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ORIGINAL PAPER
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THE POTENTIAL TO MITIGATE THE EFFECTS OF CLIMATE CHANGE ON SELECTED EXAMPLES OF HOUSING ESTATES IN THE CITY OF POZNAŃ

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ABSTRACT

Motives: The article presents examples of settlements with various possibilities of mitigating the effects of climate change. The analyses (involving a case study) were presented for ten selected housing estates in Poznań in terms of compensating for the effects of climate change.
Aim: The aim of the study was to analyze the possibilities of health-promoting transformation of urban systems on selected examples of housing estates in Poznań. They were characterized in terms of important features that provided a basis for developing green growth indicators. The studied estates were then ranked using the linear ordering method.
Results: The results indicate that the examples of housing estates from the mid- and late twentieth century selected for the analysis have a much higher share of green areas and a much greater potential to mitigate the negative effects of climate change than contemporary housing estates. This hypothesis was partially verified by analyzing the possibilities of air filtration through the green wall system in one of the housing estates.

Keywords: mitigating the effects of climate change, housing estates, greenery, urban planning norms, urban planning postulates, environment.

INTRODUCTION

A resilient city is one that anticipates, plans, and acts to prepare for and respond to unexpected crises. The adverse effects of climate change are most noticeable, among others, in multi-family residential areas. The aim of the study is to analyze the possibilities of health-promoting transformation of urban systems on selected examples of housing estates in Poznań. In the context of climate change, an extremely important indicator for housing estates is the amount of green areas and undeveloped areas that can be shaped to reduce the impact of adverse climate change, such as excessive heating (heat island, drought). The possibility of modelling and modifying existing green areas and the development of greenery

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in undeveloped areas make it possible to reduce the adverse effects of climate change in the form of violent weather phenomena (gusty flows of air masses along with the transfer of dust, windbreaks, damage to facilities and technical infrastructure, local flooding of facilities and areas – flash floods). The size of green areas in the form of lawns, medium and high greenery as well as undeveloped areas was considered in our research as a measure of the potential (possibilities) of adaptation to climate change. The aim of the study was to determine these values for selected examples of housing estates and multi-family housing complexes. The aim of the study was to determine these values for selected examples of housing estates and multi-family housing complexes.

LITERATURE REVIEW

The search for opportunities to mitigate the effects of climate change should be carried out in spatial and functional aspects (Stawasz et al., 2012). One of them is green infrastructure planning (Szulczewska, 2020), which should take into account the creation of optimal conditions for the provision of ecosystem services and a proactive, multifunctional and multidisciplinary approach to spatial planning, increasing our capacity to deal with climate change on an urban scale. These issues need to be considered at the level of the concepts and principles of urban adaptation planning and how urban adaptation planning can be put into practice (Ramyar et al., 2021). We are talking about ecosystem strategies (Iwaszuk et al., 2019), and blue-green infrastructure are elements of land development or development in the form of various forms of natural greenery, such as parks, forests, meadows, or greenery modeled in the form of green roofs, walls, screens. Blue-green infrastructure can play a key role in mitigating the effects of climate change if it is designed while using a variety of green and open water structures. Urban lakes, ponds, and community reservoirs can act as water retention areas, and streams can support water flow during extreme rainfall (Domanowska & Kostecki, 2015; Pamukcu-Alberst et al., 2021). On the other hand, blue infrastructure also includes areas or fragments of buildings for which development elements are provided in the form of surface or underground tanks, intended for rainwater retention – ponds, ponds, ditches, rain gardens and above-ground tanks or on the roofs and terraces of facilities, as well as infiltration boxes and underground containers (Garrison et al., 2012; Jopek, 2019; Pikoń & Bogacka, 2020). We have solutions at our disposal that can have a positive impact on improving the condition of the ecosystem or increasing the amount and role of ecosystem services (Wróblewski & Kroc, 2022). Examples of research to date on the importance of blue-green infrastructure for mitigating the effects of climate change have shown that covering 100% of buildings with green roofs in US cities offset the projected global warming (Hobbie & Grimm, 2020). An attempt at adaptive design and management of greenery was made in Porto, Portugal, which is carried out in three phases: climate change assessment, plant species database and plantation design and management procedure (Teixeira et al., 2022). Another aspect of how cities and settlements can adapt to climate change is modifying the intensity of the urban heat island by using trees and vegetation to shade surfaces and provide evaporative cooling, and reducing greenhouse gas emissions (Douglas, 2010). These strategies are also based on nature. The use of vegetation to adapt to climate change must be locally tailored to the specificities of the regional climate and the intensity of heat island effects in individual cities. Increased biodiversity, increased carbon storage, reduction of extreme temperatures and protection against rainfall floods are crucial for the environment in these cases. Significant improvements can be made by planting woody species and installing bright, permeable walkways and fountains, which allows the average radiant heat temperature to be reduced by 25.5°C and air temperature by 0.5°C and 2.5°C respectively in specific places (Epelde et al., 2021). These activities should be carried out in accordance with Nature-Based Solutions, which are based on the following principles: cost-effectiveness – economically efficient, efficiency in the use of resources, benefits – ecological, economic, social, support – adaptation

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to climate change, adaptation – to local conditions (Epelde et al., 2021; Hobbie & Grimm, 2020; O'Hogain & McCarton, 2018). In terms of ecosystem services, we can also talk about the selection of species adapted to climate change. Novel combinations of native and non-native species thriving in harsh urban environments enable the creation of ecosystems that are well equipped to cope with the effects of climate change, e.g. reducing the intensity of the urban heat island by using trees and vegetation to shade surfaces and provide cooling In this respect, urban areas can act as living laboratories – a living-lab concept whose main assumption is the cooperation of different groups of social stakeholders towards a specific goal, e.g. enabling the modelling of species sets dedicated to different local needs (Teixeira et al., 2022). Local authorities and public organizations play an important role in finding opportunities to mitigate the effects of climate change. Local government institutions, such as urban green areas and recreation departments, are responsible for managing urban and peri-urban ecology, as they have the majority of urban green spaces. The levels of adaptation of these institutions vary across ecoregions, and direct experience of mitigating the effects of climate change has been a major contributor to the scaling up. This information indicates that some regions have significant problems in this regard, e.g. urban parks and recreation departments in the U.S. are still unprepared for a changing climate (Cheng et al., 2021). The situation is similar in many housing estates in Poland. This situation can also be improved by social activities aimed at adapting to climate change by involving local housing communities in the creation of high, ornamental and functional green structures, e.g. as part of Urban Farming and Green Cities initiatives and programs. An example of such activities is the city of Alcaldia de Medellin in Colombia, where, due to the high level of unemployment, people from poor backgrounds were trained to work. They were hired as gardeners and technicians as part of the implementation of the Green Corridor program to cool the city by 3°C by planting 358,000 shrubs and trees, which also contributed to reducing crime and improving public health (Egerer et al., 2021). Reference should also be made here to the activities of local governments, which focus on the creation of adaptation strategies. Policies – include top-down strategies that determine what type of urban development or construction project is allowed. They are based on regulations, regulations, standards and codes. Hard infrastructure strategies – these are strategies that build on hard infrastructure to increase resilience to climate impacts. Ecosystem-based are also referred to as green and blue infrastructure. Cross-cutting strategies – include activities such as awareness campaigns and education that stimulate community behavior to increase resilience to the impacts of climate change. These can be driven by top-down government policy measures or bottom-up and community-based initiatives (Boyd et al., 2021).

MATERIALS AND METHODS

The aim of the study was to identify the possibilities of mitigating the negative effects of climate change in the areas of post-war Poznań housing estates. The selection of examples of housing estates and fragments of multi-family housing was guided by the following criteria: homogeneity in terms of the dominant residential function, location in different areas of the city and the period of construction. Ten selected examples of housing estates in their current state of use and investment were examined in the paper (Fig. 1). The analyses were based on the results of empirical research (calculations of thirteen parameters and indicators presented in Table 1, part 1 and part II) made by the authors for selected housing estates. To calculate the studied parameters, the Auto Cad graphics program and the authors' professional knowledge of the architectural and urban structures of the studied housing estates and the data of the Central Statistical Office. The research was carried out in the field of eight basic urban parameters and coefficients (Table 1, part I): 1 – year of construction of the housing estate, 2 – number of inhabitants (according to the number of dwellings and the average number of people per 1 dwelling), 3 – number

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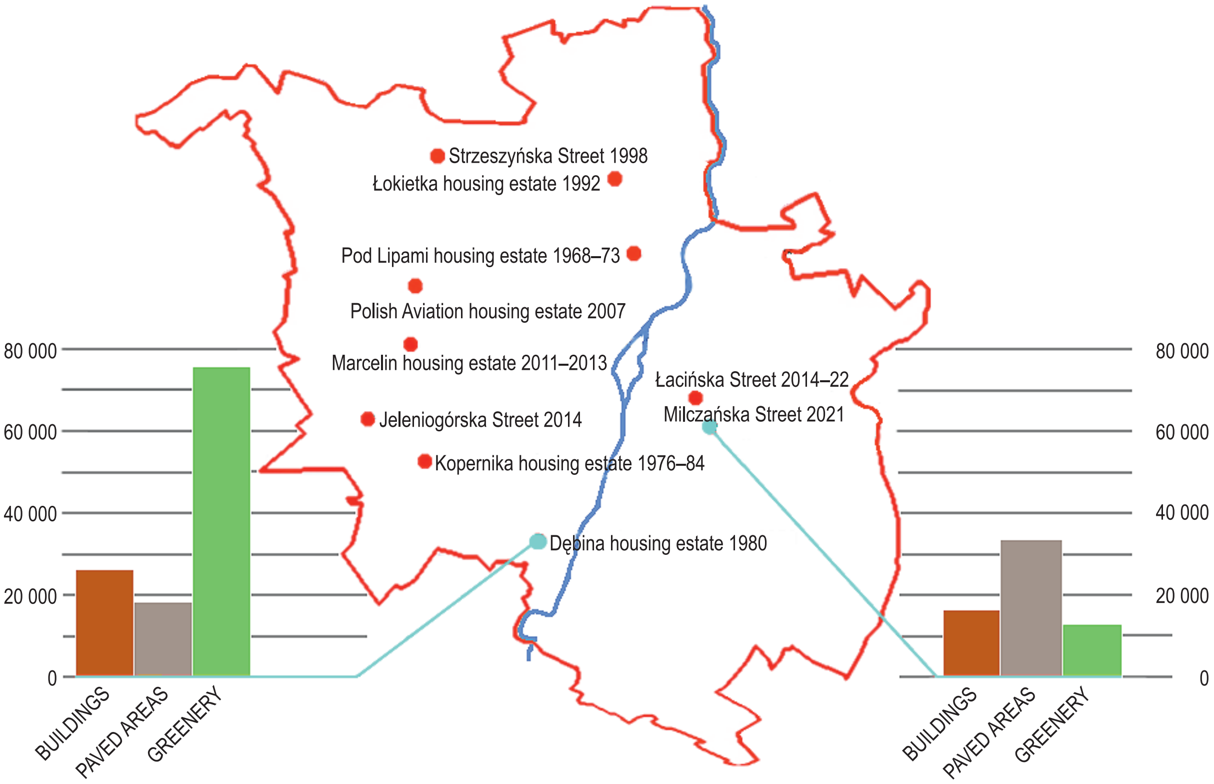

Fig. 1. Locations of the analyzed cases of settlements
Source: own elaboration.

of dwellings, 4 – area of the housing estate, 5 – area of buildings, 6 – area of paved areas, 7 – area of green areas, 8 – number of trees in the housing estate (according to the tree map and in situ surveys) and five indicators: 9 – share of green areas in the area of the estate, 10 – green areas per unit area of the estate, 11 – average distance between buildings, 12 – area of green areas per one inhabitant, 13 – number of trees per one inhabitant (Table 1, part II). A graphical and descriptive method was used in the field of balancing areas (Figures 2 and 3). The biodiversity of residential phytocoenoses has not been studied in detail. The dominant green structures were determined, such as: tall greenery – the number of trees for the studied settlements was calculated (mainly deciduous trees) and low greenery – shrubs, lawns, ornamental beds, which were included in the scope of green areas. Then, using the linear ordering method, the relationships between the listed values for the studied examples were established, and the results were summarized in tables and graphs.

RESULTS

Analysis of greenery intensity parameters in selected housing estates

The study covered 10 selected housing estates of the city of Poznań. For the synthetic presentation of the results of graphic and verbal analyses, two examples of housing estates "I" and "C" (markings according to Table 1) were selected, which were built in different periods and have different building structures: housing estate "C" dates back to the 1980s and is located in the southern part of the city, housing estate "I" was built in the 20s of the 21st century, on the eastern side of the Warta River. These examples indirectly present extreme cases.

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In the graphic analysis of the projections of housing estates – building complexes, the areas of built-up and undeveloped areas (buildings, greenery, paths, roads and parking lots) and the basic dimensions of the geometry of the development plan (distances between buildings) were determined and balanced. The possibilities of locating rain gardens and eco-parking lots have been determined. The descriptive part of the analyzed area takes into account numerical data obtained from own research and from available statistical data.

Example "I" – Milczańska Street

The complex of buildings at Milczańska Street belongs to a larger area unit of Łacina in the New Town district. The estate consists of seventeen, three-, four- and five-staircase, four- and five-storey residential buildings. The complex of buildings was completed in the twenties of this century. The analyzed residential complex is located between the following streets: Milczańska and Kórnicka (Fig. 2).

In the "I" housing estate, there are the following elements that are not conducive to mitigating the effects of climate "change":

- much less undeveloped land and shorter distances between buildings, making it impossible to plant larger trees and shrubs;
- poor green structures consisting mainly of low greenery (lawns, flower beds and small shrubs) and a small number of small trees in the ground and in pots – a total of 109 trees;
- fragmentation of land into small areas preventing the planting of larger specimens of shrubs and trees and the location of rain gardens;
- large areas of parking lots and paved areas, small possibilities of locating eco-parking lots with surfaces permeable to rainwater.

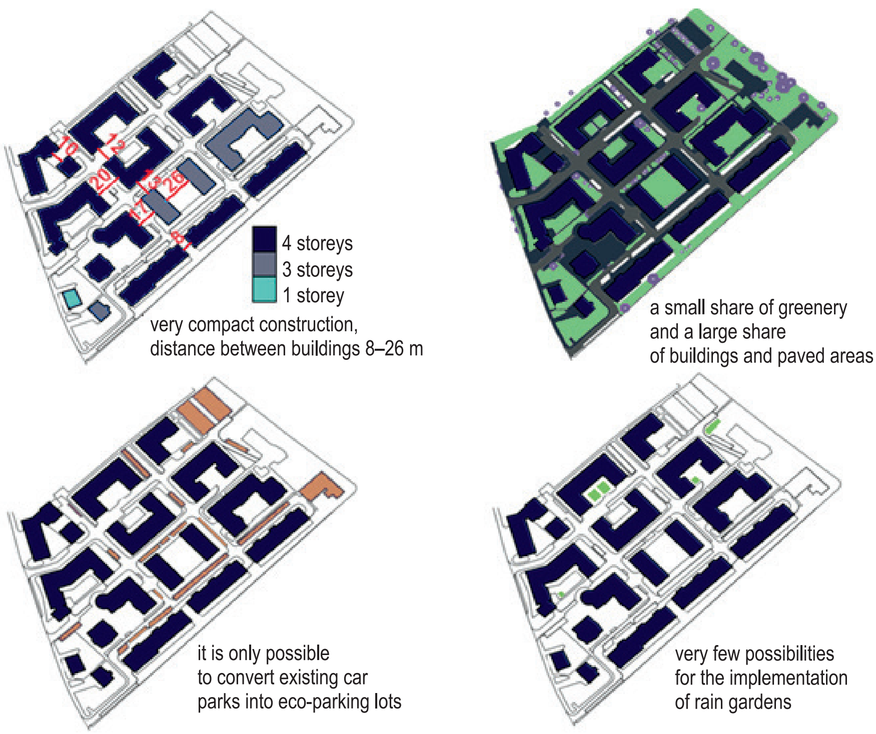

Fig. 2. Example "I" – Milczańska Street
Source: own elaboration.

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Example "C" – Dębina housing estate

The Dębina housing estate is part of a larger residential unit Dębiec in the Wilda district. The development of the estate consists of nine, two-staircase, eleven-storey residential points, three, eleven-storey eight-staircase buildings, two, five-staircase four-storey buildings and eight one- to two-storey service buildings. On the south-eastern edge of the estate there are ten single-storey garage buildings. The estate was completed in 1980 and the area of the estate is bounded by the following streets: 28 June 1956, Łozowa, Błogosławionej Poznańskiej Piątki and Dębina housing estate (Fig. 3).

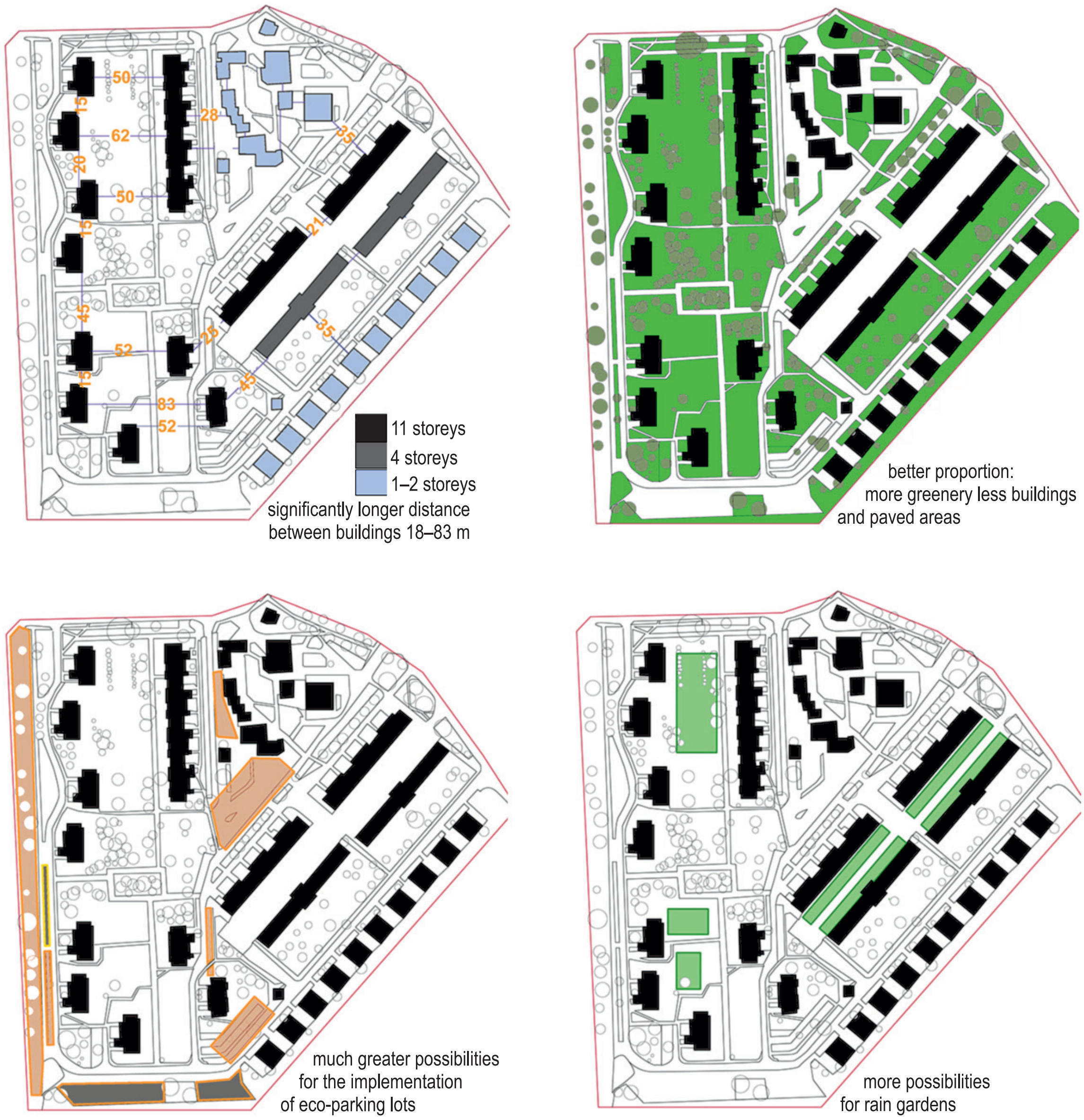

Fig. 3. Example "C" – Dębina housing estate
Source: own elaboration.

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Elements that increase the capacity to mitigate the effects of climate change are:
- in the "C" housing estate, three groups of land development elements can be distinguished, which are conducive to and increase the possibilities of mitigating the effects of climate change;
- significant undeveloped areas occurring in large compact fragments;
- significant areas of high and low green areas (251 trees);
- 2–3 times greater distances between buildings in the "C" housing estate in relation to the "I" housing estate, enabling the location of eco-system services, eco-parking lots, rain gardens and new tree plantings.

The results of the analyses for all 10 studied housing estates are presented in Table 1 – containing general data on the characteristics of the housing estates and a summary of the values of coefficients in the field of green areas, which are important in determining the possibility of mitigating the effects of climate change in the areas of these settlements. Then, as part of the ranking (Fig. 4), two groups of settlements were compared for selected relevant coefficients: five settlements from the 20th century (A–E designations according to the table) and five settlements from the 21st century (F–J).

According to the authors, the following parameters are important factors – indicators that determine the possibilities of mitigating the effects of climate change:
- the area of green areas per area of the estate;
- green areas per unit of building area;
- average distances between buildings;
- area of green areas per one inhabitant;
- number of trees per capita.

In the category (Table 1) – the share of green areas in the area of the housing estate in [%] – the highest values are presented by housing estates from the years 1980 [70.7%], 1976–84 [63.0%], 2007 [47.9%], 1968–73 [41.7%] and 1992 [38.7%]. These values for the remaining housing estates were at the level of 16–37.4% of the housing estate's area.

In the category – green area per built-up area [sq.m/sq.m] – the highest values were recorded for housing estates from 1980 [5.70] and 1976–84 [4.86].

In the category – average distance between buildings, the highest values were recorded for housing estates from the years 1976–84 [58.6], 1992 [45.8], 1980 [43.9] and 1968–73.

In the category – green area per 1 inhabitant of the housing estate [sq.m/1 inhabitant] – the highest values were achieved by housing estates from 1998 [36.50], 1992 [22.61] and 2007 [22.16], followed by housing estates from 1976–84 and 1998.

In the category – number of trees per 1 inhabitant – the highest values were achieved by the 1976–84 [0.265] and 1968–73 [0.217] settlements, followed by the 1998 and 2007 settlements.

The analysis of the above parameters shows that the settlements of 1976–84, 1980 (Kopernika and Dębina settlements) had the highest results, the next settlements in this classification were those of 1968–73 and 1992 (Pod Lipami and Lokietka settlements).

The parameters studied – the indicators of settlement land use selected by the authors – make it possible to indicate settlements with a higher/lower share of greenery in their structures (green intensity) and can be helpful in determining which solutions are more suitable for use in settlements with a high share of greenery (undeveloped land), and which can improve the situation where greenery and available undeveloped land are scarce.

The scopes of mitigation programs and development principles will depend on the indicators described and local conditions.

For settlements with a significant proportion of undeveloped land (mid- to late-20th century settlements), the preferred mitigation measures will be:
- Realization of new structures and plantings with tall greenery using species dedicated to new and more difficult climatic conditions, which will be more resistant to drought, pollution, salinity (constant stress for plants) and extreme weather events: common maple – Acer platanoides, field maple – Acer campestre, red maple – Acer rubrum, silver linden – Tilia tomentosa also known as Hungarian linden and its Warsaw variety – Tilia tomentosa 'Varsaviensis'; ornamental varieties with smaller dimensions also tolerate urban conditions well: small-leaved pear – Pyrus calleryana in varieties

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Table 1. Selected parameters of the characteristics of housing estates

No	Name of area	Pod Lipami estate	Kopernika estate	Dębina estate	Łokietka estate	Strzeszyńska street	Polish Aviatione state	Marcelin I, II, III estate	Jeleniogórska street	Milczańska street	Łacina street
		A	B	C	D	E	F	G	H	I	J
	Part I – General Data										
1	The year the settlement was established	1968–73	1976–84	1980	1992	1998	2007	2011–23	2014	2021	2014–22
2	Number of residents*	7270	12471	2014	2915	5658	1136	13061	4237	1878	6376
3	Number of dwellings*	2733	4688	757	1096	2127	427	4910	1593	706	2397
4	Area Estate [ha]	26.23	42.50	10.40	17.02	28.78	4.78	35.00	9.12	6.00	18.06
5	Development area [ha]	6.08	5.94	1.29	2.56	5.03	0.84	7.95	2.42	1.62	3.56
6	Area Pavedareas [ha]	7.47	13.40	1.78	7.87	8.22	1.65	16.77	3.39	3.20	7.75
7	Area of green areas [ha]	10.94	26.86	7.35	6.59	8.74	2.29	5.49	3.32	1.19	6.75
8	Number of trees	1582	3300	251	311	950	150	950	463	109	274
	Part II – Indicators										
9	Share of green areas in the area of the settlement [%]	41.7	63.0	70.7	38.7	30.4	47.9	16.0	36.4	35.66	37.4
10	Green areas per unit area of development [sq.m/sq.m]	1.80	4.86	5.70	2.57	1.74	2.73	0.69	1.37	0.73	1.90
11	Average distance between buildings [m]	40.5	58.6	43.9	45.8	15.9	17.6	21.0	18.0	15.14	19.2
12	Area of green areas per 1 resident [sq.m/1 inhabitant]	15.05	21.54	36.50	22.61	15.43	22.16	4.20	7.84	0.63	10.59
13	Number of trees per 1 inhabitant	0.217	0.265	0.125	0.110	0.168	0.132	0.073	0.119	0.058	0.043

Blue color indicates the highest values

Source: own ,elaboration; and *(Ambroch 2023), http://sip.poznan.pl/model3d/#/legend, according to CSO 2022 2.84 (2011 year) 2.47 (2012 year) average 2.66 from last decade person per household.

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'Chanticleer', 'Red Spire', and ginkgo – Ginkgo biloba, gleditsia triacanthos and white robinia – Robinia pseudoacacia, commonly known as acacia;
- Required implementation and modeling of structures of high and low greenery to better adapt public spaces (also in the immediate vicinity of development) to improve usable comfort (see section 3.2.) and functional comfort (growing traffic needs – parking in housing estates), as well as organizing spaces of different nature, adapted to the needs of people of different ages for passive and active recreation (Szumigała, 2015);
- Realization of widespread rainwater retention in residential areas in the form of numerous rain gardens, surface and underground reservoirs of varying structures and sizes used to cool and supply water to green areas during periods of high temperatures.
- Implementation of new eco-parking lots and/or reconstruction of existing parking lots to change the surface to permeable rainwater;

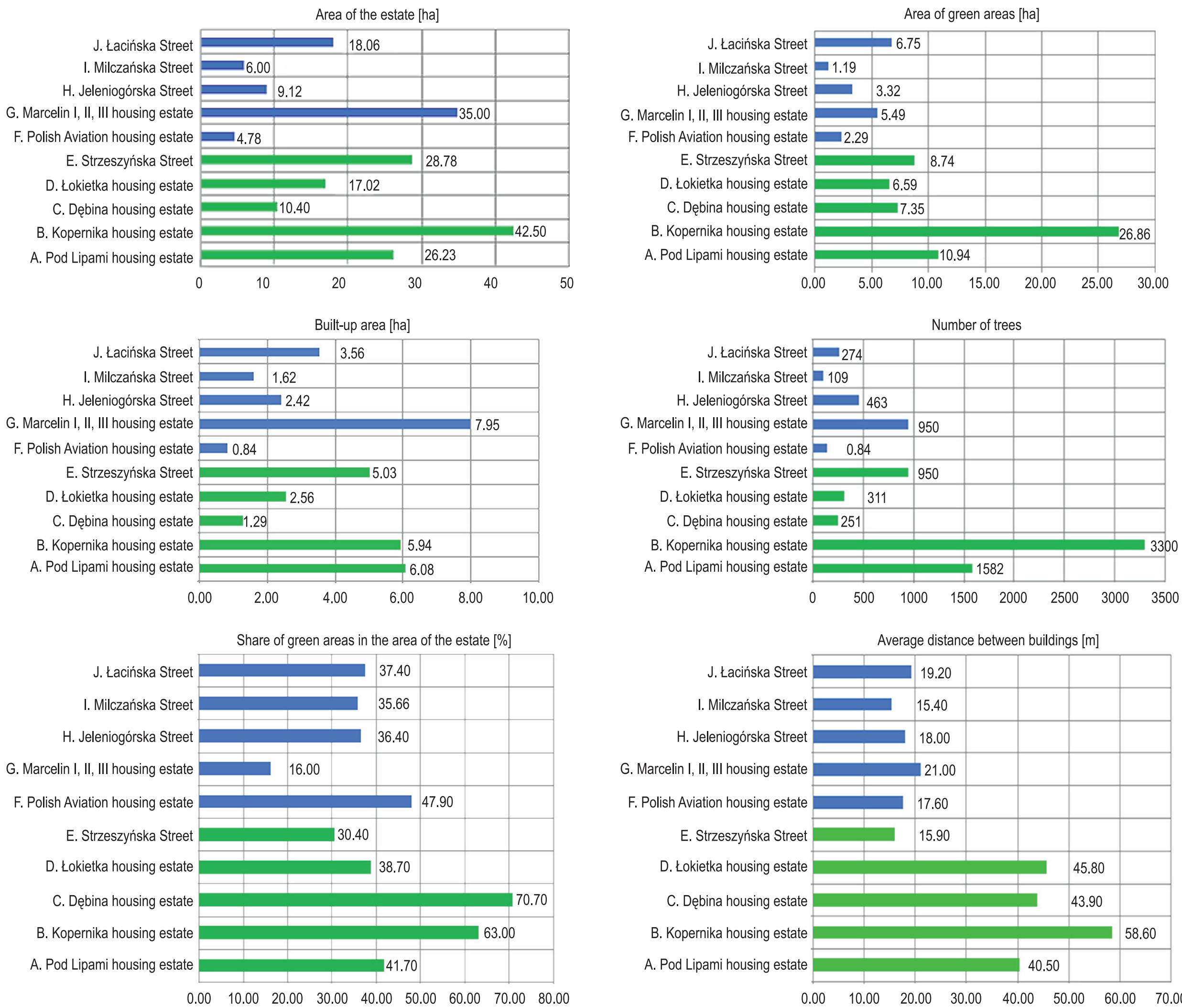

Fig. 4. Comparison of settlements in terms of six indicators: a – area of the settlement, b – area of green areas, c – area of buildings, d – number of trees, e – average distance between buildings, f – share of green areas in the area of the settlement. Estates of the mid- to late 20th century. A–E – green color, settlements of the 21st century, F–J – blue color
Source: own elaboration.

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- Reconstruction of paved surfaces – pedestrian, bicycle and vehicular roads (where this is possible in terms of function and technical feasibility) to natural improved surfaces with rainwater permeability;
- For settlements with a smaller share of undeveloped areas (21st century modern settlements), the possibilities for introducing new high greenery and surface water structures (green and blue infrastructure) are significantly limited due to the smaller overall share of undeveloped areas (green spaces) and the fragmentation and much smaller areas of land for planting new trees. In this situation, possible solutions could be;
- Realization of green roofs, walls, terraces, screens and screens, gardens on roofs and terraces, e.g. of the Urban Farming type, towards utilitarian and ornamental crops (Szumigała & Szumigała, 2018); a social, aesthetic and, to a lesser extent, economic aspect appears here at the same time;
- Technical solutions for introducing surface water into the space of settlements in reservoirs and growing plants (especially smaller trees) in permanent and mobile containers;
- The significantly larger share of green areas in the leading ranking settlements (on average 2–3 times larger) than contemporary settlements makes it possible to model greenery structures to a greater extent in terms of their impact on the thermal conditions of the settlement during summer (shading – protection against heating) and during low temperatures (protection against strong flow of cold air masses and cooling of spaces and buildings). Examples of the effects of modeling settlement greenery structures are presented in Chapter: Health-promoting effects of the greenery system within the urban areas.

Impact of greenery intensity on important parameters of urban structure aeration

One of the key health-promoting factors in housing estates is proper aeration of the space between buildings. By using appropriate greenery systems in built environments, we can ensure not only proper air flow, but also its sufficient cleaning, refreshment and oxygenation. The necessary condition here is, of course, a sufficient share of non-built up space in the overall area balance of the estate, in other words: an area on which an appropriate "green filter" system can be implemented. From this point of view, settlements from the 20th century have a greater potential to adapt to climate change than contemporary settlements and provide more opportunities for modeling new green structures (Boyd et al., 2021; Pamukcu-Alberst et al., 2021; Ramyar et al., 2021).

In large areas of development without sufficient greenery, there are many unfavorable phenomena related to the flow of atmospheric air masses through them. If the area of the built-up area is too large, natural aeration processes are unable to displace polluted atmospheric masses and replace them with fresh ones. Instead, the air heats up and rises above the area. Then, as it cools, it flows centrifugally to its edges, giving way to the heated ascending air. From the outskirts of the area, it is "sucked" back to the heated center and again accumulates new pollutants in the next circulation cycle. The circulating, increasingly polluted air is closed above the buildings. An additional unfavorable phenomenon that often accompanies such circulation is turbulent air movement between the estate's buildings. Regardless of the existence of a heat island, the growing wind in the space between buildings picks up and carries more and more harmful particles, aerosols, microbes and volatile substances heavier than air, previously "inactive" and remaining in caverns and depressions in the area. The concentration of harmful substances depends on air movement (Stunder & Arya, 1988).

Therefore, if local aerodynamic turbulence is additionally accompanied by movements of polluted air, characteristic of a heat island, then the unfavorable phenomena are multiplied. As research shows (Kozaczko, 2018), there is a close relationship between the shape of the greenery inside the estate and its functional and sanitary parameters.

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Health-promoting effects of the greenery system within the urban areas

A properly designed greenery system can effectively slow down the wind speed in the estate. Slowing down the local speed of this movement reduces the amount of pollutants contained in the air. The greenery system can therefore effectively perform a filtering function (Kozaczko, 2018, pp. 121–126). Such filtration is also accompanied by an improvement in the chemical composition of the air, thanks to the processes of oxygenation and sorption taking place in the zones of deliberately shaped greenery. Its proper distribution and appropriate species structure help stabilize the thermal and humidity parameters of the air (Stanisławska, 2022).

Using the example of the Dębina housing estate, the possibilities offered by introducing such a system between existing buildings were discussed.

Table 2 highlights some important parameters of the wind slowed down by the greenery system inside the housing estate. The table columns contain the values of wind speed between buildings, as well as their significant derivative effects: wind pressure force and airborne pollutant concentration. The variability of the parameters from Table 2 is shown in Figure 5. The middle, blue graph shows the primary aeration factor, which is the wind speed in the housing estate. The wind speed decreases depending on the greenery used inside the estate. Its effectiveness in reducing wind speed is shown on a four-point scale in the first column of the table. A value of 1 on this scale corresponds to the wind speed in open areas, outside the housing estate. The unslowed air flow between the estate's buildings reaches a speed of 1.7 m/s (which

Table 2. Microclimatic effects of wind speed reducing greenery system

Four degrees of tightness of greenery (causing the slowing down of the wind in percentage)	Wind velocity [m/s]	Wind force reduction factor	PM10/PMmax the amount of exceedance of the permissible pollution standard
1 (100% primary wind speed)	1.70	1.00	2.30
2 (75% primary wind speed)	1.28	0.57	1.72
3 (50% primary wind speed)	0.85	0.25	1.16
4 (25% primary wind speed)	0.40	0.05	0.58

Source: own elaboration based on Kozaczko (2018).

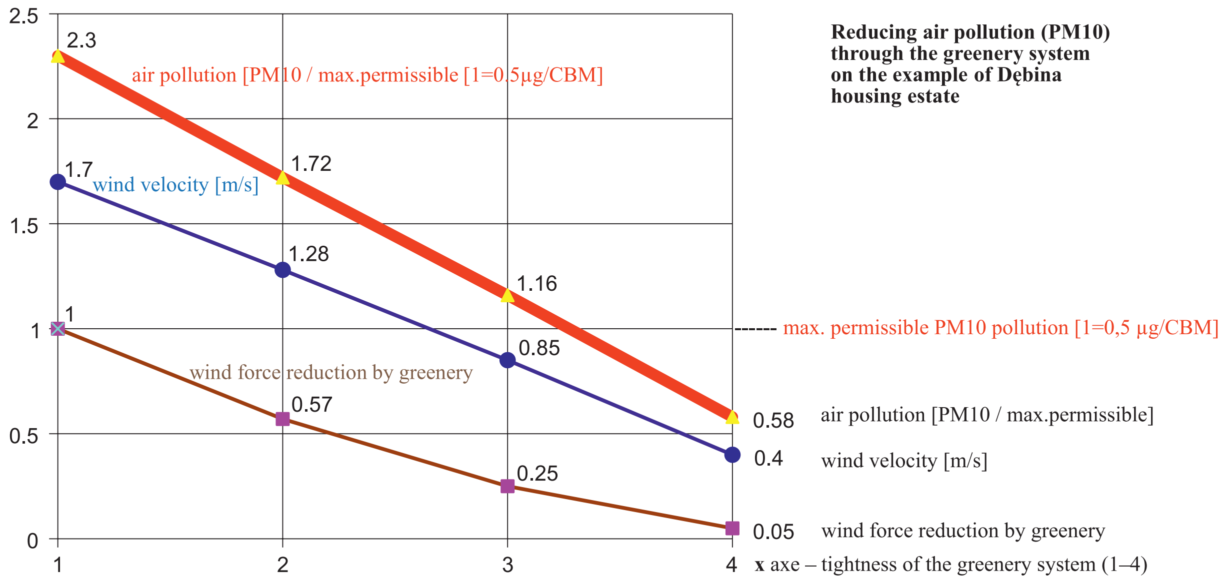

Fig. 5. Reducing air pollution through the greenery system. Graphs of wind velocity, wind force and air pollution (represented by PM10)
Source: own elaboration based on Kozaczko (2018).

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is an example average value here). This flow can be slowed down to a speed of 0.4 m/s (value 4 in the second column of the table, which corresponds to the wind speed reduced to 25% of the initial value).

The third column of the table (and the lower graph) shows the relative wind strength reduced by the greenery system: from the value of 1.0 (no system) to the value of 0.05 (highly effective system). As you can see, slowing down the wind four times reduces its negative potential by as much as twenty times (namely, it reduces the force to pick up and carry harmful pollutants).

The fourth column of the table (and the upper, red graph) reveals the effectiveness of the greenery system in reducing the amount of PM10 suspended dust in the spaces between the buildings of the estate. These are relative values shown in relation to the permissible PM10 standard (0.5 μg/CBM). Therefore, if in a housing estate without a greenery system, air pollution exceeds the permissible limit more than twice (value 2.3 at the top of the column), an effective "green filter" system can reduce this PM10 concentration to a level almost twice lower than the permissible value (relative value: 0.58 at the bottom of the column, corresponding here to the actual absolute concentration ofPM10 of 0.29 μg/CBM).

Of course, the technical and habitat aspects of the distribution and structure of greenery species with

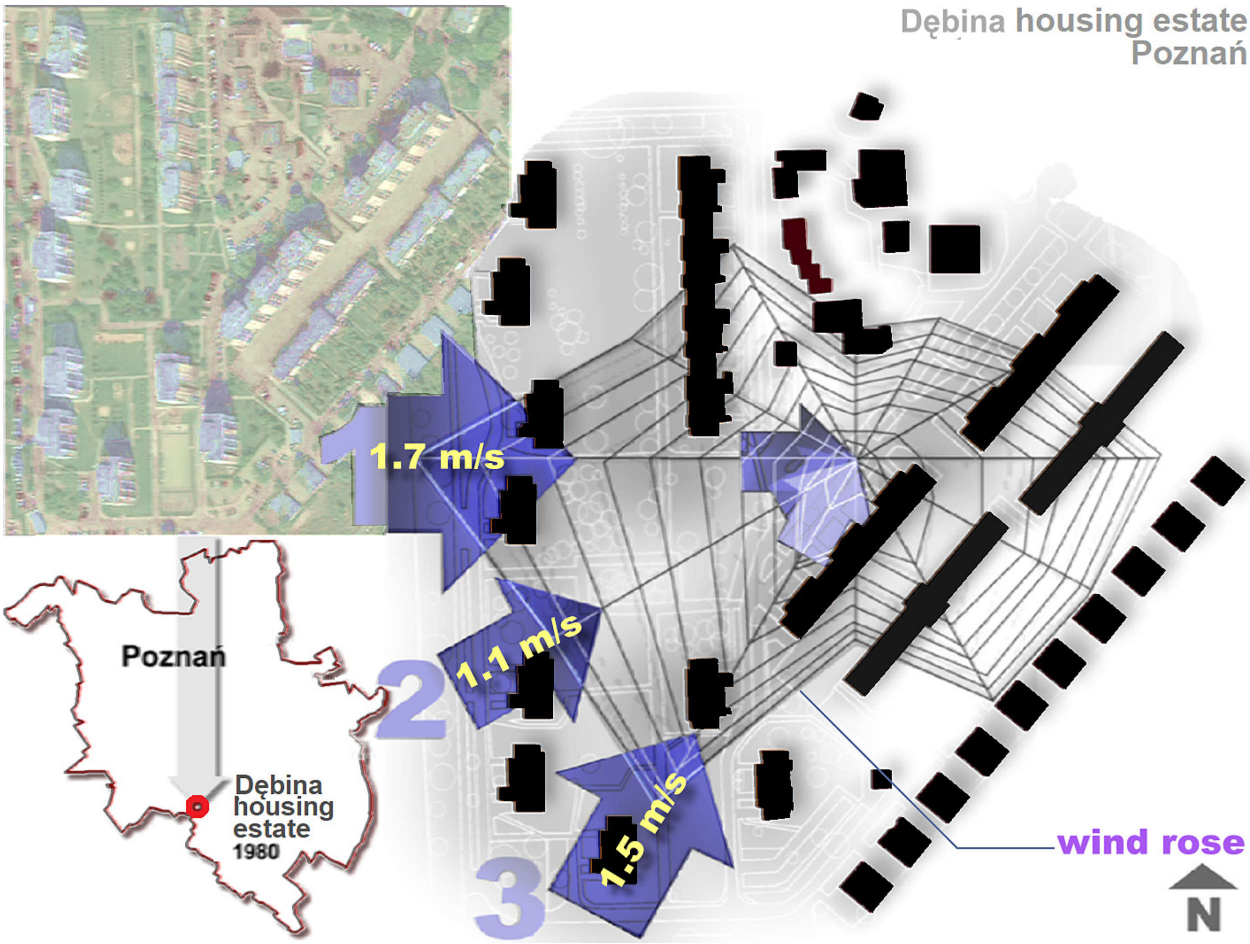

Fig. 6. Example "C" – Dębina housing estate: orientation of the estate towards the cardinal directions, location of the estate, prevailing wind directions (wind rose)
Source: own elaboration.

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appropriate tightness are a detailed design issue not considered here, closely related to the conditions prevailing in a given location. This study shows a kind of "absorption capacity" of the Dębina estate area, expressed in the possibility of using the extensive structure of the "green" regulator in Figure 7. Such effects should also be expected in housing estates with general geometric characteristics similar to Dębina.

Figure 6 shows a satellite photo of the Dębina estate and its location in Poznań. The external aerodynamic conditions in the form of a wind rose for this area were plotted on the building layout. As you can see, the prevailing directions of air flow over the estate are west and south-west. The analysis of aerodynamic effects involved a wind speed of 1.7 m/s (2° on the Beaufort scale – the so-called weak wind). Figure 7 shows an example of a greenery system introduced between buildings to slow down the wind flow. This is, of course, a sketch of the system, showing the capacity of the estate area on the scale of the development: the possibility of saturating it with filtering greenery, reducing wind speed. Taking into account the relatively loose development and using the appropriate species structure of the introduced vegetation, reducing the wind speed to 25% of the initial value will not be a big problem. In the described simulation, it was assumed that the concentration of PM10 pollutants in the air was initially

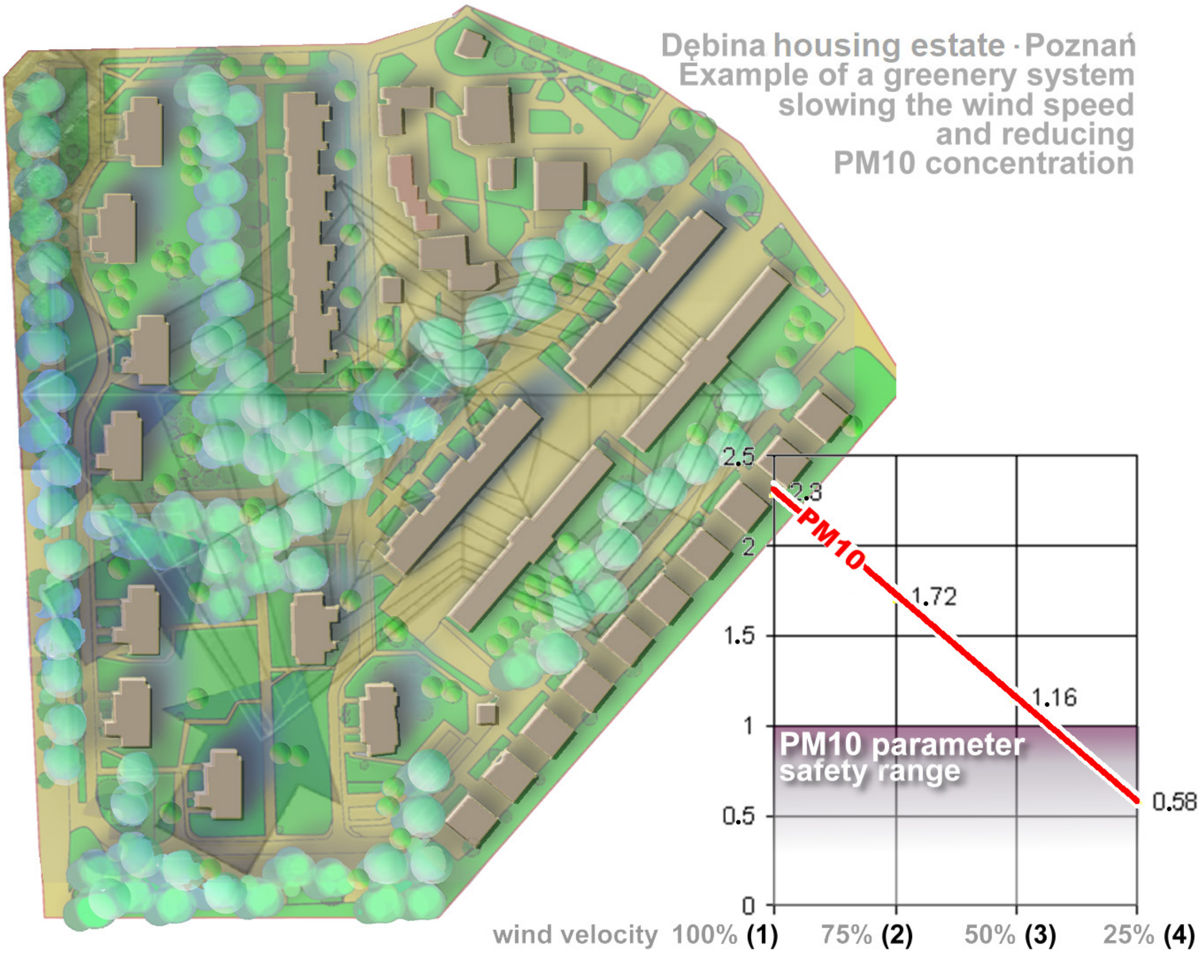

Fig. 7. Example "C" – Dębina housing estate
Source: own elaboration.

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1.1–1.2 g/CBM (taking into account the wind directions and the location of external emission sources, such or higher concentration of pollutants is now undoubtedly a common phenomenon).

On the right side of Figure 7 there is a coordinate system. Its x-axis indicates the degree to which the wind is slowed down by the greenery system (see Table 2), while the y-axis is the axis of the pollution concentration values (represented by PM10 dust). The values are shown relative to the pollution standard, marked as 1 (the absolute value of this parameter is 0.5 μg/CBM). A green filter reducing the initial wind speed to 25% would allow concentrations to be reduced well below the health standard. As you can see in the Figure 5, even slowing down the wind by half allows the PM10 concentration indicator to reach a value that is relatively safe for health.

DISCUSSION

The study examined, among other things, the relationship between two basic variables: 1 – the size of green areas, which enable the modelling of green structures – especially tall greenery (including undeveloped areas that can be developed with greenery) and 2 – the size of built-up areas (including paved areas). The relationship between these values, referred to as "green intensity", makes it possible to determine the potential – possibilities of adaptation to climate change in the field of modelling green structures resulting from the size and geometry of green areas (area and distances between buildings of residential structures).

The structure of the article is layered and the presentation of research results has two clearly outlined aspects. The first part, the general part, preceded by a literature review, refers to the issue of "green intensity" in the studied areas of multi-family housing. The results of this study, which were based on thirteen indicators, indicate the importance of "green intensity" in areas of multi-family housing structures in the context of climate change. Adaptability increases with the increase in the size of green areas and the increase in the distance between buildings. The practical application of these results should translate into a change in the currently applicable urban planning indicators in order to ensure a greater share of green areas in the areas of newly designed housing structures. The internal and external validation of the results is most influenced by the accuracy of measurements in determining the coefficients (the accuracy of measuring the area of greenery, buildings, unpaved and paved areas and the number of people living in the study area). The presented investigations extend the research methodology with a new set of coefficients used for the analysis of urban structures. The limitations of the research are the availability of statistical data in terms of the number of inhabitants and the accuracy of measurements of the examined parameters – the area. Overcoming the limitations of research is possible through the use of methods for measuring surfaces and mapping structures using GIS modeling.

In the second part of the article, in order to "check" the hypotheses and conclusions contained in the first part, an analysis of the impact of the modeled structure of tall greenery is presented only in terms of improving the aerodynamics of the housing estate by means of different "intensity of greenery". The conclusions from this part constitute partial evidence for the correctness of the theses presented in the first part (Michalik, 2018).

The issue of the development of green areas in residential areas is also described in the literature on the subject in the aspect of social activities such as Urban Farming, which are aimed at the development of greenery for own needs: wastelands, green areas of housing estates, areas between facilities, post-industrial areas, roofs, balconies, terraces and external and internal walls in residential, service and industrial facilities (Abdulateef & Al-Alwan, 2022; Szumigała & Szumigała, 2018). In this case, green areas occur in the form of vegetables, herbs, fruit shrubs and they have a much lower impact on mitigating the adverse effects of climate change in relation to the modelling of high green structures in the areas of housing estates described in the study.

The aspect of adaptation of urban structures to climate change is also described in the broader

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context of adapting multi-layered planning and modifying cities, which confirm the need to apply the basic principle of increasing the share of greenery in built-up areas (Kalbarczyk & Piegat, 2021; Kalbarczyk & Roszyk, 2023).

CONCLUSIONS

In conclusion, it should be emphasized that the possibilities of adaptation to climate change discussed on selected examples of Poznań housing estates of the 20th and 21st centuries show significant differences resulting primarily from the periods of implementation of the estates. Therefore, there is a need to identify a set of recommended measures for the design and management of greenery and surface water: for 20th-century settlements, there are significant opportunities for modeling existing and designed greenery structures through species replacement, increasing species diversity, densification and dispersal, accommodating transportation, aesthetic and utility needs in undeveloped areas, and opportunities for implementing surface and groundwater retention reservoirs; for 21st century settlements, due to much less green space and undeveloped areas, adaptation and adjustment of urbanized structures and paved areas towards the introduction of greenery and water on the surfaces of roofs, walls and squares in permanent and mobile/seasonal containers are feasible on a larger scale. The authors emphasize the fact of the complexity of the discussed issue of climate change adaptation in relation to the recommendations.

The preferred dense planting of large trees in residential blocks may come into conflict with the need for car parking, for example, and this is particularly evident in the settlements of the 20th century. However, the priority in the context of the following climate change is to improve environmental and usable conditions in settlement spaces. The growing need for parking in settlements can be met by using appropriate planting structures and species, as well as permeable surfaces for parking. Arranging parking spaces, according to local conditions, among trees and "tree-lined parking lots" can improve the coexistence of vehicles and greenery in settlements in this regard.

Excessive shading of apartments located on lower floors also becomes an important aspect if new tree plantings are implemented. In this case, it is necessary to use modeling of high and medium greenery structures (trees and large shrubs) in zones adjacent to residential buildings, for example, by changing the rhythms of planting, grouping, zoning, locating such structures in the area of the gable walls of residential blocks – where there are no windows of apartments, and species selection of trees and shrubs, characterized by smaller, slenderer and less compact crowns.

The listed set of recommended actions is an attempt to implement an intentional tool, postulated in the Second Athens Charter, as a filter/regulator. It is not defined there, although its individual elements are applied in dispersed form. These elements should be assembled into a system whose effectiveness will synergistically exceed the simple sum of the effectiveness of its components. The core of this tool (with respect to aeration and aerodynamics) can be formed by wind protection belts that are expanded and modeled to local conditions.

The multilevel structure and appropriately selected cross-section of the windbreak belt, as well as the dedicated species (described above) of plants used in it allow, among other things, a local reduction in the speed and force of wind pressure and the resulting direct: effective centrifugation of all dust, adequate filtration of the air and absorption of the poisons contained therein, as well as its better oxygenation; increased convenience of use of the space inside the estate (minimization of wind resistance to pedestrian traffic, which is an extremely important factor of comfort) (Hon Koo & Al-Obaidi, 2013); a significant reduction in the energy intensity of heating buildings.

The City of Poznań is part of the list of the 44 largest Polish cities that have developed Municipal Adaptation Plans7 to climate change. Poznan's MPA to 2030 takes the form of a comprehensive set of urban guidelines – general principles of action, contained in four sectors with the greatest sensitivity to the effects of climate change: public health, spatial management,

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water management and transport (Municipal Climate Change Adaptation Plan, Poznan.pl).

Thus, it can be concluded that properly shaped intra-neighborhood greenery is an extremely desirable tool of modern urban planning. Such a natural system does not have to be – contrary to popular stereotypes – very extensive in order to effectively carry out its tasks. Much greater adaptability in this regard is demonstrated by settlements implemented in the 1950s–80s according to the old urban planning norms of the 1980s (Ordinance No. 9) and earlier, as opposed to settlements implemented today. The presented land development solutions are also of an applied nature in the aspects of efforts to adapt residential settlements to climate change.

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