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Experimental investigation of wind effects on a high-rise building with permeable façades

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SUMMARY:
Wind loading is a critical design aspect for permeable double-skin façades (PDSFs), increasingly used in buildings to enhance their energy efficiency. Despite their growing application, their aerodynamic behaviour remains insufficiently understood due to the complexity introduced by porous geometries. This study presents an experimental investigation of the aerodynamic response of a high-rise building model equipped with porous envelope systems. Wind tunnel tests were conducted on a rigid square-cylinder model in six configurations, including a reference bare case and five cases with different permeable façade typologies. The analyzed solutions comprise perforated sheets with varying porosity levels and opening geometries, as well as louver-based systems providing directional permeability. The influence of the porous envelopes is assessed through measurements of global wind loads (drag and lift coefficients), local pressure distributions (mean and fluctuating pressure coefficients), and wake flow characteristics. In particular, wake velocity measurements are used to analyze modifications in vortex shedding behaviour. The results provide quantitative insight into the effectiveness and limitations of PDSFs in modifying wind-induced loads and contribute to their aerodynamic characterization for structural design applications.

Keywords: permeable double-skin façade, porous elements, wind tunnel tests

1. INTRODUCTION

Permeable double-skin façades (PDSFs) are increasingly adopted in high-rise buildings to improve energy efficiency and environmental performance. These systems, often implemented through brise-soleil or porous external skins, provide solar shading and promote natural ventilation within the façade cavity. However, their presence significantly alters the aerodynamic interaction between wind and structure. Compared to conventional solid façades, PDSFs introduce additional complexity due to their porous nature and multi-scale geometry. The interaction between the external flow, the permeable envelope, and the inner building leads to modified pressure distributions (Giachetti et al., 2025; Pomaranzi et al., 2022) and potentially altered vortex shedding mechanisms (Catania et al., 2026). Despite their growing application, the aerodynamic behaviour of such systems remains insufficiently understood, particularly in terms of their impact on both global wind loads and local pressures.
This is the main research gap addressed by the PRIN project SaFEx, which aims to investigate the aerodynamic behaviour of PDSFs and provide guidelines for their testing and design. The project combines a complementary and synergistic use of large-scale wind tunnel tests and Computational Fluid Dynamics (CFD) simulations. The former are based on rigid scaled model tests, while the latter rely on homogenised porous-media approaches, such as the Pressure–Velocity Jump model (Xu et al., 2020, 2023). The present study, carried out within the framework of the SaFEx project, focuses on the experimental campaign. The objective is to quantify the influence of porous façade systems on global forces, surface pressure distributions, and wake flow characteristics, as well as to provide a high-quality dataset for the validation of CFD models.

2. METHODOLOGY

Wind tunnel tests were conducted on a rigid square-cylinder model representative of a high-rise building in the boundary layer test section of the Politecnico di Milano Wind Tunnel, as shown in Figure 1. Six configurations were analysed: a reference bare model ("naked", with characteristic length $D = 0.2\,\mathrm{m}$ and height $H = 6D$) and five cases with porous envelope systems ("porous"). Three perforated façade configurations were investigated, all consisting of a square external shroud with edge length $D_{\mathrm{ext}} = 1.25D$. The envelopes differ in porosity β - and so pressure loss coefficient k - and opening geometry: NQ7 ($\beta = 65.8\%$, $k = 1.7$), NQ5 ($\beta = 46.5\%$, $k = 5.0$), and NT5 ($\beta = 40.3\%$, $k = 7.3$). In addition, louver-based systems were tested to assess directional permeability effects. Figure 2a reports the geometrical characteristics of the tested envelopes, while their installation on the tower is shown in Figures 2b–e.

Experiments were performed under smooth flow conditions ($I_u = 2\%$, $L_u^x = 0.2\,\mathrm{m}$). Global forces were measured using a high-frequency balance, while surface pressures were acquired through pressure taps distributed on both the inner tower and the porous envelopes, allowing the measurement of net pressures. The aerodynamic response was evaluated in terms of drag and lift coefficients, defined as:

$$C_F(t) = \frac{F(t)}{0.5\rho U^2 BH}, \tag{1}$$

where $F(t)$ is the aerodynamic force in either the drag or lift direction, B is the prism side (i.e. D for the naked configuration and D_{ext} for the porous configurations), and H is the model height. Non-dimensional pressure coefficients,

$$C_p(t) = \frac{p(t) - p_{ref}}{0.5\rho U^2}, \tag{2}$$

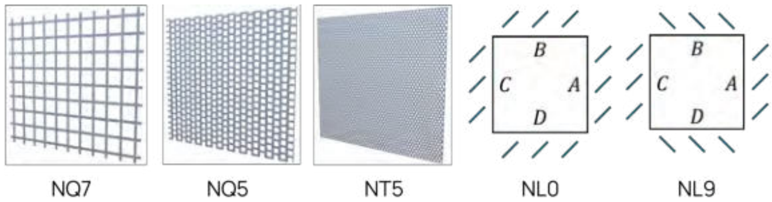
are used to characterise wind-induced pressures. Wake flow characteristics were analysed through velocity measurements downstream of the model. The vortex shedding frequency was identified from spectral analysis of both force and velocity signals and expressed through the Strouhal number ($St = f_{vs}D/U$).

(a) NAK configuration. **(b)** Reference system.

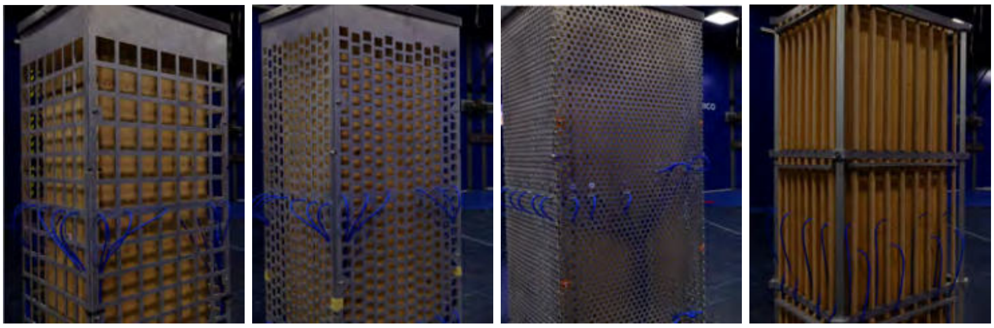
Figure 1. Experimental setup and naked configuration tested in the wind tunnel.

3. RESULTS

Figure 3 presents the polar plots of drag and lift coefficients for the reference (naked) configuration and the cases with porous envelopes. A significant reduction in the drag coefficient is observed at 0°, when considering the porous configurations with respect to the fully solid case (NAK curve). Such reduction progressively decreases as the wind angle approaches 30°, where



(a) Tested porous envelopes configurations. From left to right: NQ7, NQ5, NT5, NL0, NL9.



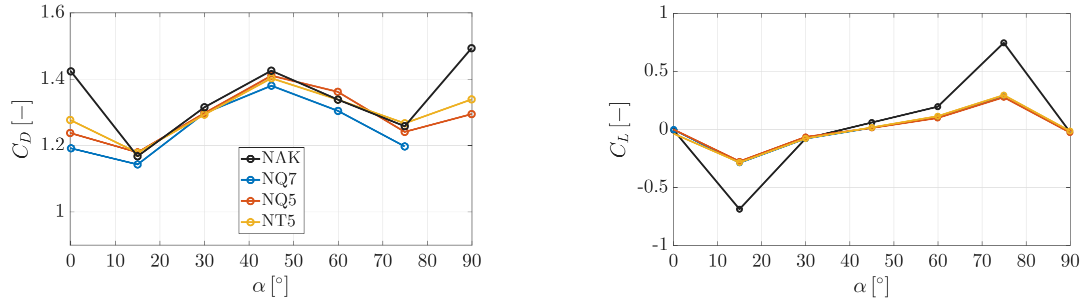
(b) NQ7. **(c)** NQ5. **(d)** NT5. **(e)** NL0.

Figure 2. Experimental porous configurations tested in the wind tunnel.

differences between configurations become negligible. Among the tested solutions, the NQ7 configuration exhibits the largest drag coefficient reduction, while NQ5 and NT5 show similar behaviour, suggesting a dominant role of porosity in governing the aerodynamic response. Regarding lift coefficient, no significant dependency on the porous layer properties is found. The maximum reduction occurs at 15°, where all porous configurations lead to a noticeable decrease in C_L compared to the reference case.
Figure 4 shows the mean pressure coefficient distributions at floor 2 for an incoming wind direction of 15°. The naked configuration is reported in Fig. 4a, while Fig. 4b and Fig. 4c present the results for the inner layer and the permeable envelope of the NT5 configuration, respectively. The presence of the porous screen leads to a general attenuation of both positive and negative pressure peaks on the inner tower, indicating a shielding effect. This reduction is more pronounced in separated flow regions, particularly on the leeward and rear faces. In these regions, the porous envelope weakens the intensity of suction, especially on the leeward face, consistently with the observed drag reduction. The net pressure acting on the porous layer (Fig. 4c) exhibits positive values on the windward face and strong suction peaks near the corners. This behaviour reflects the interaction between the incoming flow and the separation regions at the edges, highlighting its interference on the separation behavior of the tower. A more detailed description of the envelope effect on the local and global aerodynamics of the tower, along with a comprehensive analysis of the wake characteristics, will be reported in the full paper.

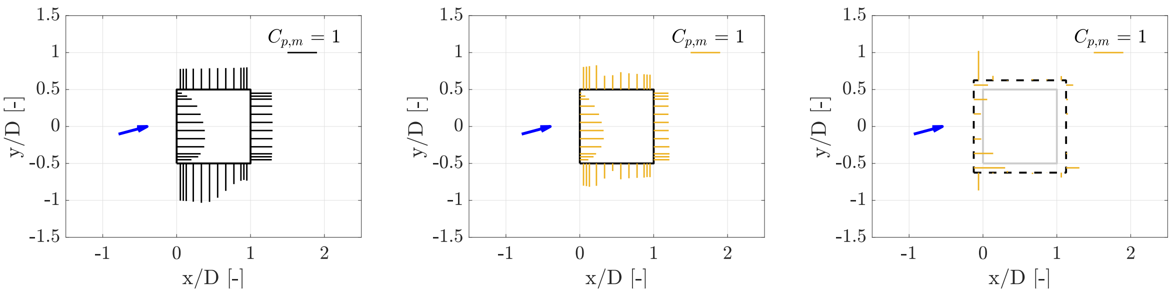
4. CONCLUSIONS

This research project aims to describe the aerodynamic variation induced by the presence of a porous envelope over a square prism, representative of a high-rise building. From the wind-tunnel results, it results that the drag coefficient for the porous configurations is smaller than the one associated to the naked case at zero angle of attack. The reduction is proportional to the envelope porosity and, as inferred from the analysis of the local pressure coefficient distribution, is related to reduced suction on the leeward face. In skewed wind conditions, the



(a) Drag coefficient. **(b)** Lift coefficient.

Figure 3. Polar plot of the aerodynamic coefficients of all the configurations against attack angle.



(a) NAK configuration, inner tower. **(b)** NT5 configuration, inner tower. **(c)** NT5 configuration, porous envelope, net pressure coefficient.

Figure 4. Mean pressure coefficient (C_{p_m}) at 15 attack angle, floor 2.

beneficial effect on the total lift is maximum at 15° and, interestingly, is null at 30°. These preliminary results help to understand the complex wind interaction with PDSF systems. Wind tunnel data will be made public to help engineers in the design of next-generation cladding systems based on permeable elements, while providing the scientific community with a large and accurate dataset to validate and train numerical models.

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REFERENCES

Catania, M., G. Pomaranzi, and A. Zasso (2026). From vortex shedding to Vortex-Induced Vibrations: The role of porous façades. Journal of Fluids and Structures 143, 104538.

Giachetti, A., G. Manara, and G. Bartoli (2025). Permeable building envelopes: a literature review and a novel classification from the wind load perspective. Journal of Building Engineering, 114005.

Pomaranzi, G., G. Pasqualotto, and A. Zassso (2022). Investigation of the effects due to a permeable double skin façade on the overall aerodynamics of a high-rise building. Wind & structures 35, 213–227.

Xu, M., L. Patruno, Y.-L. Lo, and S. D. Miranda (2020). On the use of the pressure jump approach for the simulation of separated external flows around porous structures: A forward facing step. Journal of Wind Engineering and Industrial Aerodynamics 207, 104377.

Xu, M., L. Patruno, and S. D. Miranda (2023). A pressure–velocity jump approach for the CFD modelling of permeable surfaces. Journal of Wind Engineering and Industrial Aerodynamics 233, 105317.