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MORPHOLOGY OF BUILDING DEVELOPMENT AS AN ELEMENT OF URBAN VENTIALTION SYSTEM

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Abstract
Problems related to air quality in large urban agglomerations (e.g., high concentration of pollutants, the urban heat island phenomenon) make it necessary to take comprehensive measures to improve air exchange in urban areas. The paper concerns the relationship between wind phenomena observable in cities and the geometrical features of building development. The knowledge on the subject is already well-founded and has been intensively developed. Regardless, it remains relatively poorly applied to urban planning. Based on the analysis of source literature, the classification of features and spatial elements of building development that are crucial for ventilation is conducted in the following paper. Five different cities are also analyzed regarding how the air exchange improvement policy should be pursued through conscious building development shaping. The cities selected for analysis include Warsaw and Cracow in Poland, a large agglomeration of New Dehli in India, the experimental Masdar City in the United Arab Emirates, and the newly designed Jätkäsaaridistrict of Helsinki. Based on the example of the above cities, the paper investigates the possibilities of combining spatial features of building development that are essential to aerodynamics, in order to create effective ventilation systems.

Keywords: **Sustainable City, Urban Heat Island, Urban Planning, Urban Ventilation Strategies.**

1. INTRODUCTION

Air quality is among the major problems related to living conditions in large cities. Efforts to improve it should be made in two ways. Most importantly, it is necessary to reduce pollutant emissions by transforming the economy towards clean technologies (e.g., transport and industry) and renewable energy sources. On the other hand, measures are needed to stimulate pollutant removal. The potential solutions include increasing the share of biologically active areas that absorb certain pollutants and intensifying urban space ventilation. Air-change processes in extensive, highly urbanized areas are dynamic, complex, and difficult to predict. In general, average wind velocities in cities are reduced by 20–30% annually, while winds of low velocities are accelerated [1]. At the same time, air stagnation zones, as well as rapid acceleration and turbulence zones, may occur in a relatively small area. The current research tools allow for a better recognition of these phenomena and simulation thereof in laboratory conditions or digital reality. However, a strong connection between urban aerodynamics and spatial planning is still lacking. Still, this relationship should provide the key factor for the city ventilation strategy [2].

The following paper discusses building development as a factor that can be applied in such strategies.

Building development elements and spatial features that influence aerodynamic processes were systematized. Then, the analysis of their significance for urbanized space ventilation was conducted on selected examples of cities and/or their parts. Five examples were selected, including two large Polish cities, i.e., Warsaw and Cracow, New Dehli – the largest metropolis of India, the experimental Masdar City in the United Arab Emirates, and the newly designed Jätkäsaari district in Helsinki. Such a selection of areas made it possible to present various combinations of spatial features of building development as a system of interrelated elements. The large geographical spread, thus the diverse climatic, cultural, political, and economic contexts of these examples, shows how the knowledge background influences planning decisions in order to improve air exchange. The analysis presented below should be seen as a contribution to the development of methodology for broader future research.

2. BUILDING DEVELOPMENT SHAPE AND VENTILATION

Analyzing the current state of knowledge on the relationship between building development and urban ventilation processes allows for identifying several key spatial features of building development and its elements. These features refer to various spatial scales; they are presented in Table 1.

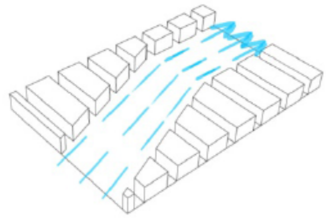
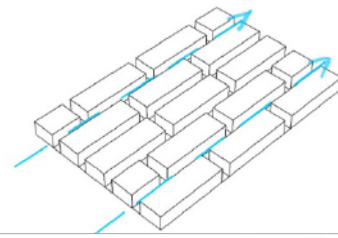
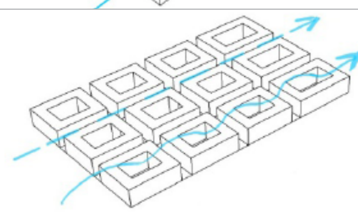
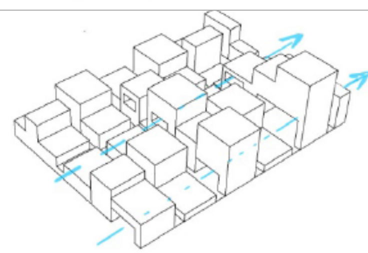
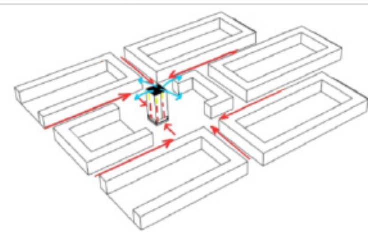
The most common spatial solution used to support ventilation on the city scale comprises aeration corridors, also known as aerosanitary corridors [3]. These consist of undeveloped strips of land that separate strongly urbanized city parts. These corridors provide the airflow channels that connect the city downtown with its outskirts. The differences in temperature between the two zones cause the air to move naturally towards the center. Moreover, the corridors channel the naturally blowing winds. These greenery-covered zones are excluded from development; they often consist of naturally formed valleys or areas of natural value. The emergence of the modern aeration corridor systems is usually associated with a point in history when a given city was significantly enlarged or reconstructed. In large Polish cities, such as Warsaw and Cracow, this occurred at the beginning of the 20th century. Unfortunately, the corridor systems have failed to survive to the present day in a fully planned shape; especially so in the areas where no natural limitations to building development existed. However, what is left of the former corridor system is now being classified as protected areas. Guidelines have been introduced regarding the possibilities of introducing new buildings in these areas, designing building development in the corridors' boundary lines, and forming greenery within them. Such provisions are introduced into *Studies on the conditions and directions of spatial development*, a document that constitutes the basis for local spatial development plans.

Another group of spatial features regarding building development, listed in Table 1, concerns a smaller scale of impact. The research in this field has already been well-established and is constantly being developed. As shown by it, the building development geometry may be seen as a tool to optimize airflow in spaces between buildings, adequately to the needs. For example, these spaces may increase ventilation or, on the contrary, protect from the wind. The 1970 research by Jean Gandemer provided a breakthrough scientific achievement in this field. The study concerned the so-called aerodynamic effects around free-standing buildings and simple building layouts [4]. The analysis of contemporary research on the building development morphology as a factor that regulates the urban space ventilation processes [3, 5, 6] allows for listing three features that are crucial for ventilation. These include: orientation, compactness, and building development porosity.

The building development orientation can be compared to the operation of the aforementioned air corridors. A long street with clearly shaped, compact frontages serves as a wind channel (it can even alter the natural wind direction), whereas a short, discontinuous street inhibits airflow. Therefore, properly designed long streets can act as extensions of the main aeration corridors in the areas where their continuity has been deranged. Alternatively, such streets can form an air distribution subsystem [6, 7].

Compactness, which has not yet been precisely defined by researchers, is another vital factor. A particular set of geometric parameters to describe it is yet to be determined so as to take into account the features important for aerodynamics. It is known that the street cross-section ratio, expressed as h/s, i.e., buildings' height in relation to the width of the space between them, is important. Numerous studies show this coefficient's limit values, above which the space between buildings will be inadequately ventilated (i.e., in the case of deep, narrow streets) [3, 5, 6, 8]. However, this parameter is not sufficient to describe the compactness feature. The extent to which urban interiors, i.e., streets, squares, or courtyards inside the quarters, are built up continuously, i.e., the extent of their enclosure

Table 1.
Spatial features and elements that influence urban ventilation processes, along with sources in the literature; a study by the authors

	Spatial feature/element	Model	Literature
1	Aeration corridors (aerosani tary corridors)		Daniels, K. (1998), Błażejczyk K., Kuchcik M., Milewski P. and others (2014), Mabon L, Kondo K., Kanekiyo H., Hayabuchi Y., Yamaguchi A. (2019)
2	Orientation of the street layout		Gandemer J. (1978), Oke T.R.(1988), Bottema M. (1993), Daniels K. (1998), Krautheim, M., Pasel, R., Pfeiffer, S.,&Schultz-Granberg, J. (2014)
3	Compactness, formation of closed interiors		Hussain M., Lee B. E. (1980), Oke T. (1988),Bottema M. (1993), Daniels, K. (1998),Krautheim, M., Pasel, R., Pfeiffer, S.,&Schultz-Granberg, J. (2014)
4	Building development porosity		Priyadarsini R., Wong N.H. (2005), Krautheim, M., Pasel, R., Pfeiffer, S. &Schultz-Granberg, J. (2014), Yuan C. (2018)
5	Forms that support vertical ven-tilation - chimneys, towers		Priyadarsini R., Wong N.H. (2005), Flaga A., (2018), Guttikunda S, Jawahar P (2020)

and openness to the wind flow (e.g., through gates, gaps between buildings) is crucial as well [2, 3, 9]. The closure or openness of urban interiors to air can also be regulated by the building development height, namely by equating or differentiating it [3]. The available studies provide no clear indications on how to describe this relationship with the help of geometric parameters that can be used in urban planning.

Another feature seen as important for the aerodynamics aspects in built-up areas is the building development porosity [3]. It has been defined as a measure of the void, i.e., undeveloped cubature measured as a percentage of the entire urbanized space volume. Porosity can be tested horizontally - as a system of gaps between buildings, vertically - as a system of openings in buildings at different heights or as differentiation of building heights. This geometric feature remains relatively least recognized, although it is believed to be of particular importance to intensively urbanized areas [10].

The final elements listed in Table 1 comprise forms that support vertical ventilation. These relatively new concepts have so far been implemented in single prototype structures, such as various types of towers and ventilation and smog chimneys [6]. In these cases, analogies to ventilation solutions used in buildings, such as wind towers or traditional Arabic wind catchers (badgirs), can be noticed. If these installations are to work on a much larger urban scale, very tall elements must be used and equipped with mechanical installations. Although these solutions are debatable in many respects, research is being conducted on the possibility of such implementations in cities particularly affected by smog.

3. ANALYSIS OF VENTILATION STRATEGIES OF SELECTED CITIES AND DISTRICTS

3.1. Warsaw

Warsaw, the largest Polish city, is located in the central part of the country, on the Middle Mazovian lowland, on the Vistula River. According to the Köppen-Geiger classification, the city is situated in a humid continental climate zone. It covers an area of 517 km^2 and has a population of 1.8 million. Due to natural and historical conditions, Warsaw's building development forms a compact central system cut by the Vistula valley. Like most large cities, Warsaw is affected by the urban heat island phenomenon, which is sure to increase as a significant increase in building development is planned there over the next 50 years [10, 11]. Smog is another progressing climate problem. According to the current IQAir rankings, among Polish and European cities, Warsaw ranks relatively high in this respect [13]. The system of ventilation corridors, created in 1916 by Tadeusz Tołwiński as part of the Sketch of the Warsaw Regulatory Plan, is of fundamental importance for the ventilation of Warsaw. The system emerged during a crucial period when loosely built-up suburbs were incorporated into the city's territory, whereas its area tripled (from 33 to 121 km^2). The system consists of 9 greenery-covered, undeveloped strips of land that stretch in a radial pattern from the outskirts to the city center (Fig. 1). They provide the route of air inflow from the outer city areas to the downtown. The airflow is caused by local winds or city breezes on windless days (the period of weak winds and atmospheric silence in Warsaw amounts to 1/3 of the year) [11]. In the 1990s, the aeration corridors were freed from the administrative protection of agricultural land. Since then, they have become the most attractive locations for housing investments, whereas continuous attempts are being made to develop the areas gradually. The Vistula valley remains the only continued uninterrupted corridor in the central part of Warsaw.

Figure 1.
Scheme of the plan of Warsaw with aeration corridors; developed on the basis of [14]

This system, although already depleted, remains important for air exchange in Warsaw and is thereby protected by The Study of the conditions and directions of spatial development in Warsaw [14]. However, no coherent pro-ventilation policy exists regarding buildings developed in the areas outside the corridors. The existing planning regulations and procedures with which the intensity parameters and the building development shape issues are regulated fail to account for the ventilation criterion. Thus, spatial characteristics such as the orientation, compactness, and porosity listed in Table 1 are not applied in the aerodynamic aspect. This observation is disturbing, as a large part of the development is shaped in a quarterly form, closed to the free wind flow. Thus, the intensive building development densification process in Warsaw, which has been underway since the 1990s and is forecast for the next 30 years, may significantly inhibit air exchange in the city.

3.2. Cracow

Krakow is located on the Vistula River in the southern part of Poland, at the junction of the Cracow-Częstochowa Upland, the West Beskidian Foothills, and the Sandomierz Basin. It is located in the same climate zone as Warsaw. The city area equals 327 sq. km, whereas its population equals 0.8 million. Althugh Cracow is smaller and less populated than Warsaw, it is more clearly affected by smog. In fact, it takes the lead as a large Polish city most exposed to this phenomenon. This is due to the geographically unfavorable shape of the city, whose center is located in a valley. Thus, Crakow is not susceptible to prompt air exchange. The smog situation has recently improved thanks to administrative measures to reduce the number of coal-heated households and limit transport pollution. However, the complete elimination of smog requires multidirectional actions, including air exchange intensification. Air exchange is also important with regard to the urban heat island phenomenon. Although less intense in the case of Cracow as compared to Warsaw, the problem also occurs and requires intervention. Cracow's building development is formed as a central system, slightly more stretched along the east-west axis, along the Vistula riverbed.

Unlike in Warsaw, no clear layout of corridors free of building development is present in Cracow's urban structure. Naturally-formed terrains in the form of river and stream valleys and terrain depressions act as corridors. In The Study of the conditions and directions of spatial development in Cracow, seven such corridors and four areas (called aerosanitary corridors) were distinguished, with recommendations for their protection [15]. However, these areas can hardly be called a continuous, comprehensive system that could operate on the scale of the city as a whole. As in the case of Warsaw, such a system had been initiated during the partitions as part of The Regulatory Plan for Great Cracow, when the city's territory was significantly enlarged by new peripheral areas [16].

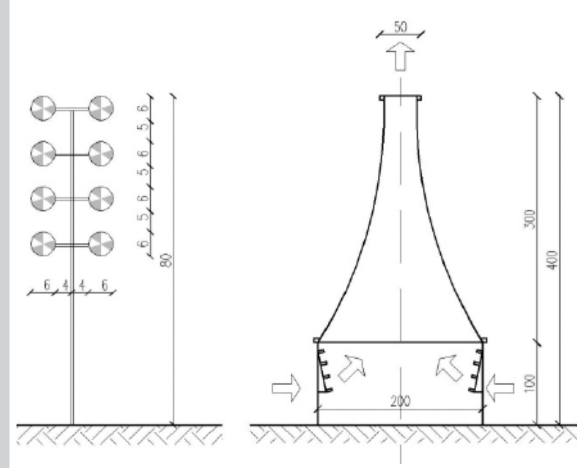


Figure 2.
Scheme of the ventilation tower (left) and the ventilation chimney (right); developed on the basis of [17]

However, the system failed to be recognized as important for city ventilation and was insufficiently protected. Over 100 years later, only certain areas have remained excluded from development for natural reasons. These, however, influence the local climate rather than the mesoclimate of the entire city. Despite the efforts made by the authorities to extend the protection of these areas (for example, the western corridor was enlarged), the situation can only be improved to a limited degree. The building development spatial features, such as orientation, compactness, and porosity, fail to be accounted for in the aerodynamics context. Thus, similar to other large

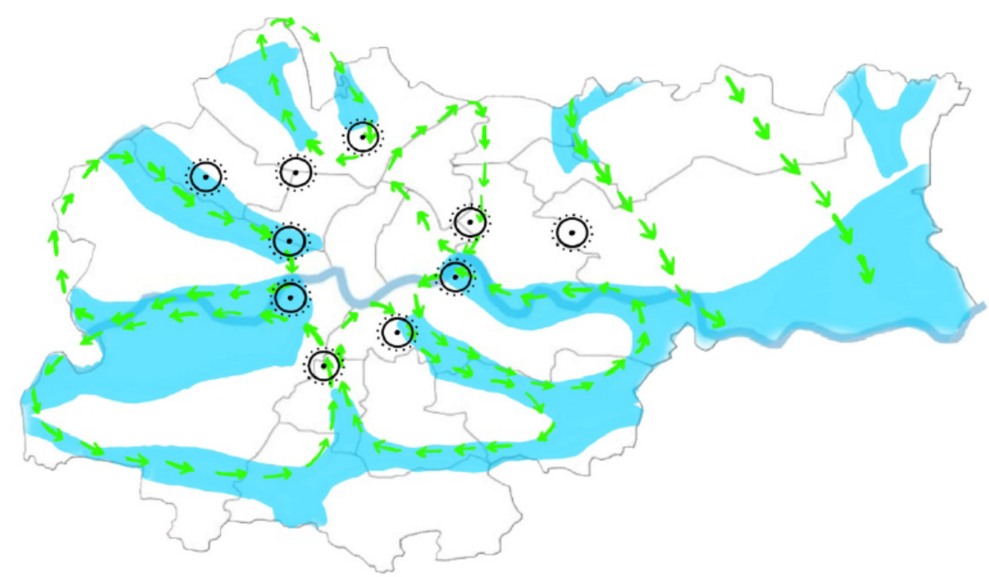


Figure 3.
Plan of Cracow with aeration corridors (in blue) and a diagram of the operation of ventilation towers (circulation is marked with arrows), and the potential location of ventilation chimneys (marked with black circles); developed on the basis of [15, 17]

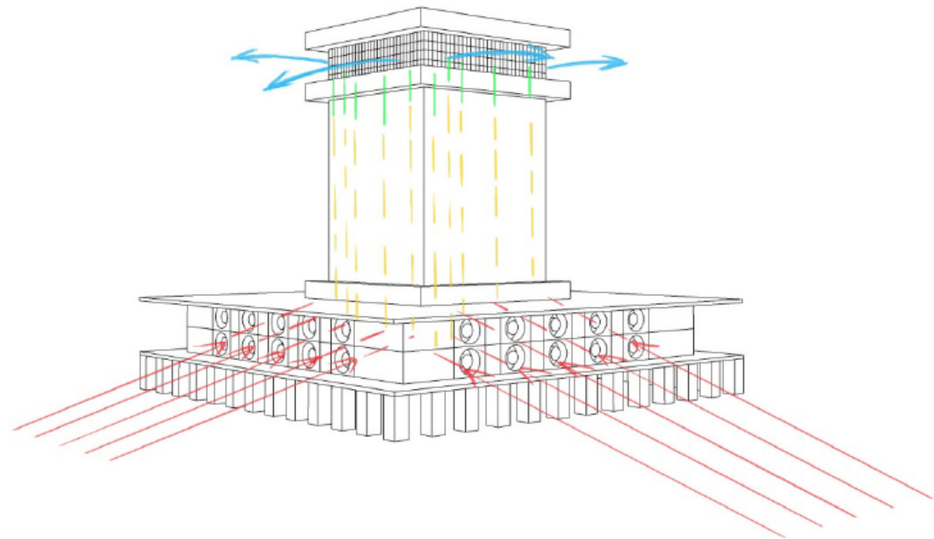


Figure 4.
Scheme of operation of the smog tower in New Delhi; developed on the basis of [18]

Polish cities subject to the process of development densification, Cracow faces the risk of inhibited city ventilation due to intensified development and continuous increase in the paved area ratio.

In recent years, research has been undertaken on the so-called dynamic ventilation of Cracow generated by a system of ventilation towers and chimneys (Fig. 2) [17]. Such possibilities are tested at The Wind Engineering Laboratory, Cracow University of Technology by Andrzej Flaga's team. The concept is to use ventilation towers (in the form of masts with a fan system) to stimulate horizontal air movement along the existing aerosanitary corridors. The air directed in this manner would reach a system of central ventilation chimneys, where it would be discharged upwards above the temperature inversion zone (Fig. 3). The size of such structures would be considerable. The towers' height is estimated at 80 meters, whereas the chimneys would stand at 400 meters. Work to assess the feasibility of implementing this solutionis is underway. The research results indicate measurable effects in terms of air exchange. Nevertheless, such implementation is rather costly and generates several obvious problems (e.g., overwhelming scale, aesthetic consequences for the city image), as well as issues that might be difficult to predict. Advanced research into the effectiveness of the system and the possibilities of its implementation is underway. However, it seems unlikely that it will be implemented.

3.3. New Dehli

The capital of India, New Delhi, is the world's third-largest agglomeration. The city is located on the Yamuna River in the northern part of India in the Hindustan lowlands.

Delhi is located in the subtropical humid climate zone. It covers an area of 1483 km^2, whereas its population stands at 26 million. The city has a central layout, with the eastern part of the very center situated on the river. In India, as in other cultures based in hot climates, solutions to protect against the sun and intensify natural air exchange are rooted in the traditions of building development shaping and urban layouts. However, the city's size, the density of its population, the transport concentration, and the industry make New Dehli one of the world's most air-polluted cities (alongside some Chinese cities and other cities in India) [12]. This situation results from significant emissions of pollutants related to high population density, energy based mainly on fossil fuels, and economic activities. Agricultural activities, for example, consisting of burning fields surrounding the city (a practice rooted in the water protection law, which shortens the time to clear the fields following harvests) are another reason. The situation is further aggravated by the city's poor ventilation, especially in cooler, windless autumn and winter seasons, when the air becomes dry. The area's physiography is also unfavorable, as it is sheltered from the wind by a mountain range.

India is not rich or developed enough to introduce effective, systemic political and economic strategies for pollution source reduction in cities. New Dehli covers a vast area and is marked with a complex structure of buildings created and transformed since Antiquity. Neglected, chaotic, and overcrowded districts occupy large areas of the city. In this situation, creating a coherent aeration corridor system seems unfeasible, especially given that air pollution is also present in the city outskirts. It is also impracticable to use the morphological features of building development, listed in Table 1, for airflow regulation at a scale big enough to reduce the problem significantly. Traditional Indian architecture was adapted to the local climate by using solutions which increase ventilation. Yet, these methods were not applied in the contemporary architecture and urban planning of New Dehli. Hence, the plans to build ventilation towers, known as smog towers, began to be considered.

The first tower of this type was implemented in a compact, post-colonial development on one of the commercial streets of New Delhi. The tower stands at the height of 24 m. In the part of the ground floor, which forms a kind of a wide pedestal, fans were introduced. Hepa-filtered air is discharged through a centrally-located chimney (Fig. 4). The data published in commercial materials concern the possibility to purify air within the area and a radius of 1 km of the tower to harmless values. [18]. Although the city authorities are proud of this investment and have announced the construction of further towers, strong criticism of this solution is being raised. The implementation lacks system assumptions, unlike in the case of the solution considered for Krakow; scientists question the tower's effectiveness [19]. In addition, the tower is to be powered by grid-supplied electricity, with over 70% of India's electricity generated by burning coal. Therefore, the solution may be seen as a temporary provisional measure, rather than part of a well-considered ventilation concept.

3.4. Masdar City

Masdar City is a new eco-city erected in the United Arab Emirates in 2006. It belongs to the Emirate of Abu Dhabi (in the northern part of the Emirates, along the Persian Gulf) and is located several kilometers from its borders. The city lies in the desert climate zone, and its area equals six sq. km. Currently, the number of permanent residents amounts only to around 300, but ultimately the area should be populated by about 50,000 inhabitants. Masdar City is an experimental development implemented as a testing ground for new pro-ecological technologies. It may be seen as a display of possibilities, technological advancement, and wealth of the United Arab Emirates; thus, it faces a certain amount of criticism from communities promoting sustainable development. However, it should not be overlooked that the city boasts numerous well-thought-out passive urban solutions. New concepts are combined with traditional solutions, characteristic to hot climates, that support ventilation inside buildings and around them [3]. The possibility to design the building development completely from scratch allowed for creating a system of smaller and larger spaces where airflow is properly directed. The main part of the city is arranged in the shape of a square intersected by two diagonal, wide corridors covered with greenery. Hot, northwestern winds fall into the corridor spaces. After being cooled by green areas, the air is introduced into built-up structures through the lateral exchange. Colder winds from the east also penetrate the main corridors and enter deeper into the building development. The street grid is shaped in such a way as to avoid elongated corridors, which allows the free flow of hot north-west winds. The cool breezes from the east are caught by evenly spaced wind towers modeled on traditional Arabian wind catchers (bagdirs) (Fig. 5). Thanks to them, cool air reaches the lower parts of the streets, contributing to a favorable microclimate at the pedestrian level. The city uses model solutions that combine various environmental and utility goals, with no need for advanced and costly technologies but rather in a way close to local tradition and culture.

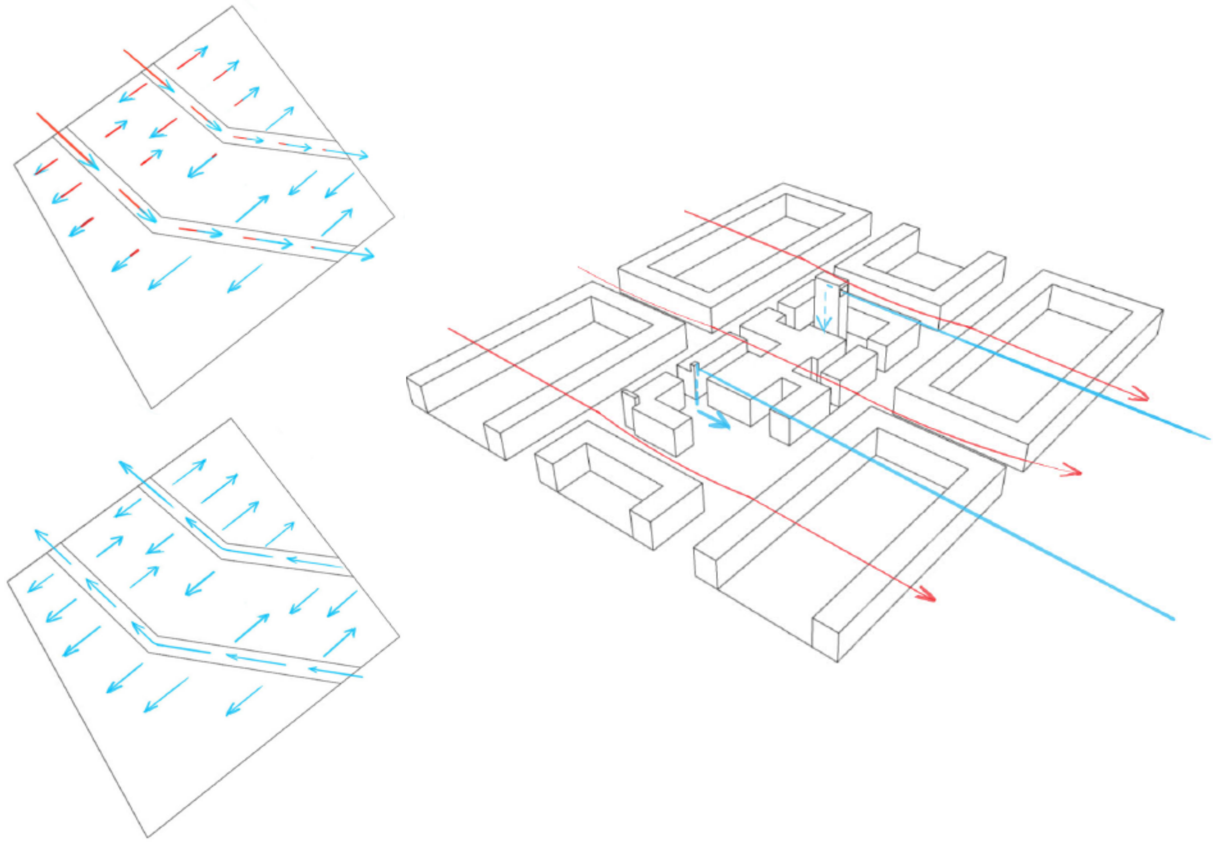


Figure 5.
Diagram of aeration corridors operation with hot north-westerly winds (top left) and cooler east winds (bottom left); ventilation diagram of the space between buildings (right); developed on the basis of [3]

3.5. Helsinki - Jätkäsaari

Jätkäsaari is a new residential area in Helsinki. Currently, the area is under construction, and its completion is scheduled for 2030. The district is located in the southwestern part of the city, on a peninsula in the Finnish Baltic Bay. Helsinki lies in a humid continental climate. The area of the district covers 0.68 km^2, whereas its projected population will amount to around 18,000. As in the case of Masdar City, planning the development for a relatively large area from scratch allowed for the implementation of a well-thought-out ventilation strategy based solely on designing the development properly [3]. The district's structure is based on a grid of rectangular closed quarters. Both the targeting and the size of the quarters have been adapted to climatic conditions. Building development quarters pass each other, thus creating a discontinuous street pattern in the direction of cold period winds. The quarters guided in this direction have narrower sides, which prevents the penetration of cold air inside the courtyard sand the streets are winding, discontinuous. Warm summer winds, in turn, hit the streets continuously. Such an arrangement constitutes natural channels with which the penetration of warmer air into the city at the pedestrian level is enabled. The longer dimensions of the building development quarters' sides towards this direction provide the courtyards with ventilation in the summer. Additionally, air exchange is favored by differences in the heights of building development quarters (Fig. 6). Jätkäsaari is an example of an urban structure in which, despite the lack of large open areas, prompt ventilation has been achieved solely through the morphological features of the building development.

4. RESULTS

The analysis results are summarized in Table 2. The compilation shows the combination of solutions applied in each tested case. The differences between the analyzed cities' conditions are significant and substantially impact the decision which solutions could be considered a feasible ventilation strategy option.

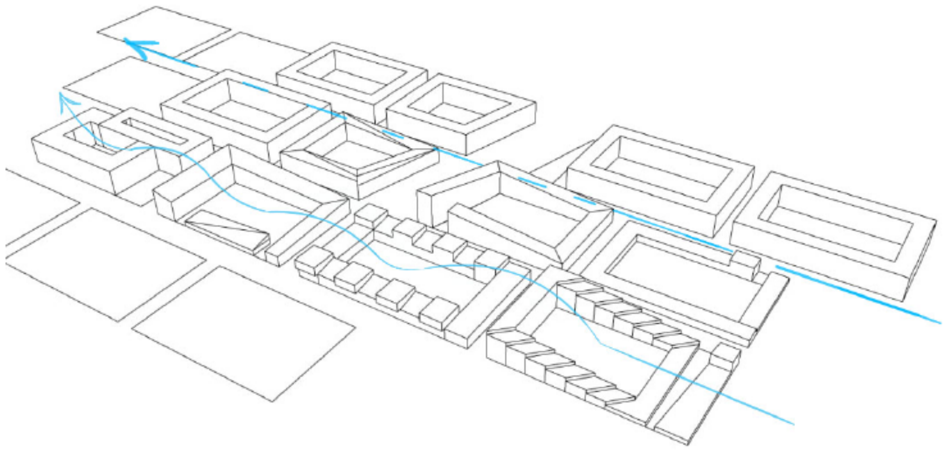


Figure 6.
Diagram of the wind flow through the structure of quarter buildings in Jätkäsaari; developed on the basis of [3]

Table 2.
Synthesis of the analysis of 5 cities in terms of ventilation strategies that take advantage from the building development shape; C – conditions, S – solutions; a study by the authors

City		Warsaw	Cracow	New Dehli	Masdar City	Helsinki - Jätkäsaari
C	Climate	Continental humid	Continental humid	Subtropicalhumid	Desert	Continental humid
	Area	517 km^2	327 km^2	1483 km^2	6 km^2	0.68 km^2
	Population	1.8 mln	0.8 mln	26 mln	0.05 mln	0.018 mln
	Erectionprocess	gradual	gradual	gradual	from scratch	from scratch
	Mainconcern	UHI, smog	smog, UHI	smog	UHI, smog	UHI, smog
S	Corridors	+	+	-	+	-
	Direction	-	-	-	+	+
	Compactness	-	-	-	+	+
	Porosity	-	-	-	+	+
	Verticalelements	-	+	+	+	-

The main differences are visible between newly-erected and existing cities and neighborhoods. The former include Masdar City and Jätkäsaari. The bigger of the two, i.e., Masdar City, is the only analyzed area where a full range of solutions was applied, whereas the vertical elements can be classified as passive, vernacular solutions rather than technologically advanced ones. The city can be considered as model project, as it is deeply thought-out and adapted to the climate conditions. Jätkäsaari occupies a much smaller area; in this case, a purposeful shaping of the building forms was enough to achieve three of the five features listed in Table 1.

The use of morphological features is much more difficult within existing urban structures. In Warsaw and Cracow, i.e., in cities comparable in terms of climate and subject to the same economic and political conditions, the building development morphology is not applied as a tool for regulating airflow. Such solutions are certainly difficult to implement, as both of these cities face a densification process rather than being planned from scratch. Thus, the newly designed tissue is mixed with the existing one, creating smaller or larger enclaves. In this case, it is impossible to achieve the effects comparable to Jätkäsaari, planned in its entirety. However, the manner and extent to which the building development can be compacted and closed in order not to impede ventilation should be controlled. Yet, this would require a design approach absent from the framework of the planning procedures in force in Poland. Such procedures fail to include morphological studies on building development designed in relation to the existing buildings or the resulting master plans for larger areas.

In the case of Warsaw and Cracow, ventilation strategies are enacted on a larger scale, i.e., aeration corridors. Warsaw's potential in this respect is clearly greater thanks to the strong connection of the aeration system with the general city development city from 1916, which assumed the division of the newly attached areas into zones in accordance with the radial layout of the corridors. Warsaw is also in a much more favorable physiographic situation. The bold concept of supporting the operation of corridors in Cracow with vertical elements seems an unrealistic implementation option from today's perspective. However, it must be admitted that this scenario is likely to remain unchanged in the near future, and dynamic vertical ventilation will become a necessary solution. Compared to the concepts for Krakow, the smog tower used in New Dehli is a solution to a smaller local range. There is no information on how to create a larger system of such towers as a large-scale solution to improve living conditions in the poorest districts. Moreover, no connection between these plans and other measures to improve air quality has been proposed, unlike in Cracow, where the policy to reduce pollutant emissions is clearly outlined and has already yielded the first results. Therefore, the case of New Dehli is not an example of building a strategy but rather an ad hoc implementation of not fully considered solutions. However, it should be noted that New Delhi is in the most difficult situation among all the analyzed locations, while the greatest climate problems occur there. Thus, the path of local pilot actions that are not subject to central planning may be the only option in this case.

5. DISCUSSION AND CONCLUSIONS

The analysis conducted in this paper is contributory. Cities of different sizes (New Dehli is about five times bigger than Cracow) and much smaller urban units (Masdar City can be compared to a suburban district, whereas Jätkäsaari is the size of a large estate) were compared. Thus, the obtained results cannot be seen as binding. Neither can the research presented in the above paper be understood as the final systematization of issues. However, the analysis allowed for the formulation of preliminary conclusions regarding the potential of the systemic approach to building ventilation strategies that benefit from the building development shape. In the analyzed cities, the ventilation systems consist of a more or less complex combination of individual features; it is possible to identify areas of unrealized potential. These aspects largely involve the morphological features of building development, such as orientation, compactness, and porosity. Moreover, the analysis indicates the gravity of the situation in large cities devoid of a system of aeration corridors, especially where such solutions have not been arranged, but also in cases where they have been subject to development. Elements intended to support dynamic vertical ventilation are the most recent and least verified of all the analyzed solutions, although their development and gradual dissemination are likely. Such arrangements are dedicated to cities exposed to smog rather than overheating and should only serve as part of a wider scope of activities.

In each of the analyzed cases, the importance of the context is noticeable. The climatic, physiographic and natural conditions, the area's history, traditions, economic and political situation, as well as the legal regulations in force in a given country all play a role. Perhaps these contextual issues should provide the basis for selecting a more extensive group of cases, their systematization, and further analysis.

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