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Wind Load Analysis and Pressure Distribution on Rooftop PV Installations

Dr P Surendra Reddy

Lecturer in Physics
General Section, Government Polytechnic, Proddatur, A.P, India

Abstract

Harnessing solar photovoltaic technology through rooftop installations presents a practical and environmentally sustainable approach to reducing reliance on conventional fossil fuel–based energy sources. Deployed on residential and commercial buildings, these systems facilitate distributed power generation, contributing to enhanced energy autonomy and the promotion of sustainable energy practices. To ensure the structural safety and efficient performance of rooftop solar arrays, it is essential to examine the pressure distribution acting on their surfaces, particularly under wind-induced loading conditions. This study examines the aerodynamic response of rectangular and pentagonal solar panels installed at a tilt angle of 12°, subjected to wind velocities of 5 m/s and 25 m/s with incident angles of 0°, 45°, 135°, and 180°. Computational Fluid Dynamics (CFD) techniques are utilized to evaluate surface pressure distributions, enabling precise estimation of aerodynamic loads, assessment of structural durability, optimization of panel configurations, and identification of regions susceptible to stress concentration. The outcomes of this investigation provide valuable insights for the safe, reliable, and efficient deployment of rooftop photovoltaic systems.

Keywords: Pressure, Computational Fluid Dynamics, Roof Mounted

1. Introduction

Solar photovoltaic (PV) rooftop systems have become a promising solution to environmental challenges by reducing dependence on conventional fossil fuels. Installed on the rooftops of residential buildings, commercial properties, and other structures, these systems occupy significantly less space than large-scale ground-mounted solar farms, which require vast amounts of land. Although the energy generation capacity of rooftop solar systems is relatively modest—around 20 kW for residential buildings and approximately 100 kW for commercial complexes—the electricity generated can be fed into the public grid, allowing building owners to earn a tariff for the power they contribute.

Urban environments, with their abundant underutilized rooftop spaces, present an excellent opportunity for generating clean energy. This approach not only helps in creating a greener environment but also promotes sustainable energy production in densely populated areas. By utilizing rooftops for solar installations, cities can reduce their reliance on fossil fuels while simultaneously supporting the grid with renewable energy.

Once a solar system is installed, it typically operates without much concern. However, improper installation or neglecting specific factors can lead to potential issues. Some common challenges that need careful consideration include:

1.1. Wind Effects: Winds from various directions can exert different pressures on the building's walls and, subsequently, on the solar panels. Understanding these pressures is essential to ensuring the stability of the system .

1. **Water Leaks**: Poor installation can lead to water penetration, causing leaks. Ensuring a proper installation with adequate sealing is vital to preventing roof damage.
2. **Insufficient Solar Exposure**: To maximize energy production, solar panels should be installed at optimal angles to capture sunlight effectively.
3. **Electrical Connections**: Incorrect electrical connections can lead to dangerous situations, including the risk of fire. Proper installation of electrical components is critical for the safe operation of the system.

In India, several challenges hinder the widespread adoption of rooftop solar energy, despite its potential. Some of these challenges include:

1. **High Initial Costs**: Although the cost of solar panels has decreased, the initial investment remains a significant barrier. Alternative models like Power Purchase Agreements (PPAs) could help alleviate the financial burden.
2. **Slow Adoption**: Limited awareness and uncertainty about rooftop solar energy slow down its adoption rate in India.
3. **Lack of Clear Policies**: While some states have introduced policies, there is still a lack of consistent regulations at the national level, making implementation difficult.
4. **Delayed Government Subsidies**: Delays in the disbursement of government subsidies have also been a major obstacle.

If these challenges are overcome, rooftop solar energy could significantly contribute to urban development and provide a reliable, green energy source for households across India.

2. Methodology

Computational Fluid Dynamics (CFD) is a specialized branch of fluid mechanics that employs numerical methods and computational algorithms to analyze and solve problems involving fluid flow. CFD simulations facilitate the investigation of free-stream flow behavior and its interaction with solid boundary surfaces. For complex and large-scale simulations, high-performance computing resources are often required to achieve accurate and reliable results. CFD has widespread applications across multiple domains, including engineering design, industrial processes, weather forecasting, and environmental studies.

ANSYS CFD is a powerful simulation tool used to predict and optimize system performance by numerically modeling fluid flow phenomena prior to physical prototyping. The CFD modeling workflow generally consists of three fundamental stages:

1. **Pre-Processing:** This stage includes the development of the computational geometry and the generation of an appropriate mesh to discredited the flow domain.

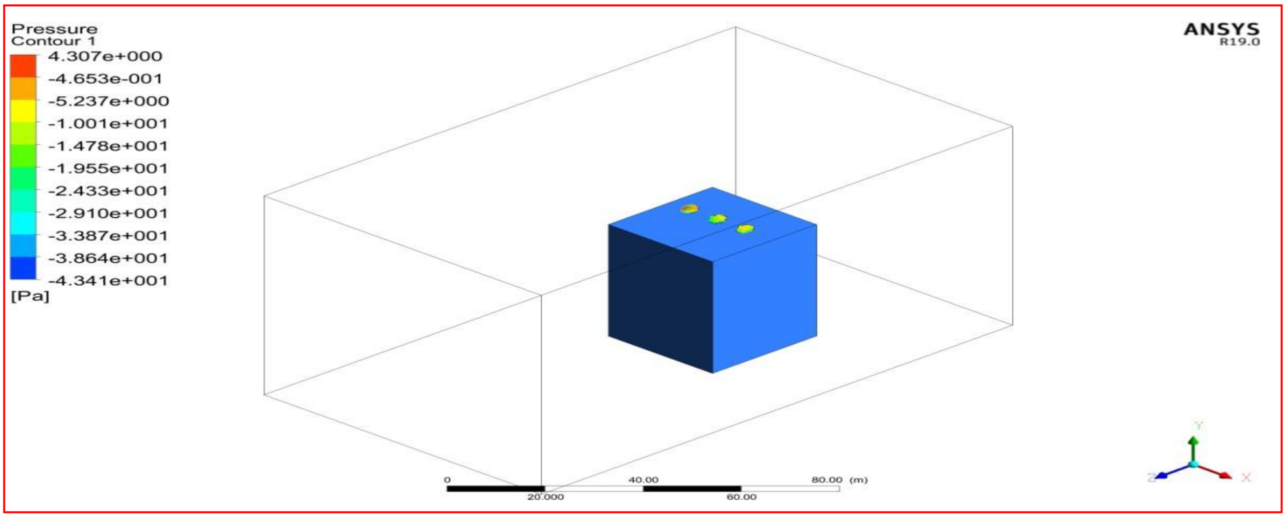
2. **Solver:** In this stage, the governing fluid flow equations are solved numerically within the defined computational domain.
3. **Post-Processing:** The simulation results are visualized and analyzed using graphical and numerical tools, enabling clear interpretation of flow behavior and performance characteristics.

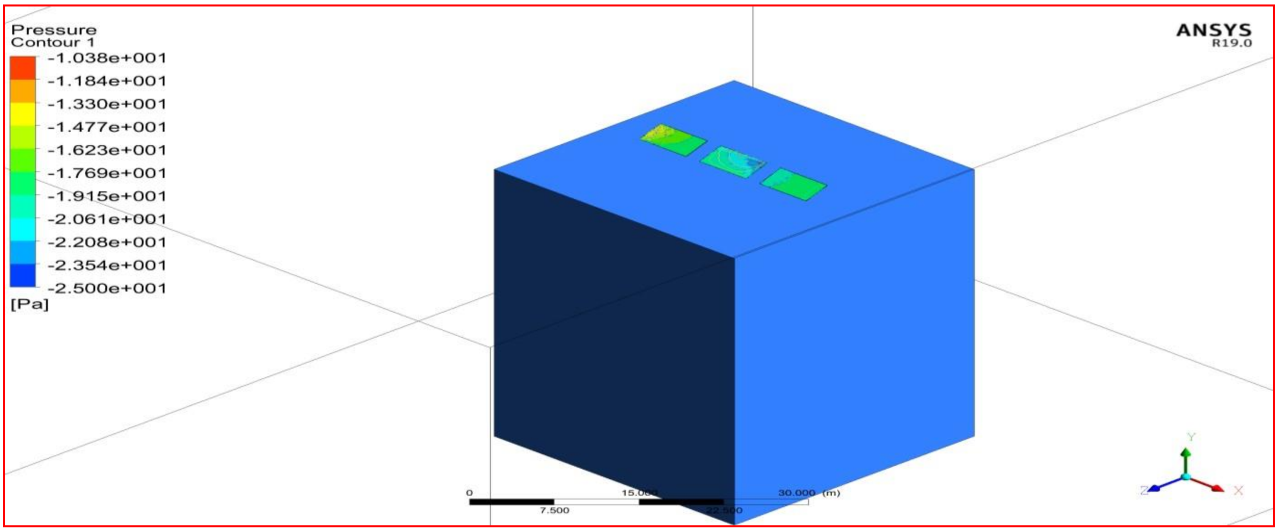
3. Roof-Mounted Solar Panels

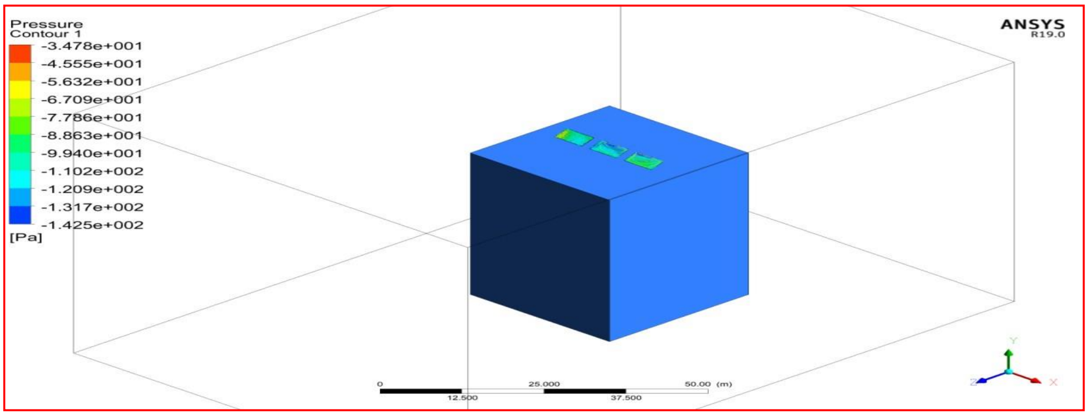
Simulations for roof-mounted solar panels are conducted to study the effects of wind on the panels at both low and high wind velocity regimes. The computational domain, as shown in Figures 3.1.1 (a), (b), and (c), is designed with a 5-storey building on which the solar panels are placed. Four different cases are simulated to assess the wind loads on the solar panels.

3.1 Pressure Distribution On Roof-Mounted Solar Panels

Pressure profiles are crucial in understanding the force distribution and aerodynamic behavior of objects like solar panels. In this study, rectangular and pentagonal solar panels are placed at a 12° tilt relative to the roof surface. The panels are subjected to wind velocities of 5 m/s and 25 m/s at four different angles of attack (AOA): 0°, 45°, 135°, and 180°. Simulation results for pressure distribution under different conditions are shown in Figures 3.1 (a)-(d), 3.2 (a)-(d), 3.3 (a)-(d), and 3.4 (a)-(d). The results indicate that the maximum pressures developed on the rectangular panels when subjected to wind velocities of 5 m/s and 25 m/s are 101314.62 Pa and 101290.3 Pa, respectively. In comparison, the pressures on the pentagonal panels are 101329.3 Pa and 101304.65 Pa, respectively. The results suggest that pentagonal panels experience slightly lower pressures, likely due to their shape and aerodynamic properties.







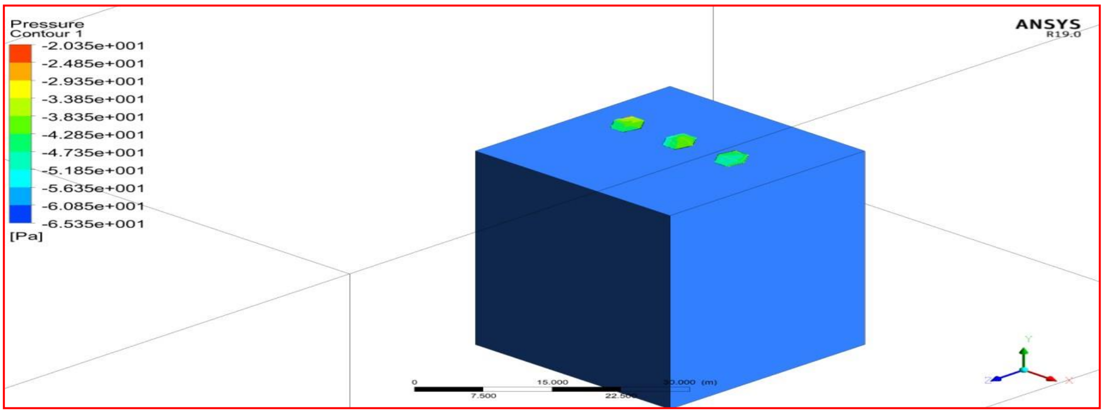


Figure 3.1: Pressure profile for roof-mounted solar panels at AOA θ = 0°

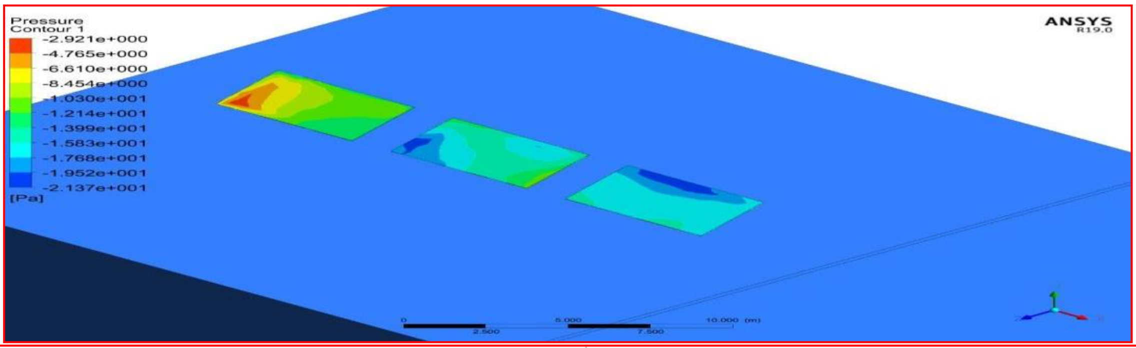
(a) Traditional roof-mounted panels with U = 5 m/s, θ = 0°

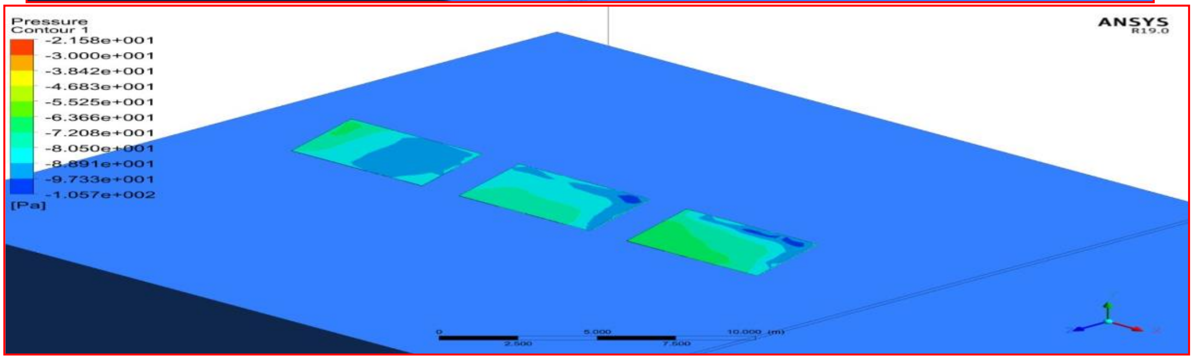
(b) Optimized roof-mounted panels with U = 5 m/s, θ = 0°

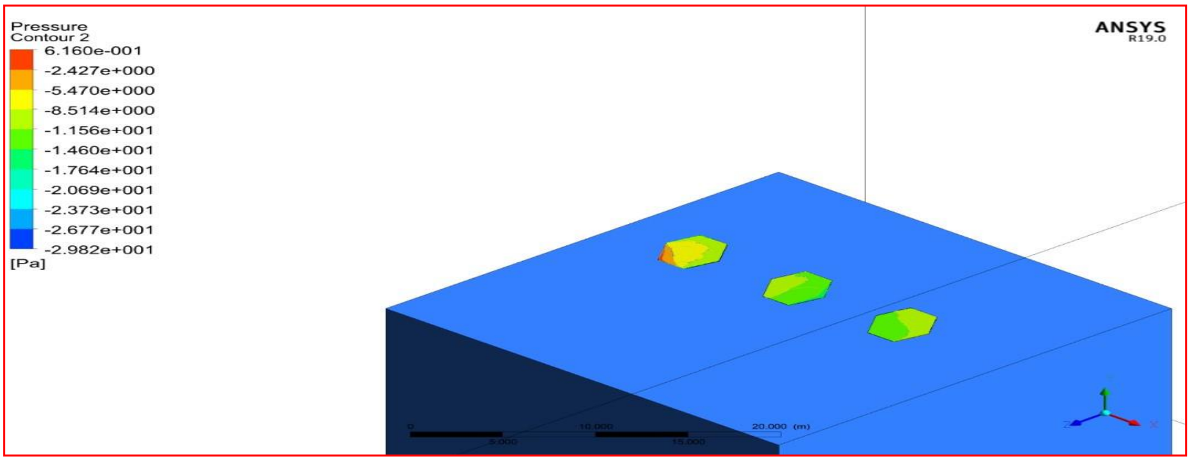
(c) Traditional roof-mounted panels with U = 25 m/s, θ = 0°

(d) Optimized roof-mounted panels with U = 25 m/s, θ = 0°

The next simulation scenario involves an AOA of 45° with wind speeds of 5 m/s and 25 m/s. Results are shown in Figures 5.2 (a)-(d). The maximum pressures for rectangular panels at these velocities are 101322.1 Pa and 101303.5 Pa, respectively, while the pressures on pentagonal panels are 101331 Pa and 101365.65 Pa, respectively. These results confirm the earlier finding that pentagonal panels are more aerodynamically favorable under these conditions.







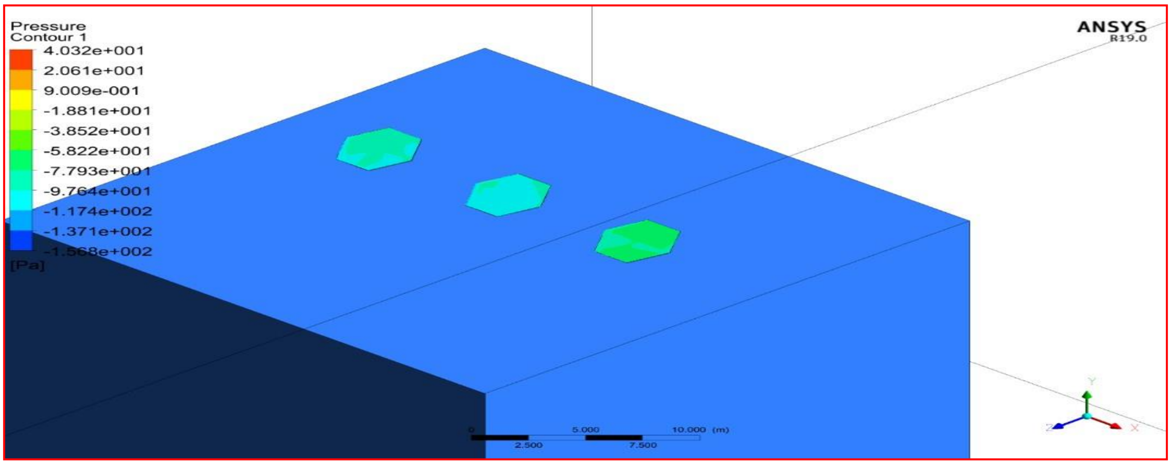
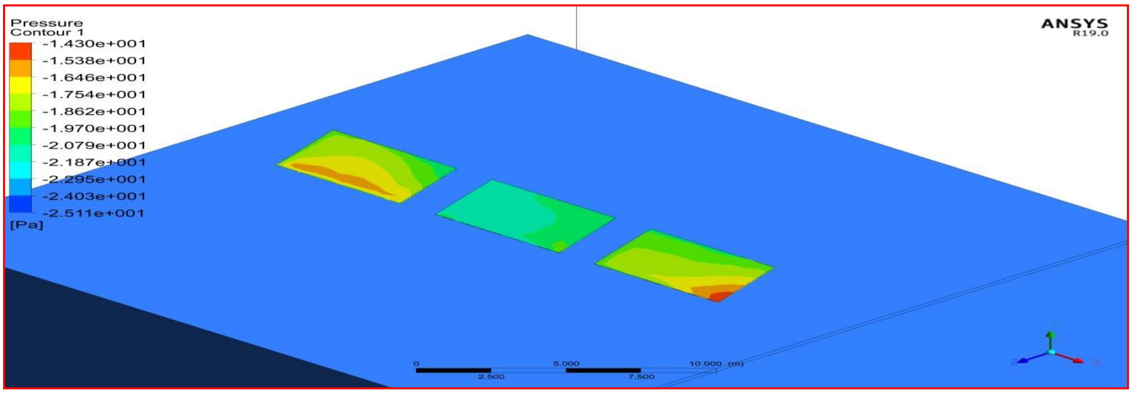


Figure 3.2: Pressure profile for roof-mounted solar panels at AOA θ = 45°
(a)Traditional roof-mounted panels with U = 5 m/s, θ = 45°
(b) Optimized roof-mounted panels with U = 5 m/s, θ = 45°
(c) Traditional roof-mounted panels with U = 25 m/s, θ = 45°
(d) Optimized roof-mounted panels with U = 25 m/s, θ = 45°

In this simulation, the roof-mounted panels are exposed to airflow with an angle of attack (AOA) of 135°, and wind speeds of 5 m/s and 25 m/s. The resulting pressure distributions for both traditional and pentagonal panels are presented in Figures 3.4(a)-(d). However, due to the AOA of 135°, the direction of the airflow is reversed; meaning the inlet and outlet are swapped. Consequently, the pressure contours shown in the figures were derived by flipping the domain. In all cases, the highest pressure occurs on the side of the panel furthest from the airflow, as the air moves from the outlet toward the inlet. From Figures 3.4(a) and (c), the maximum pressures on the conventional panels are 101310.7 Pa and 101231 Pa at wind speeds of 5 m/s and 25 m/s, respectively. In comparison, the maximum pressures on the optimized pentagonal panels under the same conditions are 101319.8 Pa and 101314.4 Pa, respectively. Overall, these results suggest that pentagonal panels are a suitable and effective choice for installation on the rooftop of a 5-storey building exposed to the specified operating conditions.


Pressure
Contour 1
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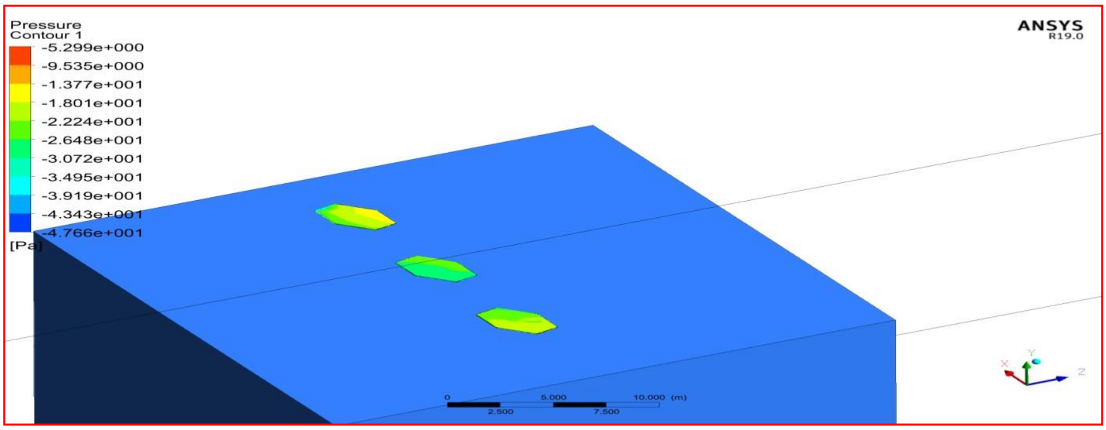
-1.538e+001
-1.646e+001
-1.754e+001
-1.862e+001
-1.970e+001
-2.079e+001
-2.187e+001
-2.295e+001
-2.403e+001
-2.511e+001
[Pa]
ANSYS
R19.0


Pressure
Contour 1
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-9.535e+000
-1.377e+001
-1.801e+001
-2.224e+001
-2.648e+001
-3.072e+001
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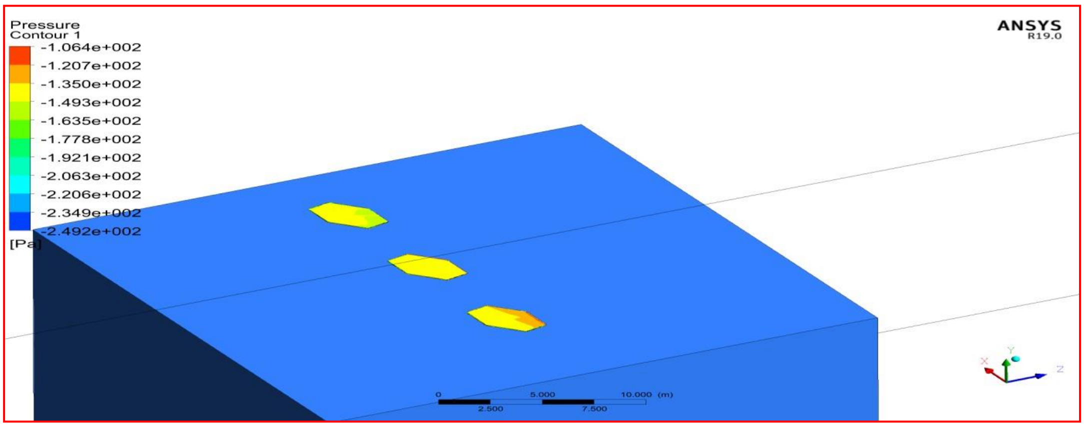
-3.919e+001
-4.343e+001
-4.766e+001
[Pa]
ANSYS
R19.0


Pressure
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-1.350e+002
-1.493e+002
-1.635e+002
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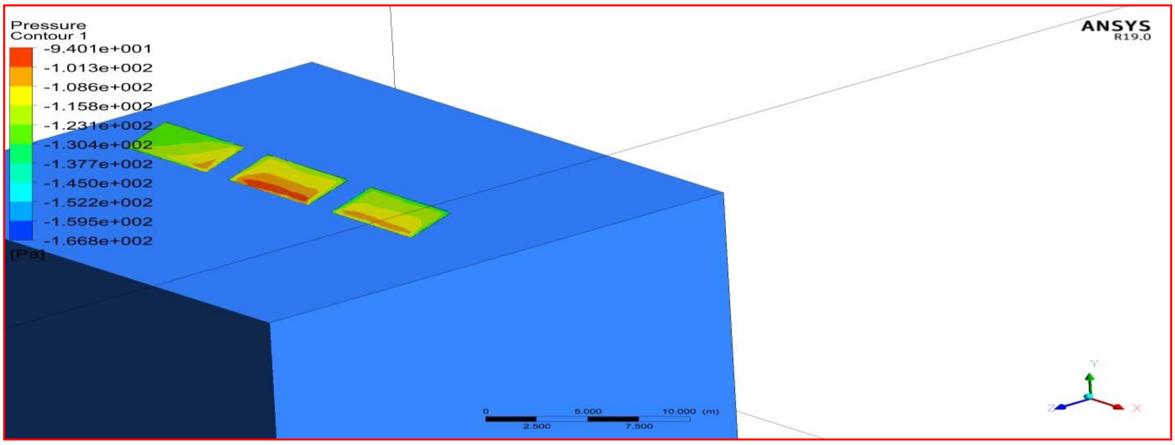
-2.492e+002
[Pa]
ANSYS
R19.0


Pressure
Contour 1
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-1.013e+002
-1.086e+002
-1.158e+002
-1.231e+002
-1.304e+002
-1.377e+002
-1.450e+002
-1.522e+002
-1.595e+002
-1.668e+002
[Pa]
ANSYS
R19.0

Figure 3.3: Pressure profile for roof-mounted solar panels at AOA θ = 135°

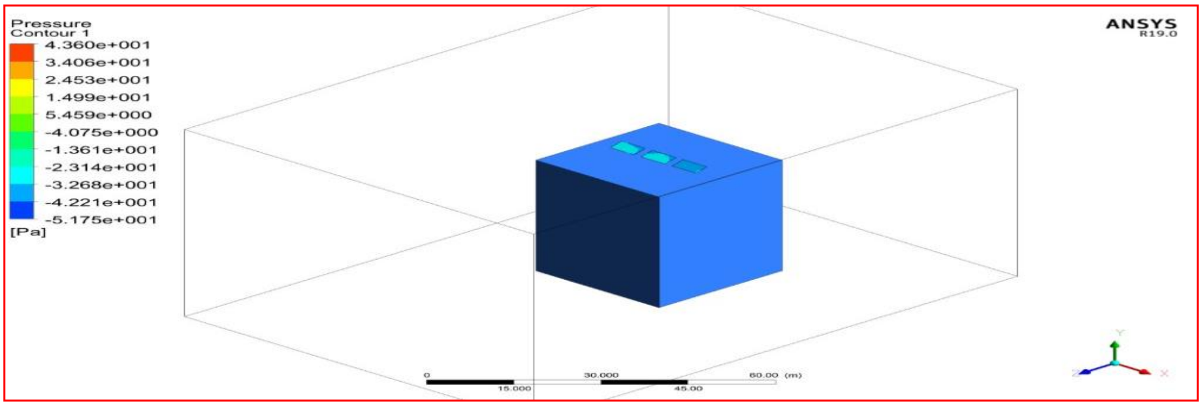
(a) Traditional roof-mounted panels with U = 5 m/s, θ = 135°

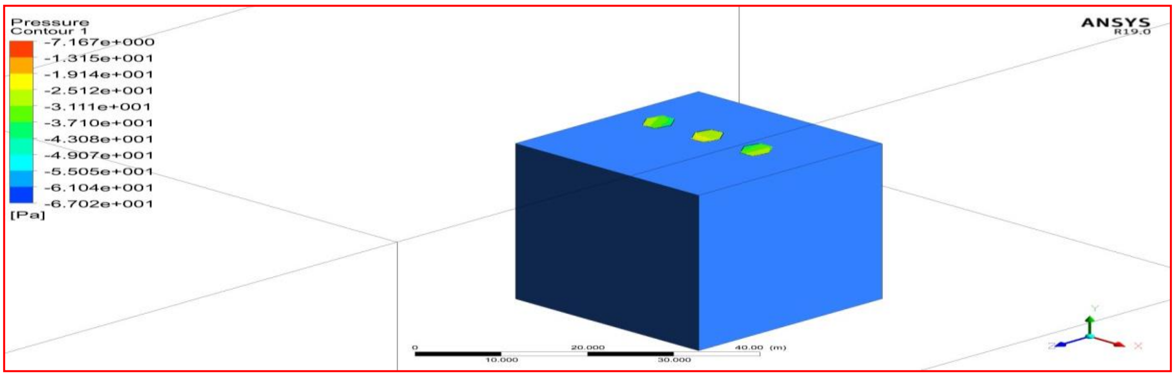
(b) Optimized roof-mounted panels with U = 5 m/s, θ = 135°

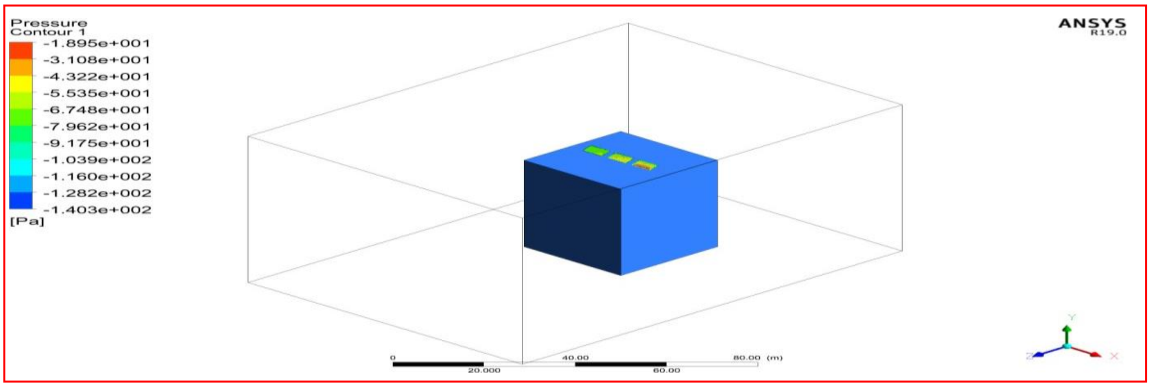
(c) Traditional roof-mounted panels with U = 25 m/s, θ = 135°

(d) Optimized roof-mounted panels with U = 25 m/s, θ = 135°

In this simulation, the panels are subjected to an AOA of 135° with wind velocities of 5 m/s and 25 m/s. The pressure profiles are shown in Figures 3.4 (a)-(d), where the maximum pressures on rectangular panels are 101310.7 Pa and 101231 Pa, respectively, while on pentagonal panels, they are 101319.8 Pa and 101314.4 Pa, respectively. These results suggest that pentagonal panels are advantageous in terms of aerodynamics and can be effectively utilized under the specified conditions.







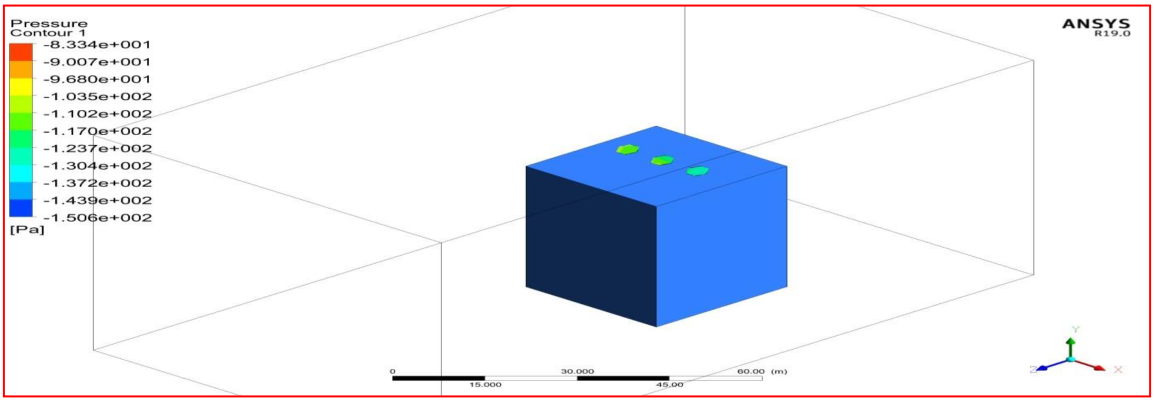


Figure 3.4: Pressure profile for roof-mounted solar panels at AOA θ = 180°

(a) Traditional roof-mounted panels with U = 5 m/s, θ = 180°

(b) Optimized roof-mounted panels with U = 5 m/s, θ = 180°

(c) Traditional roof-mounted panels with U = 25 m/s, θ = 180°

(d) Optimized roof-mounted panels with U = 25 m/s, θ = 180°

4. Conclusion

This study examined the pressure distribution and aerodynamic behavior of roof-mounted solar panels with rectangular and pentagonal geometries under varying wind conditions. The panels, installed at a tilt angle of 12°, were analyzed for wind velocities of 5 m/s and 25 m/s at angles of attack of 0°, 45°, 135°, and 180° using Computational Fluid Dynamics (CFD) simulations. The pressure profiles obtained from the simulations provided valuable insights into the influence of panel geometry on aerodynamic loading.

The results demonstrate that wind velocity significantly affects the pressure magnitude on both panel configurations. Rectangular panels experienced maximum pressures of 101314.62 Pa at 5 m/s and 101290.3 Pa at 25 m/s, while pentagonal panels exhibited maximum pressures of 101329.3 Pa and 101304.65 Pa under the same conditions. Although the pressure differences are relatively small, the pentagonal panels showed marginally improved aerodynamic performance, which can be attributed to their geometry promoting smoother airflow and reduced pressure concentration.

5. Authors Biography

Dr. Panga Surendra Reddy is a Lecturer in the Department of Technical Education at Government Polytechnic, Proddatur. He received his doctoral degree from KL University in April 2023 and has published six research papers in reputed journals. His research interests include renewable and alternative energy materials, nanomaterials, thin films, nanophotonics, computational physics, and solar energy optimization

References

1. Wiser, Ryan, et al. "The environmental and public health benefits of achieving high penetrations of solar energy in the United States." Energy, 113 (2016): 472-486.
2. Li, Hongqiang, et al. "Exergy and environmental assessments of a novel trigeneration system taking biomass and solar energy as co-feeds." Applied Thermal Engineering, 104 (2016): 697-706.
3. Zeaiter, Joseph, et al. "Waste tire pyrolysis using thermal solar energy: An integrated approach." Renewable Energy, 123 (2018): 44-51.

4. Mehrpooya, Mehdi, and Ali Dadak. "Investigation of a combined cycle power plant coupled with a parabolic trough solar field and high-temperature energy storage system." Energy Conversion and Management, 171 (2018): 1662-1674.
5. Tehrani, S. Saeed Mostafavi, et al. "Annual comparative performance and cost analysis of high-temperature, sensible thermal energy storage systems integrated with a concentrated solar power plant." Solar Energy, 153 (2017): 153-172.
6. Hemmer, C., et al. "Early development of unsteady convective laminar flow in an inclined channel using CFD: Application to PV panels." Solar Energy, 146 (2017): 221-229.
7. Edgar, R., et al. "A computational fluid dynamic study of PV cell temperatures in novel platform and standard arrangements." Solar Energy, 144 (2017): 203-214.
8. Al-Waeli A. H. A., et al. Modelling and experimental validation of a PVT system using nanofluid coolant and nano-PCM. Solar Energy, Vol. 177, Issue 1, 2019, p. 178-191.
9. Hemmer C., et al. Early development of unsteady convective laminar flow in an inclined channel using CFD: Application to PV panels. Solar Energy, Vol. 146, 2017, p. 221-229.
10. Edgar R., et al. A computational fluid dynamic study of PV cell temperatures in novel platform and standard arrangements. Solar Energy, Vol. 144, Issue 1, 2017, p. 203-214.