CFD STUDY ON EFFECT OF ROOF ANGLE ON PRESSURE DISTRIBUTION AROUND THE BUILDINGS ARRANGED IN TANDEM

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Abstract— In this Study, the Numerical study has been completed to measure Pressure Coefficients on rectangular gable roof buildings in tandem arrangements by ANSYS-CFX Package. There was a major effect of change in roof angle (α) of both buildings as 10˚, 15˚, 20˚ for constant Height Ratio (H_2/H_1) of Principal Building to Interfereing Building with the change in Span Ratio (S_1/S_2). The spacing between two buildings is 1.5 m. The Numerical Simulation is carried out by Shear Stress Transport (SST) turbulence model. And also study the effect of different roof angle of both buildings, in which roof angle (α2 = 15˚) of tall building and roof angle (α1 = 10˚, 15˚, 20˚) of the small building is studied. From these study, comparison is done of PCOE between same roof angle and different roof angle for single span ratio. A Measure effect is due to change in roof angle (α) on Leeward Roof – 1, Leeward Wall – 1, Windward Wall – 2, Windward Roof – 2, Leeward Roof – 2. After the Simulation of all models, the comparison of PCOE of different roof angle for single span ratio is done. Numerical Simulation has indicated the importance of the span ratio and roof angle.

Index Terms—Roof Angle, SST Turbulence Model, Span Ratio, ANSYS CFX

I. INTRODUCTION

R. P. Hoxey et. al. [2] had been studied full-scale investigation of distribution of external pressure and internal pressure of single span building. In this study, they considered Height, Span and Roof Angle of the building as study parameters. From this study, Approximating the non-uniform wind load over a roof slope by an area-averaged pressure coefficient leads to acceptable predictions of stresses and deflections. If the building has a dominant opening then Internal pressure and External pressure considered for Dynamic Analysis of Wind Load. Rocky Patel et. al.[4] suggested the optimum domain size for the numerical wind simulation in ANSYS CFX for low rise bluff bodies. Rocky Patel et. al.[3] carried out done 2D numerical simulation for understanding impact of windward building geometry on overall Pressure distribution by K-ε Turbulence Model in ANSYS CFX. The Author Concluded that the pressure coefficient derives from Numerical simulation by CFX as having the fair agreement with wind tunnel data. Neel Patel et.al. [5] done 3D numerical simulation of two rectangular roof pitched buildings in tandem arrangement with different Height Ratio and Span Ratio with in between Spacing by standard Standard k- ε and SST Turbulence model in ANSYS CFX. The author suggested that the SST model gives the highly accurate prediction of onset and amount of flow separation under adverse pressure gradients by the inclusion of transport effect into the formation of eddy viscosity. SST model combines the advantage of both Standard k-ε and k-ω model. The spacing between buildings affects the pressure co-efficient around various faces and pressure distribution around both buildings. It was concluded that the SST turbulence model gives nearest results with compared to the IS-875 (Part-3).

II. GOVERNING EQUATIONS:-

RANS (Reynolds-Averaged Navier – Stokes) Equations:-

Navier-Stokes equations are highly sensitive to Initial condition and must abrase the wide range of Length scale and Time-scale. To reduce this complexity, consider the statistical average for the Navier-Stokes equations which are known as RANS (Reynolds-averaged Navier–Stokes) Equations. RANS equations is derived from the Navier-Stokes equations.

$$\rho\bar{u}_j\frac{\partial\bar{u}_i}{\partial\bar{x}_j} = \rho\bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial\bar{u}_i}{\partial x_j} + \frac{\partial\bar{u}_j}{\partial x_i}\right) - \rho\overline{u_i'u_j'}\right]$$

SST (Shear Stress Transport) Turbulence Model:-

The k- ε based SST model accounts for the transport of the turbulent shear stress and gives highly accurate predictions of the onset and the amount of flow separation under adverse pressure gradients. The proper transport behavior can be obtained by a Limiter to the formulation of the eddy-viscosity.

$$\boldsymbol{V_t = \frac{\alpha_1 k}{max\alpha_1\omega, SF_2}}$$

Where, $V_t = \frac{\mu_t}{\rho}$

Wind Velocity Profile

The approaching wind was created from a power-law model to approximate the mean velocity profile:-

$$V(y) = V_g \times (y/H)^{0.143}$$

The gradient height H was assumed to be 6.7 m at top of the building and the mean wind velocity V_g at the gradient height (Max. Building Top Height) is 10.6 m/s for open terrain.

Pressure Distribution:

The mean pressure coefficient along the wind direction is $\frac{1}{2}\rho v^2$, where ρ is the density of air which is 1.185 kg/m^3.

$$Mean\ Pressure\ Coefficient\ (PCOE) = \frac{Mean\ Pressure}{\frac{1}{2}\rho v^2}$$

The general characteristics and effect of pressure distribution were measured at mid-length of the building on Windward and Leeward faces of Square and Rectangular building models at wind incidence of 0°.

III. GEOMETRICAL NOTIFICATION FOR DOMAIN AND BUILDING AND RELATED INPUT PARAMETERS

From the Study of Rocky Patel et. al. [4] the optimum domain size for 3d simulation in ANSYS-CFX is considered distance from Inlet to Windward face (L_1) = 5H, distance from Leeward Face to Outlet (L_2) =15H, Total Domain Height (Y) = 10H, $B_1 = B_2$ = 5H (Side Distances from Right and Left Side of Building to respective Domain Sides), Where H = Height of the Taller Building. All the notifications are shown in below figure. In models of buildings H_1 = Height of Upstream Building, S1 = Span of Upstream Building, α_1 = Roof angle of Upstream Building, H_2 = Height of Downstream Building, S_2 = Span of Downstream Building, α_2 = Roof angle of Downstream Building. The Length of both building L = 20 m perpendicular to wind direction, Rectangular plan (L × S_1 orS_2) = (20 × S_1or S_2) m^2.

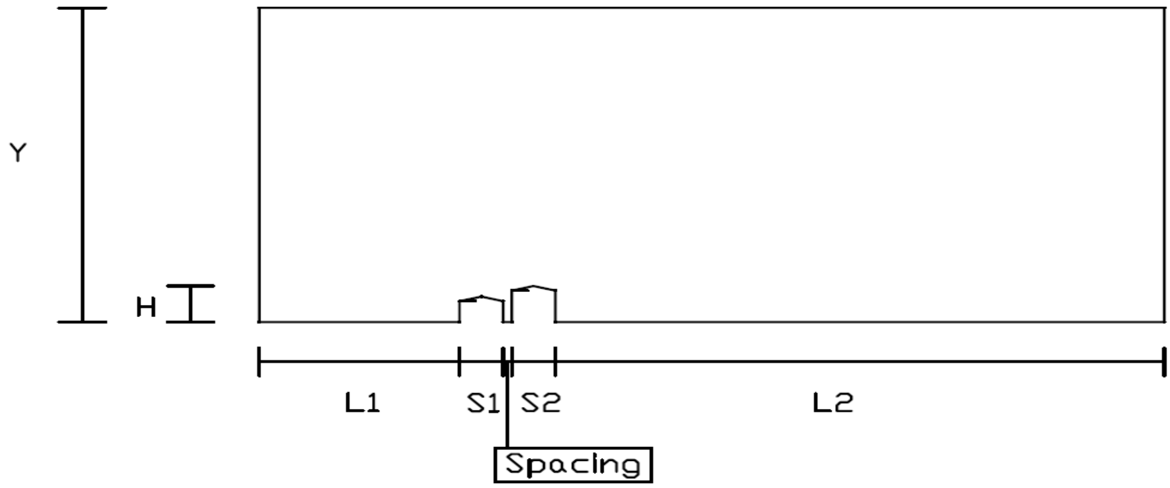
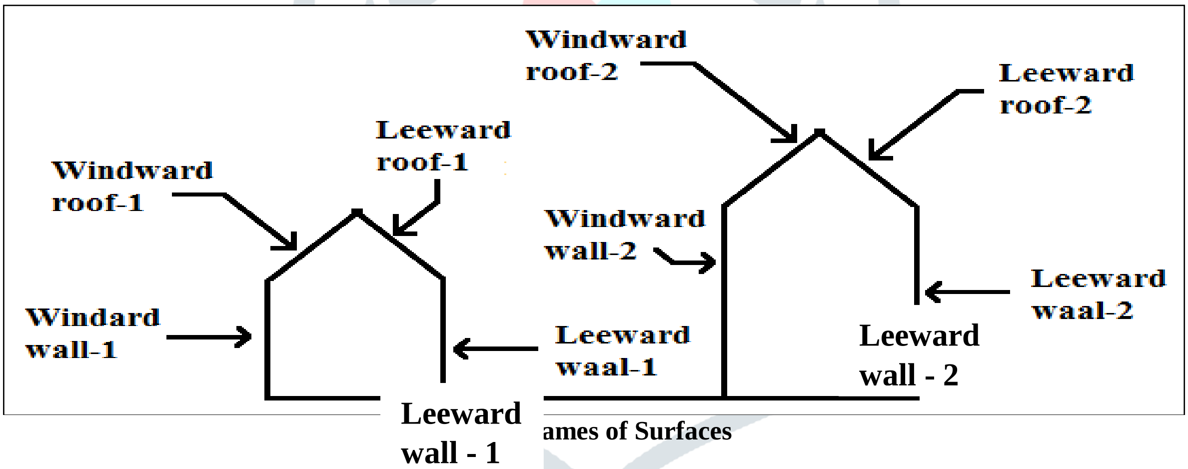


Fig. 1 Geometrical Notification of Buildings and Domain



ames of Surfaces

IV. MESHING : -

Medium mesh was applied on the domain surfaces and application of refinement on the building surfaces where done for getting accurate results of pressure distribution as shown in below fig. 3 in meshing modular.

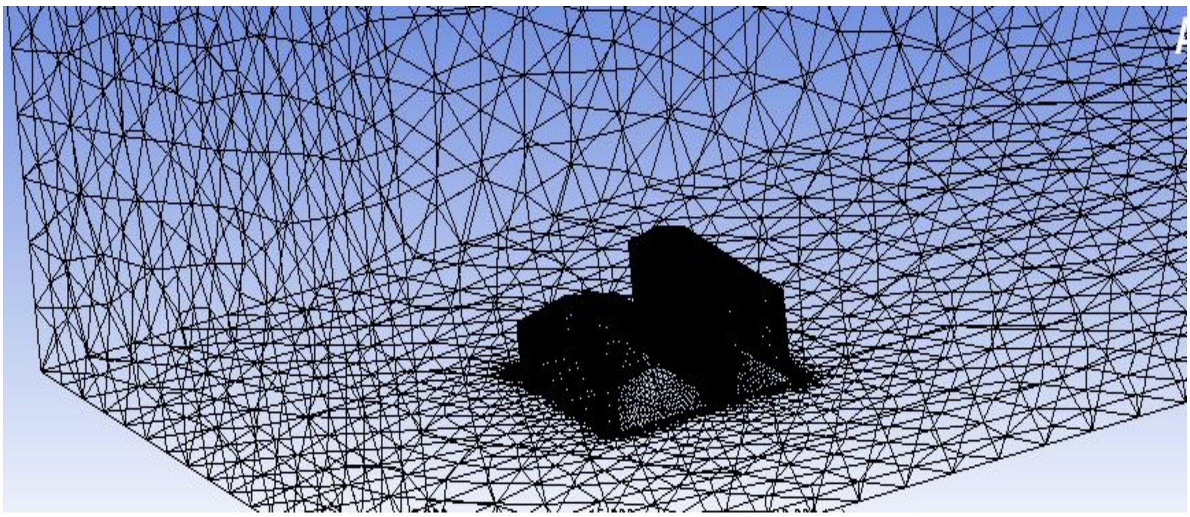


Fig. 3 Refinement on Buildings Surfaces

Table 1 Geometry details of Parametric Models for Study - 1

Model	Model no.	Geometry Details						Domain Details			
		H1	H2	S1	S2	α_1&α_2	Spacing	L1	L2	H	B1 & B2
								5h	15h	10h	5h
H_2/H_1= 2 & S_1/S_2=0.8	1.1	3	6	4	5	10	1.5	30	90	60	30
	1.2	3	6	4	5	15	1.5	30	90	60	30
	1.3	3	6	4	5	20	1.5	30	90	60	30
H_2/H_1= 2 & S_1/S_2=1.2	2.1	3	6	6	5	10	1.5	30	90	60	30
	2.2	3	6	6	5	15	1.5	30	90	60	30
	2.3	3	6	6	5	20	1.5	30	90	60	30
H_2/H_1= 2 & S_1/S_2=1.8	3.1	3	6	9	5	10	1.5	30	90	60	30
	3.2	3	6	9	5	15	1.5	30	90	60	30
	3.3	3	6	9	5	20	1.5	30	90	60	30

In study - 1, total 9 models having same Height Ratio and Change in Span Ratio as 0.8, 1.2, 1.8 is carried out for in-between spacing of 1.5 m for both the buildings. For each Span ratio, there were three models having the variation of roof angle (α) as 10˚, 15˚, 20˚ of both buildings. Both the buildings have same roof angle. Dimensions of Domain Size for each model were given in Table.

Table 2 Geometry details of Parametric Models for Study - 2

Model	Model no.	Geometry Details							Domain Details			
		H1	H2	S1	S2	α_1	α_2	Spacing	L1	L2	H	B1 & B2
									5h	15h	10h	5h
H_2/H_1= 2 & S_1/S_2=1.8	4.1	3	6	9	5	10	15	1.5	30	90	60	30
	4.2	3	6	9	5	15	15	1.5	30	90	60	30
	4.3	3	6	9	5	10	15	1.5	30	90	60	30

In study - 2, there was the study of total 3 models having single height ratio 2 and span ratio 1.8 for in-between spacing of both buildings is 1.5m. In this study, there was roof angle of both buildings are not same and after the simulation pressure coefficient compares with both building have same roof angle.

Table 3 Boundary Conditions

Surface Name	Name of Boundary Condition
Ground of Computing Domain	No Slip Wall
Top of Computing Domain	Free Slip Wall
Side Surfaces of Computing Domain	Free Slip Wall/Symmetry
All Surfaces of Buildings	No Slip Wall

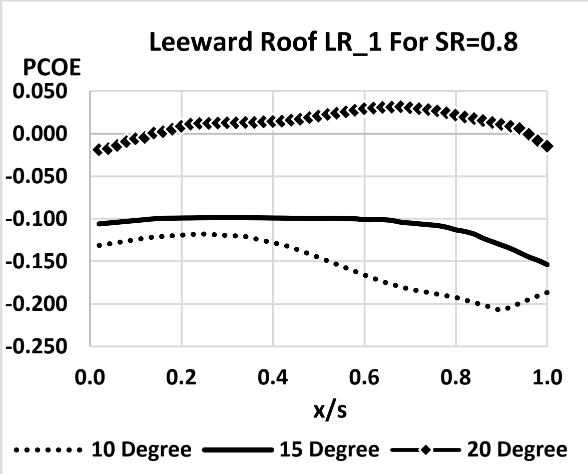
Normal and tangential velocity are set to zero at solid boundary surfaces. Boundary condition near the solid wall is described by wall roughness of 5 mm. The ground at the bottom of the computing domain was simulated with no-slip boundary condition. The free-slip boundary conditions are applied to top and side surfaces of computing domain. The flux normal to the boundary is considered zero. The no-slip boundary conditions are applied to the surfaces of building geometries.

Table 4 Input data summary for simulation in ANSYS CFX

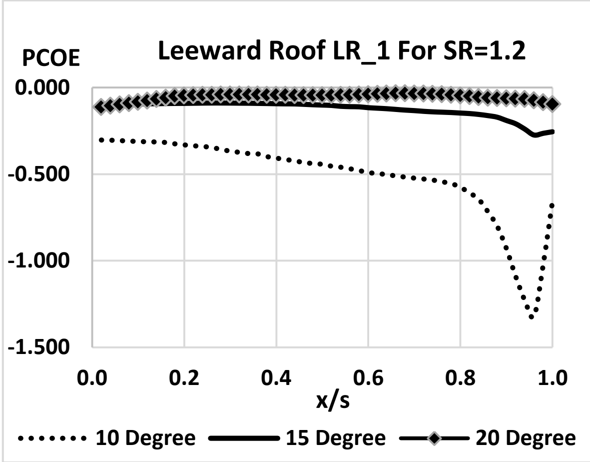
No.	Parameters	Value
1	Velocity Profile	$V(y) = 10.6\times (\frac{y}{6.7})^{0.143}$
2	Ground Roughness	5 mm
3	Turbulence Intensity at Inlet	5%
4	Density of Air	1.185 kg/m^3
5	Viscosity of Air	1.7594×10^5 kg/m. s
6	Turbulence Model	SST Model
7	Length Scale	1:1

V. RESULT COMPARISON FOR SAME ROOF ANGLES OF BOTH BUILDINGS ($A_1 = A_2 =$ SAME) FOR STUDY - 1

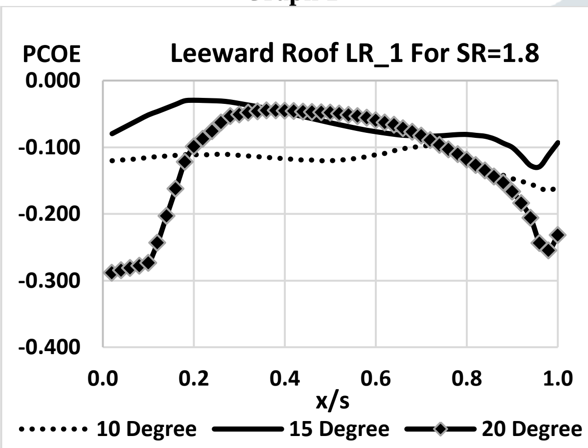
The graphs of Pressure coefficients (PCOE) compared for same roof angle of both buildings with different span ratio for Leeward Roof – 1, Leeward Wall – 1, Windward Wall – 2, Windward Roof – 2, Leeward Roof – 2.



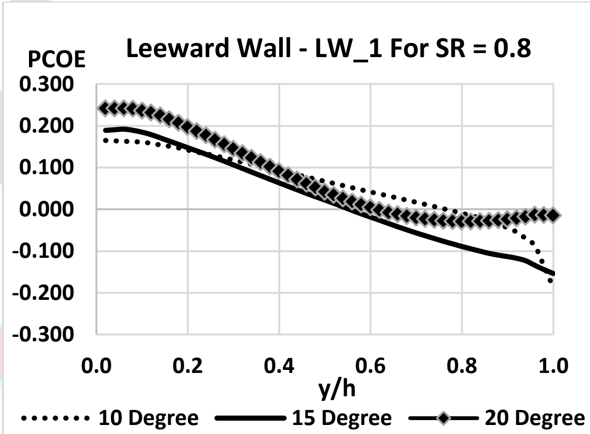
Graph 1



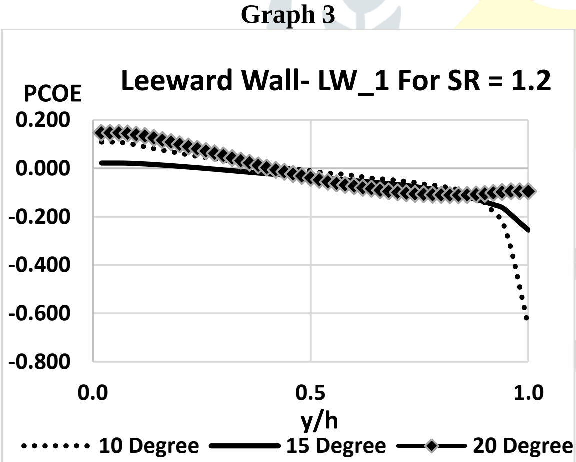
Graph 2



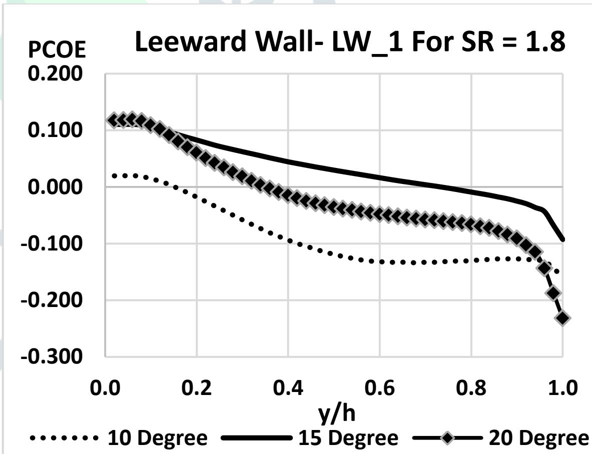
Graph 3



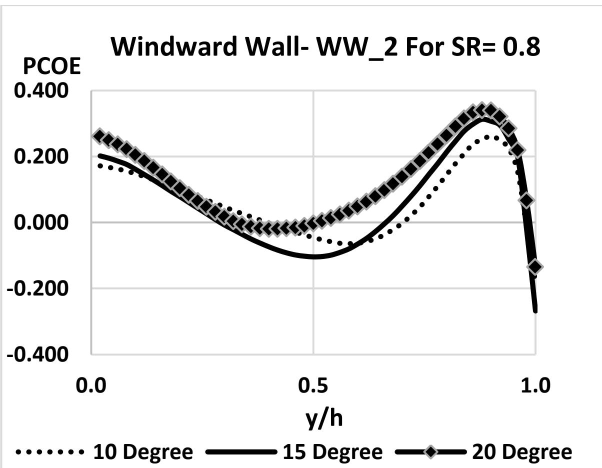
Graph 4



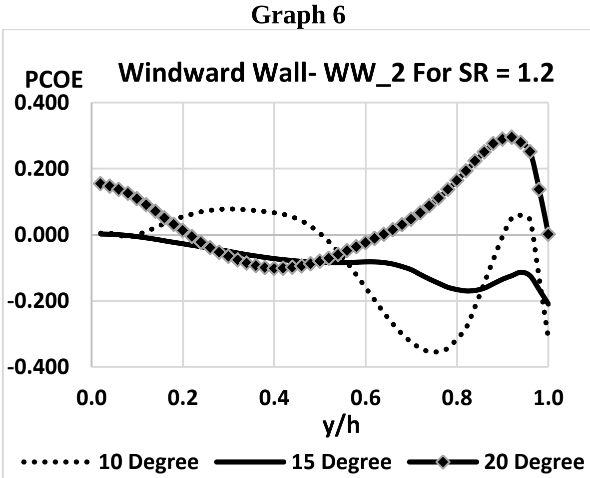
Graph 5



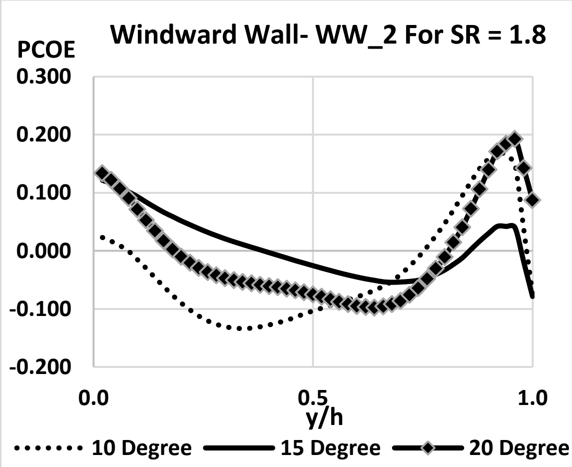
Graph 6



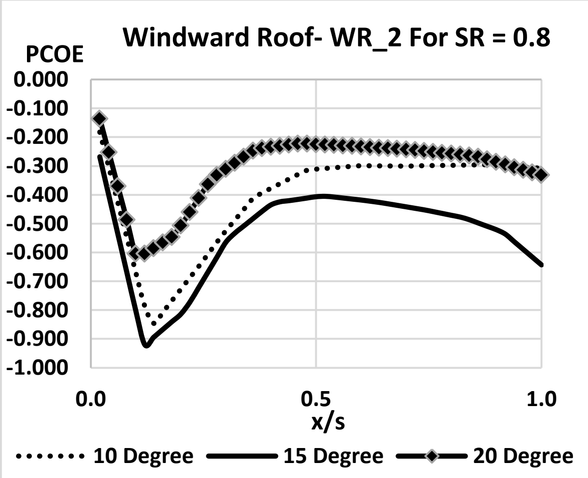
Graph 7



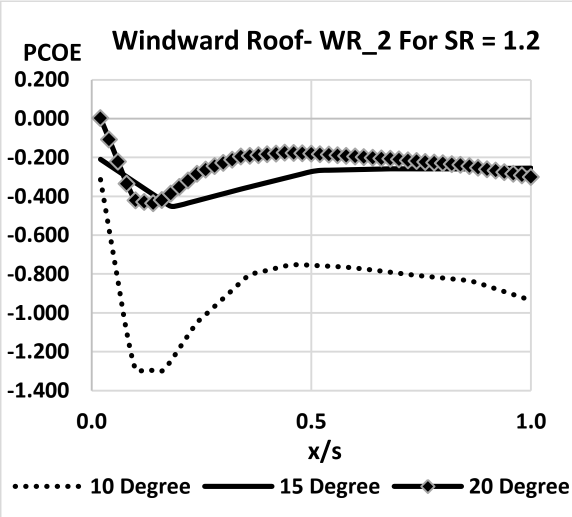
Graph 8



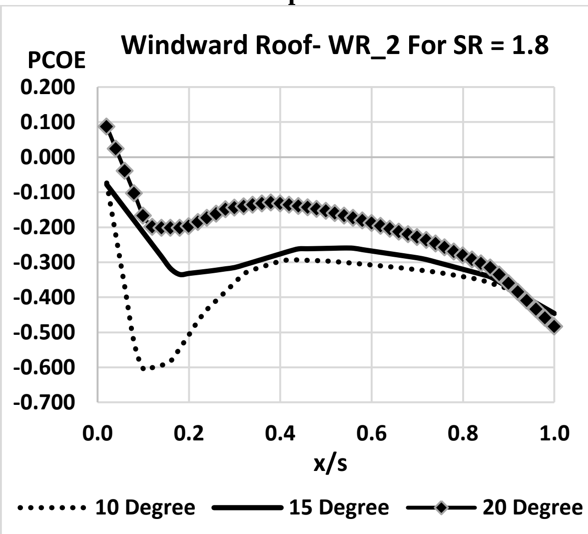
Graph 9



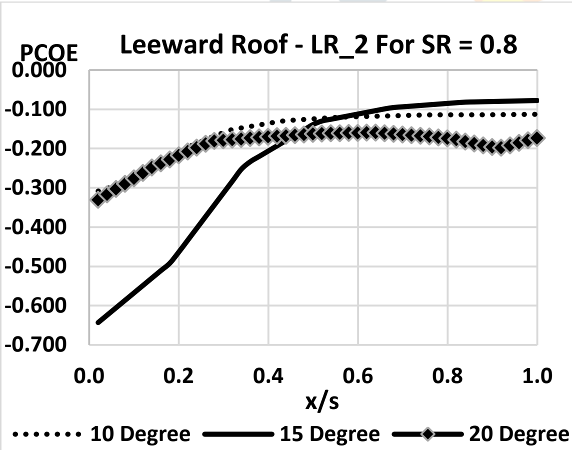
Graph 10



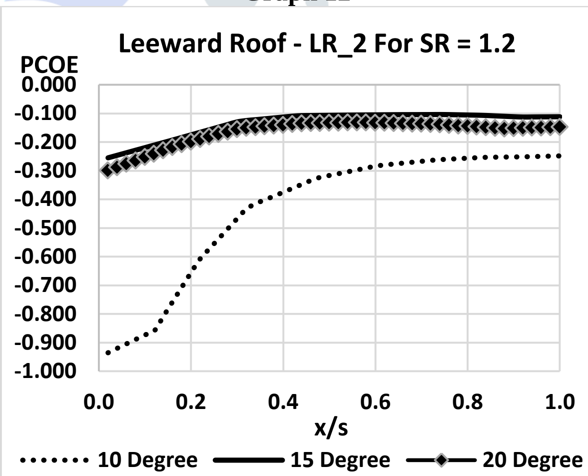
Graph 11



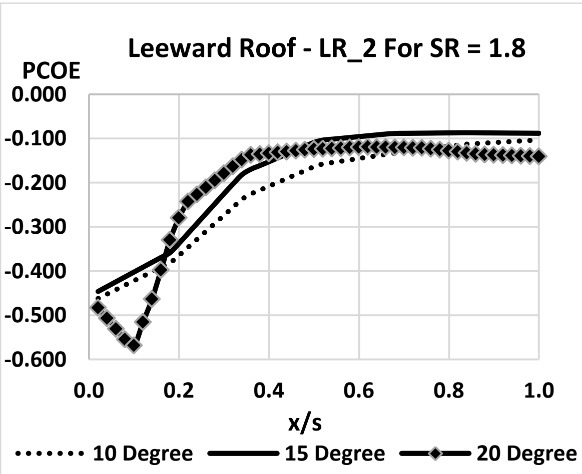
Graph 12



Graph 13



Graph 14



Graph 15

Observation for study - 1:-

Leeward Roof -1: - There is high suction value get in SR = 1.8 with 20˚ roof slope at the ridge height but in SR=1.2 with 10˚ roof slope has peak value compare to other span ratio and roof angles according to Graph 1, 2, 3.

Leeward Wall -1: - There is 10˚ roof slope has greater suction pressure at eave height compare to 15˚ and 20˚ roof slope for SR = 1.2, in SR = 1.8 with 20˚ roof slope has the high pressure and suction compare to 10˚, 15˚ and for SR = 0.8 with 20˚ roof slope has high pressure from different span ratios and roof angles according to Graph 4, 5, 6.

Windward Wall -2: - In SR = 1.2, 20˚ roof angle has high pressure compare to 10˚, 15˚ and 10˚ roof angle has high suction near the eave height. Otherwise in other span ratios have same behavior but values are different according to graph 7, 8, 9.

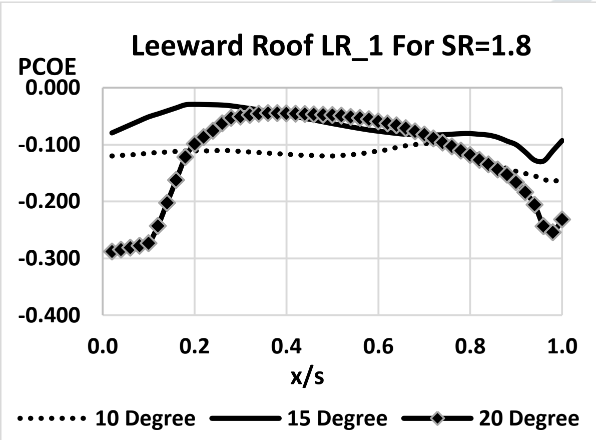
Windward Roof -2: - In SR = 1.2, 10˚ roof angle has high suction near the eave height compare to other span ratios and different roof angles. SR = 1.8 and 1.2 have some positive pressure near the eave height for 20˚ roof angle compare to 10˚, 15˚ according to graph 10, 11, 12.

Leeward Roof -2: - In SR = 1.2, 10˚ roof angle has high suction compare to other roof angles and span ratios. In SR = 0.8, 15˚ roof angle has high suction compare to 10˚, 20˚ roof angle near the ridge of the taller building. Allover leeward roof – 2 has suction pressure for all span ratios.

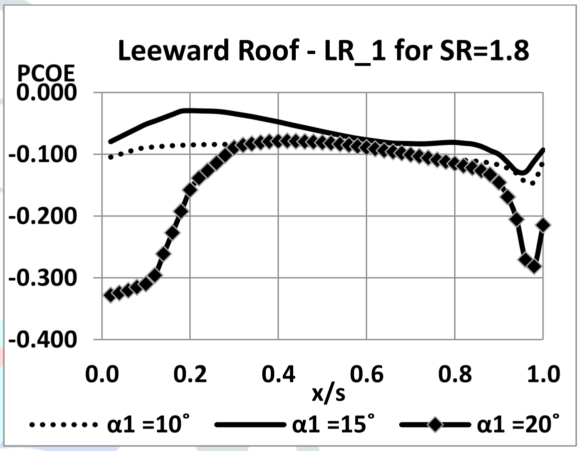
VI. PCOE COMPARISON FOR DIFFERENT ROOF ANGLES OF BOTH BUILDINGS FOR SR = 1.8 FOR STUDY - 2

The results of Pressure coefficients (PCOE) of both buildings having different roof angle compared with same roof angle for single span ratio 1.8 of Leeward Roof – 1, Leeward Wall – 1, Windward Wall – 2, Windward Roof – 2, Leeward Roof – 2.

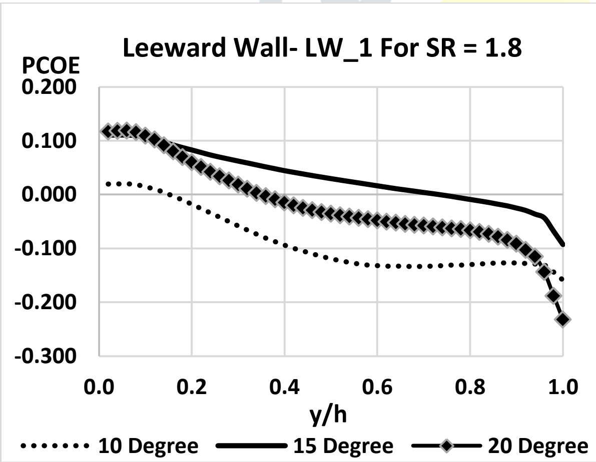
$\alpha_1 = \alpha_2$= Same **{α_1=10˚, 15˚, 20˚} [α_2= 15˚Same]**



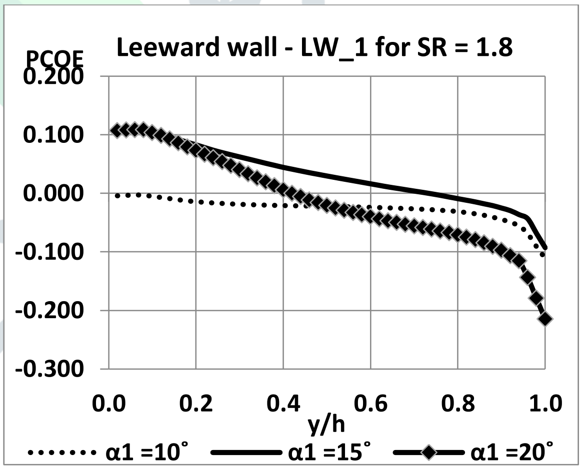
Graph 16



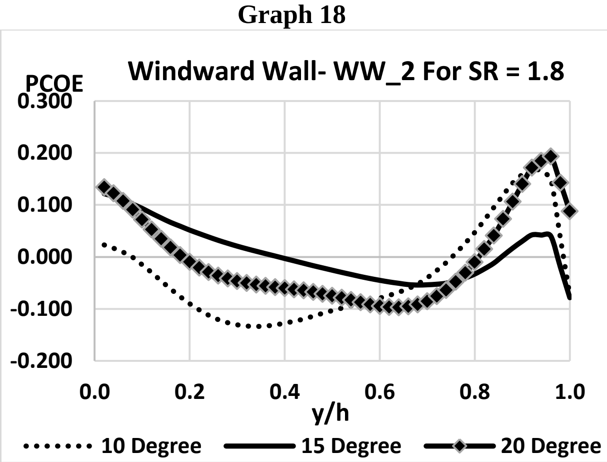
Graph 17



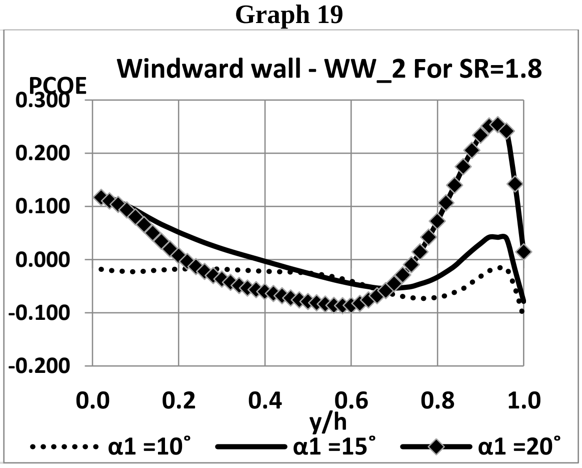
Graph 18



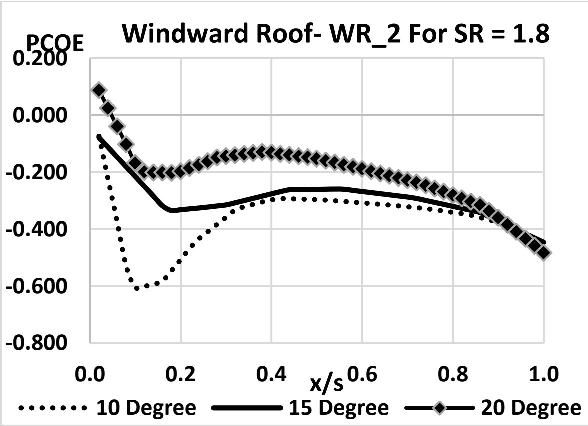
Graph 19



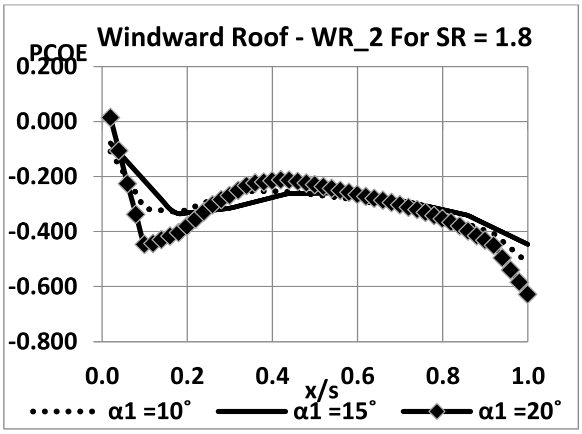
Graph 20



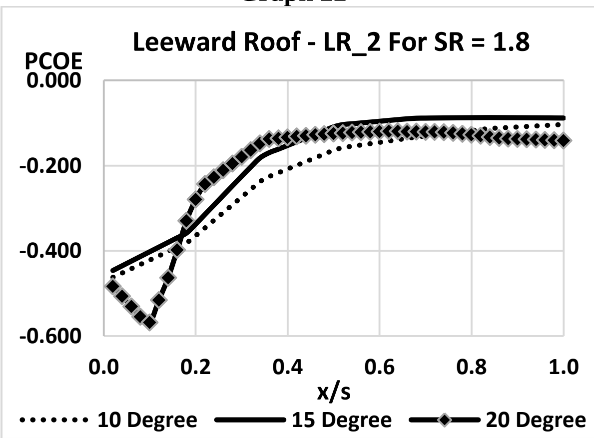
Graph 21



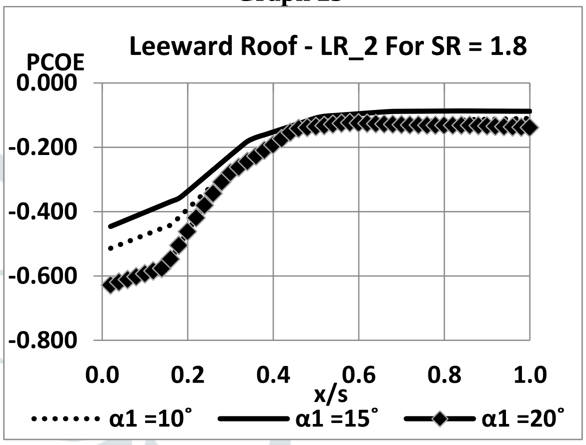
Graph 22



Graph 23



Graph 24



Graph 25

Observation for study - 2:-

Leeward Roof -1: - The behavior of pressure distribution for this face has same but having some different value change. From the comparison of graphs 16 and 17, 20˚ roof angle of building -1 has same behavior but it has high suction at the ridge and the eave height compare to the middle portion of surface.

Leeward Wall -1: - From the comparison of graph 18 and 19, there is α_1 = 10˚ roof angle has different behavior. 15˚ and 20˚ roof angle have almost same behavior and same value of pressure coefficients.

Windward Wall -2: - From the comparison of graph 20 and 21, PCOE has high pressure at eave height for α_1 =20˚ compare to same roof angles of both buildings. Roof angle α_1 =10˚ has different behavior near the middle portion the wall compare to same roof angle of both buildings.

Windward Roof -2: - From the comparison of graphs 22 and 23, PCOE has low suction at eave height for α_1 =10˚ compare to same roof angles of both buildings. In α_1 =20˚ has more suction compare to same roof angles of both buildings.

Leeward Roof -2: - In this surface the behavior of all roof angles α_1 =10˚, 15˚, 20˚ have similar with different values of PCOE compare to same roof angles of both buildings in graph 25. From the graph 24, the value of PCOE for 20˚ roof angle varies compare to 10˚, 15˚ roof angle for both buildings at the ridge.

CONCLUSION:-

From the above two study of same roof angle and different roof angle , it is observed that the pressure distribution on the leeward roof - 1, leeward wall -1, windward wall - 2, windward roof -2 and leeward roof - 2 vary significantly for same span ratio (S_1/S_2). Hence, the detailed parametric study should be conducted to quantify the exact effect on pressure coefficient of various building surfaces due to change in roof angle – 1 (α_1).

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