Physical Simulation of the Surface Pressure Field on a 5-Storey Residential Building and Application to Natural Ventilation

Khrystyna Myroniuk[1,2*], Vasyl Zhelykh[2], Yurii Furdas[2], Mike Jesson[1] and Stergios-Aristoteles Mitoulis[1]
[1]Department of Civil Engineering, University of Birmingham
Birmingham, UK
[2]Department of Heat and Gas Supply and Ventilation, Lviv Polytechnic National University
Lviv, Ukraine
[*] E-mail: k.myroniuk@bham.ac.uk

1 INTRODUCTION

A large proportion of existing residential structures incorporate a natural channel ventilation system. This ventilation approach offers several benefits, primarily its capacity to function without requiring energy consumption. However, this method is susceptible to external aerodynamic conditions and lacks controllability, and consequently it is currently difficult to predict how well it will operate and presents challenges to systematic study of the issue. Additionally, its effectiveness can diminish following alterations to the building, such as insulation upgrades (thermal retrofitting).

2 MAIN PART

2.1 Literature review

For a comprehensive understanding of the interaction between buildings 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 facilitates the precise determination of pressure values on the building surface under varying wind speeds and turbulent flow conditions [1–3]. Such studies are instrumental in identifying critical pressure values that pose significant risks to the structural integrity of buildings [4–6]. Furthermore, aerodynamic experiments provide insights into wind effects from various directions, considering the correlation between wind speed and flow turbulence [7–9], which is particularly crucial for the design of high-rise structures [10].

Another critical aspect is the influence of natural obstacles, building dimensions, and adjacent structures on the 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 [5]. Various geometric dimensions and their spatial arrangement can also create complex aerodynamic conditions, depending on the density of the surrounding structures [11]. The interaction between buildings affects the pressure distribution and associated aerodynamic phenomena [11,12].

Computer modeling emerges as a cost-effective method for studying aerodynamic phenomena, including the evaluation of natural and hybrid ventilation, and is essential for analyzing wind effects on buildings [13,14]. Determining the aerodynamic coefficient helps in understanding the extent of wind impact on buildings [7]. The results of computer simulations are particularly vital when assessing the impact of wind on high-rise buildings and structures of various architectural configurations [15,16]. The interaction between buildings and the assessment of external elements, such as topography and natural features, also play a significant role [13,14]. This methodology allows for the modeling of urban microclimates and the estimation of harmful substance concentrations in residential areas [3].

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 [17].

2.2 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 in the city of 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

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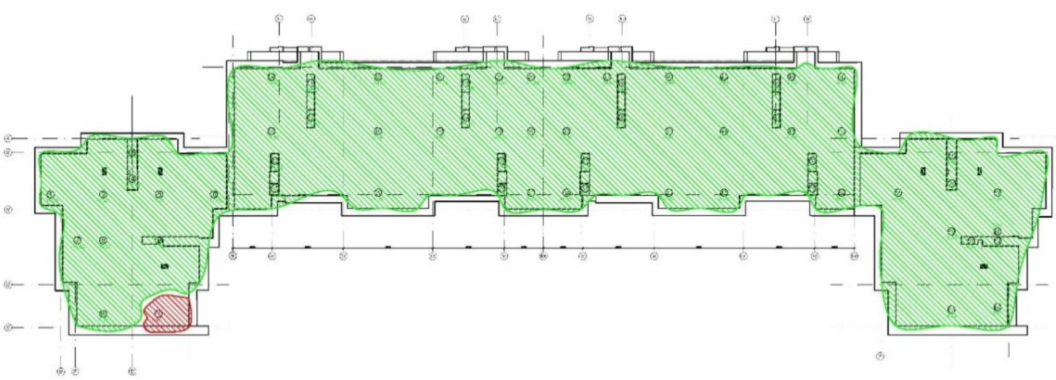
Laboratory. The scaling matches the scale of the ABL flow generated within the tunnel. Pressure coefficients have been measured over the roof of the model for three cases: an isolated building with a surrounding, flat, 1m (300m full-scale) fetch; the building at the centre of a 300m (full-scale) radius 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 (Fig. 1). 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.

Figure 1, three series of measurements were carried out: 1 - a house without parapet; 2 - a house with a parapet; 3 - a house without surrounding buildings.

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.

$$\pm c = \frac{P}{\frac{\rho \cdot v^2}{2}} \tag{1}$$

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.



a) an isolated building with a surrounding, flat, 1m (300m full-scale) fetch

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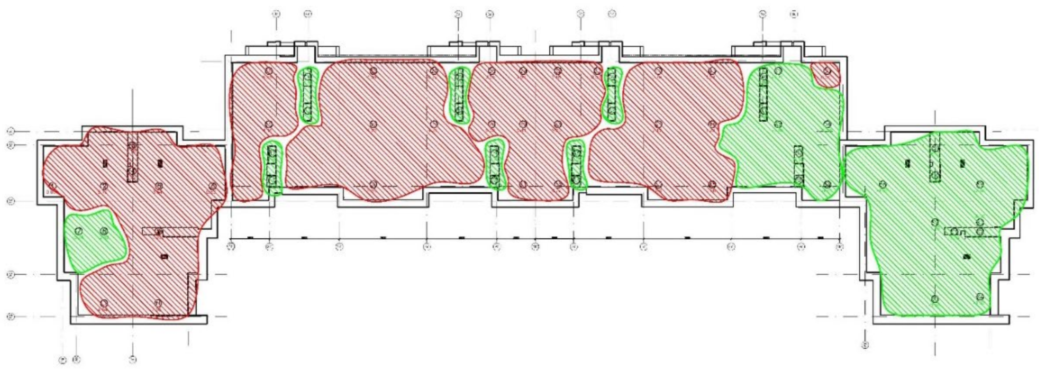

b) the building at the centre of a 300m (full-scale) radius model of the city

Figure 2, pressure distribution on the roof surface: the red zone shows the zone where there is excess pressure, the green zone indicates the rarefaction zone

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°).

3 CONCLUSIONS

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 the quality and efficiency of 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 and foster comfortable and healthy living conditions. 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 consumption.

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