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ANALYSIS OF WIND CONDITIONS AROUND A BUILDING DEVELOPMENT AS A PART OF ITS FORM DESIGNING PROCESS, A CASE STUDY

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Abstract
Aerodynamic phenomena that occurs around building developments exert a significant impact on the quality of climate in cities. Environmental wind engineering is a dynamically developing field of knowledge that offers a chance to study and, in consequence, regulates the air flow around buildings and complexes of building developments. The following paper discusses the issue of wind conditions that may be experienced on pedestrian level. Such conditions should allow for a proper ventilation of city spaces, at the same time eliminating uncomfortable, sudden accelerations in the wind speed and wind turbulence.
The present paper discusses whether it is possible to include the above mentioned issues in the process of urban and architectural design of medium-high urban building development units on the example of a particular project. The paper is aimed to test the validity of the use of aerodynamic tests and the possibilities of their introduction in the conceptual phase of architectonic design. Design methods based on the realities of common practices and legal conditions in Poland have been juxtaposed to research methods in the field of aerodynamics. Experimental studies in wind tunnel, using oil visualization method have been applied, as such a method allows to promptly arrive at a qualitative identification of the airflow around the building on pedestrian level.

Keywords: **Architectural design; Airflow around Buildings; Air Stagnation; Bioclimatic Architecture; Environmental Wind Engineering; Urban climate; Wind Comfort.**

1. INTRODUCTION

The need to ensure healthy and comfortable environmental conditions for city residents is one of the assumptions that define the concept of sustainable urban development. Factors, such as feeling the temperature, air movement, air smell or humidity, contribute to the quality in use of urban space and, indirectly, also the buildings themselves. Modern cities, especially the largest cities, face problems of air pollution, insufficient air exchange rate and overheating, all of which appear in built-up areas. Among the factors causing such a situation, a high concentration of buildings and hardened surfaces in cities may be mentioned. Solar energy is accumulated through building walls and surfaces, whereas the release of solar energy is impeded by the wind velocity slowdown, a characteristic phenomenon in case of cities, which is estimated at 20–30% in relation to air movement in city outskirt areas [1]. In spite of the slowdown mentioned, varied wind phenomena in a relatively small area, such as turbulence and rapid airflow acceleration and air stagnation may occur around buildings simultaneously. The dependence of these phenomena on the shape of buildings and the distance between them is clearly visible and proven [2, 3, 4]. Within the scope of environmental wind engineering, knowledge is developed which deals with the issues of wind comfort for pedestrians and of the possibilities for ventilating urban spaces.

The following paper concerns the possibility of including the above mentioned issues in the process of urban and architectural design in case of designing medium-high urban building developments, on the example of a particular project. In accordance with the current legal situation in Poland, aerodynamic analyses are required only for high-rise building projects, as well as for building developments located in aeration corridors. The paper is aimed to test the validity of the application of aerodynamic tests also while designing dense urban development units. Moreover, it concerns the possibility of introduction of such tests in the concept phase of a project, when basic decisions regarding the shape of buildings and their arrangement are made. Design methods based on the factual data concerning common practices and legal conditions in Poland have been juxtaposed to research methods in the field of aerodynamics. The subject of the research concerns a conceptual design of a building development that is intended to fill the urban quarter at the junction of Street Woronicza and Aleja Niepodległości (Independence Avenue) in Warsaw. In the process of forming buildings, experimental studies in wind tunnel, using oil visualization method have been applied. The method allows for a relatively prompt qualitative identification of the airflow around the building on the pedestrian level (the studies were conducted at the Department of Aerodynamics, Faculty of Power and Aeronautical Engineering, Warsaw University of Technology).

2. THE ISSUE ASSUMED AGAINST THE BACKGROUND OF THE PRESENT RESEARCH CONDITION

Research in the field of environmental wind engineering has been intensively developed since the second half of the 20th century. Such studies belong with the field of physics known as fluid dynamics (FD). It is believed that a research which led to a breakthrough in connecting environmental wind engineering directly to architecture was the study by Gandemer, who, in 1975, identified and described the twelve so-called aerodynamic effects created around detached buildings and buildings arranged in the form of simple systems [5]. This study provided the basis for creating design guidelines for architects and urban planners. Gandemer applied tunnel experiments, which were then developed at the turn of the 80s and 90s by subsequent researchers (Hussain and Lee, Brown and DeKay, and, especially, Oke).

The experiments helped to understand the nature of wind phenomena in a three-dimensional system and were acknowledged as an important element of the pro-ecological approach to design in the 1990's [6]. The importance of phenomena occurring in arrangements known as *street canyons*, namely the spaces between two parallel lengthened buildings, the typical street layouts in cities, has been emphasised in the experiments. Simultaneously, studies on numerical methods of wind simulation (computational fluid dynamics CFD) were being developed [7].The first achievements concerning space ventilation between buildings in the area of CFD include there search in 1993 by Walker, Shao and Willscoroft. This research method continues to be explored till the present day [8], especially in the scope of the connection between building development geometry and the airflow around it. Especially complex systems corresponding to the actual geometric characteristics of cities pose a great challenge [2, 9]. Despite the significant development in research methods, also numerical ones, with certain exceptions, aerodynamic research still fails to be included in spatial planning processes, whereas the level of knowledge displayed by architects and urban planners on this subject is insignificant.

The issues raised in the present paper concern wind conditions that occur between buildings and create wind comfort for pedestrians (it was assumed to appear at 1.5 m above the ground). The presence of the comfort requires protection against both, violent gusts of wind and against wind turbulence (the phenomena occur at building edges or in building narrowing). Moreover, it is crucial to prevent air stagnation from occurring. The latter leads to an insufficient ventilation in the spaces between buildings, overheating in the summer, the retention of unpleasant odours and air pollution.

From the research quoted by, among other researchers, Daniels [6], it stems that in the wind direction perpendicular to the street axis, uninterrupted ventilation in street space occurs when the parameter h/w ("h" is the height of buildings and "w" is the distance between them) is less than 0.37. As the value of the parameter is increased, the air ventilation gradually reduces, whereas above the h/w value equal to 0.74, the air exchange stops completely. Similar data is also provided in publications by further authors (namely, Oke, Harmana, Okamoto, Castro and Robins). Observing the implementations of contemporary development housing estates, as well as the buildings that fill of the existing downtown development of large Polish cities, it is easy to identify buildings with geometry posing such a risk [4].

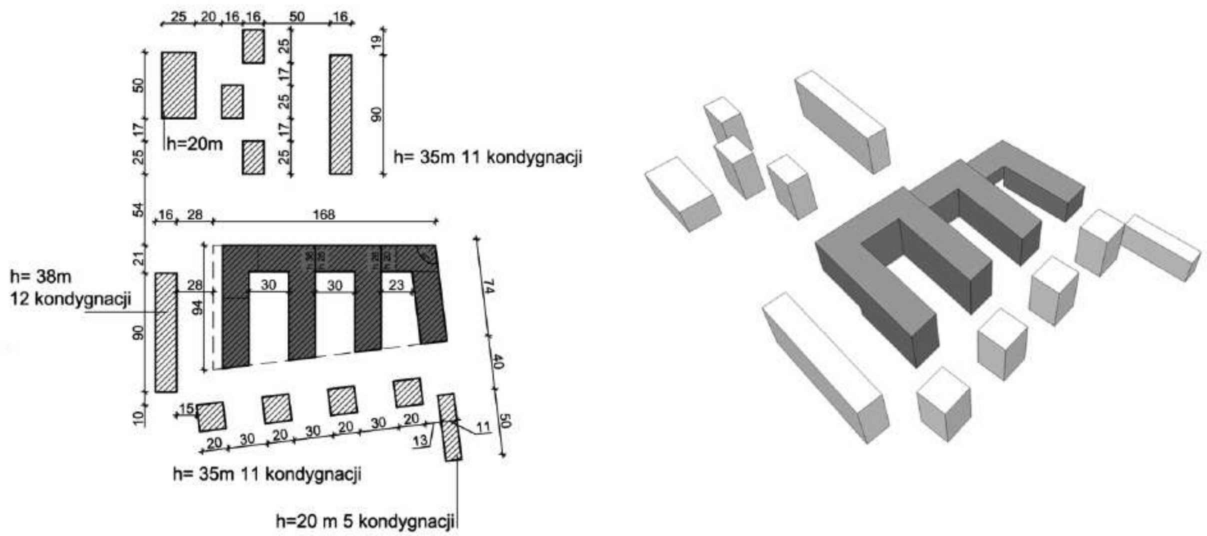

Figure 1.
Situational plan (on the left) and axonometric view of the designed building (on the right), together with the surroundings. The designed building is marked in grey; author's own study

In the present paper, attempt is made to verify, using a particular example, whether by means of designing buildings to fill of an urban quarter in accordance with the principles commonly applied in development investments in Poland, a risk of uncomfortable aerodynamic phenomena arises and whether such risks can be counteracted by introducing proper improvements in the shape of buildings.

3. RESEARCH ASSUMPTIONS

First, a building structure concept was created for the building development that was intended to fill the selected plot. The function assumed for the building was of residential and service nature. During the research, the plot was not subject to the local development scheme, which would provide design guidelines. Thus, the form of the building was shaped according to the following criteria:

- maximum use of the spatial potential of the plot so as to get as much useable space as possible in the designed building (it was the initial criterion, analogically to what is most often the case in the practice of development investments),
- obtaining the required conditions for the location of the building,
- creating a harmonious spatial composition with neighbouring buildings.

Once the urban conditions had been analysed, a comb-shaped building was formed (Figure 1). In such a way, courtyards were formed that open towards the south, thus provided with good access of light. The presence of courtyards offers a possibility to develop a continuity with the existing green areas and introduce such areas into the interior of the projected building development quarter. Moreover, such a shape of the designed building makes it possible to provide a good lighting of rooms in it. Bearing in mind the existing residential building situated to the west (38 m high), the designed building development has been moved away from the plot border by a distance of over 7 m. A distance of about 30 m between the buildings was obtained in this way. This allowed to maintain the current conditions of insolation for the existing building.

A varied height of the building was assumed (36, 28 and 20 m in order to harmonize it better with the heights of neighbouring buildings) and two wide gates were introduced (for the sake of a better communication between the street and the courtyards)

As a result, an initial concept for the building development shape was created. In the form a layout that covers also neighbouring buildings, the structure was subjected to tests in the wind tunnel. The research resulted in a general diagnosis of wind conditions and in identification of problem areas. On the basis of the test, the shape of the designed building development was adjusted and subjected again to experimental research in the tunnel. The research resulted in the decision to introduce another modification to the shape of the building. The resulting version of the

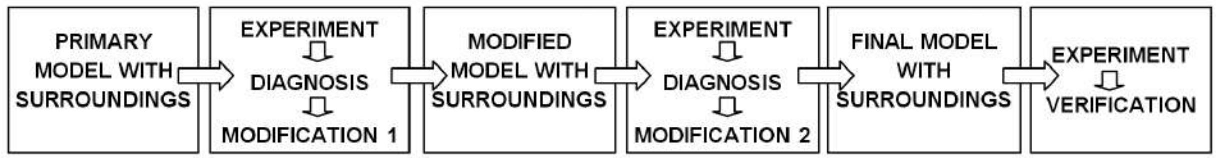

Figure 2.
The scheme for combining experimental research with the process of designing the body of the building; author's own study

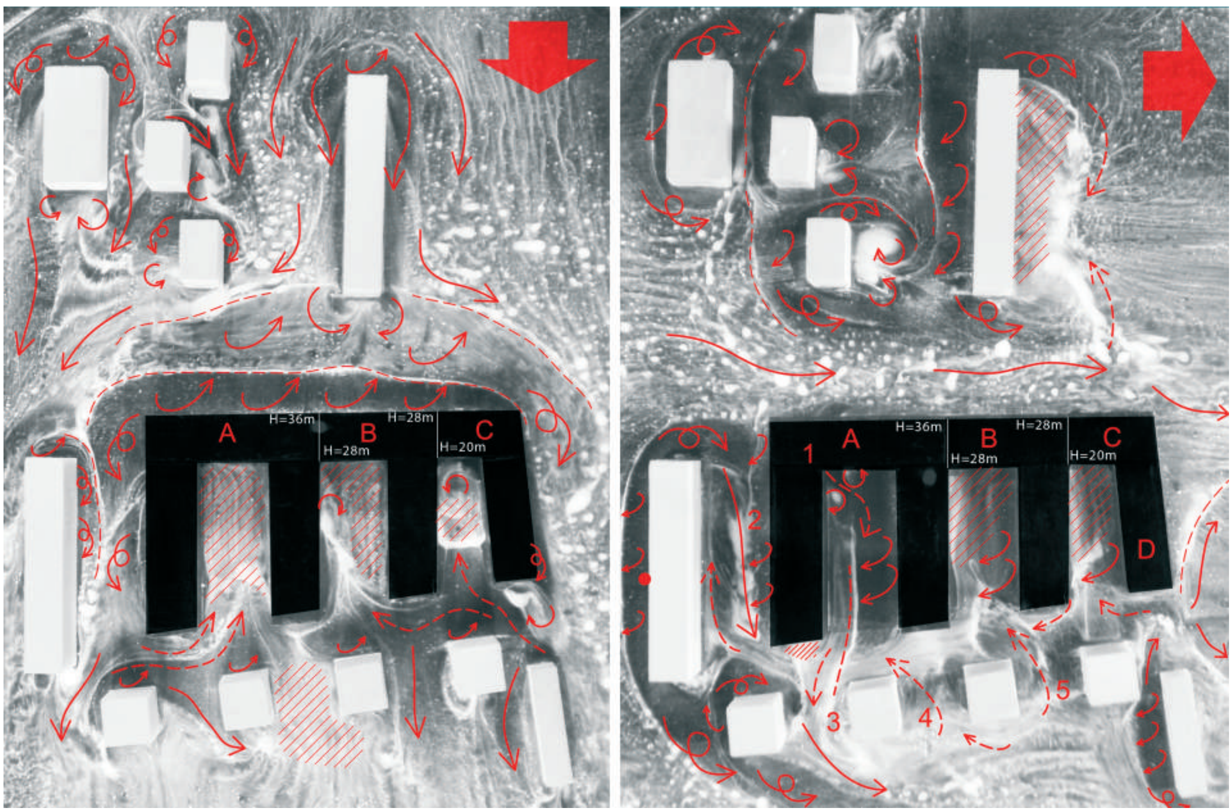

Figure 3.
Photographs that present the visualization of air flow around the designed quarter of building development (initial situation) conducted in the wind tunnel with the use of the oil method; on the left – for the northern wind direction, on the right – for the western wind direction; arrows indicate directions of air movement and air movement turbulence that occurs between buildings, hatched areas indicate air stagnation zones; photo: P. Łuszczyński

project was considered final and thus it was evaluated. The scheme of the described action plan is shown in Fig. 2.

Experimental studies in the aerodynamic tunnel of medium-speed were used. The oil visualization method was selected [4, 10, 11, 12], as it provides qualitative results. The picture presenting the results, although it fails to provide reference to numerical values, makes it possible to identify the nature of wind conditions prevailing at the pedestrian level, which is an important zone, due to the presence of both, too violent gusts of wind and air stagnation. It is therefore an adequate method for the initial phases of the project. At the same time, the method is relatively simple and not that time-consuming, as compared to other experimental methods.

The research was conducted in a tunnel of 1 mx 1m measuring space cross-section. The model of the designed building with the surrounding building developments, made on 1:500 scale, was attached to the base, made of black glass, in the shape of a circle whose diameter equalled 1 m. The arrangement elements designed and introduced intentionally at the tunnel inlet made it possible for the researchers to depict the wind velocity profile commonly found in urban areas. The base was painted with a mixture of

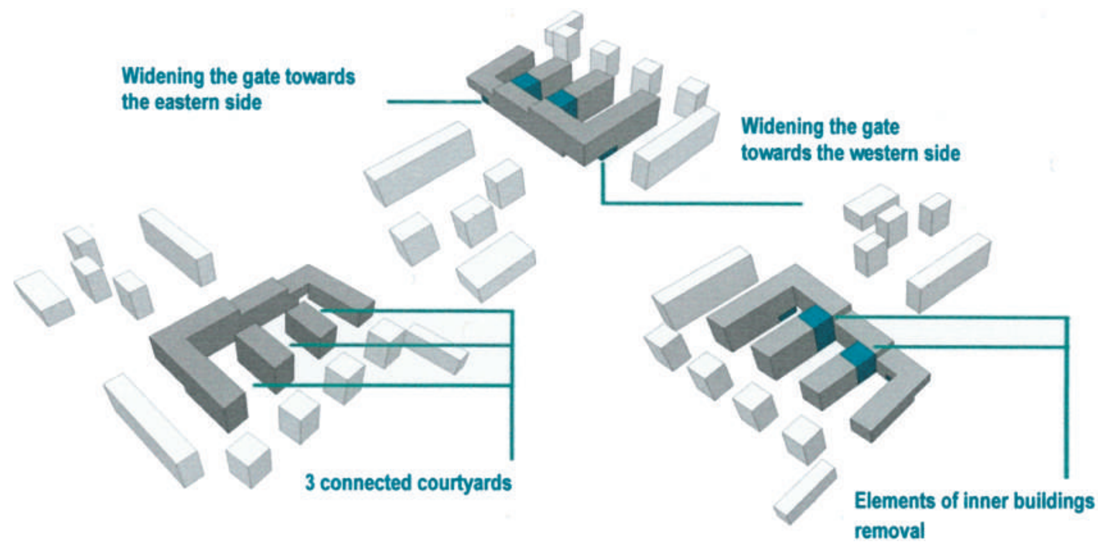

Figure 4.
The first modification to the shape of the building following the first series of tests (variant 1); author's own study

oil and white marker. During the wind simulation, the higher the wind velocity that exerted impact on the glass surface in a given area, the more oil mixture was blown off the surface. Having been stabilised, the obtained image enabled the researchers to read the wind flow directions and identify zones of wind acceleration, swirling and suppression.

4. TEST RESULTS

4.1. Initial model

The tests were carried out for the northern and western wind direction. These wind directions prevail in the tested area. The analysis results concerning the initial situation of the project have been presented below. In Fig. 3, a picture is displayed that presents the results of visualization tests, together with graphical indications reflecting the nature of wind phenomena.

Analysis of the sequence of photographs taken in the course of the research (every 15 seconds during a 20-minute experiment in the tunnel) made it possible to gain a fairly accurate recognition of air movement in various parts of the studied area in the pedestrian zone. In the case of wind blowing from the north, inside the three courtyards and around the existing point buildings, extensive air stagnation zones (hatched area) have become visible. In case of the western wind, similar phenomena occur within two courtyards. The presence of a gate situated in the western corner of the building only slightly facilitated the ventilation, the gate in the eastern corner failed to affect the courtyard ventilation process even slightly. It can be expected that the spaces marked in Fig. 3 with hatching, especially the courtyards confined on three sides, suffer from an insufficient intensity of ventilation.This situation causes the most serious aerodynamic problem regarding the layout of the building developments designed in this way.

Moreover, in several places the phenomenon of sudden gusts of wind has been observed. In such a situation, a discomfort for pedestrians may appear, especially if the wind blows from the north between the designed building and the high-rise building to the west side, as well as in case of western wind.

4.2. Adjustments in the shape of the building.

On the basis of the above mentioned observations, decisions regarding the modification in the shape of the designed building were arrived at (Fig. 4). The dense comb-shaped layout was slightly loosened by means of separating the inner wings from the main body of the building development. The widths of the gates in the corners of separate buildings have also been increased. These changes were intended to intensify the air exchange inside the courtyards and to restrict the unfavourable gusts of wind in the zone between the designed building and the one existing to the west.

Further tests for the modified building development model were conducted. The study showed that the direction assumed in order to adjust the shape of the building is correct, but the widening of the two gates,

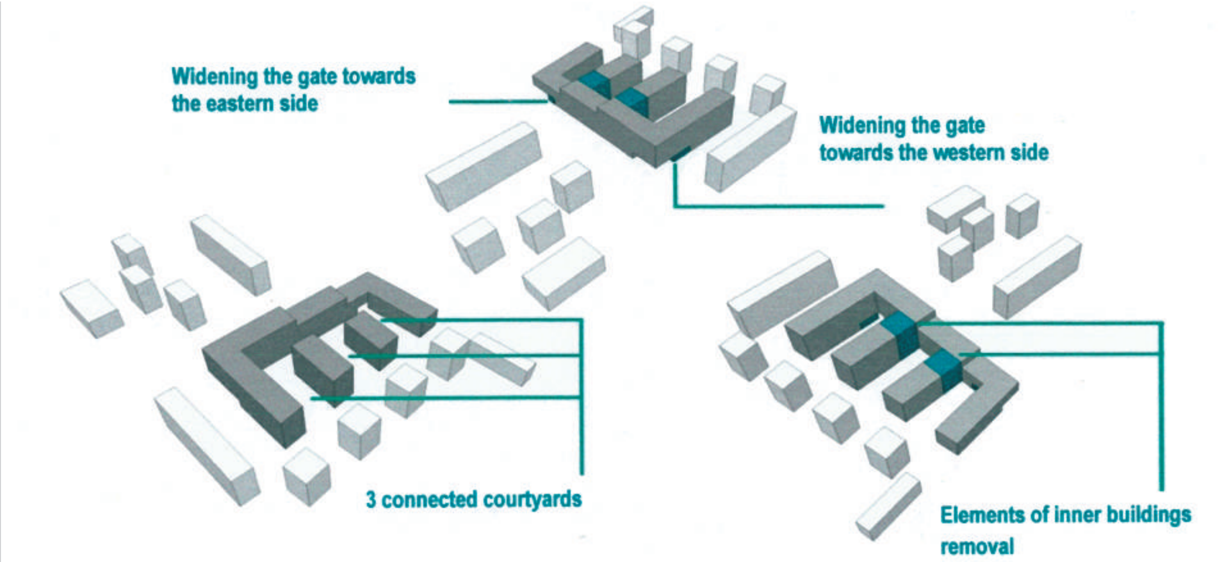

Figure 5.
The second modification to the shape of the building following the second series of tests (variant 2); author's own study

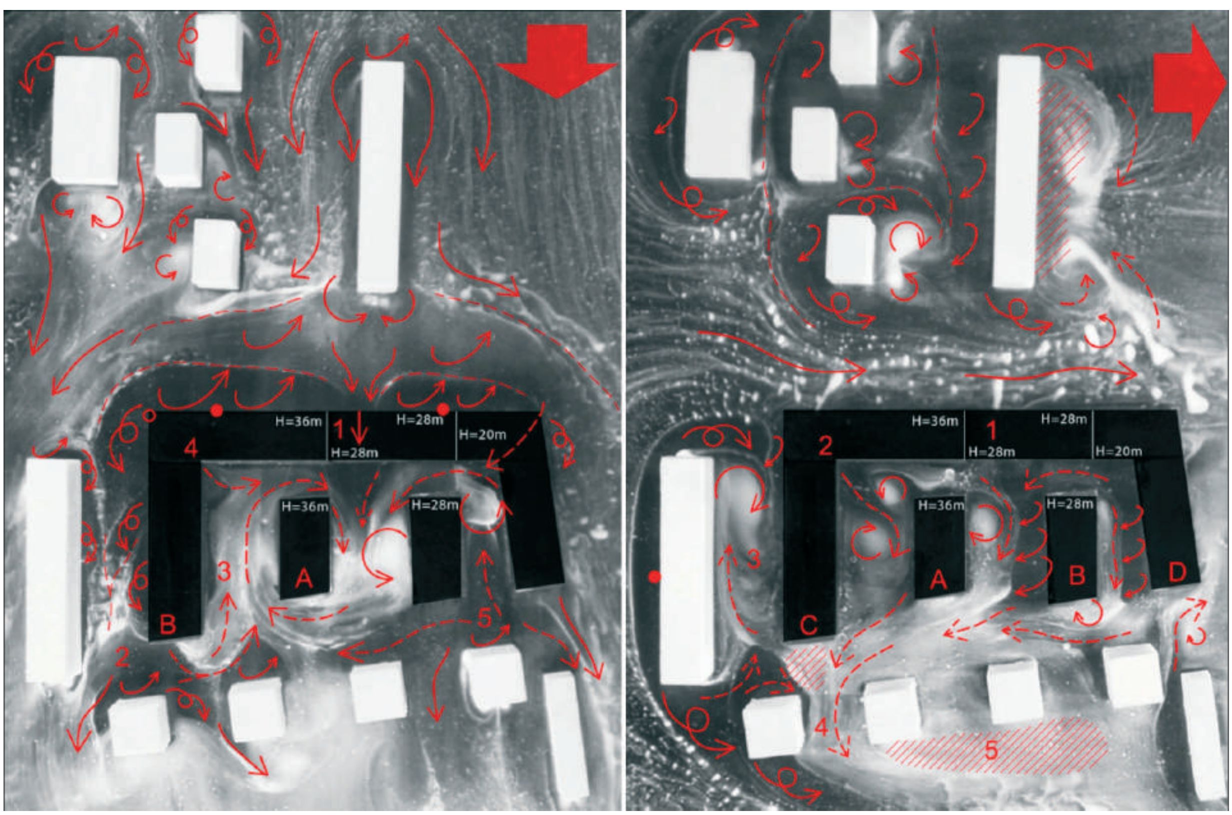

Figure 6.
Photographs presenting the visualization of airflow around the designed building development quarter (final situation) conducted in the wind tunnel using the oil method; on the left – for the northern wind direction, on the right – for the western wind direction; the arrows indicate directions of air movement and its turbulence in between buildings; photo: P. Łuszczyński

the western and eastern one, proved insufficient. The elongated northern wall of the building continued to constitute a large barrier to the airflow, which, in turn, caused a lack of sufficient ventilation inside the central courtyard. The stagnation zone occurred also between the designed building and the existing one (from the south-west). Therefore, further design modifications were proposed: a new gate opening was introduced in the middle part of the north facade of the building, one of the buildings inside the building development quarter was shortened, whereas the ground floor in the west wing of the building was shortened (Fig. 5).

The adjustments introduced to the shape of the building made it possible to significantly reduce the main problem noticed in case of the initial model. It was manageable to intensify the air movement, especially in the case of the northern wind (Fig. 6). Designing a gate opening in the northern wing of the building and the separation of the two central buildings from the main body of the development quarter improved the aerodynamic layout significantly, which would probably result in improving comfort in use of all three courtyards (compared to the initial model). The only problem that arises from the new design may be related to the potentially high speed of airflow through the northern gate, but this problem should be levelled by the whirling motion in vicinity of buildings around the central courtyard. Due to the shortening of the west wing of the building, it was also feasible to eliminate whirls likely to occur between the designed building development unit and the existing building located to the west, as such whirls would be potentially inconvenient for pedestrians.

The airflow layout for the wind from the western direction rendered to be a less fluid one, due to the presence of a large obstacle in the form of the existing residential building situated to the west. Eventually, the gate widening, together with the shortening of the west wing of the building resulted in improved airflow towards the south. No potential turbulence zones or areas of rapid gusts of wind can be observed in the adjusted model.

5. CONCLUSIONS

The results yielded by the research, though only of qualitative character, allow conclusions to be drawn referring to a high probability of occurrence of problems concerning wind comfort in vicinity of the exemplary building development layout, originally assumed for the sake of research. Moreover, the results indicate the possibilities for improving the situation by means of such shape adjustments that lead to the "loosening" of a too dense urban layout. The research technique adopted for the study proved to be a correct one, although it would be reasonable to compare its effectiveness with numerical methods. Such methods tend to be more modern and cheaper, as well as they provide researchers with greater opportunities in terms of the promptness of obtaining results and in terms of the amount of results they yield. Still, such methods are less reliable than tunnel tests, in addition to being burdened with a larger margin of error. Currently, it is recommended to combine both methods, especially at the initial stages of research, to use the experimental research to properly select the input parameters for numerical simulations and to check the comparability of results in control situations [3, 11, 13]. Thus, the wind tunnel method described in the present paper could serve two purposes – initial verification of the building structure concept and the appropriate setting of numerical research, useful for further detailed research, should such research be required.

The research conducted has proven that the regulations applicable in Poland fail to take sufficient account of issues related to wind conditions in the areas of building developments. These regulations oblige architects to meet numerous criteria regarding the formation and location of buildings, including, aspects regarding the quality of microclimatic conditions, so as to ensure the minimum conditions of insolation and lighting of rooms with the use of daylight. However, the regulations fail to specify issues related to the field of aerodynamics, whereas studies on the impacts the newly designed building exerts, both on its immediate surroundings and larger complexes or new districts are not required. As a result, with the exception of precisely defined situations, any modifications to aerodynamic conditions remain uncontrolled, eventually which fact resulting in deterioration of comfort felt by users of urban spaces and buildings. The issues, in fact, provide untapped potential of possibilities for the care of the quality of the microclimate, both on a small areas scale and the city as a whole.

Insufficient air exchange intensifies the occurrence of the urban heat island phenomenon, that is characteristic for urban areas, together with its consequences (e.g. increased mortality, increase in energy consumption for cooling buildings, increased amounts of ozone). Other problems include increased pollution and concentration of exhaust gases, fog retention unpleasant odours retention. Rapid gusts and wind swirls, in turn, result not only in discomfort or even threats to passers-by, but may also lead to uncontrolled blowing of snow and dirt, damage to building elements.

It would be advisable to consider cases of urban and architectural design in which wind engineering research should be obligatory. Examples of such cases should include complementing the city dense building development, a group of buildings of varying heights, or entirely new quarters of building developments. Particular attention should be paid to areas of diversified spatial structure and function, as well as to very dense, intense building developments. It is in the surroundings of such complex building development layouts that the most diverse aerodynamic phenomena arise. It is, however, difficult to predict such phenomena solely on the grounds of theoretical knowledge.

These issues are prevailing in case of big cities, including Polish ones, which allocate new areas for development (such as post-industrial, railway areas). This leads to a rapid densification in their spatial structure. Cities that fail to foresee the consequences of such major spatial changes in time lose control over the quality of urban space.

REFERENCES

[1] Lewińska, J.(2000). Klimat miasta, zasoby, zagrożenia, kształtowanie (Climat of the city, resources, threats, shaping.). Kraków: Instytut Gospodarki Przestrzennej i Komunalnej.

[2] Givoni, B. (1998). Climate considerations in building and urban design. New York: Wiley.

[3] Krautheim, M., Pasel, R., Pfeiffer, S. & Schultz-Granberg, J. (2014). City and wind. Climate as an architectural instrument. Berlin: DOM Publisher.

[4] Zielonko-Jung, K.&Poćwierz, M. (2018).The impact of forms of the buildings on the air exchange in their environment on the example of urban development in Warsaw in Design solutions for nZEB retrofit buildings. Pensylvania: IGI Global, 310–330.

[5] Gandemer, J. (1978). Discomfort Due to Wind Near Buildings: Aerodynamic Concepts. Building Research Translation. Washington: National Bureau of Standards Technical Note, 710–9.

[6] Daniels, K. (1998). The technology of ecological buiding. Berlin: Birkhauser.

[7] Blocken, B.50 years of Computational Wind Engineering. Past, present and future. *Journal of Wind Engineering and Industrial Aerodynamics,* 129, 69–102.

[8] Tamura, Y. &Yoshie, R. (2016). Advanced Environmental Wind Engineering. Springer.

[9] SakrFadl, M.&Karadelis, J. (2013). CFD Simulations for wind comfort and safety in urban area: zcase study of Coventry University Central Campus. *International Journal of Architecture, Engineering and Construction 2*(2), 131–143.

[10] Jędrzejewski, M., Poćwierz, M. & Zielonko-Jung, K. (2017). The problem of airflow around building clusters in different configurations, *Archive of Mechanical Engineering 64*(3), 401–418.

[11] Gumowski, K., Olszewski O., Poćwierz, M. & Zielonko-Jung, K. (2015).Comparative analysis of numerical and experimental studies of the airflow around the sample of urban development. *Bulletin of the Polish Academy of Sciences Technical Sciences 63*(3), 729–737.

[12] Poćwierz, M. &Zielonko-Jung K. (2017). Wind conditions in urban layout. Numerical and experimental research. *AIP Conference Proceedings 1922*(1), 110004 (1–9).

[13] Rajasekarababu, K.B., Vinayagamurthy, G &SelviRajan, S. (2019). Experimental and computational investigation of outdoor wind flow around a setback building. Building Simulation, https://doi.org/10.1007/s12273-019-0514-8,1–14.