# STUDY OF INTERFERENCE EFFECT ON TALL HEXAGONAL TWO BUILDING AND THREE BUILDINGS CONFIGURATION AT DIFFERENT WIND INCIDENCE ANGLES

A

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

**MASTER OF TECHNOLOGY**

**IN**

**STRUCTURAL ENGINEERING**

Submitted by

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## CANDIDATE'S DECLARATION

I, Ambika Priyadarshini, (2K22/STE/02) student of M.TECH (Structural Engineering), hereby declare that the project dissertation titled as **"Study of interference effect on tall hexagonal two building and three building configuration at different wind incidence angles"** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Ambika

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Place: Delhi

Date:



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## CERTIFICATE

I hereby certify that the Project Dissertation titled as **"Study of interference effect on tall hexagonal two building and three buildings configuration at different wind incidence angles"** which is submitted by **Ambika Priyadarshini, 2K21/STE/02** Student of **M.TECH (Structural Engineering),** Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

**(Prof. RITURAJ)**

Date:

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**ABSTRACT**

Hexagonal tall buildings are gaining traction due to their structural efficiency and aesthetic appeal. The interference effects are examined by comparing the aerodynamic forces acting on the buildings in isolation versus in close proximity. Additionally, the impact of varying wind incidence angles on these cases is studied to understand the aerodynamic behaviour of hexagonal tall buildings. In this research the analysis is done using ANSYS CFX to determine the wind pressure at different heights and faces of the building. Further pressure coefficients(Cpe) , interference factors(I.F) and interference difference(I.D) is found out at each face of the single building , 2 building and 3 building cluster at different wind incidence angles starting from 0 degrees to 90 degrees with an interval of 15 degrees. In case of 2 building and 3 building cluster , pressure coefficients(Cpe) is calculated on each face and is compared with the pressure coefficients(Cpe) of each face of a single hexagonal building. The value of pressure coefficients versus the wind incidence angle for each face of the single building,2 buildings and 3 buildings are shown in the form of a bar graph. A schematic graph of Interference factor(I.F) and interference difference(I.D) versus the wind incidence angles will also shown in the respective graphs.

**Keywords:** Computational Aided Design (CAD), ANSYS Workbench, Hexagonal Building, wind incidence angles, Interference factor(I.F), Interference difference (I.D), Pressure Coefficients(Cpe)

# CONTENTS

## NOMENCLATURE

I.F = Interference factor

I.D = Interference Difference

CFD = Computational Fluid Design

Cp = Pressure Coefficient

# CHAPTER 1
# INTRODUCTION

## 1.1 General

As cities around the world become denser and land becomes scarcer, the need for innovative architectural solutions has never been greater. One design that has gained significant traction in recent years is the hexagonal skyscraper. These unique structures offer several advantages over traditional rectangular towers, making them well-suited for the urban landscapes of the 21st century. One of the main motivations for researching hexagonal skyscrapers is their capacity to lower wind resistance and enhance air flow at extremely high altitudes, as a wealth of information is available in various international standards [11–14] for isolated wind incidence conditions only, and that too only for regular square, rectangular, and cylindrical shapes. The hexagonal shape, with its gently sloping sides, creates a more aerodynamic profile compared to rectangular buildings with flat facades. This streamlined design minimizes the formation of severe vortices and turbulence around the structure, reducing wind loads and mitigating the need for excessive structural reinforcement. Moreover, the hexagonal shape allows for more efficient use of interior space, as the angled walls create unique floor plans that can be tailored to specific needs. This versatility in layout design can lead to improved space utilization, making hexagonal skyscrapers an attractive choice for mixed-use developments that combine residential, commercial, and recreational facilities. As cities continue to grow vertically, the importance of tall hexagonal buildings will likely increase, as they offer a practical solution to the challenges of limited space and the need for sustainable, wind-resistant architecture. Hence Interference effect on two and three building each having equal volume have been considered. Using computational fluid dynamics, the wind-induced pressure coefficient, interference factor, and interference difference are computed. (CFD) simulations in “ANSYS WORKBENCH” for the corresponding building configurations. The models of the building considered is in the scale of 1:100.

While the concept of hexagonal skyscrapers has gained popularity in recent years, there has been relatively limited academic research specifically focused on the design and performance of these structures. However, some scholars and architects have explored the potential benefits and challenges of hexagonal tall buildings. It is clear from the literature that the majority of earlier studies on interference concentrate on finding the best construction arrangements and separations between interfering models with square or rectangular plan shapes. For instance, the interference effects on a row of five tall buildings with square plan shapes were examined by Lam, Zhao, and Leung [16]. The mean interference effects between two nearby rectangular structures arranged in 'L' and 'T' shapes were computed by Amin and Ahuja [17]. Hui, Tamura, and Yoshida [18] found notable changes in values between isolated and interference experiments when they investigated the peak interference effects of a square plan shape model on a rectangle plan shape model and vice versa. Similar to this, Bairagi and Dalui [19] looked into the interference effect between twin rectangular models at different separations in order to figure out the ideal distance between them when the wind angle was between 0° and 90°. Furthermore, at different distances, some researchers [20–23] have examined the interference effects among twin square plan shape models. It is apparent that no experimental research has been done on complex plan shape tall buildings, which emphasizes the necessity of conducting interference studies involving complex plan shape structures that interact with one another in the same or distinct plan shapes.

In this study focus is on the study of interference effect for all conditions that is isolated, two building and three building configurations, 7 wind incidence angles starting from 0 degree to 90 degree at an interval of 15 degrees are considered. The distance between the buildings in two and three building configuration is fixed and taken to be equal to the distance between parallel sides of an isolated building (termed as B)

The variation in pressure coefficients with respect to face of the building and wind incidence angles will be shown using graphs. Similarly the graph between Interference factor (I.F) and Interference Difference (I.D) with respect to the faces of the corresponding building will also be analysed later on in the results and discussion using Ansys CFX . The findings of this study provide valuable insights for engineers, and urban planners involved in the design of tall buildings, particularly those opting for hexagonal structures. Understanding the interference effects and the influence of wind direction can lead to more efficient and sustainable tall building designs, contributing to the development of resilient and environmentally conscious urban environments.

## 1.2 Objectives of the study

The objectives of the present study, which focuses on the following:

- To consider different plans of hexagonal building configuration(2 and 3 buildings cluster) and comparing the pressure coefficients results with single hexagonal building.
- To identify interference factor and interference difference due to the building present in close proximity on each face of 2 building and 3 building.
- To draw the contour lines and streamlines for the specified boundary condition.

## 1.3 Organization of the thesis

The project work is organized in five different chapters whose content are summarized below:
Chapter 1 is an introductory chapter which describes the motivation behind the work, objectives and scope of the project.

Chapter 2 is and introducing the existing literature for the study carried for the Interference effects and mean pressure coefficients in different types of building such as high rise , low rise with the inclusion of different kinds of roofing as well.

Chapter 3 focuses on the methodologies used in the analysis.
Chapter 4 focuses on the results and discussions of the analysis.
Chapter 5 is concluding chapter in which conclusions are discussed.
Chapter 6 shows the references used for the above study.

## 1.4 Scope of the work

Furthermore, this study highlights the importance of considering the number of buildings in a cluster and their relative positioning when evaluating wind loads and pressure distributions. The findings emphasize the need for tailored design approaches that account for the specific characteristics of building clusters, ensuring the safe and efficient construction of wind-resistant structures in urban areas. There will be further improvements and comparisons which could also help in finding different aspects of hexagonal buildings such as

- It can be investigated for various spacing between the buildings and considering different shapes of the buildings as well as varying configurations.
- The analysis could be done using ANSYS CFX and the results should also be verified by wind tunnel testing. This would be a physical approach for carrying out the analysis
- Assessment of aerodynamic modifications like openings, corner cut, recessed, chamfered etc. on the wind pressure distribution.
- Dynamic response analysis of the buildings using time varying wind data
- Practical implications: Evaluate the practical implications of the study's findings. Consider how the results can be applied in real-world scenarios and their potential impact on design, construction, or policy-making. Assess the feasibility and practicality of implementing the recommendations derived from the study.

# CHAPTER 2
# REVIEW OF LITERATURE

## 2.1 Literature review

**Khanduri A C, Stathopoulos T and Be´dard C 1998**

The main tools for assessing wind loads on buildings are codes and standards, the specifications for which are frequently drawn from wind tunnel tests carried out on stand-alone buildings in open spaces. However, a number of studies have shown that wind loads on real-world structures can differ dramatically from isolated building records. Neighboring structures can increase or reduce the flow-induced stresses on a building, depending mostly on its shape and arrangement, orientation relative to the direction of flow, and the upstream terrain conditions. Thus, this effect—also known as interference—needs to be carefully evaluated by planners and designers. This paper reviews and analyzes interference effects research that has been conducted over the past 60 years.

**Ozmen Y,2016** Through the use of experimental and numerical techniques, the turbulent flow fields surrounding low-rise building models with gabled roofs at different pitch angles (15°, 30°, and 45°) in an atmospheric boundary layer were studied. This study made use of scale models of the test building owned by the Belgian Building Research Institute (BBRI). Flow visualization, velocity measurements, and surface pressure measurements were performed in wind tunnel tests with a wind direction of 90°. To get 3D flow field solutions, two distinct turbulence models were utilized. It was shown that the profiles of mean velocity and kinetic energy of turbulence were considerably affected by the roof pitch. Due to flow separation, recirculation zones were seen on the leeward side of the roofs and behind the models. As the roof pitch increased, these regions became more noticeable and extended up to the roof ridge. The roof level had the highest values of turbulence kinetic energy, indicating the existence of a mixing layer between the reverse flow zone and the free stream flow. The 15° roof pitch produced higher critical suction on the roofs than the 30° and 45° roof pitches, according to analysis of surface mean pressure distributions.

**Tamura Y (2001)** In order to obtain the largest quasi-static wind load effects at the base of low-rise building models with square and rectangular floor plans, the paper first analyzes the wind pressure distributions that are conditionally sampled. Furthermore, it investigates the maximum normal stresses in column members while taking into account the three moment wind load, along-wind, across-wind, and uplift components. The distributions of wind pressure that cause the highest quasi-static stresses in structural frames are then examined in the research. Next, these distributions are contrasted with the quasi-steady pressure distributions and Kasperski's load-response-correlation formula.

**Uematsu Y and Isyumov** N **(1999)** The findings from several field and lab investigations that look at how wind pressure affects low-rise buildings are examined in this document. A variety of experimental results are presented, with an emphasis on studies pertaining to cladding design. The only investigations considered are those carried out at full size or in conditions similar to the simulated atmospheric boundary layer. The features of average and variable wind pressures are compared across multiple sources. The results imply that a quasi-steady technique can be used to forecast the statistical features of fluctuating pressures on corners and roof edges. Moreover, the peak-factor method is considered appropriate for evaluating design wind loads. Additionally discussed is the connection between time and geographical averages.

**Revuz, J (2012)** The correct application of computational fluid dynamics (CFD) in wind engineering has been governed by rules for many years. These rules give precise information about the optimal size of the flow domain surrounding a building, given its height, represented by the letter H. The recommended domain sizes are reasonable and produce results that are largely independent of blockage effects for low-rise buildings. But when it comes to high-rises or tall structures, figuring out the domain size based only on the building's height leads to a much larger domain. Many of the cells in this wider domain are found distant from the building or wake region, which is frequently the result of the larger domain.

This study examines the effects of changing the domain size near a tall building, challenging the recommendations now in place about domain size. With the exception of the domain size, all steady-state solutions are analyzed using the RNG k-ε turbulence model with the same mesh resolution in the wake region and building. Comparisons between pressure coefficients on the building and velocity fields in the near-field provide the basis of the assessment.

Based on the results of this investigation, a domain size of roughly 10% of the volume advised by the current guidelines might be used in this specific instance with less than a 10% drop in accuracy.

**Yang Q (2019)** The study involved conducting wind tunnel tests in an open terrain scenario to examine the interference effects that a high-rise building and similar low-rise buildings can have on the peak pressure coefficients of a low-rise, flat-roof building. Both the maximum pressures on the roof area distant from the high-rise building and the minimum pressures (negative suctions) at the roof edge of the low-rise building next to the high-rise building showed significant amplification interference effects, according to the results. As the high-rise building's height climbed, so did the low-rise building's envelope peak pressure coefficient magnitudes. While other roof regions experienced shielding effects at small spacing ratios, the envelope minimum peak pressure coefficients in the middle roof area parallel to the high-rise building exhibited amplification effects at large building heights and small spacing ratios. The interference factors of the envelope minimum peak pressure coefficients also rose as the height and spacing ratio increased.

**Dai Y (2015)** In structural wind engineering, the interference effect is a hot topic. Using computational fluid dynamics methods in the Fluent software, a number of scenarios were simulated in order to study this phenomenon. Building matrices, double interfered buildings, and single interfered buildings were among these examples. The results of the simulation showed that the buildings that interfered had a major impact on the windward pressures. Furthermore, correlations between the pressures that resulted from the distances between the structures and specific patterns were noted.

**Yoshida A 2013** A systematic analysis of the effects of a group of buildings on the wind pressures encountered by a typical low-rise building was done through wind pressure measurements. Understanding the quasi-static wind load combinations and wind force correlations for a particular model within the group was the primary objective. Data on along-wind force, across-wind force, uplift force, along-wind overturning moment, across-wind overturning moment, and torsional moment were obtained via the calculation of fluctuating pressures across different surfaces. First, force coefficients, phase-plane expression, and cross-correlation coefficients for an isolated model and a model in the group were examined in respect to the wind force correlations. To assess the impact of wind load combinations, the peak normal stresses in columns of a simple frame model were then analyzed. Finally, a shielding factor was proposed as an exponential function to account for combination factors.

**Kargarmoakhar R 2016** Rather than aerodynamic concerns, architectural considerations, functional requirements, and site constraints typically influence the design of a building's outward shape and orientation. Because of the consequences of wind-structure interaction, this frequently leads to structures becoming bluff bodies vulnerable to significant wind-induced loads. New methods of mitigating aerodynamic effects and best practices for designing aerodynamic shapes can greatly minimize these effects. In order to lessen wind loads on buildings by altering their designs or adding straightforward architectural elements, this paper summarizes previous and current research on a variety of aerodynamic mitigation strategies. A review of aerodynamic mitigation strategies for both high- and low-rise buildings is conducted.

Furthermore, the applicability and difficulties of applying Computational Fluid Dynamics (CFD) for this purpose are examined, as are aerodynamic form optimization methods for lowering wind loads on tall buildings. A summary is given of optimization strategies, specifically approaches that are gradient-based and methods that are not. The goal of this research is to raise awareness of the use of aerodynamic shapes and the importance of early design consideration of a structure's shape in relation to wind performance. Additional resources regarding other methods of lowering wind loads on structures can be found in the study.

**Leung M Y H 2011** This study investigates the effects of wind-induced interference on a row of five tall, square-plan buildings that are located in close proximity to one another. Every building element has its mean and variable wind loads monitored, and the high-frequency force-balance approach is used to determine the dynamic responses caused by wind on the buildings. An envelope interference factor represents the variations in building reactions caused by interference over a realistic range of lowered velocities. Two building arrangement patterns in the row, namely parallel and diamond, four distinct building separation distances, and a range of wind incidence angles are all tested in wind tunnels along with reaction assessments. The findings imply that, while response reduction is also noted in some wind conditions, building interference can result in higher dynamic reactions in many cases.

Five different wind incidence sectors with different amounts and mechanisms of interference impact are identified in the instance of a parallel pattern constructing row. For torsional responses, the greatest envelope interference factor values might reach 2.4. A "wind catchment" effect causes wind excitation to increase at various wind angles when tall structures are placed in a diamond pattern. The interference factors show higher peak values, going over 4 in torsion and up to 2.1 in sway directions.

However, during the peak resonant dynamic responses of a single isolated building, these notable amplifications of building responses do not take place. Therefore, when a tall building is arranged in a row, its peak dynamic response design values are not significantly raised.

**Amin J A and Ahuja A K 2012** The average interference effects between two nearby rectangular structures organized in a 'L' and 'T' shape configuration are investigated in this study. Rigid models at a 1:300 scale are used for wind tunnel testing in the inquiry. The average surface pressure distributions on each wall of the two closely spaced buildings are measured in the study, both when they are near together and when one of them is isolated. To get complete data, the wind directions are changed across a large range.

This study examines the average interference effects between two adjacent rectangular constructions arranged in a 'L' and 'T' shape arrangement. The investigation uses rigid models for wind tunnel testing at a scale of 1:300. When the two closely spaced buildings are near an other and when one of them is separated, the study measures the average surface pressure distributions on each wall. The wind directions are varied across a wide range in order to obtain comprehensive data.

The findings indicate that when block-1 is upstream, block-2's average along-wind displacement is reduced by up to 25% and 71% in the 'L' and 'T' shape arrangements, respectively, at a wind incidence angle of 0°, as opposed to when block-2 is isolated. However, in comparison to the maximum average torque created on a similar isolated block, the presence of the upstream block-1 raises the maximum average torque on block-2 by as much as 28% and 88% in the 'L' and 'T' shape arrangements, respectively.

**Hui Y, Tamura Y and Yoshida A 2012** Through wind tunnel tests, this study explores the effects of interference between two different-shaped high-rise structures, with a particular focus on local peak pressure coefficients. For each measurement site "i" on the main building, the study offers and examines the interference factors for the maximum positive and minimum negative peak pressures in order to fully explore the interference effects on local peak pressures. The results show that the wind directions and the forms of the structures have a major impact on these interference effects. The findings also indicate that special attention should be given to the cladding design at the vertical edges, especially the building corners, since the minimum peak pressure on a building facade may be up to 40% higher than in an isolated

Version 1 of this study uses wind tunnel experiments to investigate the effects of interference between two tall structures with varied geometries, with a particular emphasis on local peak pressure coefficients. In order to thoroughly examine the interference effects on local peak pressures, the research shows and discusses interference factors for the maximum positive and minimum negative peak pressures at each measurement location "i" on the main building. The findings show that the wind directions and building shapes have a significant impact on these interference effects. The study also emphasizes how crucial it is to give careful thought to cladding design at vertical edges, especially building corners, since the minimum peak pressure on a building face can be up to 40% higher than in an isolated state.

**Bairagi A K and Dalui S K 2014** Computational Fluid Dynamics (CFD) simulations are used in this study to numerically investigate the optimal separation between an interfering building and a primary building, at which point interference effects are removed and the primary building behaves as a freestanding structure. In order to discover the ideal distance between the primary and interfering buildings at wind angles of 90° and 0°, a series of Fluid Flow (CFX) assessments are performed on the analytical results for rectangular plan-shaped prismatic bluff bodies. The principal building's Interference Factor (IF), which converges to a freestanding building's as the distance between the interfering and primary structures grows, is the focus of the study.

Every building has a rectangle plan with similar size and main axes. The IF for different spacing configurations between the interfering building and the principal building is also visually presented in the study.

**Isyumov N 2014**Aerodynamic interference, or the wind's interaction with surrounding structures, has a considerable impact on how tall buildings in metropolitan settings are affected by wind. Because the factors involved are complicated, current wind loading algorithms do not take these interference effects into consideration. Urban planners and structural engineers would benefit from recommendations on building layouts that can cause interference effects. Tests in wind tunnels were performed to assess the interference effects of a single building upstream that had the same height and shape as the building under consideration.The findings are discussed together with the aerodynamic mechanics involved, and the results are provided as interference factors (IFs) comparing the loading and reaction under interference to those of a solitary building. The IFs for aerodynamic wind loading and peak response are shown using contour graphs. In the early stages of a project's design or site selection, the IFs for peak responses might be useful in locating any interference problems. The results imply that the peak response index factor (IF) in some codes may be similar to the partial wind load factor, contingent on exposure and dynamic features.

**Gu M 2015** The interference effects on wind pressure distributions between two buildings with diverse tandem, oblique, and parallel layouts were fully examined using the synchronous pressure measurement approach. Specifically, the study concentrated on four height ratios (Hr=Hinterfering/Hprincipal) and six breadth ratios (Br=Binterfering/Bprincipal) to comprehend the features of wind pressure distribution, especially in the most disadvantageous parallel installations. The results showed that, because of shielding, the mean pressure was frequently favorable, but the peak pressure on the lateral facade next to the interfering building was mostly magnified.

The related shielding and amplification effects become stronger as Br and Hr values increased. Due to the influence of three-dimensional flow dynamics, the local mean and peak pressures on the lateral facade in the tandem configuration significantly increased when Hr<1. These increases were 56% and 53%, respectively. The channeling effect in the parallel configuration must be given sufficient consideration because the mean and peak pressures' maximum interference factors (IFmax) can be as high as 1.91 and 2.6, respectively. Finally, in order to determine the link between the maximum block interference factor (BIFmax) and building spacing in the parallel layout, exact regression equations were provided.

**Zu G B and Lam K M 2018**The purpose of this research article is to examine the mechanism underlying the excitation of cross-wind force interference between two tall, staggered buildings. In order to complete the study, precise measurements of the turbulent flow fields surrounding the two buildings must be made, and the pressure on the main building downstream must also be measured concurrently. Through the examination of the instantaneous flow fields and pressure distributions on the walls, a synchronization mechanism is found between the upstream building's wake's sideways oscillation and the downstream main building's vortex creation and shedding.

Additional investigation employing the phase-averaging method verifies that within a particular area of building configurations, the synchronization of five quasi-periodic aerodynamic phenomena magnifies the variations in the across-wind force. The core of this region is located at a lateral separation of 2.5D and a longitudinal separation of 5 building breaths (D). In addition to this area, the study finds three additional flow regions in the staggered configuration: "proximity interference region," which is defined by channeled flow through a narrow gap between the two buildings; "weak interference region." In this region, the wake development on the main building is influenced by the meandering wake from the upstream building at a close lateral separation.

**Zu G B and Lam K M 2018** The purpose of this work is to investigate the excitation mechanism responsible for the across-wind force interference between two tall structures placed in a staggered configuration. In order to do this, the researchers assessed the pressure on the primary building downstream while also performing in-depth measurements of the turbulent flow fields surrounding the two structures. They found a synchronization process between the production and shedding of vortices from the downstream major building and the sideways oscillation of the wake from the upstream building by examining the instantaneous flow fields and pressure distributions on the walls. It was determined by additional investigation that the variations in across-wind forces are amplified by the synchronization of five quasi-periodic aerodynamic phenomena. A certain area of building layouts with a lateral separation of 2.5D and a longitudinal separation of 5 building widths (D) is where this phenomena happens. In addition, three additional flow regions were identified by the study within the staggered arrangement: "wake interference region II," which is characterized by channeled flow through a narrow gap between the two buildings; "proximity interference region," where the meandering wake from the upstream building influences the wake development on the principal building at close lateral separation; and "weak interference region."

**CHAPTER 3**

**METHODOLOGY**

## Experimental Programme

### 3.1 *Details of the model*

The simulations and calculations have been done in Ansys Workbench. In this experiment hexagonal building models considered is in the scale of 1:100 with a height of 600mm and and distance between parallel sides (B) to be 200mm. A total of 3 configurations have been taken into account

I. Isolated Building
II. Two buildings
III. Three building

at a fixed distance of B as indicated above. All the plans views of the models are mentioned in figure 1. The buildings indicating (face a to face f) are principal building while (face g to face l) indicating interfering building 1 and (face m to face r) indicating interfering building 2.

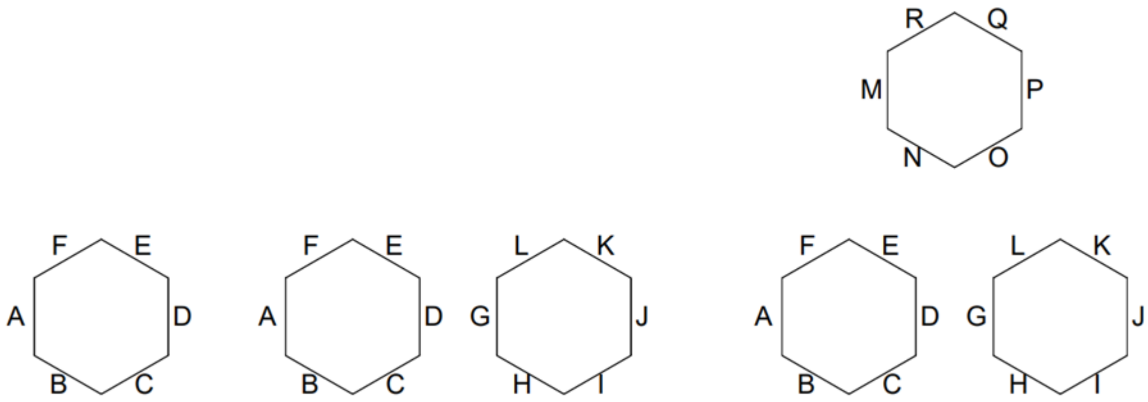



Figure 1. Models with various configuration of building

### 3.2 *Boundary Conditions*

Using the CFD simulations, the impact of wind on building models is investigated. In order for CFD to function, an area is divided into the grid with many cells. The grid of cells is then initialized, encircled by boundaries that replicate the surfaces, opened and closed spaces, boundary pressure, and air movements inside the cell. In order for simulation to develop the flow effectively, as advised by Revuz et al. [5] and Frank et al. [6], the inlet, top, and sidewall borders are taken into consideration 5 H from the model, while the outlet boundary is positioned at 15 H behind the model. Figure 2 shows the domain, with the top and side walls remaining free slip condition in the CFX configuration setup. In this study, the ground and building model surfaces are regarded as no-slip walls in the context of CFX configuration setup. The definition of no-slip is "when the air velocity at the wall boundary equals the air velocity at the domain inlet". The definition of free slip is "shear stress and velocities normal to the wall are both set to zero, while velocity components parallel to the wall have a finite value". The free stream velocity at the inlet of domain considered to be as 10 m/s.

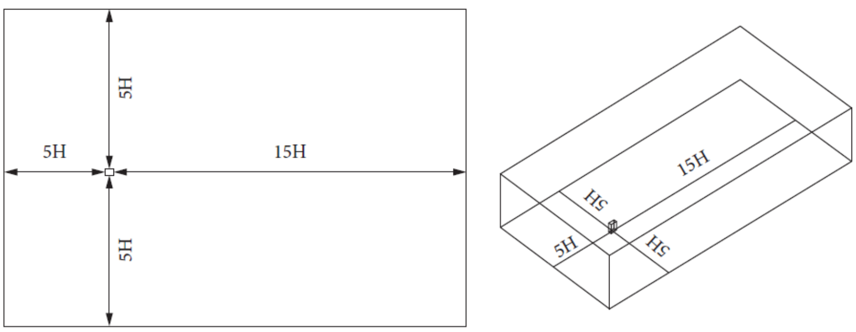



Fig 2. Domain of the models used in Ansys workbench

### 2.3*Meshing*

Meshing is a crucial step in the computational fluid dynamics (CFD) analysis process using ANSYS, as it divides the computational domain into smaller elements or cells, enabling the numerical solution of the governing equations. The quality and resolution of the mesh play a significant role in the accuracy and reliability of the simulation results. Here's a note on meshing and its importance in analyzing a structure using ANSYS CFD:

Mesh Generation: Meshing involves discretizing the computational domain into a collection of elements or cells. ANSYS offers various meshing techniques, including structured, unstructured, and hybrid meshes, allowing users to choose the most suitable approach based on the geometry complexity and physics involved. Proper mesh generation is essential to capture important flow features and ensure numerical stability and convergence.

Mesh Quality: Mesh quality is evaluated based on several criteria, such as element aspect ratio, skewness, and orthogonal quality.High-quality meshes with well-shaped elements are crucial for accurate and reliable simulation results, as they minimize numerical errors and improve solution convergence. Mesh quality checks and refinement strategies are essential to ensure the mesh meets the desired quality standards.

Mesh Resolution: Mesh resolution refers to the density of elements or cells within the computational domain.Higher mesh resolution is required in regions with steep gradients, boundary layers, or complex flow features to capture the physics accurately.Mesh refinement techniques, such as adaptive mesh refinement (AMR) or local mesh refinement, can be employed to increase the resolution in critical areas while maintaining a coarser mesh in less critical regions, optimizing computational resources.

By carefully considering mesh generation, quality, resolution, and boundary layer treatment, analysts can ensure that the CFD simulations in ANSYS provide accurate and reliable results for the structural analysis of interest. Figure 3 shows the meshing of the building and the domain. The type of meshing used using Ansys CFX is tetrahedron because tetrahedral meshes lend themselves well to parallel processing, which is essential for simulating large-scale and computationally intensive CFD problems. Different sizes of meshing at different locations are provided such as the faces of the building, ground of the domain and the whole domain body with the provision of inflation as well.

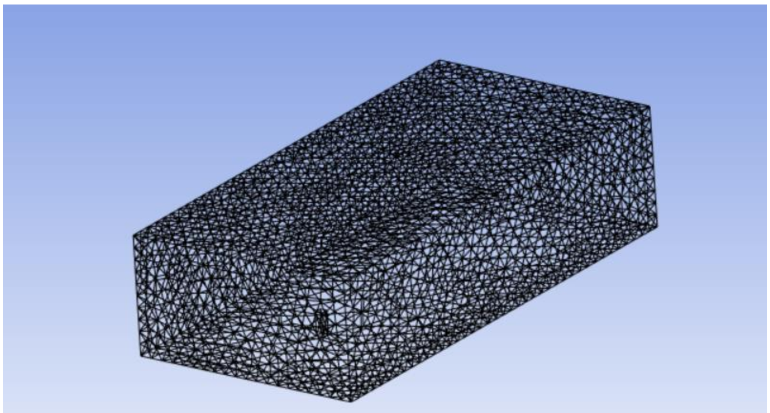


Figure 3. Meshing of building and domain

## 2.4 *Validation with Indian Code*

For validation through Indian code IS 875 Part III , we use Ansys CFX software to define the square shaped geometry of the building and further by providing meshing and boundaries conditions to the said problem we analyse it for the pressure coefficients which is being calculated by the calculator provided in the Ansys Workbench itself. Further we have compared the results obtained from the software and compared it with the code that is provided to us according to the Indian Standards. Table 1. Below shows the codal values for pressure coefficients as well as the calculated values for a square shaped building whose height is taken to be equal to 600mm and width equal to 200mm.

Table 1.Comparison of Pressure coefficient Values of square building

| Square Building (200X200mm) | IS 875 Part III values | | | Experimental results | | |
|---|---|---|---|---|---|---|
| Wind Angle | Windward side | Leeward side | Side walls | Windward side | Leeward side | Side walls |
| $0^0$ | 0.80 | -0.25 | -0.80 | 0.72 | -0.32 | -0.69 |
| $90^0$ | 0.80 | -0.25 | -0.80 | 0.71 | -0.33 | -0.70 |

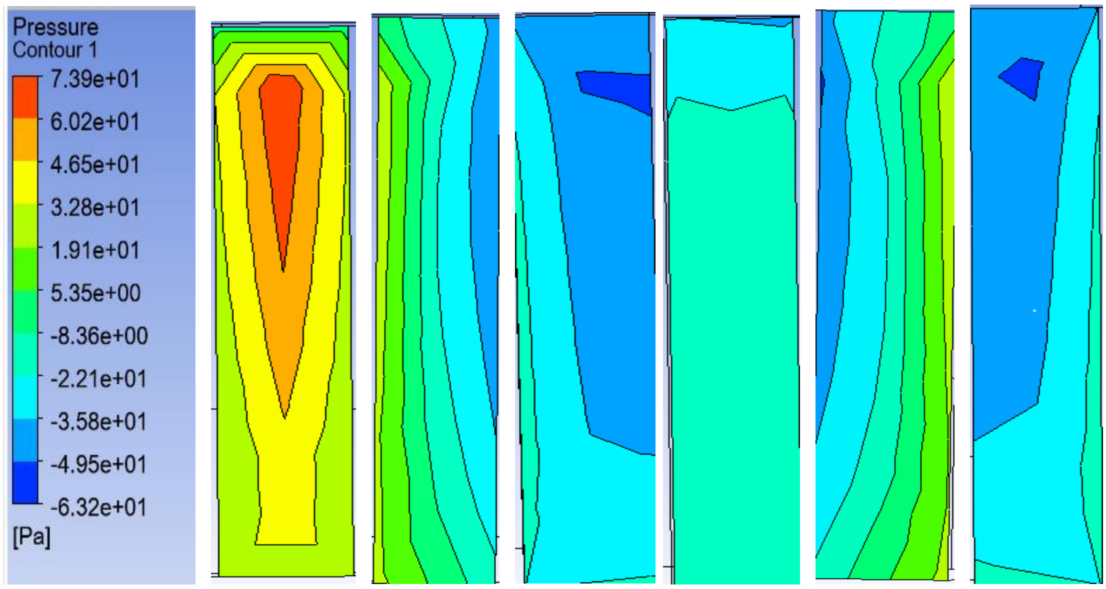
D

# CHAPTER 4

# RESULTS AND DISCUSSION

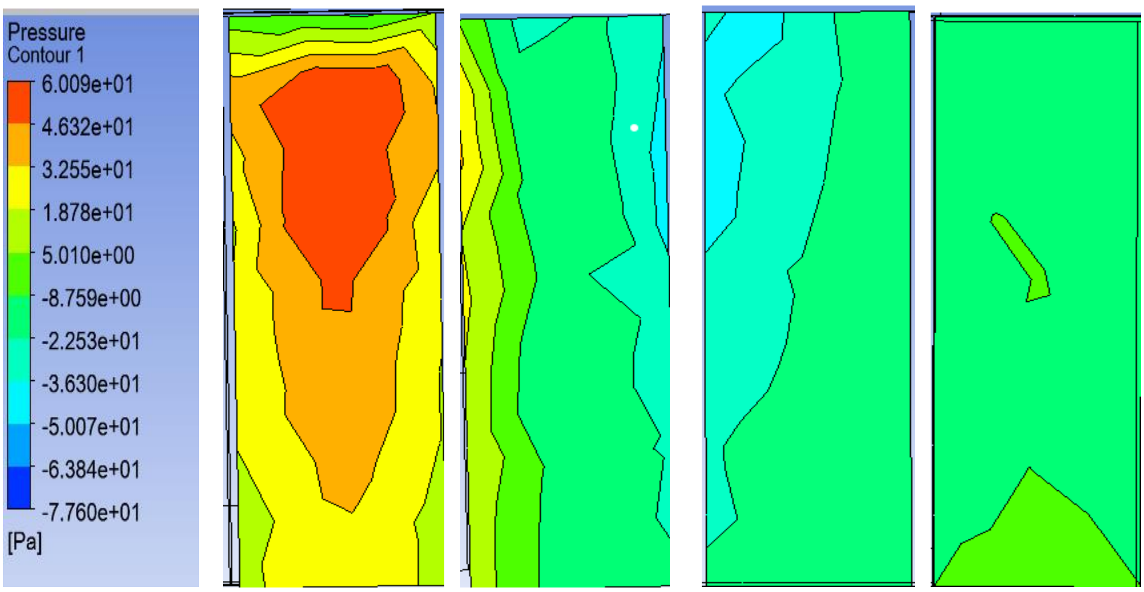
*3.1 Pressure Contours*

The pressure contours on different faces at different wind incidence angles starting from $0^o$ to $90^o$ at an interval of 15 degrees is shown for different configurations of the building i.e single, two and three hexagonal buildings for different faces. The faces shown are from A to R in 3 building, from A to L in 2 building and A to F in single building. The pressure variation on a wall is shown on the left side while the contour variation on the walls are shown on the right. Pressure contour variation for each face in each model (figure 1) has been indicated using different colours red showing the area of highest wind pressure and blue being the lowest. For example a pressure of 73.9 Pa to -63.2 Pa is shown as highest to lowest variation in the case of 0 degree wind incidence angle for a single building. The face in the windward side seems to be experiencing the maximum wind pressure for $15^0$, $30^0$ and $45^0$ as well while the leeward side has the least experience of wind pressure. The side walls have to experience a medium ranged pressure. While in the case of two buildings at $0^0$ the first building in the direction of wind will be experiencing the maximum effect of wind pressure and the face of the second building in the windward side will not be having such experience because if the shielding effect provided by the first building. The side faces of the two building will cluster will experience a medium ranges pressure 46.4 Pa to -49.5 Pa. Similarly it will happen for other several cases which is shown through the contour lines. In case of three building the first building facing the wind side acts as a shield for the other two buildings and similarly when direction of wind changes the principal building also changes.




face A face B face C face D face E face F

**fig4. Models at 0º wind incidence angles from Face A to Face F(single building)**




face A face A face B face C face D

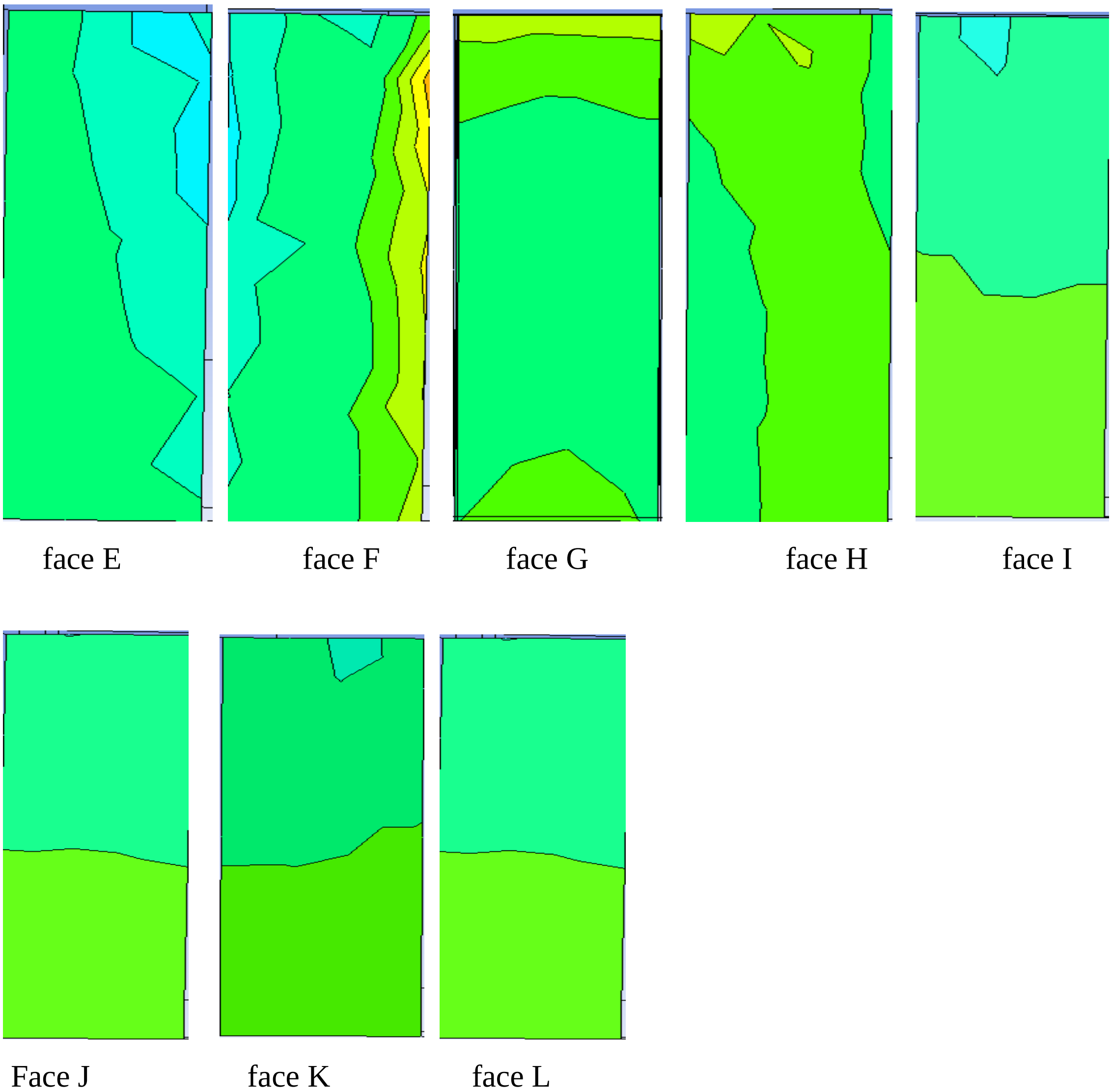
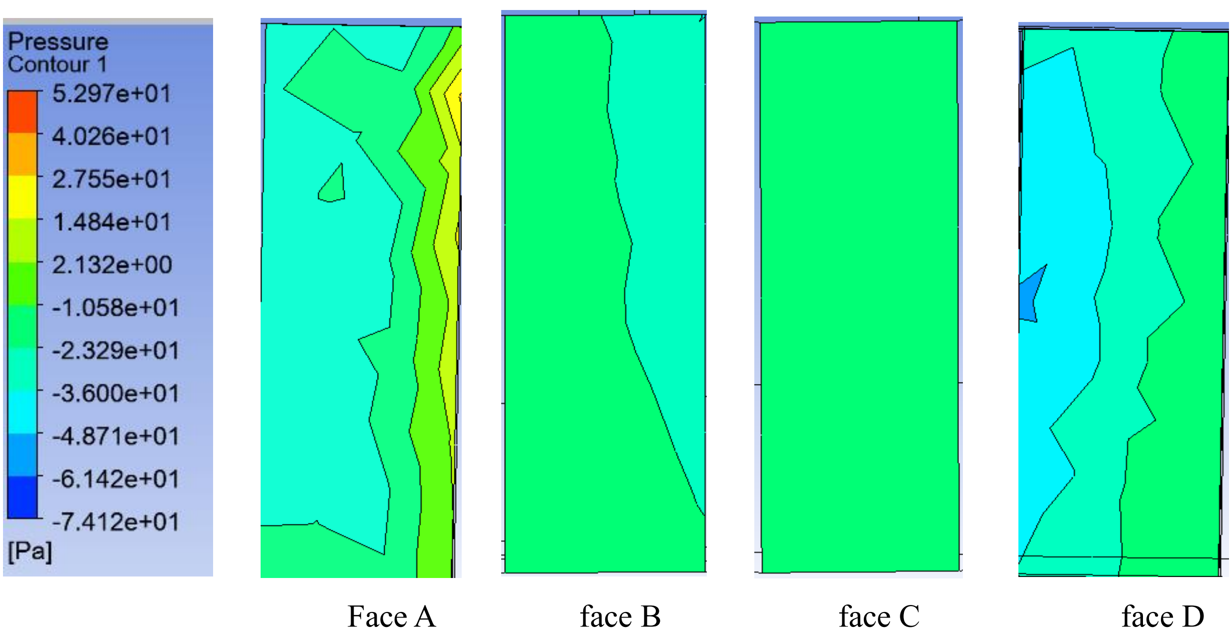
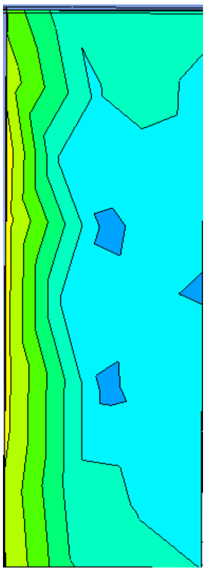
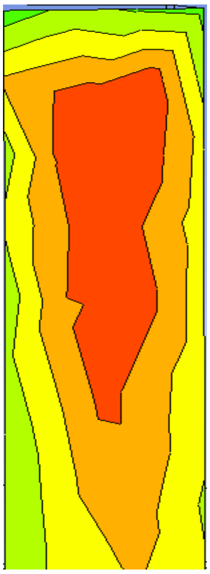



**Fig 5. Models at 0º wind incidence angles from Face A to Face L(two building)**

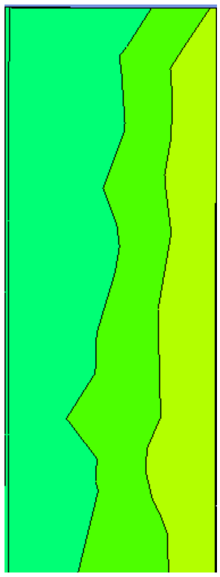




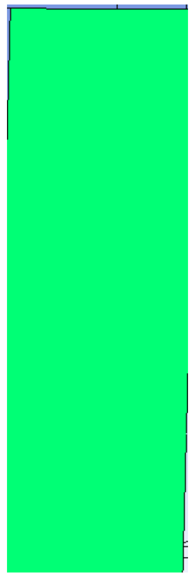
Face E



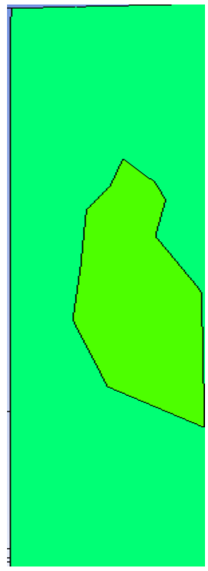
face F



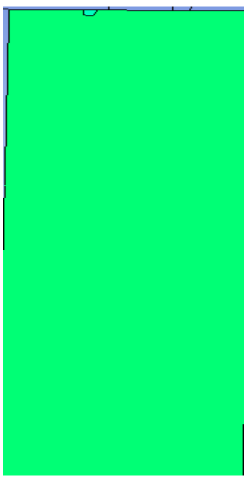
face G



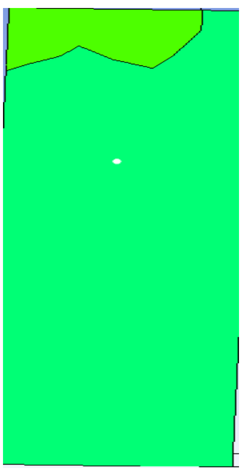
face H



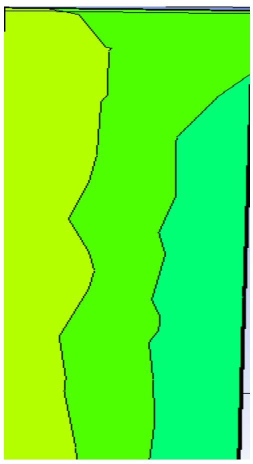
face I



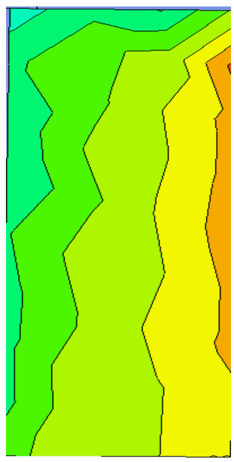
Face J



face K



face L



face M

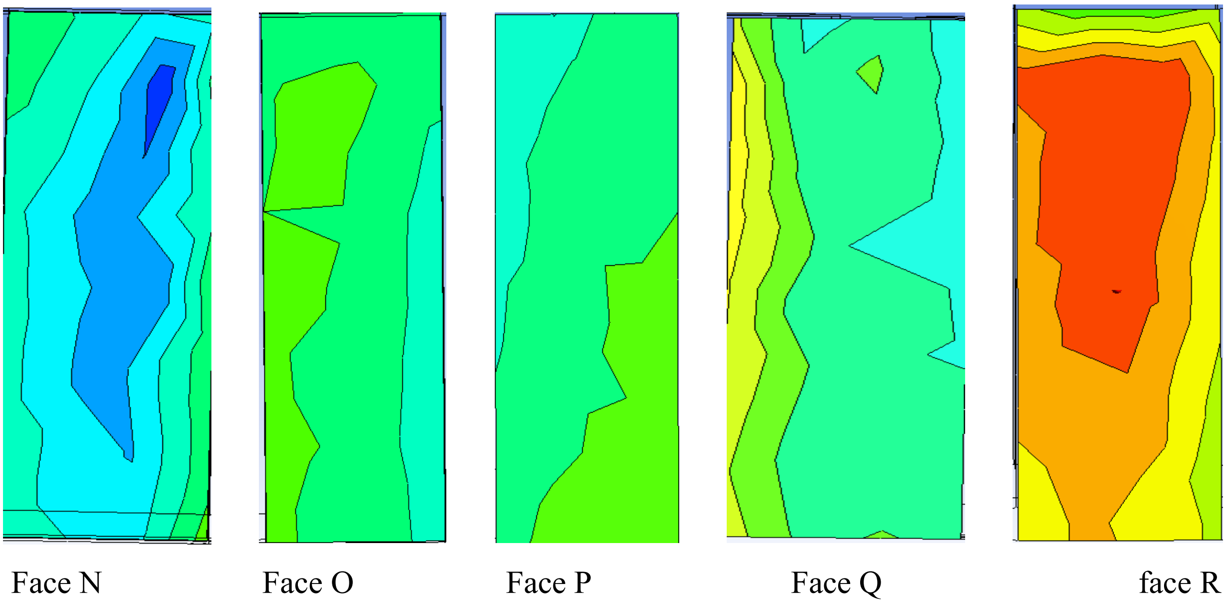



**Fig6. Models at 0º wind incidence angles from Face A to Face R(three building)**

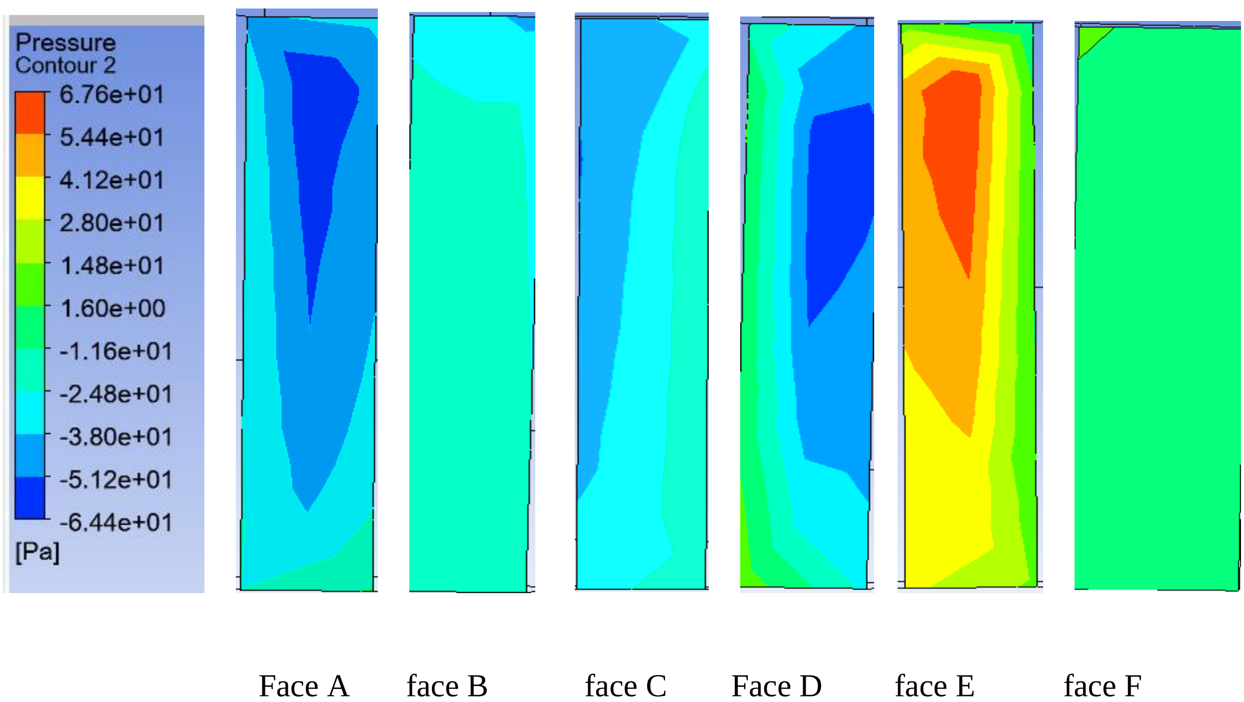
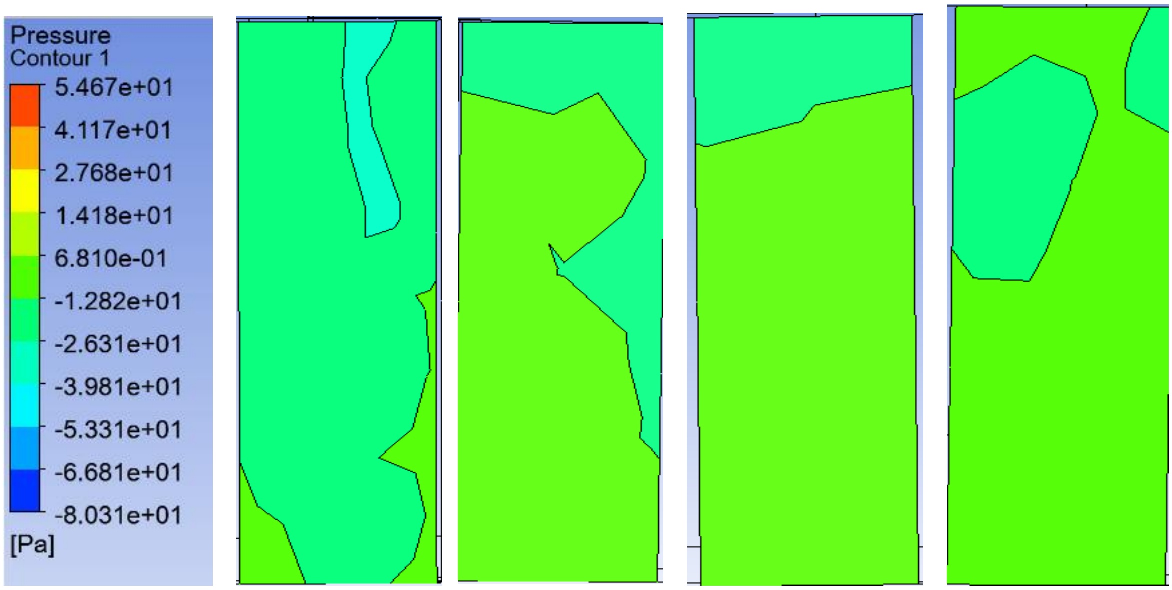
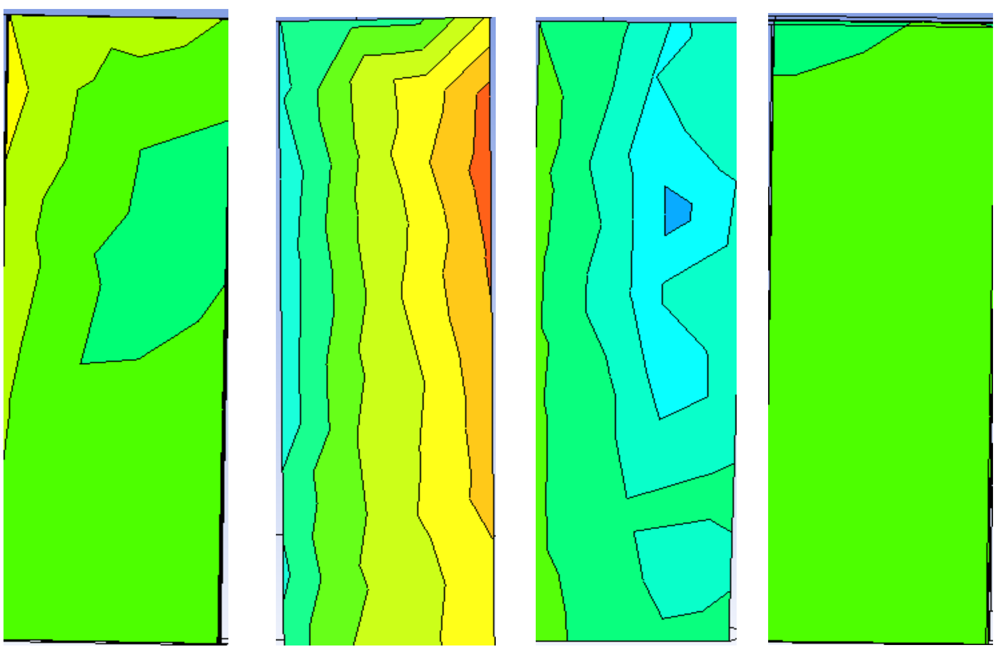


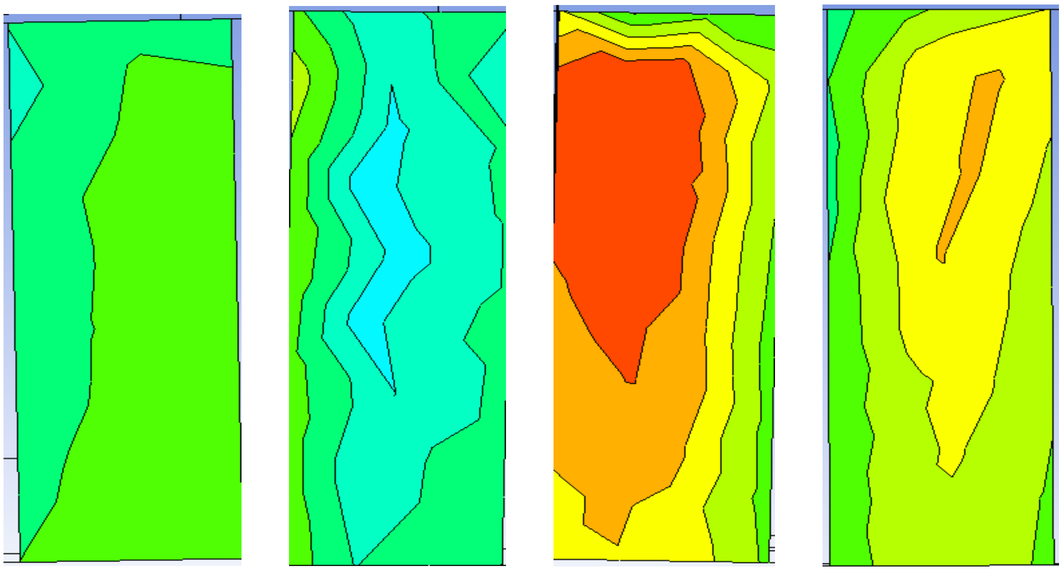

**Fig 7. Models at 15º wind incidence angles from Face A to Face F(single building)**




Face A face B face C face D

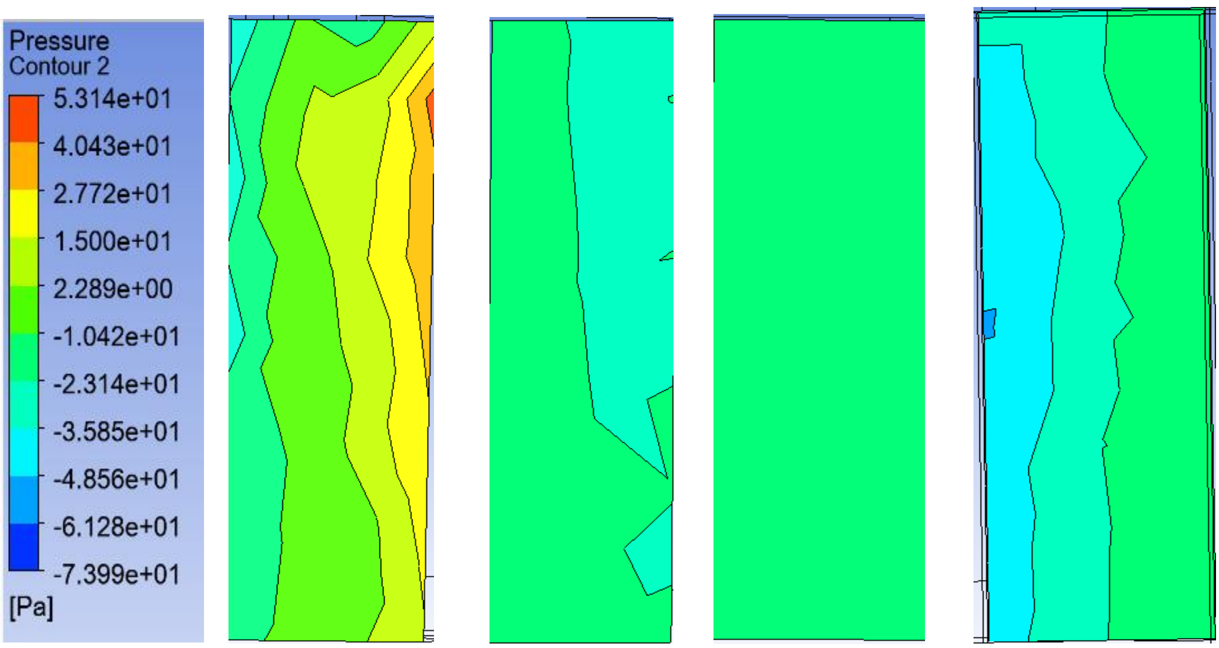


Face E face F face G Face H

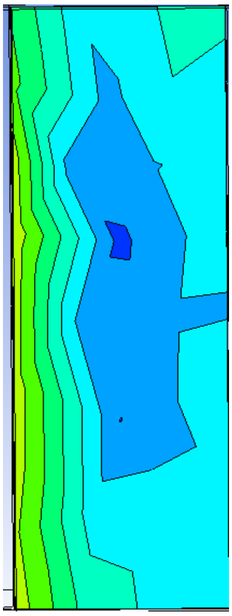


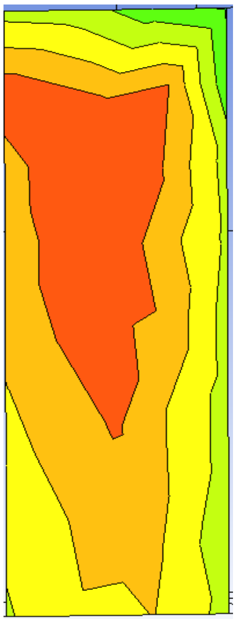
Face I face J face K face L

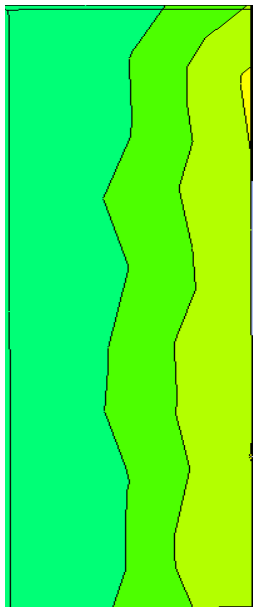
**Fig 8. Models at 15º wind incidence angles from Face A to Face L(two building)**

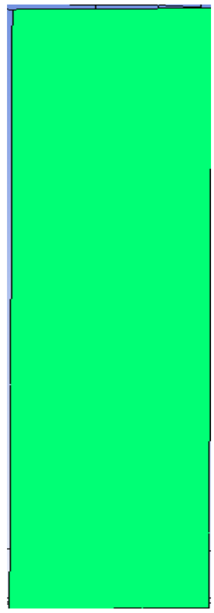


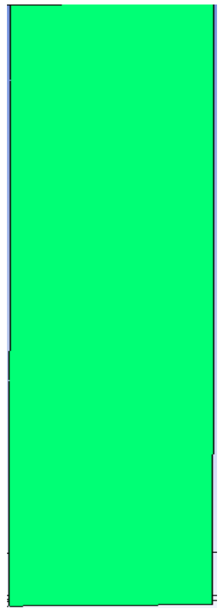

Face A face B face C face D

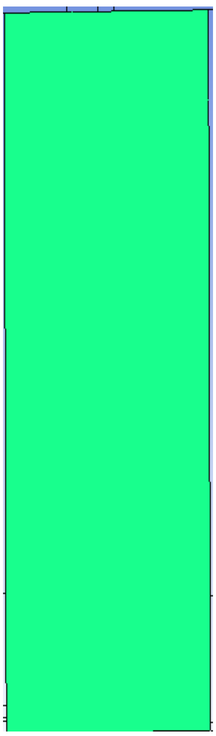

Face E

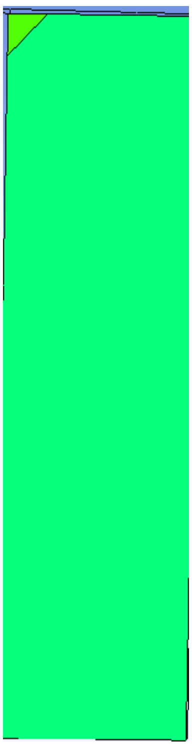

face F

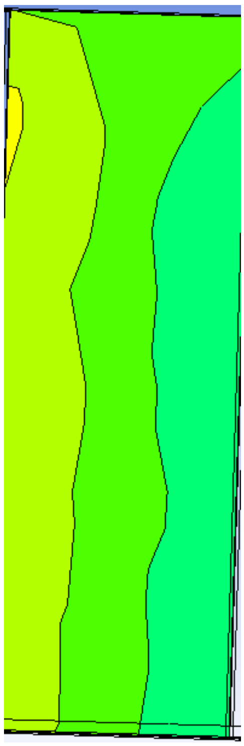

face G

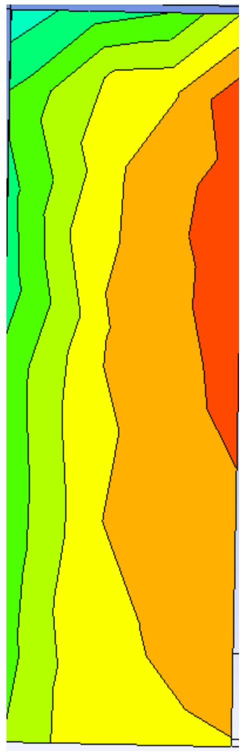

face H

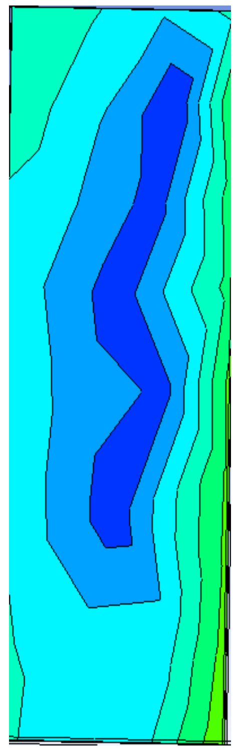

face I

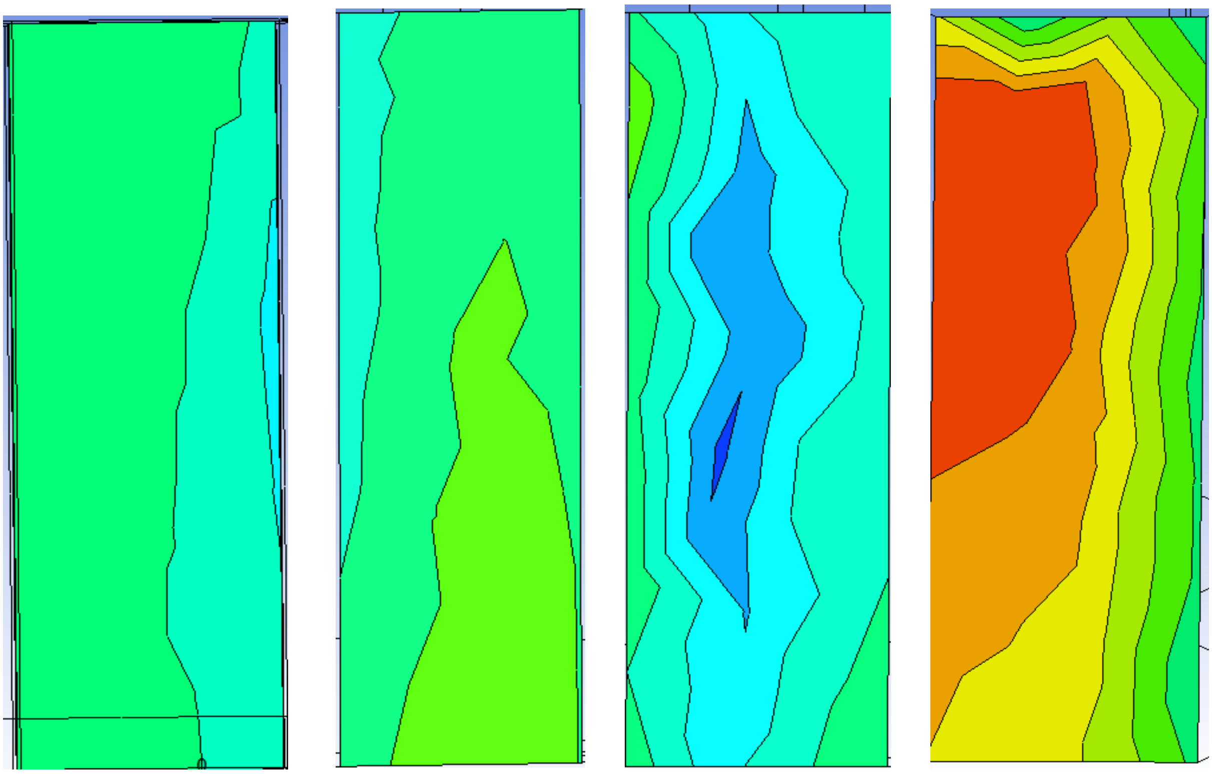

Face J


face K


face L

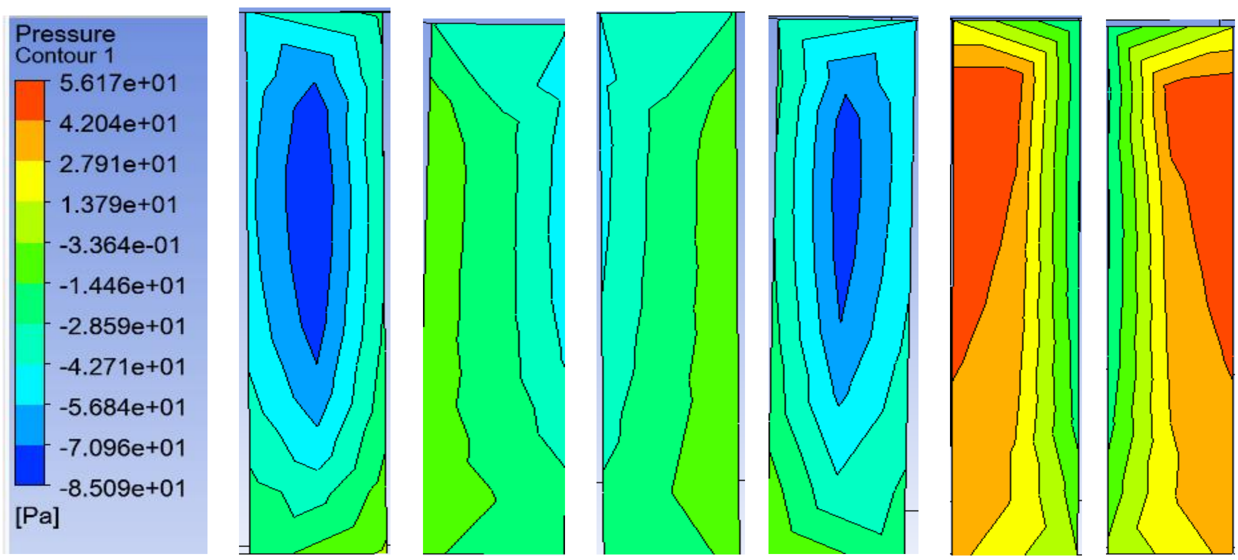

face M


face N



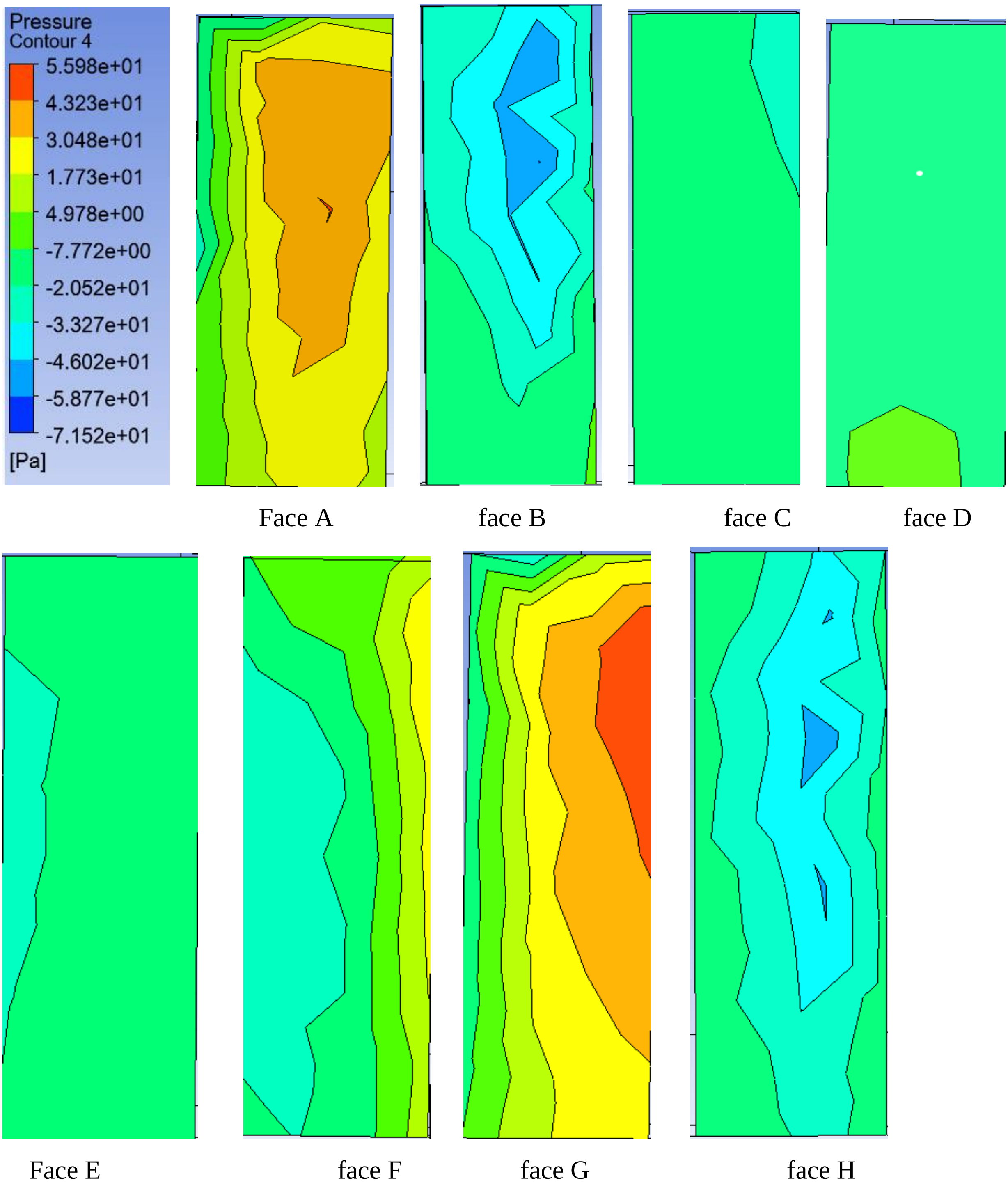
Face O face P face Q face R

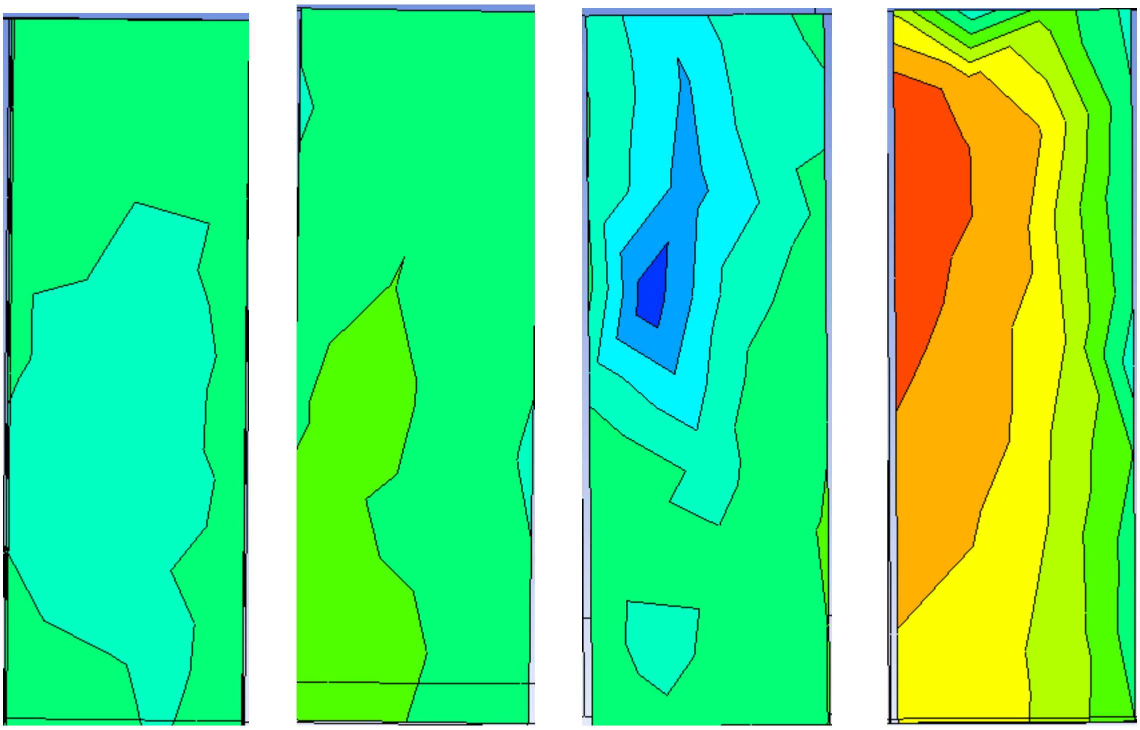
**Fig 9. Models at 15° wind incidence angles from Face A to Face R(three building)**




Face A face B face C face D face E face F

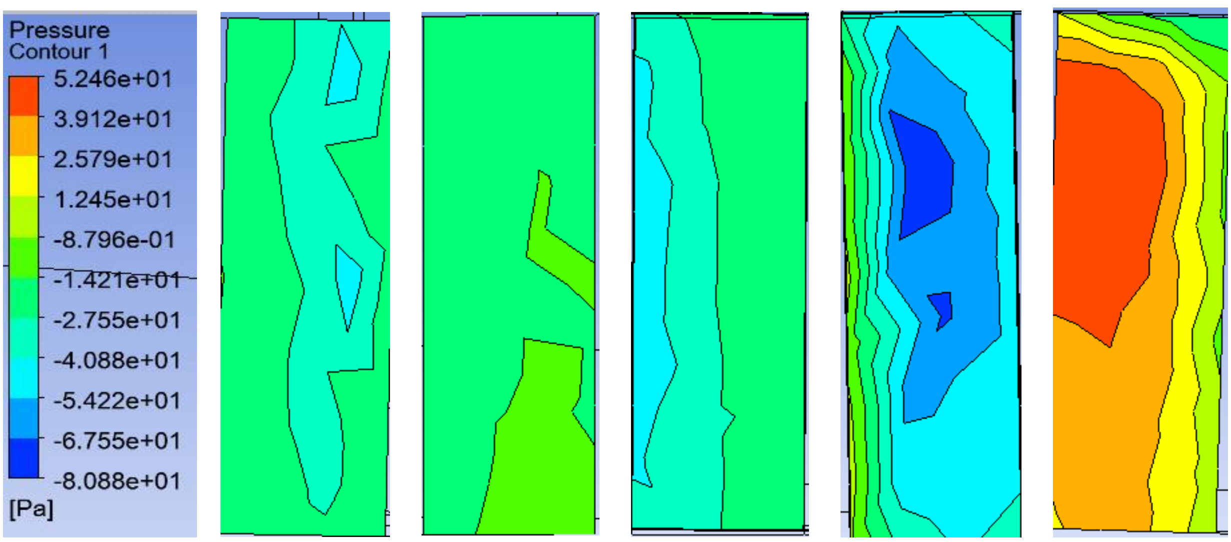
**Fig 10. Models at 30º wind incidence angles from Face A to Face F(single building)**





Face I face J face K face L

**Fig 11. Models at 30º wind incidence angles from Face A to Face L(two building)**




Face A face B face C face D face E

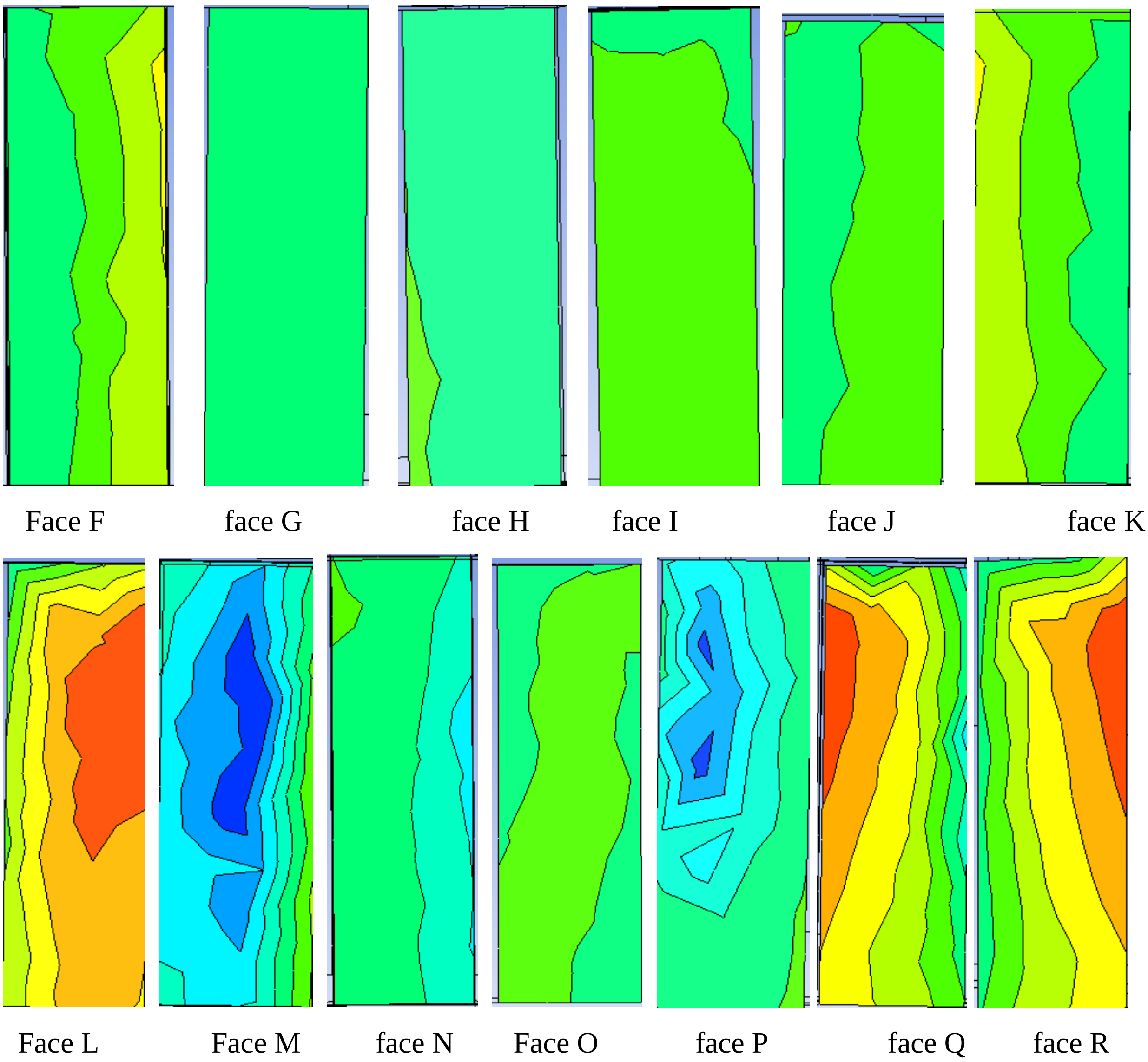



**Fig 12. Models at 30º wind incidence angles from Face A to Face R(three building)**

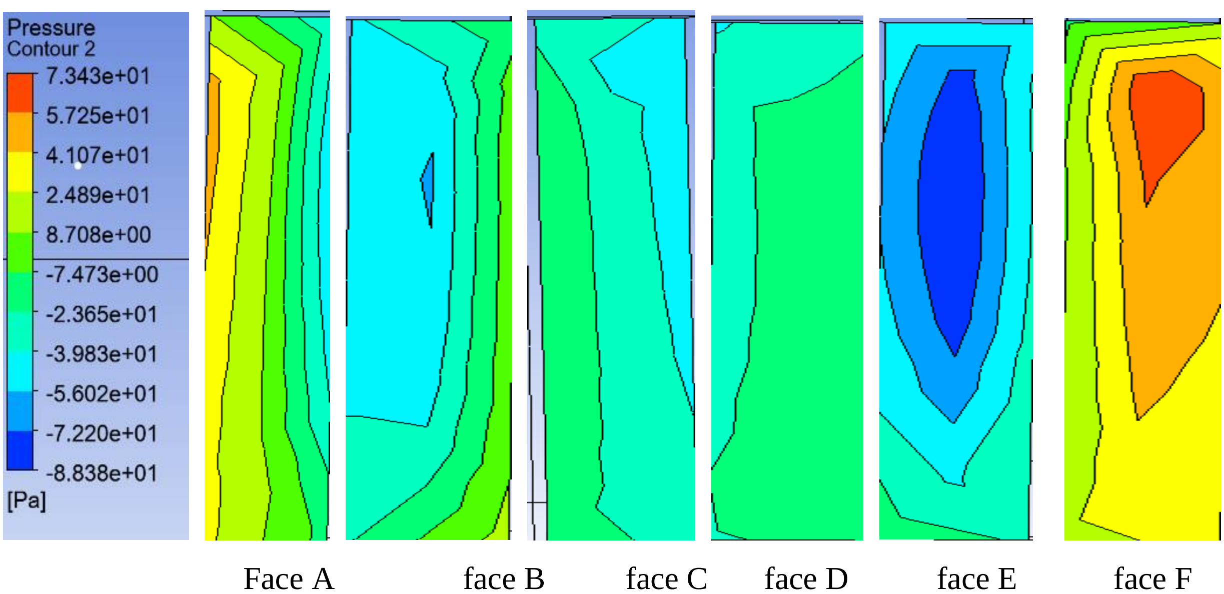
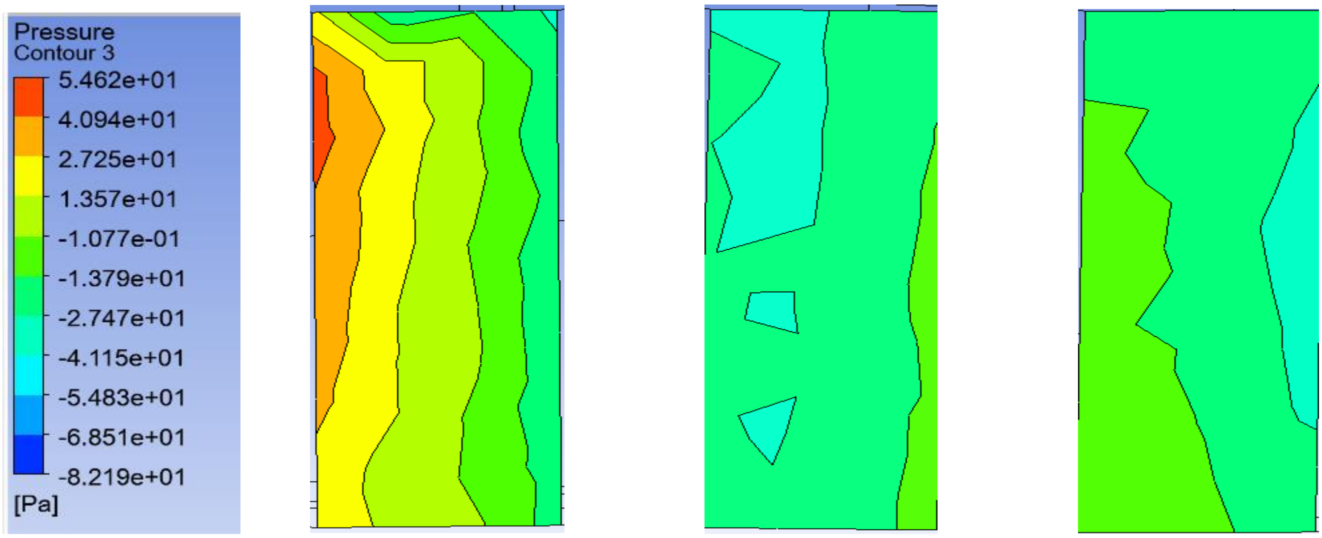
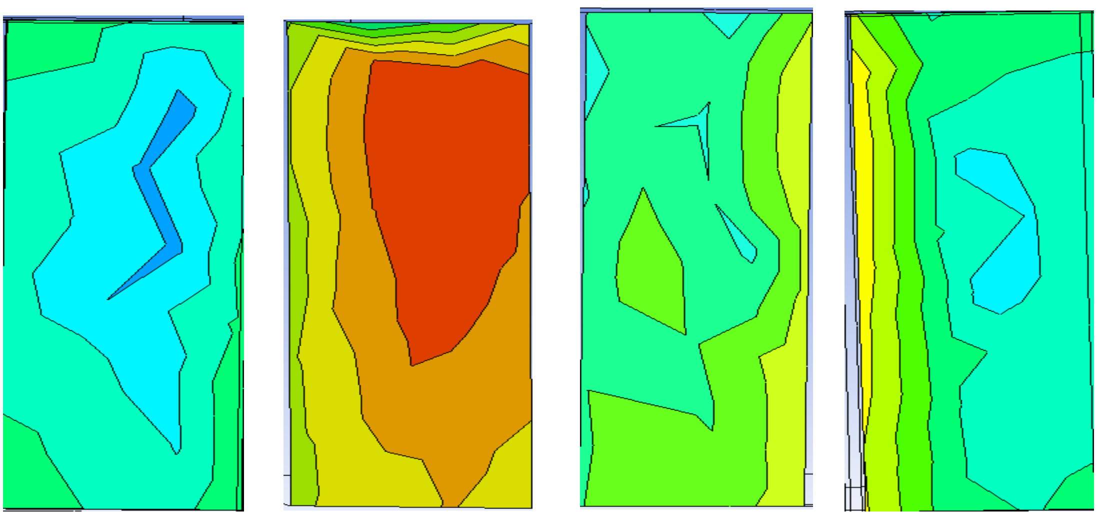


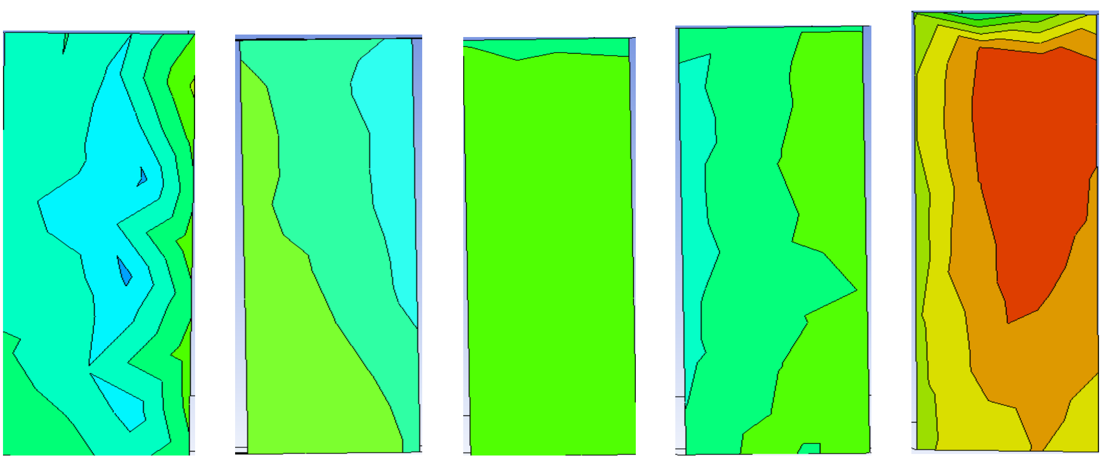
**Fig 13. Models at 45º wind incidence angles from Face A to Face F(single building)**




F face A Face B Face C



Face D Face E Face F Face G



Face H Face I Face J Face K Face L

**Fig 14. Models at 45º wind incidence angles from Face A to Face L(two building)**

*3.2 Streamlines*

Streamlines are **hypothetical** path lines which delineate the trajectories taken by fluid particles within a fluid flow, providing insight into the directional movement of fluid elements at any given point in the flow field. Figure display the streamline patterns for Models under various wind incidence angle of 0° to 45$^{o}$ condition. The presence of multiple buildings in a cluster, such as a hexagonal cluster of three buildings, can significantly affect the streamlines (airflow patterns) around the buildings compared to a single isolated building. Here are some key considerations:

1. Channeling effect: When buildings are clustered together, the spaces between them can create channeling effects, where the wind is funneled and accelerated through these gaps. This can lead to increased wind speeds and turbulence in these regions compared to a single building.
2. Wake interference: The wake region behind each building, where the wind is disturbed and turbulent, can interfere with the airflow around the other buildings in the cluster. This interference can create complex flow patterns and turbulence levels that are different from those observed around a single building.
3. Shelter effects: In some cases, the presence of multiple buildings can create sheltered regions where the wind speeds are reduced compared to an isolated building. This can occur when buildings are positioned in a way that blocks or deflects the wind away from certain areas.
4. Vortex shedding: The interaction between the buildings can lead to the formation of complex vortex shedding patterns, where vortices (swirling air motions) are shed from the buildings and interact with each other. This can contribute to increased turbulence and fluctuating wind loads on the buildings.
5. Recirculation zones: Recirculation zones, where air circulates in a closed loop, can form between the buildings in the cluster. These zones can trap pollutants or affect the dispersion of emissions, which may be different from the behavior around a single building.

The specific effects on the streamlines will depend on factors such as the relative positioning and orientation of the buildings, the wind direction, and the spacing between the buildings. Computational fluid dynamics (CFD) simulations or wind tunnel testing are often used to analyze and predict these complex flow patterns around building clusters.

It's important to note that the presence of multiple buildings can create microclimatic conditions that differ significantly from those around a single building, which can have implications for pedestrian comfort, air quality, and the overall wind loading on the structures. Figure below shows the various streamlines of various wind angles:

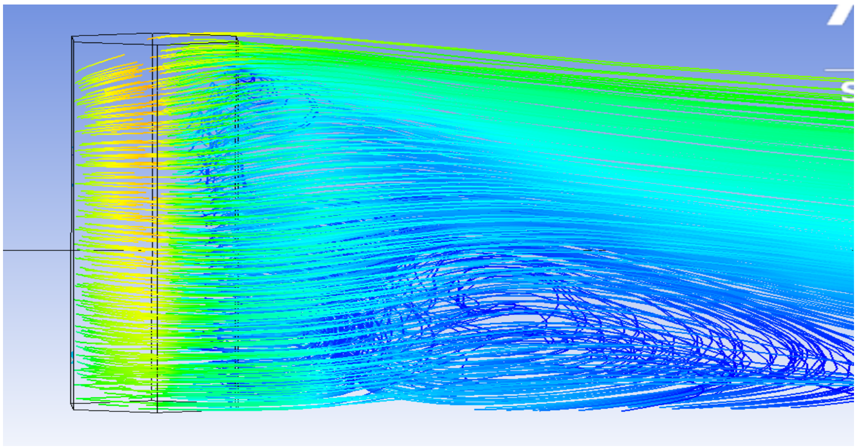


Fig 15. Streamline of single building at $0^o$

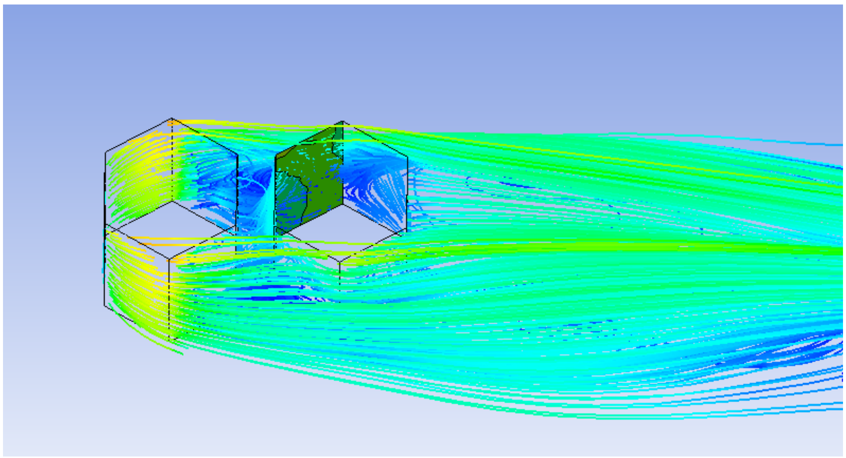


Fig16. Streamline of two building at $0^o$

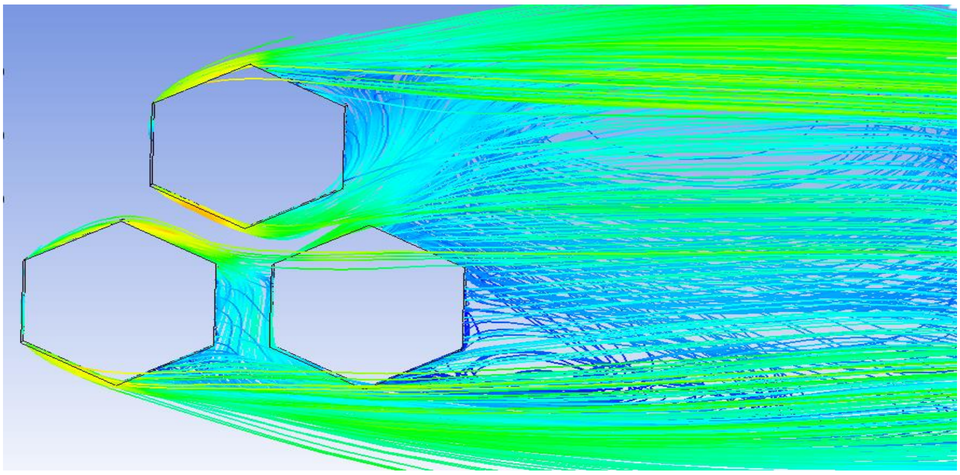


Fig17. Streamline of three building at 0°

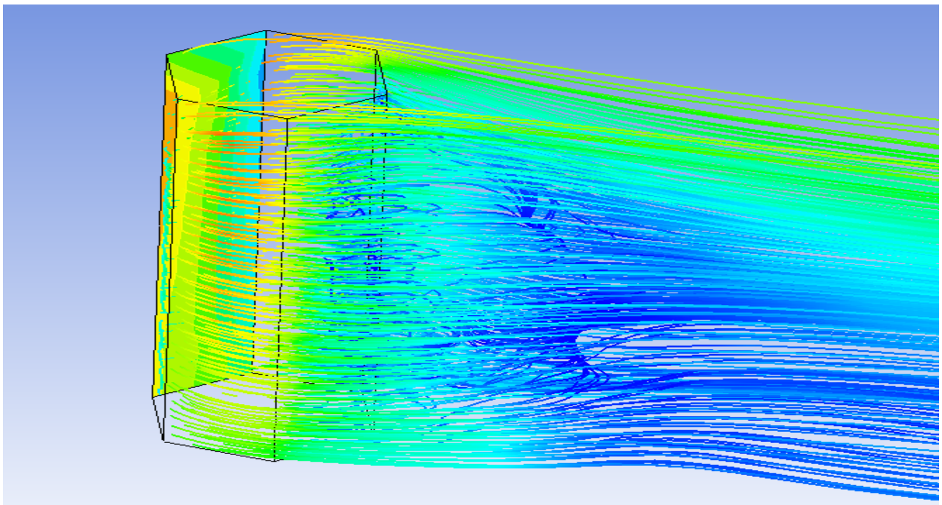


Fig18. Streamline of single building at 15°

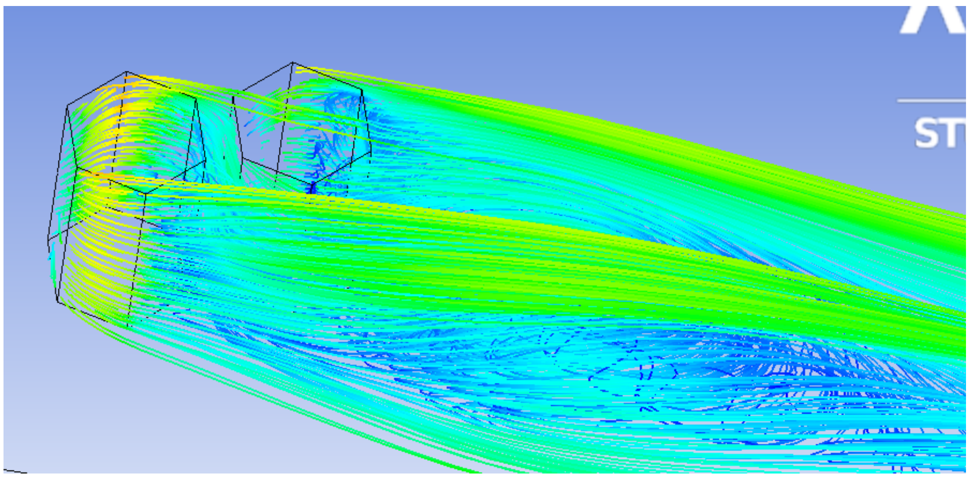


Fig19. Streamline of two building at 15°

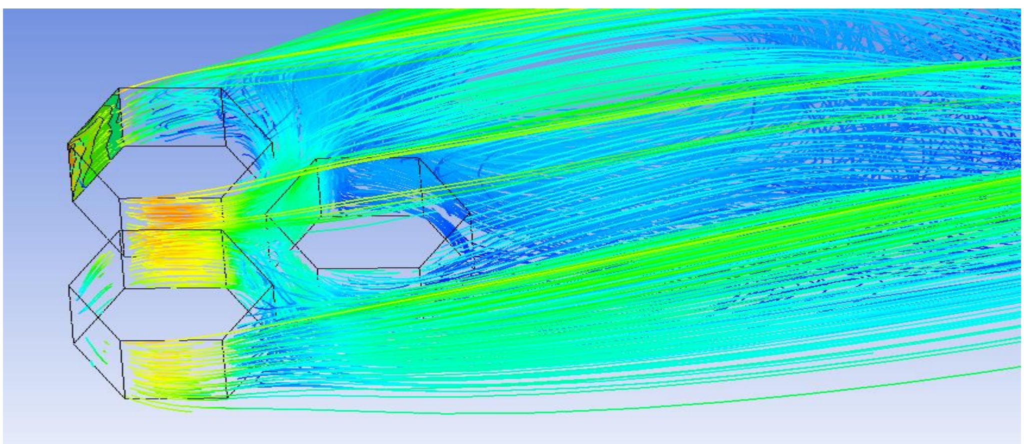


Fig20. Streamline of three building at 15°

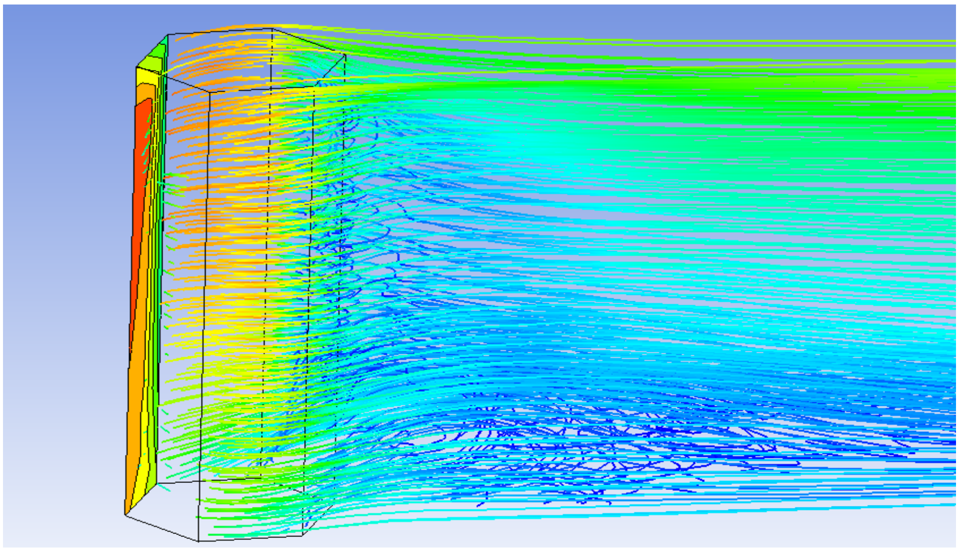


Fig21. Streamline of single building at 30$^o$

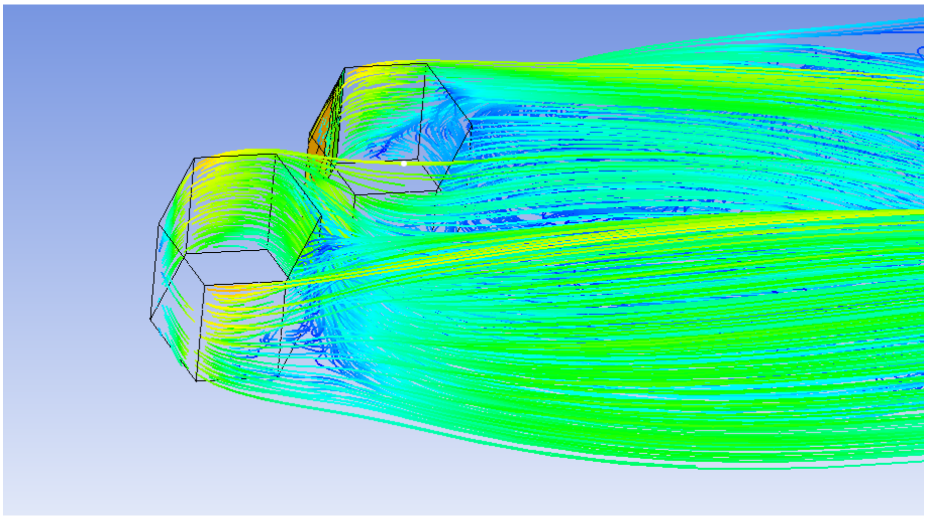


Fig22. Streamline of two building at 30$^o$

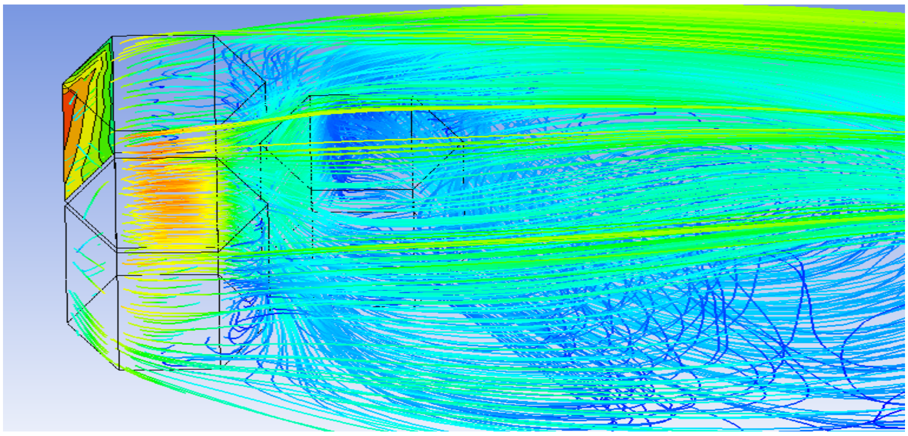


Fig23. Streamline of three building at 30$^o$

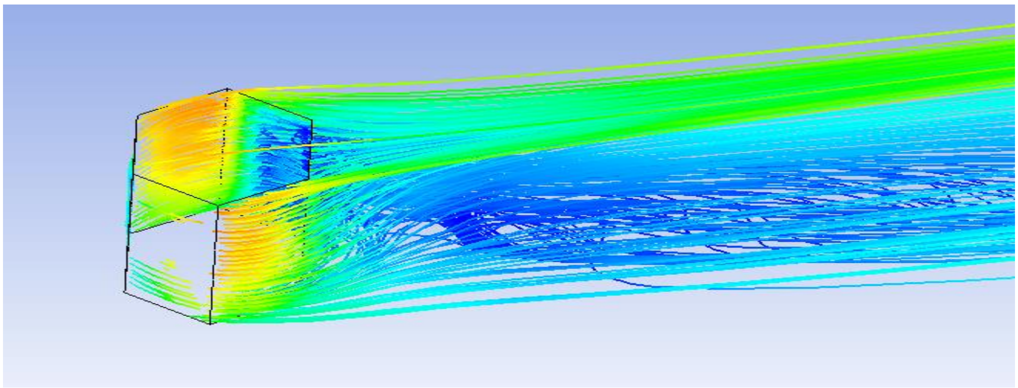


Fig24. Streamline of single building at 45$^o$

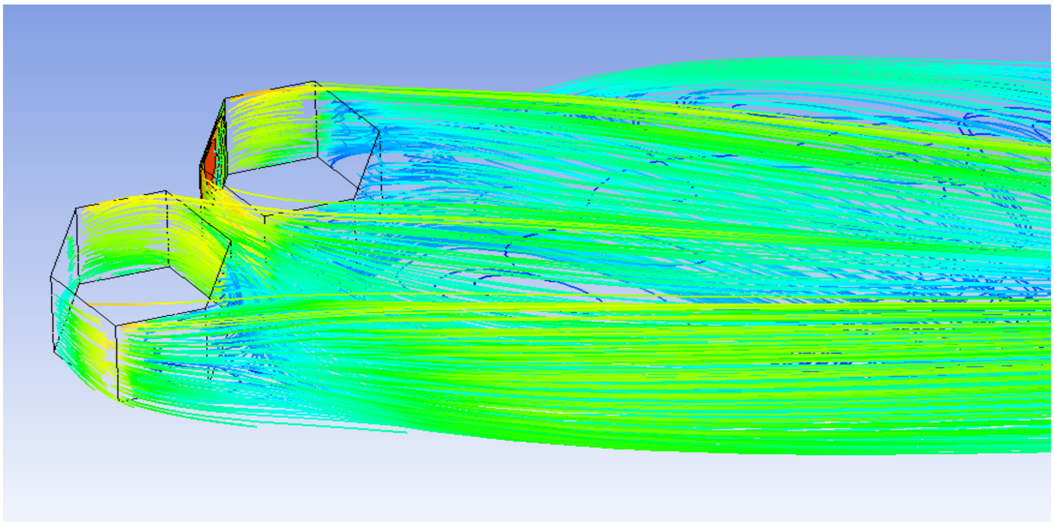


Fig25  Streamline of two building at 45$^o$

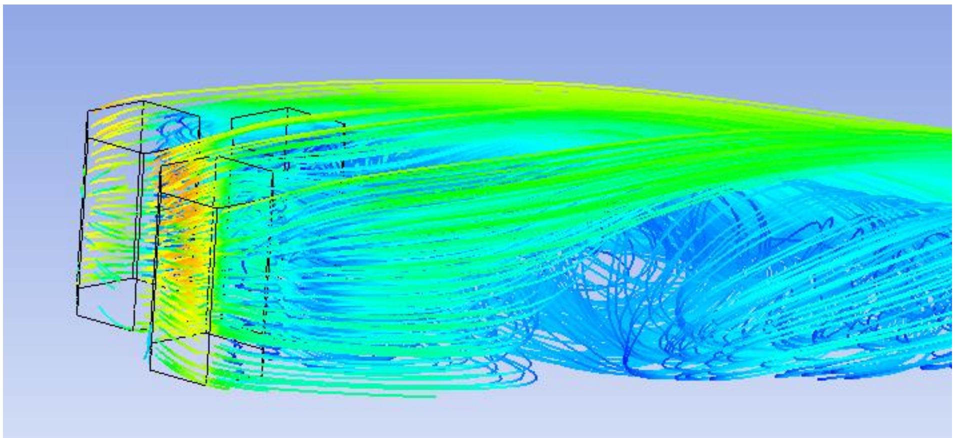


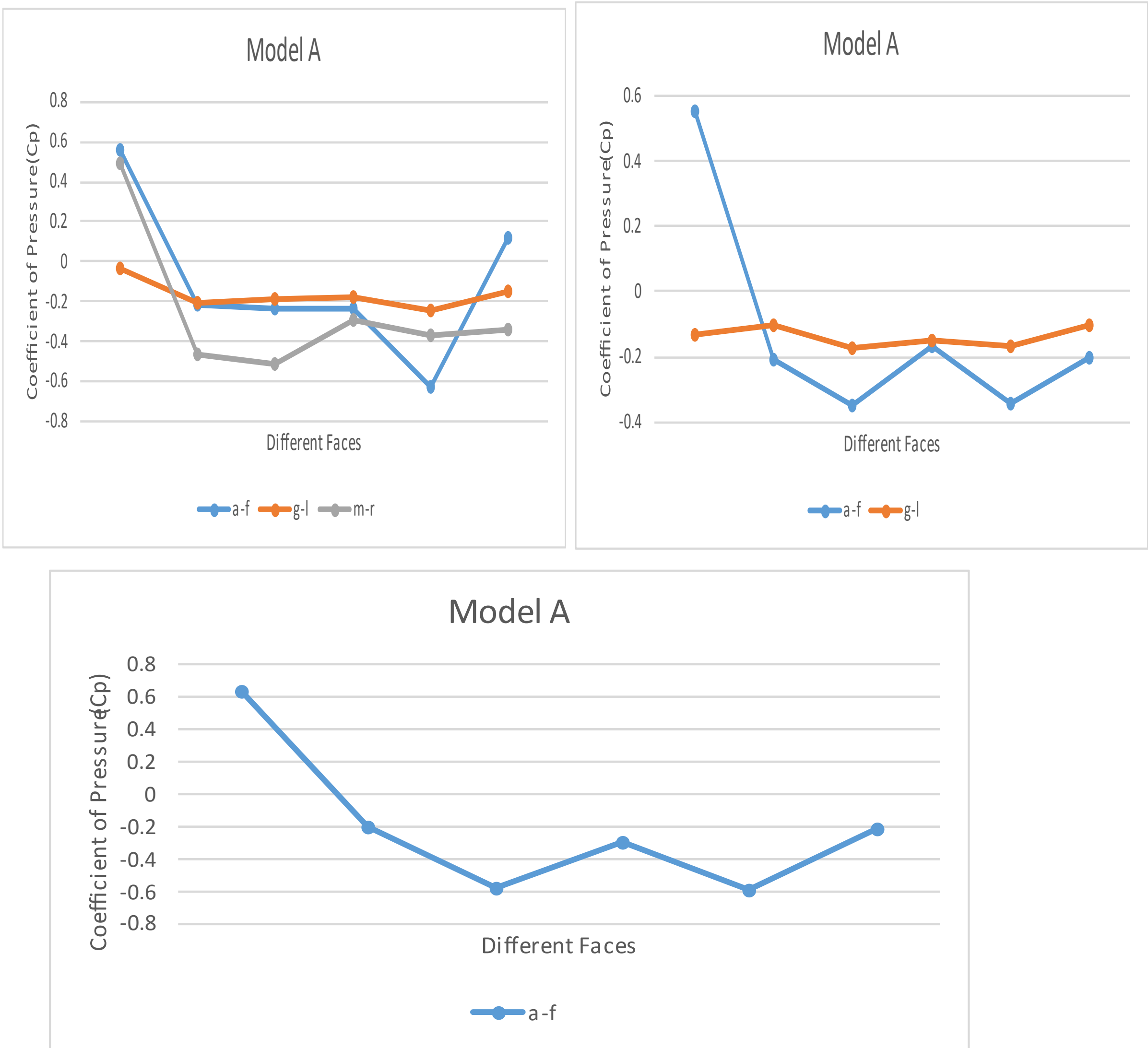
Fig26. Streamline of single building at 45$^o$

3.3 *Pressure Coefficients*

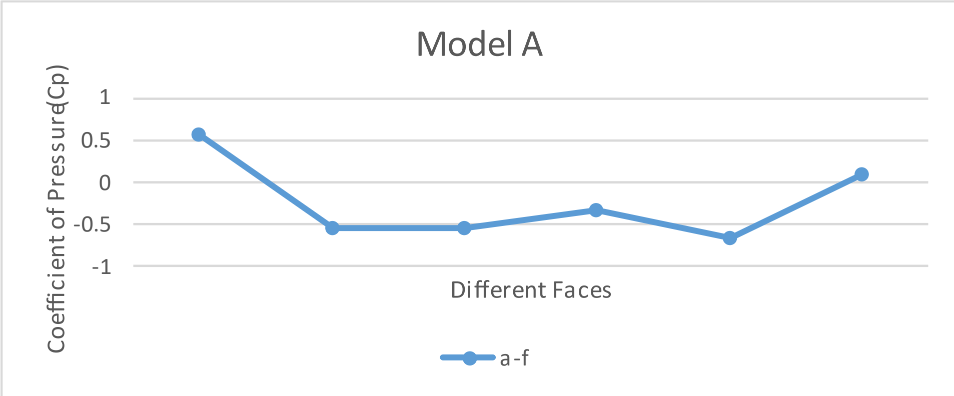
The mean pressure coefficient (Cp) is calculated from equation (1) given below, where *p* is the pressure which has been measured from the required point, $p_o$ is the reference height of steady pressure, ρ is density of the air which is taken as 1.225 [kg/m^3] and $U^2_H$ refers to the mean wind velocity at the building reference heights.[1]

$$C_{Pmean}=\frac{P-P_0}{\frac{1}{2}\rho U_H^2} \qquad \text{------ Equation (1)}$$

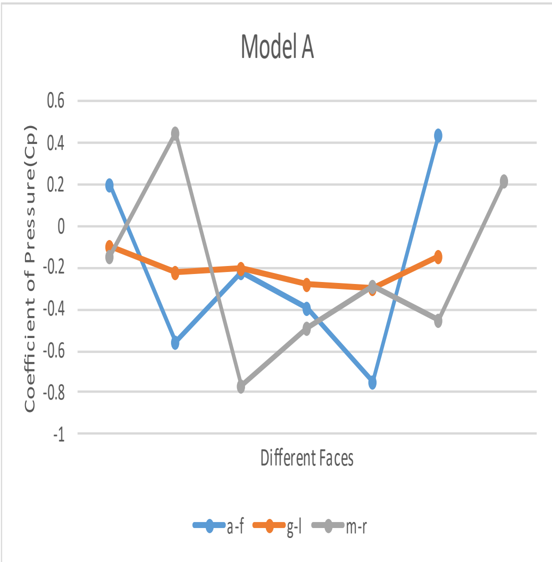
The value of pressure coefficient on the windward side is positive whereas in leeward side is found to be negative for each angle of wind incidence. The graph below shows the comparison of all the buildings in single building , two building and three building clusters. For a two building $C_p$ is shown for all the both the buildings in one graph which is similar in the case of three building. For every wind incidence angle 3 graphs for each case are indicated. In case of $0^0$ the maximum $C_p$ of 0.60 is experienced by the windward side for all the configurations while in case of three building the building(from face m to face r) on the leeward side with maximum shielding effect is having least range of variation in pressure coefficients from 0.0 to -0.1 and the other building with faces g to l the wind pressure is seem to be having an effect and a partial shielding provided by the first building is indicated to have a slightly higher variation is its pressure coefficients which is in the range of 0.50 to -0.30. In case of two building the building facing the windward side has a vast variation in coefficients from 0.60 to -0.20 whilst the building with faced g to l is having very low variation in the pressure coefficients that is from -0.17 t0 -0.15. Similarly for other wind incidence angles the building facing windward side changes and leeward side also changes providing a shielding effect to one another.



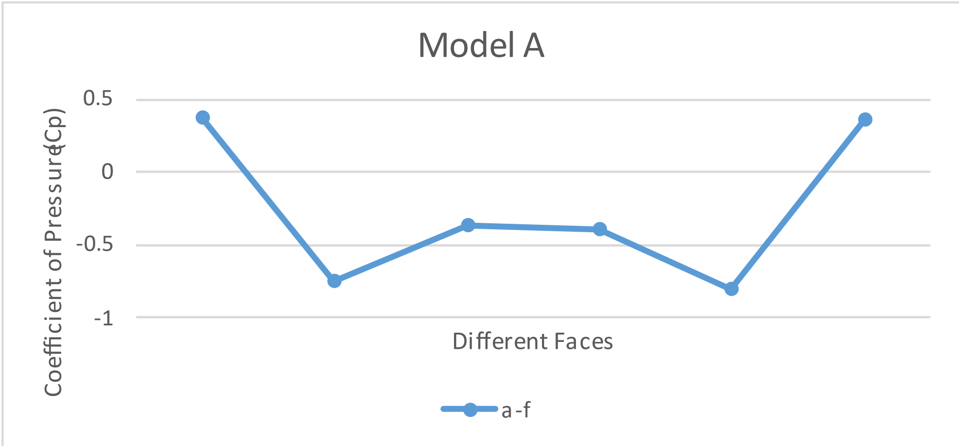

Graph 1. $C_p$ values for three, two and single building at 0$^o$




Graph 2. $C_p$ values for three, two and single building at 15°








Graph 3. $C_p$ values for three, two and single building at 30°

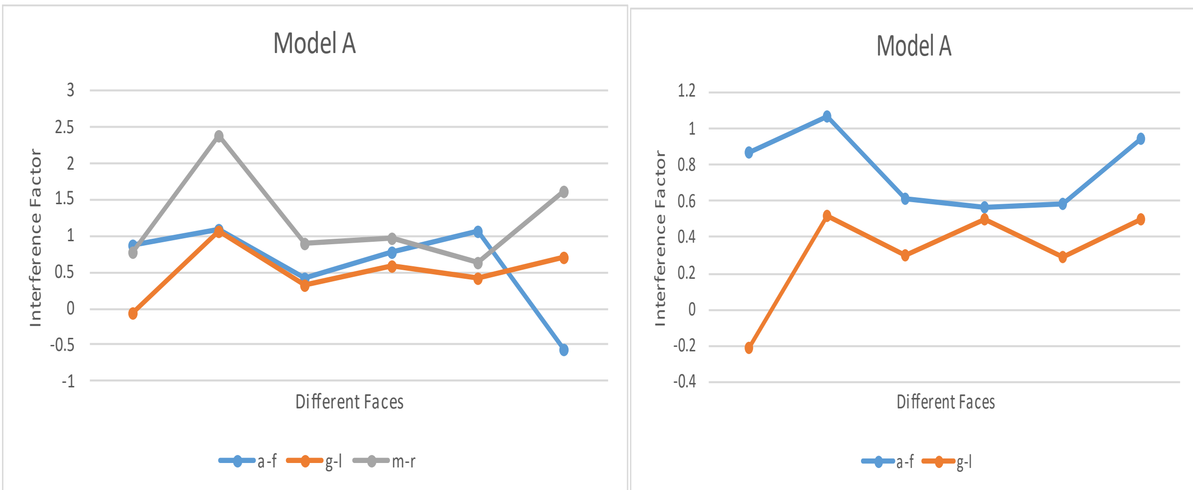

Graph 3. $C_p$ values for three, two and single building at 45$^o$

### 3.5 *Interference Factor*

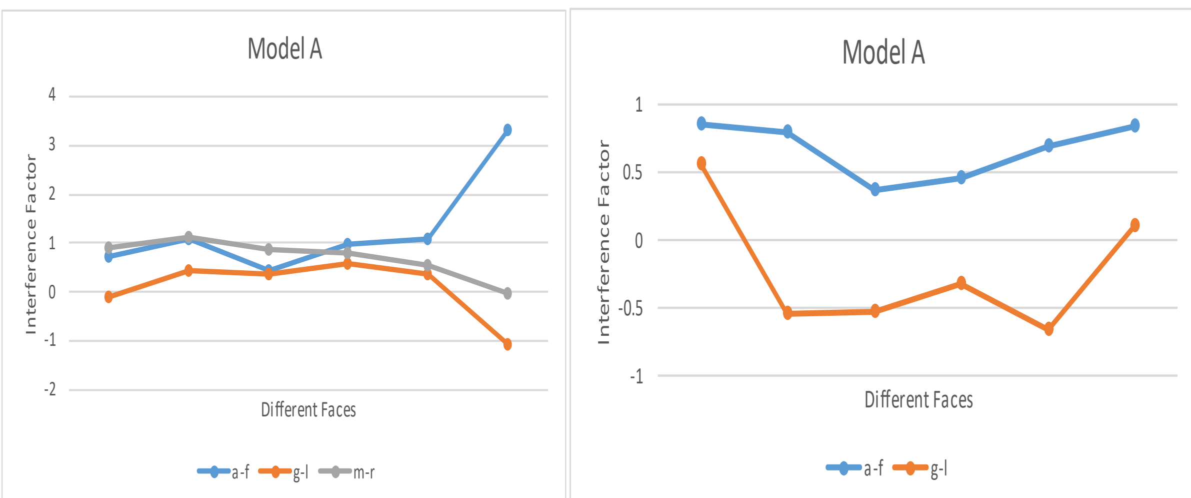
An interference factor (IF) is a dimensionless quantity that is defined as the ratio of the Cpe obtained for an interfering building to the Cpe obtained for the isolated building. With the aid of IF, the effects of varying building spacing on variations in wind-induced action can be investigated. The numerical definition of the IF is provided in Eq. 8

$$IF = \frac{Cpe\,(interferring)}{Cpe\,(isolated)}$$

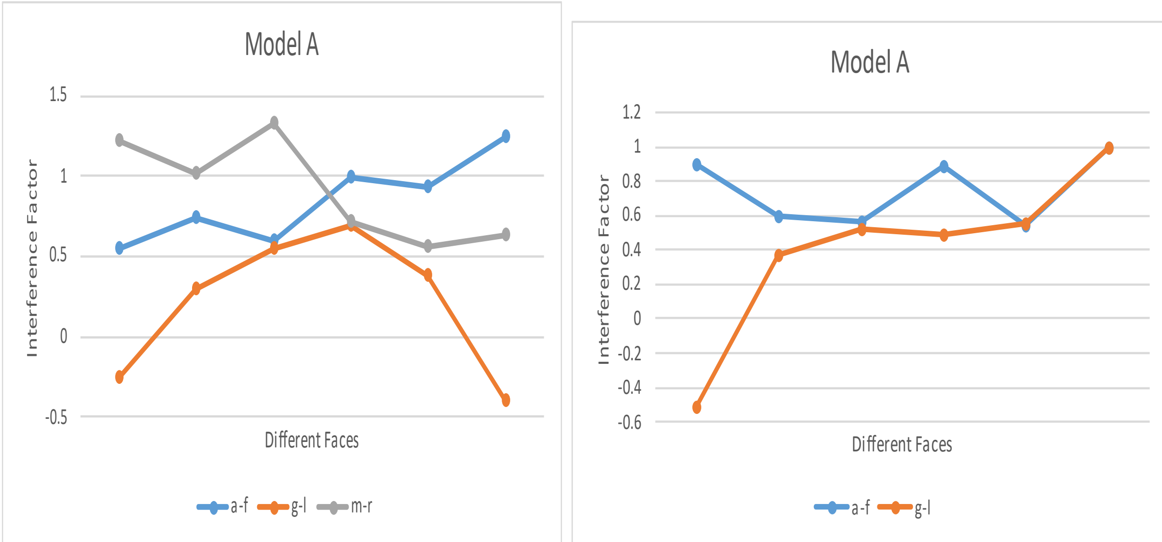
The IF can be used successfully for the numerical representation of the impacts caused by the wind action due to the interfering building on the building that is being studied. If the building under study has a lower value of Cpe as a result of an interfering building, which lowers the IF, then the building's suction is lowered as a result of the interfering building's shielding effect, but the wind action's nature remains the same. The wind-induced action on the roof of the building under consideration will be reduced the lower the value of IF. Whenever the sign of IF changes i.e., from positive to negative, then it suggests that the type of wind impact on the roof or building under examination has changed. The following graphs display the interference factor in relation to the building's faces at each angle:



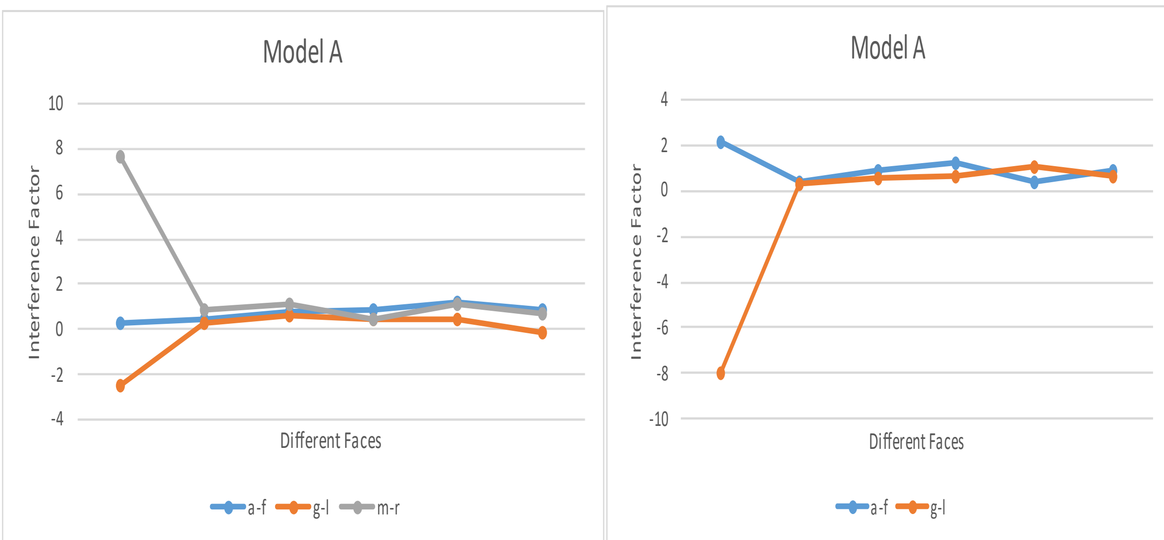

Graph 4. Interference factor values for three and two building at 0°




Graph 5. Interference factor values for three and two building at 15°




Graph 6. Interference factor values for three and two building at 30$^o$



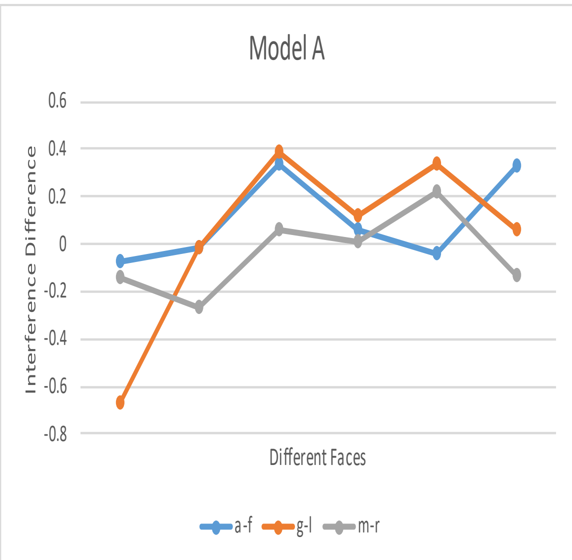

Graph 7. Interference factor values for three and two building at 45$^o$

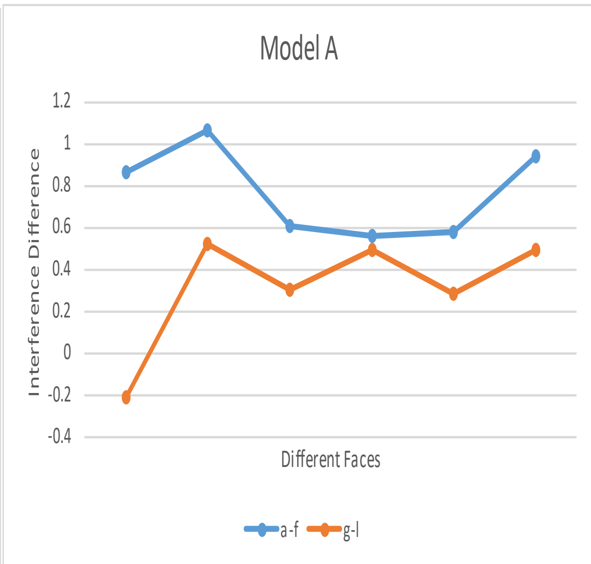
### 3.5 *Interference Difference*

The interference difference is another measure that can provide insight into the impact of an interfering building on the building under study. It turns out to be more accurate than IF since it provides an estimate of the amount of pressure or suction that is reduced on roofs as a result of interference, whereas IF can be deceptive in certain situations because it provides an extremely high magnitude at the lowest ID value. Interference difference (ID) is the difference in Cpe measured from an isolated and interfering building. The ID is found using Equation 9.

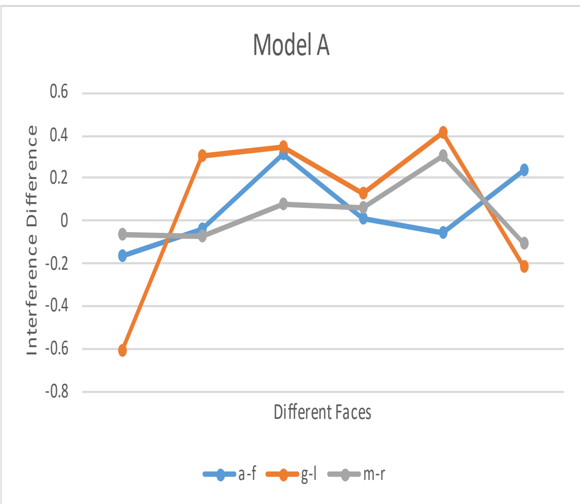
$$Interference\ Difference(ID) = Cpe(interference) - Cpe(isolated) \qquad (9)$$

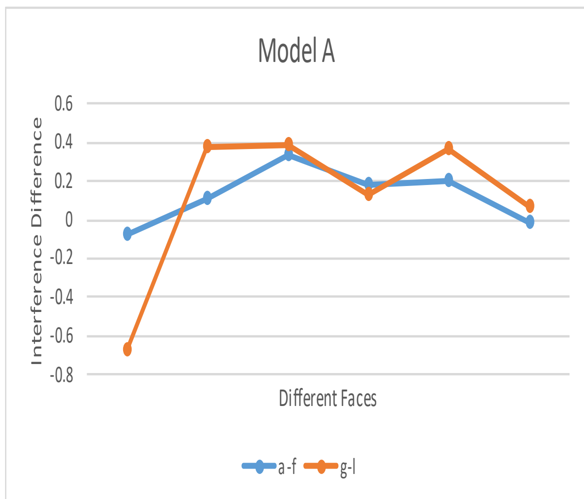
Occasionally, it is discovered that interference causes a building's pressure or suction to decrease. An example of this would be the shielding effect that an interfering building has on a roof when it is present in the upstream direction of the wind flow. The following graphs display the interference factor in relation to the building's faces at each angle:



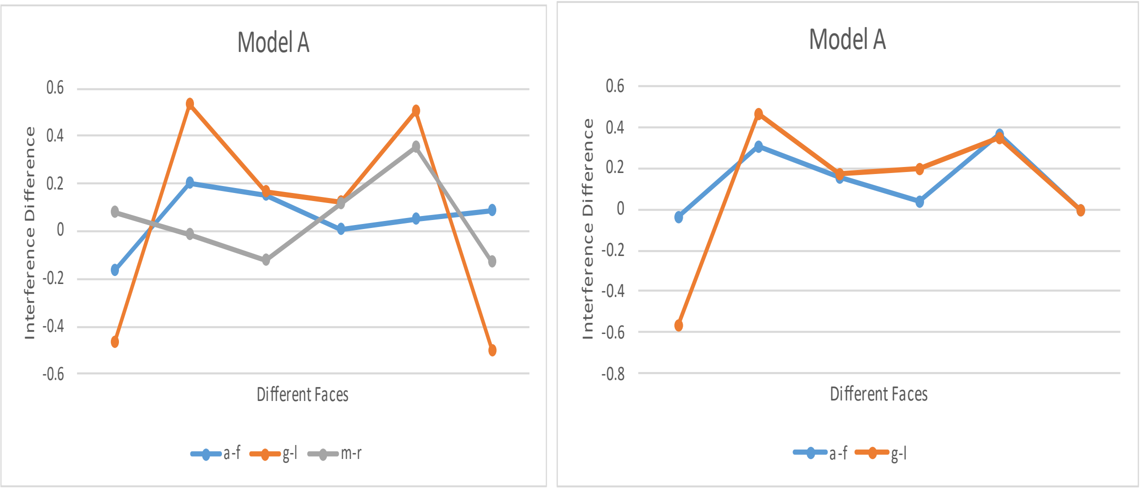




Graph 8. Interference difference values for three and two building at 0°

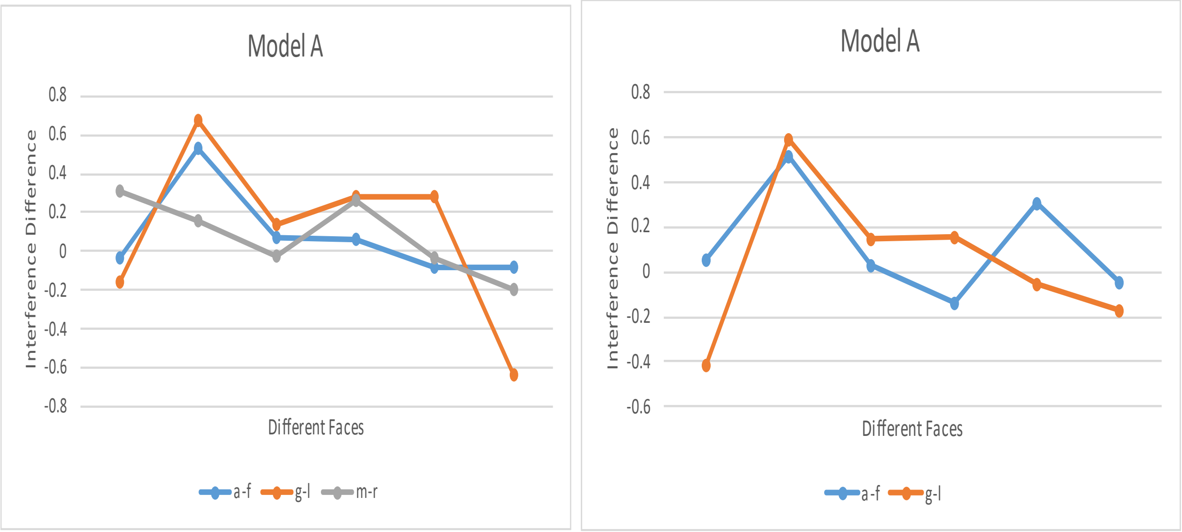



Graph9. Interference difference values for three and two building at 15°




Graph 10. Interference difference values for three and two building at 30$^{o}$




Graph 11. Interference difference values for three and two building at 45$^{0}$

# CHAPTER 5
# CONCLUSIONS

This study investigated the aerodynamic behaviour of a hexagonal cluster of three buildings and two buildings in comparison to a single isolated building. Through comprehensive computational fluid dynamics (CFD) simulations, significant insights were gained into the effects of building interference on pressure coefficients, interference factors, and interference differences.

The results revealed that the pressure distribution and flow patterns around the buildings were significantly influenced by the number of structures in the cluster. While the single building exhibited a relatively uniform pressure distribution, the introduction of additional buildings in the clusters led to localized areas of high pressure and suction, particularly in the regions between the structures.

The interference factors, quantifying the amplification or attenuation of wind loads due to neighboring buildings, displayed distinct variations among the three configurations. The cluster of three buildings exhibited higher values interference factors ranging from -0.70 to -0.20 for three building and -0.10 to 0.40 for two building cluster, indicating a greater influence of building interference on wind loads.

Notably, the interference differences, representing the discrepancies in wind loads between the clusters and the isolated building, highlighted the importance of considering building interference effects in design calculations. Significant interference differences were observed, with the three-building cluster exhibiting the largest deviations from the single building case, followed by the two-building cluster.

By providing a comparative analysis of different building cluster configurations, this research contributes to a deeper understanding of the aerodynamic behavior of urban environments. It can be concluded that

- Ordinary standards are insufficient for designing single, two, and three building clusters because the Cp values of building models with hexagonal shapes differ from those of ordinary square and rectangular models.
- Cp exhibits a higher value of magnitude under isolated condition than the principle building in 2 building and 3 building configuration.

- While the Cp values are high for face a in comparison to face g in two building, it is lesser for all other faces i.e face b,c,d,e,f in comparison to all the faces of the 2nd building i.e face h,i,j,k,l .
- In case of 3 building generally at all the wind incidence angles ,Cp values are found to be lesser for interfering having faces m to r in comparison to the corresponding faces of the principal building indicating face a to f while for the other interfering building from face g to face l the values of Cp are found to have higher values from the corresponding faces in principal building
- Graphing IF values for various orientations is used to assess the interference influence on the principal building. Values less than one imply that the observing building is shielded, whilst values greater than one indicate higher loading.
- The value of pressure coefficient decreases with increase in wind incidence angles upto $60^0$ and on going further it induces suction.
- IF for principal building (face a to face f) in case of 2 building configuration with respect to single isolated building is found to be higher in case $0^0$, $15^0$, $30^0$, $90^0$ angle of incidences while the IF for interfering building (face g to face l) seems to have a relatively lower value than the principal building.
- In case of 3 building, IF of principal building is always lower than 2nd interfering building (face m to face r) and higher for 1st interfering building (face g to face l) for the angles $0^0$, $15^0$, and $30^0$.
- In case of angle of incidence of $45^0$ and $75^0$ , the IF for interfering building of 2 and 3 buildings configuration are almost equal to the corresponding faces of their principal buildings except for face a in principal building and its corresponding face g in 2 building and face g, face m in 3 building configuration.
- At $60^0$ , the value of IF for both the configurations were very vague and not comparable to other angles.
- Moreover, the interference factor (IF) value varies with each angle of wind incidence.
- The smallest value of Cpe on an isolated structure has occasionally been reported to generate a sharp increase in the interference factor (IF). Consequently, the disparity caused by the interference factor (IF) is determined by computing the interference difference (ID).
- A positive interference difference (ID) value suggested a decrease in the shielding effect, whereas a negative ID value resulted from a decrease in the increase in wind load.

- Preferably for 2 building and 3 building configuration, angle of incidence at $45^0$ is optimum angle as its IF values are quite close to each other for each building and hence the effect of wind flow and its forces on each building will be balance each other out.
- This investigation provides a basic knowledge and understanding about interference of the hexagonal building in 3 different types of configurations. Further, it can be investigated for various spacing between the buildings and considering different shapes of the buildings as well as varying configurations. The analysis could be done using ANSYS CFX and the results should also be verified by wind tunnel testing. This would be a physical approach for carrying out the analysis.

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