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Wind-Resilient Solar: Harnessing CFD for Enhanced Load Estimation

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WIND RESILIENT SOLAR

HARNESSING CFD FOR ENHANCED LOAD ESTIMATION

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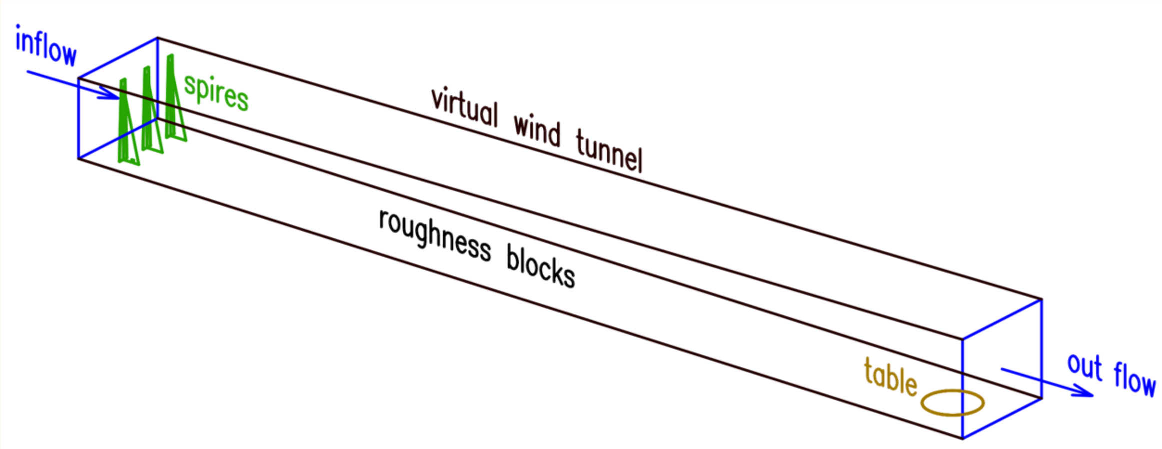
INTRODUCTION

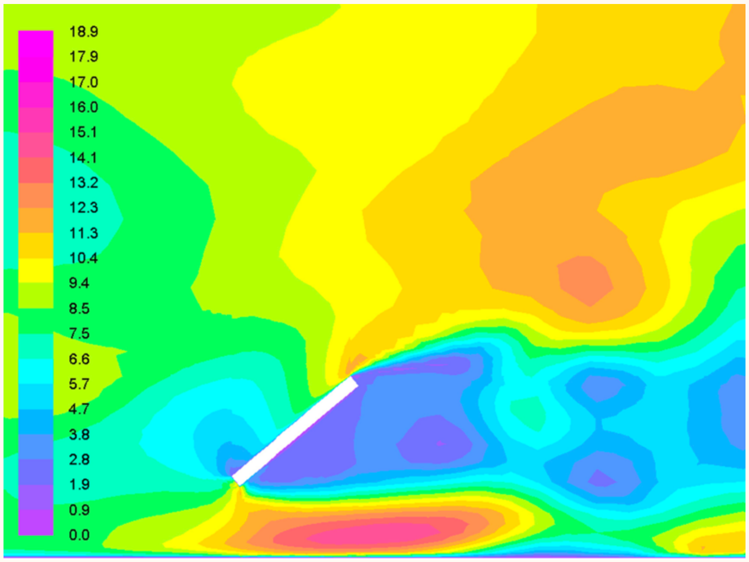
Solar panels are a cornerstone of renewable energy infrastructure, playing a pivotal role in global sustainability efforts. To ensure their resilience and long-term viability, accurate wind load estimations are essential for designing supporting structures, which account for nearly 50% of their total cost. However, traditional building codes lack comprehensive guidance for solar panels, resulting in inconsistent estimations due to discrepancies in scaled wall-bounded wind tunnel testing methodologies. These inaccuracies pose safety risks, increase costs, and hinder adoption. Emerging technologies like computational fluid dynamics (CFD) simulations offer a promising alternative by enabling full-scale analysis under realistic conditions of complete turbulence. This paper explores the impact of geometric scale and inflow turbulence on wind load estimation, providing actionable insights to standardize testing protocols, improve reliability, and advance codification efforts for engineers, policymakers, renewable energy stakeholders, and the public.

METHODOLOGY

This study employed CFD simulations alongside wall-bounded wind tunnel experimental data to investigate:

- **Geometric Scale Effects**: Analyzing how model size influences pressure coefficients.
- **Inflow Turbulence Characteristics**: Assessing turbulence's impact on peak pressures.





KEY FINDINGS

KEY FINDINGS #1

Geometric Scale Discrepancies:

- Mean pressure coefficients remain stable across scales.
- Peak pressures vary significantly due to scale differences.

KEY FINDINGS #2

Inflow Turbulence Influence:

- Lack of large-scale turbulence in wall-bounded wind tunnels leads to underestimation of peak pressures.
- Proper turbulence modeling in CFD aligns results with full-scale conditions.

KEY FINDINGS #3

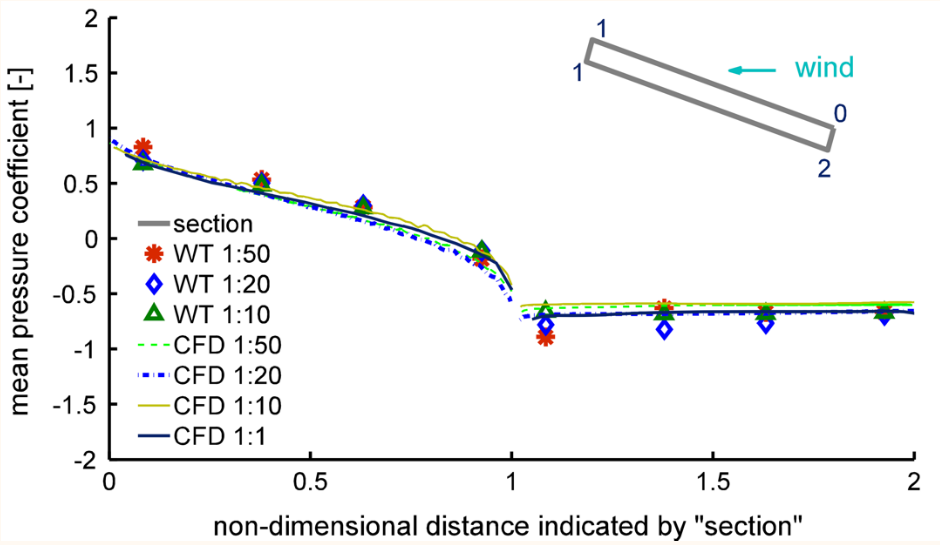
CFD vs. Wind Tunnel Results:

- LES-based CFD simulations in a virtual wall-bounded wind tunnel closely replicate experimental results for mean pressures.
- Peak pressures derived from LES CFD in a realistic computational domain are higher than those from wall-bounded wind tunnel tests due to complete turbulence.

VISUAL DATA

Key visualizations illustrating findings and recommendations for wind load estimation on solar panels [1]: (**a**) Mean pressure coefficients remain consistent across geometric scales. (**b**) Peak pressure discrepancies arise due to the absence of complete turbulence in wall-bounded wind tunnels, as well as CFD simulations intentionally designed to replicate the physics of these wind tunnels. However, a 1:1 scale CFD study, focused on replicating the full turbulence observed in real-world conditions, produces higher peak pressure values.

(a)



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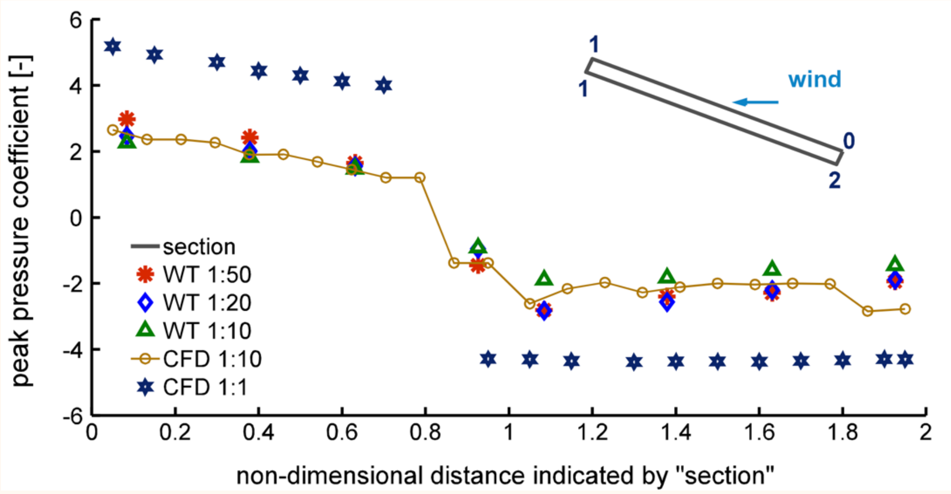

CONCLUSION

This paper highlights the critical role of geometric scale and inflow turbulence in accurate wind load estimation for solar panels. By addressing these challenges, stakeholders can ensure safer, more resilient, and cost-effective solar energy systems. The adoption of advanced methodologies such as CFD simulations and improved testing protocols is essential for standardizing practices and accelerating the codification of wind load standards.

KEY TAKEAWAYS

1. Integrate CFD and Large-Scale Physical Testing: Combine CFD simulations with open-jet wind tests to achieve comprehensive and reliable wind load predictions.
2. Refine Turbulence Modeling: Use LES-based CFD for high-fidelity analysis, particularly for critical peak pressure evaluations, while refining the experiments to account for large-scale turbulence effects, such as using Open-Jet Testing [2].
3. Codification Acceleration: Collaborate with policymakers and industry stakeholders to advance codified standards for wind load estimation on solar panels, ensuring consistency across projects.
4. Optimize Cost-Accuracy Trade-Offs: Prioritize methodologies that balance upfront costs with long-term savings, such as leveraging CFD to reduce experimental efforts without compromising accuracy.
5. Standardize Testing Protocols: Develop guidelines addressing geometric scale effects and inflow turbulence to minimize discrepancies in wind load estimations across different testing methods.

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Reference

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[2] Aly AM. Breaking Boundaries in Wind Engineering: LSU WISE Open-Jet Facility Revolutionizes Solar Panel and Building Design. Appl Sci 2023;13:12546. https://doi.org/10.3390/app132312546.

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