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The impact of architectural form on wind flow around buildings

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SUMMARY
This research explores the effects of form on airflow principles near buildings, emphasizing the relationship between form and aerodynamics. The study is based on a CFD system which uses numerical simulation of buildings in a square, circular, and rounded corner geometries. Parameters such as wind velocity, pressure coefficients on facades, and isentropic flow are carefully observed.
The findings of the investigation into the influence of wind acceleration and vortex formation are presented at the pedestrian level where these phenomena can be of vital importance to comfort and safety. Results show that intricate, sharp-edged forms produce more turbulent and accelerated flows, while rounded, smooth forms have a more favorable impact.
It shows the need for wind analysis to be carried out in early planning stages, taking architectural form as a factor controlling the factors affecting aerodynamics and the overall comfort and safety conditions of a city.

Keywords: architectural form, wind flow, turbulence

1. INTRODUCTION

Rapid urbanization and the continuous growth of high-rise buildings have significantly altered the natural wind environment in modern cities. The interaction between atmospheric flow and the built environment generates complex aerodynamic phenomena, including flow acceleration, pressure gradients, flow separation, recirculation zones, and vortex formation. These effects strongly influence pedestrian wind comfort, natural ventilation, pollutant dispersion, and the overall environmental performance of urban areas.
Among the various parameters affecting urban wind flow, the architectural form of buildings plays a fundamental role in controlling airflow behaviour. Building geometry determines how wind approaches, accelerates around edges, separates from surfaces, and develops wake regions downstream. Sharp-edged buildings generally promote early flow separation, stronger vortices, and higher wind acceleration at pedestrian level, whereas streamlined or rounded geometries tend to reduce turbulence intensity and improve airflow continuity around the structure.
Because of these aerodynamic effects, pedestrian wind comfort has become an essential design criterion in contemporary architecture and urban planning. Excessive wind speeds around buildings may reduce the usability of public spaces and create safety concerns for pedestrians. Consequently, several international guidelines, including the Lawson Comfort Criteria, Davenport Criteria, and NEN 8100, have been developed to assess acceptable wind conditions within the urban environment.

Recent advances in Computational Fluid Dynamics (CFD) have considerably improved the capability to investigate airflow around buildings. Compared with conventional wind tunnel testing, CFD provides detailed visualization of velocity fields, pressure distributions, turbulence characteristics, and flow structures while allowing efficient evaluation of alternative architectural configurations during the early design stages. Numerous studies have demonstrated the reliability of CFD for predicting pedestrian-level wind environments and optimizing building aerodynamics. Despite these advances, most published research primarily focuses on engineering aspects of urban aerodynamics, while comparatively fewer studies investigate the influence of architectural form from an architectural design perspective. In particular, limited attention has been devoted to comparative analyses of buildings with identical dimensions but different plan geometries under identical atmospheric boundary conditions, especially within the context of rapidly developing cities such as Tirana.

To address this gap, the present study investigates the aerodynamic performance of three representative building geometries—a square plan, a rounded-corner plan, and a circular plan—while maintaining identical building height, plan area, and atmospheric boundary conditions. Computational Fluid Dynamics (CFD) simulations are employed to evaluate wind velocity, surface pressure distribution, turbulence intensity, streamlines, flow separation, and pedestrian-level wind conditions. The findings aim to provide practical recommendations for integrating aerodynamic considerations into architectural design and improving pedestrian comfort in future urban developments.

2. METHODOLOGY

2.1. Building Models

To investigate the influence of architectural form on airflow behaviour around buildings, three representative building geometries were developed for numerical analysis. The selected geometries represent common plan configurations encountered in contemporary architectural design: a square-plan building (Model A), a rounded-corner building (Model B), and a circular-plan building (Model C).

To isolate the influence of geometry, all three models were designed with identical geometric characteristics, including the same building height, plan area, and total building volume. Consequently, all simulations were performed under identical atmospheric conditions, ensuring that any differences in the airflow characteristics resulted exclusively from variations in architectural form.

The models were generated as three-dimensional solid geometries and positioned individually within the computational domain. The approaching wind direction was kept constant for all simulations, allowing a direct comparison of the aerodynamic performance of the three building configurations.

The selected geometries provide a representative basis for evaluating how plan configuration influences wind velocity distribution, surface pressure, turbulence development, flow separation, wake formation, and pedestrian-level wind conditions.

2.2. Numerical Setup and Methodology

The aerodynamic analysis was carried out using Computational Fluid Dynamics (CFD) to simulate airflow around the selected building geometries. A three-dimensional computational domain was established in accordance with the COST Action 732 Best Practice Guideline (Franke et al., 2007) to minimize boundary effects on the predicted airflow field.

The incoming wind was defined using an Atmospheric Boundary Layer (ABL) velocity profile representative of an urban environment. A velocity inlet boundary condition was prescribed at the upstream boundary, while a pressure outlet condition was applied at the downstream boundary. The ground surface and building façades were treated as no-slip walls, whereas the top and lateral boundaries were defined as symmetry planes to reproduce an open atmospheric flow.

The numerical simulations were performed by solving the Reynolds-Averaged Navier–Stokes (RANS) equations using the Shear Stress Transport (SST k–ω) turbulence model, which is widely recognized for predicting separated flows around bluff bodies and urban structures. The numerical solution was considered converged when the residuals of all governing equations were reduced below $\mathbf{10^{-5}}$.

The aerodynamic behaviour of each building model was evaluated through the analysis of wind velocity distribution, surface pressure coefficient (Cp), turbulence intensity, streamlines, flow separation, wake development, vortex formation, and pedestrian-level wind conditions. All simulations were conducted under identical numerical settings to ensure that the observed differences were exclusively attributable to the architectural form of the buildings.

2.3. Evaluation Parameters

The aerodynamic performance of the three building geometries was assessed using a set of quantitative flow parameters relevant to urban wind engineering and pedestrian comfort. The analysis focused on wind velocity distribution, surface pressure coefficient (Cp), turbulence intensity, streamlines, flow separation, wake development, and vortex formation around the buildings.

Particular attention was given to the pedestrian level, where wind conditions directly affect outdoor comfort and safety. Wind velocity fields at pedestrian height were examined to identify areas of local wind acceleration and recirculation generated by different architectural forms.

To evaluate the practical implications of the numerical results, the predicted wind conditions were interpreted according to internationally recognized pedestrian wind comfort criteria, including the Lawson Wind Comfort Criteria and the Davenport Wind Comfort Criteria. These criteria provide a framework for assessing the suitability of outdoor spaces for activities such as walking, standing, and sitting, allowing the aerodynamic performance of each building geometry to be related to pedestrian comfort and urban environmental quality.

3. RESULTS AND DISCUSSION

3.1. Aerodynamic Performance of Building Geometries

The numerical simulations demonstrate that architectural form significantly influences the aerodynamic behaviour of airflow around buildings. As the approaching wind impinges on the windward façade, a stagnation region is formed, where the airflow decelerates and the surface pressure reaches its maximum. The flow subsequently accelerates around the building edges, generating pressure gradients, flow separation, and wake formation downstream. The magnitude of these phenomena varies according to the building geometry.

The square-plan building exhibits the most pronounced aerodynamic effects. The presence of sharp corners promotes abrupt changes in flow direction, resulting in local wind acceleration around the building edges and early flow separation. Consequently, this geometry produces larger wake regions and stronger pressure gradients compared with the other configurations. Positive pressure is concentrated on the windward façade, while negative pressure develops along the side and leeward façades due to flow detachment and recirculation.

The rounded-corner building modifies the airflow by providing a smoother transition between adjacent façades. The gradual curvature reduces local wind acceleration and delays flow separation, leading to a more uniform pressure distribution around the building envelope. Compared with the square

geometry, lower suction pressures and reduced pressure gradients are observed, indicating an improvement in the overall aerodynamic performance.
Among the analysed models, the circular building provides the most uniform aerodynamic response. The continuous curvature enables the airflow to remain attached to the building surface over a longer distance, minimizing pressure fluctuations and reducing the extent of separated flow behind the building. As a result, both the wind velocity distribution and the surface pressure field are more homogeneous than those observed for the square and rounded-corner configurations.
Overall, the comparative analysis confirms that building geometry has a direct influence on wind velocity distribution and surface pressure characteristics. Rounded building forms mitigate excessive wind acceleration, reduce pressure gradients, and promote smoother airflow development, thereby enhancing the aerodynamic performance of the building envelope and the surrounding urban environment.

3.2. Airflow Characteristics and Pedestrian Wind Comfort

Beyond the aerodynamic performance of the building envelope, the numerical simulations highlight the significant influence of architectural form on airflow characteristics and pedestrian wind conditions. The development of streamlines, flow separation, wake regions, and vortex structures determines the quality of the wind environment surrounding the buildings and directly affects pedestrian comfort.
The square-plan building exhibits the earliest flow separation due to its sharp edges, resulting in an extensive wake region characterized by strong recirculation and increased turbulence intensity. These flow structures generate localized wind acceleration around the building corners and unstable airflow conditions downstream, producing less favourable environments for pedestrian activities.
The rounded-corner building improves the flow behaviour by delaying separation and reducing the size of the recirculation zone. The smoother transition between façades promotes a more stable airflow pattern, decreases vortex intensity, and limits the development of highly turbulent regions. Consequently, wind conditions around the building become more uniform and suitable for outdoor use.
The circular building demonstrates the most stable airflow characteristics among the analysed geometries. The continuous curvature allows the approaching wind to follow the building surface with minimal disturbance, resulting in smaller wake regions, weaker vortex formation, and lower turbulence levels. This behaviour contributes to a more homogeneous wind environment and improved pedestrian-level conditions.
To assess the practical implications of these results, the predicted wind conditions were interpreted using internationally recognised pedestrian wind comfort criteria, including the Lawson Wind Comfort Criteria and the Davenport Wind Comfort Criteria. These criteria provide a framework for evaluating the suitability of outdoor spaces for common pedestrian activities such as walking, standing, and sitting.
The comparative analysis indicates that building geometry plays a decisive role in determining pedestrian wind comfort. Sharp-edged configurations generate higher wind speeds and stronger turbulence near pedestrian level, whereas rounded and circular forms significantly mitigate these effects by reducing flow separation and promoting smoother airflow. These findings underline the importance of considering aerodynamic performance during the early stages of architectural design, enabling the development of buildings that not only satisfy functional and aesthetic requirements but also contribute to safer, more comfortable, and environmentally responsive urban spaces.

4.CONCLUSIONS

This study investigated the influence of architectural form on airflow behaviour around buildings and its implications for pedestrian wind comfort using Computational Fluid Dynamics (CFD). Three representative building geometries—a square-plan building, a rounded-corner building, and a circular building—were analysed under identical atmospheric and numerical conditions to isolate the effect of plan geometry on aerodynamic performance.

The comparative analysis demonstrated that architectural form significantly affects wind velocity distribution, surface pressure, flow separation, wake development, and turbulence intensity. The square-plan building generated the strongest wind acceleration, larger pressure gradients, and more pronounced wake regions, whereas the rounded-corner and circular geometries promoted smoother airflow, reduced flow separation, and more uniform pressure distributions.

The assessment of pedestrian-level wind conditions further indicated that streamlined building geometries contribute to a more favourable outdoor environment by reducing localized wind acceleration and turbulence. These findings emphasize that architectural form should be considered not only as an aesthetic and functional design parameter but also as a key factor influencing the environmental performance of buildings and the quality of surrounding public spaces.

These findings demonstrate the importance of integrating aerodynamic analyses into the architectural design process. Numerical simulations provide an effective tool for evaluating alternative building configurations before construction, supporting design decisions that improve aerodynamic performance and pedestrian comfort in dense urban environments.

Future research should extend the present investigation to more complex urban configurations, including groups of high-rise buildings, different wind directions, and the influence of surrounding urban morphology and vegetation. Experimental validation through wind tunnel testing would further strengthen the reliability of the numerical predictions and support the development of design guidelines for wind-responsive urban planning.

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