

INVESTIGATION OF WIND IMPACT ON NATURAL VENTILATION IN HOUSING: ADDRESSING THE CHALLENGES OF THERMAL RENOVATION

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ABSTRACT

This paper presents findings from experimental research on the surface pressure coefficient distribution across the roof of a 5-story residential building, using a model of an actual building in Lviv, Ukraine. The model is based on a wind tunnel that simulates wind forces on residential buildings. The experimental results show that the wind-induced pressure on the roof surface of the building is significantly higher than that of the surrounding buildings, resulting in the accumulation of hazardous concentrations of harmful substances within the building. These findings are highly pertinent for formulating recommendations for the efficient operation of passive ventilation systems in existing buildings within densely constructed urban areas, thereby improving energy efficiency, indoor air quality, and reducing carbon emissions. This approach is crucial for enhancing the design methodology of new buildings and thermal retrofitting of existing ones, particularly focusing on optimizing natural ventilation in medium-rise buildings in densely populated urban areas.



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1. INTRODUCTION

A significant proportion of existing residential buildings rely on natural channel ventilation systems, which operate without external energy consumption and offer substantial potential for energy savings. These systems enhance indoor air quality and reduce carbon emissions by utilizing natural forces like wind and thermal buoyancy. However, their efficiency is often influenced by external factors such as wind dynamics, building design, and modifications introduced during thermal retrofitting.

The growing need for energy-efficient and sustainable building solutions has placed natural ventilation systems at the forefront of design and retrofitting strategies. Despite their benefits, these systems face challenges in urban environments where dense building arrangements disrupt wind flow and create pressure zones that compromise performance, while the lack of control mechanisms hinders predictable and optimized operation under varying conditions. Thermal retrofitting, which improves energy efficiency by adding insulation and sealing envelopes, can reduce natural airflow,

compromising ventilation performance. Urban environments further complicate this due to disrupted wind flows caused by dense building arrangements, creating pressure zones that hinder ventilation efficiency. This study explores the aerodynamic interactions between wind and natural ventilation systems, focusing on optimizing their performance in thermally retrofitted residential buildings. By examining wind effects, urban density, and innovative design strategies, the research aims to enhance energy efficiency, reduce carbon emissions, and promote healthier indoor environments.

Nomenclature

c	pressure coefficient
P	pressure, Pa
ρ	density, kg/m ³
v	speed, m/s

2. LITERATURE REVIEW

To comprehensively understand the interaction between building ventilation systems and wind, and the impact of wind forces on their stability and functional characteristics, it is advisable to conduct research using wind tunnel models. This approach not only facilitates the precise determination of pressure values on building surfaces under varying wind speeds and turbulent flow conditions but also helps identify critical pressure values that pose significant risks to the structural integrity of buildings and efficient operation of ventilation systems (Abdelfatah et al., 2020; An & Jung, 2024; Chauhan et al., 2022; Myroniuk et al., 2024; Vita et al., 2020; Zhang et al., 2023). Furthermore, aerodynamic experiments provide insights into wind effects from various directions, considering the correlation between wind speed and flow turbulence, which is particularly crucial for the design of high-rise structures (Kikuchi et al., 2024; Lamberti et al., 2020; Voznyak et al., 2020; Vranešević & Glumac, 2024; Yuan et al., 2023). This knowledge is crucial for optimizing building designs and enhancing the efficiency of ventilation systems, thereby improving energy performance and indoor air quality, ultimately contributing to a reduction in carbon emissions.

Another critical aspect is the influence of natural obstacles, building dimensions, and adjacent structures on pressure distribution on a building's surface. Scientific research indicates that external factors, such as neighboring buildings or natural features, can significantly alter the direction and magnitude of wind pressure. Various geometric dimensions and their spatial arrangement can also create complex aerodynamic conditions, depending on the density of the surrounding structures. The interaction between buildings affects pressure distribution and associated aerodynamic phenomena (Hubová et al., 2022; Shirzadi et al., 2020; Tominaga & Blocken, 2016). Understanding these dynamics is vital for developing energy-saving designs

that ensure better air quality and minimize the environmental impact of densely built urban areas.

Computer modeling emerges as a cost-effective method for studying aerodynamic phenomena, including the evaluation of natural and hybrid ventilation. It is essential for analyzing wind effects on buildings and determining the aerodynamic coefficient to understand the extent of wind impact on buildings. The results of computer simulations are particularly vital when assessing the impact of wind on high-rise buildings and structures of various architectural configurations. The interaction between buildings and the assessment of external elements, such as topography and natural features, also play a significant role (Elshaer et al., 2016; Feng et al., 2019; Li et al., 2024; Myroniuk et al., 2023; Sheng et al., 2018; Shirzadi et al., 2018; Zhao et al., 2022). This methodology allows for modeling urban microclimates and estimating harmful substance concentrations in residential areas, thereby facilitating the creation of healthier indoor environments and promoting energy conservation.

While computer simulations are powerful tools, they do not always capture all aspects of the real environment. Therefore, it is crucial to compare the results of computer simulations with data obtained from aerodynamic experiments. This combined approach ensures that building designs are both energy-efficient and capable of maintaining high indoor air quality, leading to significant reductions in carbon emissions and enhancing the overall sustainability of urban development.

3. EXPERIMENTAL PART

This study presents findings from experimental research on the surface pressure coefficient distribution across the roof of 5-story residential building, using a model of an actual building, built in the mid-1980s in Lviv, Ukraine (Figure 1).



Figure 1. Photo of an actual building in Lviv, Ukraine

A 1:300 scale model was fabricated and placed on a 2-metre diameter platform within the atmospheric boundary layer (ABL) wind tunnel at the University of Birmingham's Civil Engineering Laboratory. The scaling matches the scale of the ABL flow generated within the tunnel.

Pressure coefficients have been measured on the roof of the model for three cases: the building at the centre of a 300m (full-scale) radius model of the city; the building as part of the city but with the model modified to include a small parapet which runs around the edge of the roof, (Figure 2, a, b); an isolated building with a surrounding, flat, 1m (300m full-scale) fetch (Figure 2, c).

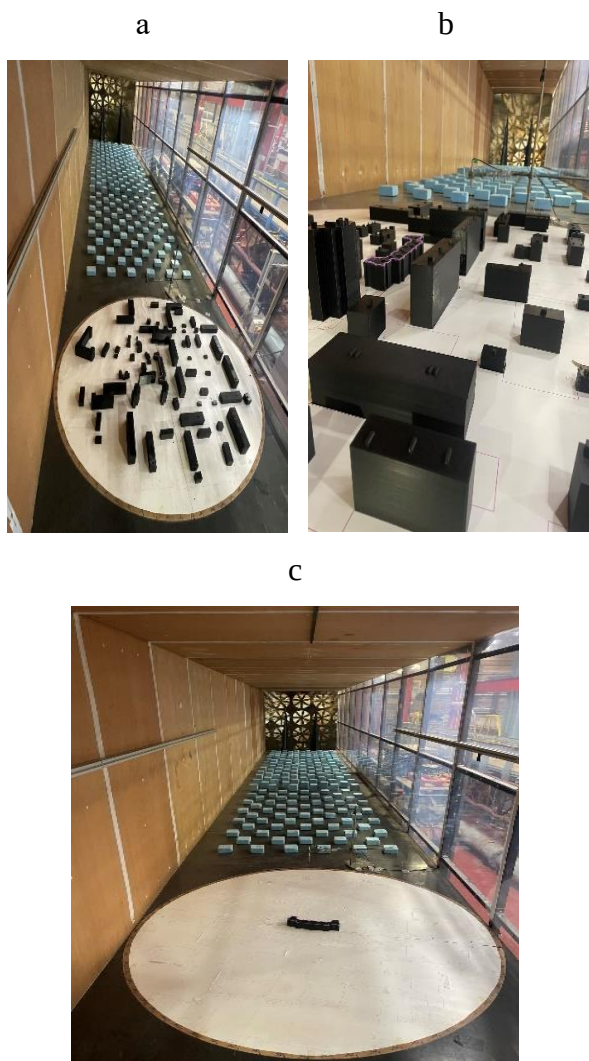


Figure 2. Three series of measurements were carried out (a) a house without parapet; (b) - a house with a parapet; (c) - a house without surrounding buildings

The primary objective of these measurements was to assess the performance of ventilation channels under wind flow conditions and to identify critical zones that pose a threat to the operation of the natural ventilation system. These research findings are highly pertinent for

formulating recommendations for the efficient operation of passive ventilation systems in existing buildings within densely constructed areas. This is particularly relevant for buildings that have undergone thermal retrofitting.

The physical emulation of wind-induced loads on residential structures involves examining house models within a wind tunnel, a facility designed to replicate wind forces on buildings. This method uses the pressure coefficient "c" to determine the relationship between excess static pressure at specific points on the building's surface and the dynamic wind pressure. While frequently employed, synthesizing data from these experiments is challenging due to the diverse configurations and placements of buildings in residential areas.

$$\pm c = \frac{P}{\frac{\rho \cdot v^2}{2}} \quad (1)$$

Around the exhaust ventilation duct outlets, building aerodynamics may lead to the formation of zones of positive pressure. This phenomenon poses a critical threat to the functionality of natural exhaust ventilation systems, as it fosters the potential for reverse air flow within the channels, consequently causing the accumulation of hazardous concentrations of harmful substances within the premises. The negative impact on the operation of exhaust ventilation channels increases with the magnitude of the positive pressure coefficient (Figure 3).

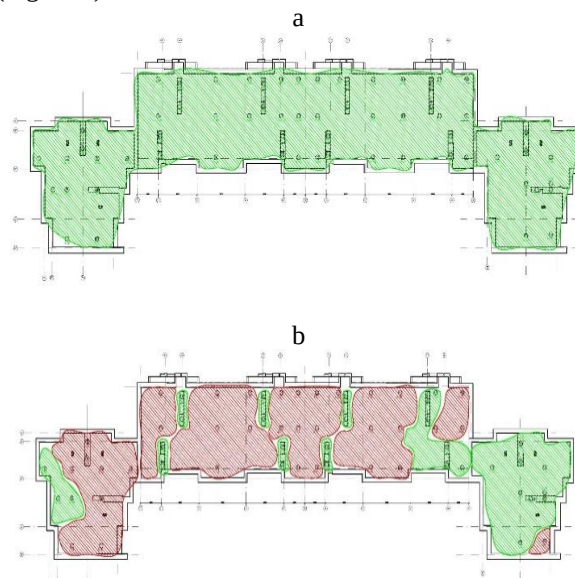


Figure 3. Pressure distribution on the roof surface: the red zone shows the zone where there is excess pressure, the green zone indicates the rarefaction zone with a wind direction of 300° (a) an isolated building with a surrounding, flat, 1m (300m full-scale) fetch; (b) the building at the centre of a 300m (full-scale) radius model of the city

The findings highlight the importance of including the surrounding buildings in the model. With an open fetch negative pressure coefficients occur around the existing ventilation outlets, which will aid ventilation, but when surrounding buildings are included the surface pressure

coefficient increases to +1.0, and as high as +5.5 when the parapet is included. These positive pressures occur for wind directions between south-westerly (270°) to westerly (305°).

4. CONCLUSION

The experimental results serve as a foundation for enhancing the design methodology of new buildings and thermal retrofitting of existing ones, particularly focusing on optimizing natural ventilation in medium-rise buildings in densely populated urban areas. This approach is crucial for significantly improving energy efficiency, indoor air quality, and reducing carbon emissions in contemporary building design.

Studies on the aerodynamics of external wind influence on the ventilation of residential buildings help identify critical points on the building's roof surface under wind pressure. These findings enable the development of new,

efficient, and environmentally friendly ventilation technologies that align with modern construction needs. Such advancements foster comfortable and healthy living conditions while significantly contributing to energy savings and emission reductions.

Thermally retrofitted residential buildings often face challenges with traditional external air inflow due to their tightness. Therefore, implementing appropriate ventilation systems is vital not only for maintaining indoor air quality but also for optimizing energy consumption. Passive ventilation systems present a promising solution, utilizing natural forces and innovative technologies to facilitate air exchange while minimizing energy use, thus enhancing energy conservation and lowering carbon footprints.

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