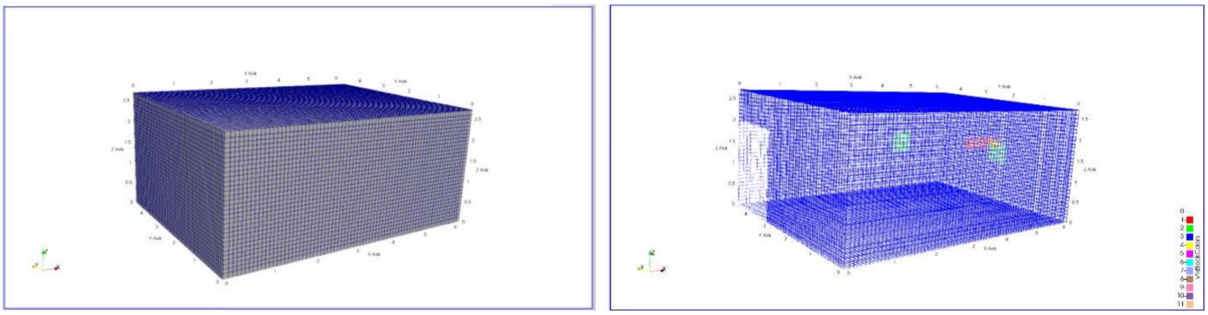


Figure 3 Cartesian mesh & wireframe model of geometry

4.2. Initial and Boundary Conditions

For Solving SimpleFoam :

- **Velocity** : door inlet velocity : 0.1667 m/s ; Ac inlet velocity : 3 m/s at 45 degrees; at walls noSlip ; at windows zeroGradient boundary conditions
- **Pressure :** At windows fixed value 0(gauge) ; for all other boundaries zeroGradient.
- **Turbulent kinetic energy:** At door inlet turbulent Intensity Kinetic Energy Inlet with Intensity 0.0435 and value 7.98e-05 m2/s2; at ac inlet turbulent Intensity Kinetic Energy Inlet with Intensity 0.0419 and value 0.0237; at windows zero gradient; at walls kqRWallFunction.
- **Turbulent Dissipation rate:** At door inlet turbulent Mixing Length Dissipation Rate with mixing length of 2m and value 8.35e-07 m2/s3; at ac turbulent Mixing Length Dissipation Rate with mixing length of 0.15m and value 0.05699 m2/s3.

For Solving artFoam :

- **Velocity:** Steady state velocity calculated by SimpleFoam solver
- **Air residence time:** at ac and door inlet fixed value 0s; at windows and walls zeroGradient boundary condition.

4.3. Solver :

Two solvers have been used to get the value of air residence time, these two solvers are simpleFoam and artFoam. SimpleFoam is the default steady-state and turbulent solver of OpenFoam, while artFoam solver was developed specifically for calculating air residence time in this case.

While using simpleFoam solver K-epsilon turbulence model is used to solve a velocity profile. Then a steady state solution of velocity is used in artFoam as an initial condition and artFoam solver is used for ART.

For the simpleFoam solution endtime is kept as 4000s and artFoam is the 2000s in both solvers we get converged solutions.

5. Methodology of ML for calculating ART in the nuclear lab :

The methodology for assessing air residence time (ART) in the nuclear laboratory involves two primary phases, tailored to the laboratory's specific requirements. Initially, the aim was to determine the ART without installing an air conditioning (AC) system, utilizing OpenFOAM for computational fluid dynamics (CFD) simulations. However, conducting these simulations with exhaust configurations proved to be computationally intensive. Consequently, a collaborative effort among a group of four members was undertaken to devise an alternative solution using AI and machine learning (ML) algorithms.

The first phase encompassed conducting CFD simulations in OpenFOAM to estimate the ART for various exhaust positions. These simulations provided the groundwork for the subsequent development of an AI-ML model aimed at calculating ART.

A total of 16 simulations were conducted in OpenFOAM to serve as the dataset for ML training, with an additional 4 simulations reserved for testing purposes. Through rigorous ML training and testing procedures, the developed model demonstrated an impressive accuracy rate exceeding 90 percent. Leveraging the insights garnered from this model, it became feasible to predict ART at any given coordinates within the specified range on the designated plane, situated 1.35 meters above the base. The coordinate range spans from (4.752,0,1.35) to (5.62,4.8,1.35), as delineated in the provided geometry files.

Subsequently, post-determination of the ART without AC installation, an air conditioning system was introduced to mitigate ART. A comparative analysis was then conducted to evaluate the efficacy of exhaust versus air conditioning strategies in achieving the desired ventilation outcomes.

6. Results and Discussions :

The main objective of this study is to see the effect of air conditioners in nuclear lab additional to the existing window and how airflow and air resident time is affected by it.
For that, we will use a simulation of the art of a Nuclear room consisting of only one window at the back face to compare it with results and effect of AC certain simulation results and comparison is shown further.

SimpleFoam solutions :

SimpleFoam resolves governing equations to determine velocity distributions across a given geometry. It was executed for two scenarios: one involving a nuclear room with air conditioning (AC) and the other without. Streamlines were derived using the paraFoam post-processing tool at various elevations for both cases. These were then compared to assess how the supplementary airflow influences velocity contours.

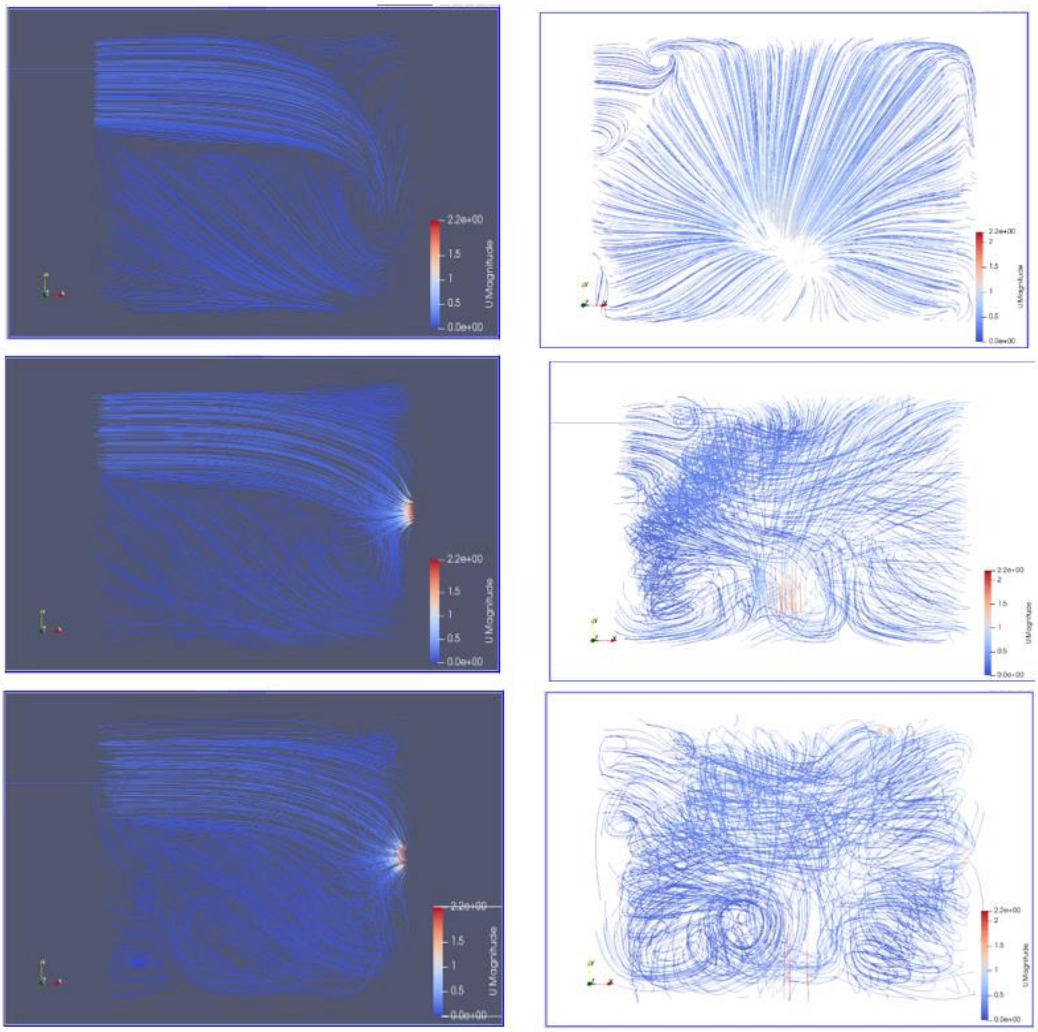
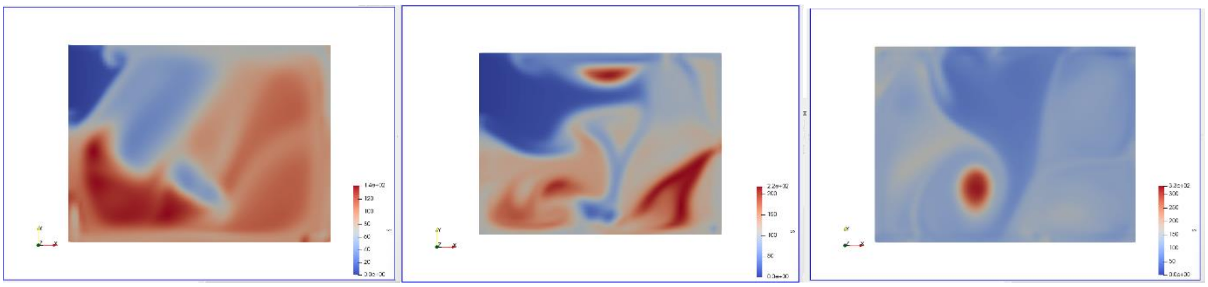


Figure 4 - Velocity streamlines for without ac(left) and with ac(right) at 0.2m, 1.35m and 2.4m height

ArtFoam solutions :



Art at different elevations for Nuclear_room with AC

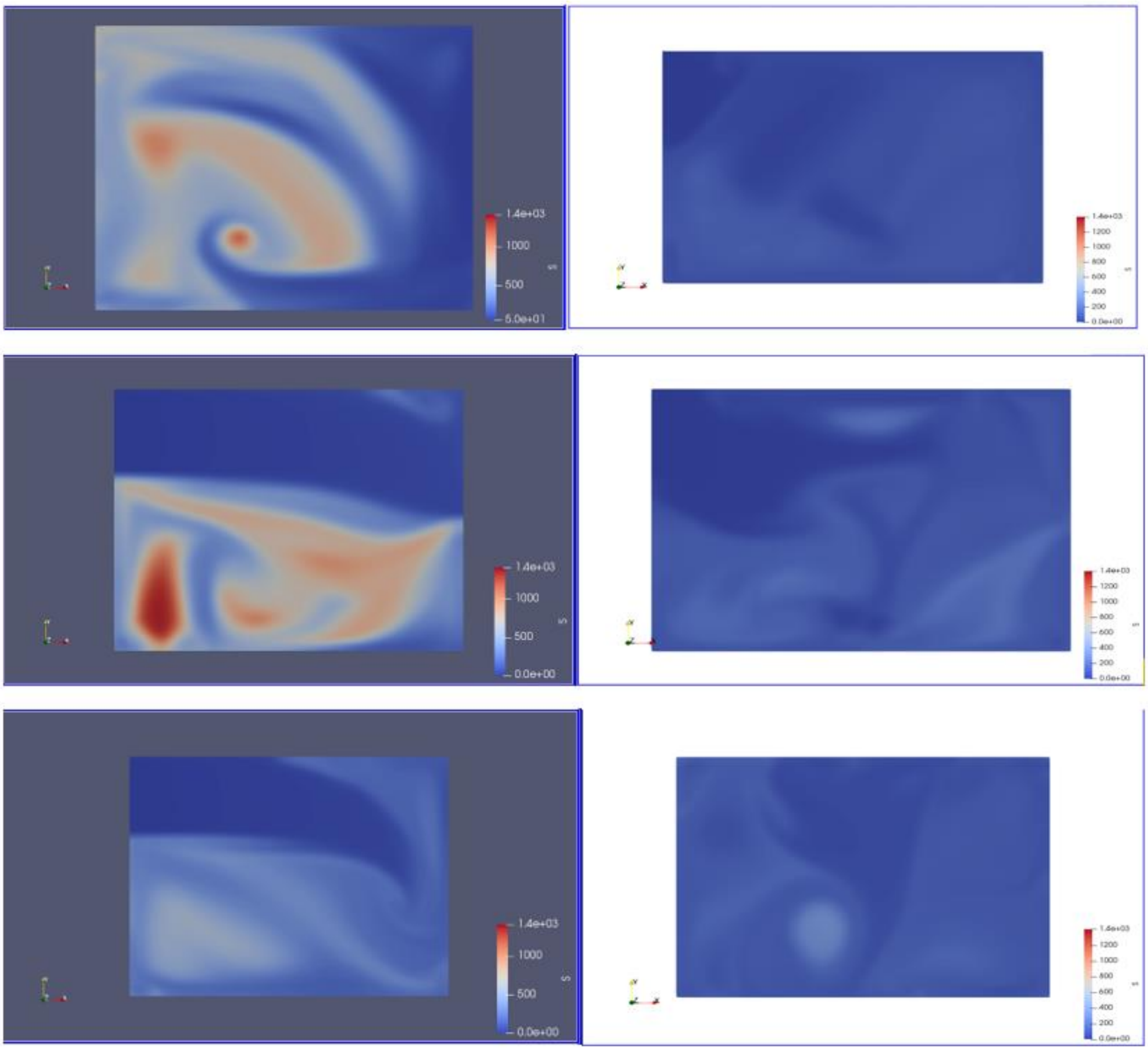


Figure 5 - ART contours without ac(left) with ac(right) at 0.2m, 1.35m , 2.4m height

As we can see from the comparison of velocity and art for both of the cases we can say that a inclusion of AC will lead to less ART compared to without AC case. As Ac provides additional flow of air in the room air gets displaced more quickly and reduces art time. A comparison of art time values for both cases is shown in the table :

Height of plane	ART(s)	ART(s)
	With only one window	With two windows and AC
0.2	790	140
1.35	1300	220
2.5	1900	330

From this, we can conclude that :

- This value shows that after installing AC and adding one more window art time reduces by nearly a factor of 5. This is due to flow coming through the ac will break certain recirculation zones which were there in the case of having only one window, as this recirculation zone tends to increase art it will be higher for normal case, as flow from AC tends to break it art time reduces by some factor.

- Another parameter that can verify this is an ACH(air changes per hour), while calculating it for simpler cases we get a value around 22 which tells that the air of the whole room is getting displaced by 22 times in one hour, this number increases to 41 times when AC is installed in that room we can also interpret it like that nearly after every 1.5 min air of the whole room is getting displaced.

In conclusion, integrating an air conditioning (AC) system strategically aligned with the location of windows can yield substantial improvements in airflow within the nuclear laboratory. This approach not only enhances air distribution but also facilitates achieving a higher air changes per hour (ACH) rate. Furthermore, the implementation of AC enables precise control over room temperature, offering a multifaceted solution to enhance the airflow dynamics within the nuclear lab at IIT Bombay.

By carefully positioning the AC units in accordance with the laboratory's layout and leveraging their functionality, significant enhancements in airflow can be realized. This not only ensures better circulation but also contributes to maintaining optimal environmental conditions conducive to the lab's operations and occupant comfort.

In essence, the integration of AC systems represents a comprehensive and advantageous solution to optimize airflow dynamics within the nuclear laboratory, ultimately enhancing the overall functionality and operational efficiency of the facility at IIT Bombay.

References :

[1] Turbulence Modelling in OpenFOAM - Additional Reading Material

[2] Effect of Ceiling Fan on the Ventilation of Nuclear Lab, IIT Bombay: Soham Sachin Purohit Indian Institute of Technology Bombay

[3] OpenFoam Documentation - www.openfoam.com