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Urban planning – architectural report on thermal stress in the city of Warsaw

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2021, DOI: 10.5281/zenodo. 5767264

This report has been created as part of the Embodying Climate Change: Transdisciplinary Research on Urban Overheating (EmCliC) project. The research project is funded from the Norway and EEA grants 2014–2021 under the Basic Research Programme operated by the Polish National Science Centre in cooperation with the Research Council of Norway (grant no 2019/35/J/HS6/03992).

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CONTENT:

Introduction

This following study was prepared on behalf of the research project entitled "Embodying climate change. Trans-dyscyplinary research on urban overheating" (EmCliC). It is a three-year research project, that brings together social anthropology, sociology, climate science, epidemiology, atmospheric physics and innovative technology, in order to understand and demonstrate the ways in which people experience climate change on a daily basis. The project is focused on studying urban heat experiences among elderly populations of Warsaw and Madrid. The research project is funded from the Norway and EEA grants 2014–2021, under the Basic Research Program operated by the Polish National Science Center in cooperation with the Research Council of Norway (grant no 2019/35 / J / HS6 / 03992).

This study concerns urban and architectural issues that affect the experience of high temperatures by people in urbanized areas, for the case study of Warsaw. The study is centered on multi-family housing development that creates an environment for the daily life of residents (especially the population of older adults in highly urbanized areas. It is such areas that tend to be most affected by the impacts of the urban heat island effect. The scope of the present study and the approach applied therein was developed during a series of consultations with the research team members and a consultant-architect from Madrid. Such cooperation is to provide support for the interdisciplinary research team in the development of research assumptions and methodology.

The study is aimed at:

1. compilation and systematization of urban-related and architectural factors that affect the phenomenon of city overheating,
2. developing a typology of housing development in Warsaw, with account to the issue of overheating, as a starting point for further research on the project,
3. presentation of urban and architectural solutions applied in order to counteract the phenomenon, as well as adaptation of city spaces and buildings in order to improve their thermal comfort during heat periods,
4. diagnosis of the current situation observable in Warsaw in terms of the risk of overheating as well as an analysis of both, the undertaken and planned activities related to architecture and urban planning at a national and local level.

The layout of the chapters of the study blow directly results from the abovementioned objectives.

Chapter 1 – Thermal comfort from architectural perspective

1.1 Thermal comfort

In the document entitled ASHRAE Standard 55, The American Society of Heating, Refrigerating, and Air-Conditioning Engineers defines thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment”. The definition means that a person feels neither too cold nor excessively warm. Such a state is of subjective nature and does not indicate that the same temperature provides comfort to everyone. The condition depends on environmental factors such as: air temperature, humidity, air flow, thermal radiation, as well as personal factors, including: a person’s physical activity and clothing worn by them (Fig.1).

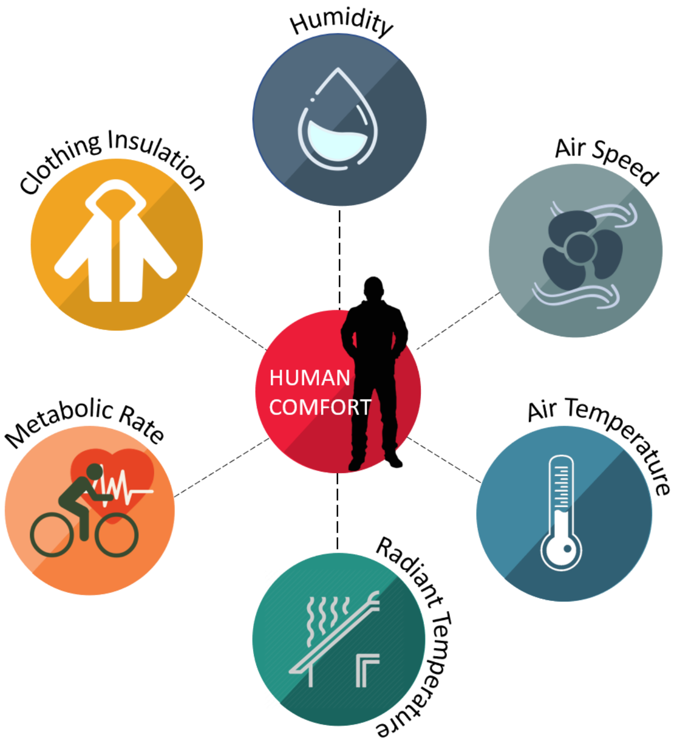


Fig 1. Environmental and personal factors that influence thermal comfort; source: https://www.simulationhub.com/blog/role-of-cfd-in-evaluating-occupant-thermal-comfort.

It is a complicated task to arrive at a definition of thermal comfort conditions as it requires capturing the correct relationship between all of the abovementioned parameters, given the fact that the "optimal" combinations vary with respect to different climatic zones worldwide. Various standards have been developed to define the requirements for designed buildings and to assess thermal comfort of existing buildings. These include the aforementioned ASHRAE Standard 55, but also ISO 7730 Standard and the EN 16798-1 Standard. In Poland, issues of thermal comfort in designed and modernized buildings are regulated based on *Rozporządzenie Ministra Infrastruktury w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie / The Ordinance of the Minister of Infrastructure on technical conditions to be met by buildings and their location*, as well as standards with which to regulate design methods. For instance, the PN-EN ISO 52016-1 standard describes a number of calculation methods that are used to determine the usable energy demand of buildings for needs related to heating, cooling, humidifying and dehumidifying indoor air. Moreover, the PN-EN ISO 52016-1 standard defines methods with which to calculate the time-variable internal temperature in buildings and to determine the heat load of heating and cooling in buildings.

1.2 The issue of overheating in the context of multi-family housing in Poland

Poland is situated in a transitional temperate climate zone. According to the classification by Okołowicz, the country lies in warm transitional climate, whereas the Köppen classification defines the conditions as a humid continental climate. The characteristics of this climate make it necessary to provide shelter from cold for most of the year, namely in winter and transition seasons, and to provide protection against excess heat in the summer months. The problem of heating spaces, especially in the case of housing construction, has constituted the major problem so far. Growing costs of energy for heating needs meant that contemporary pro-ecological solutions applied in housing construction in Poland were primarily directed at energy-saving heating systems, as well as at the possibility to use solar energy for heating purposes. The issue of interior overheating, which, due to climate change and the urban heat island effect, has recently become apparent in large cities, constitutes a new problem. The issue was absent from traditional historical solutions, unlike, for example, in the architecture of Mediterranean countries, where massive elements to accumulate thermal energy, elements to support natural ventilation and shading elements (arcades, shutters) were in common use.

Meanwhile, the issue of overheating, so far considered mainly in the context of service buildings (e.g., office, commercial buildings) or production plants, is beginning to affect multi-family housing in large Polish cities, such as Warsaw. This is reflected in a significant increase in the number of individual air-conditioning devices installed in apartments recently (Fig. 2).

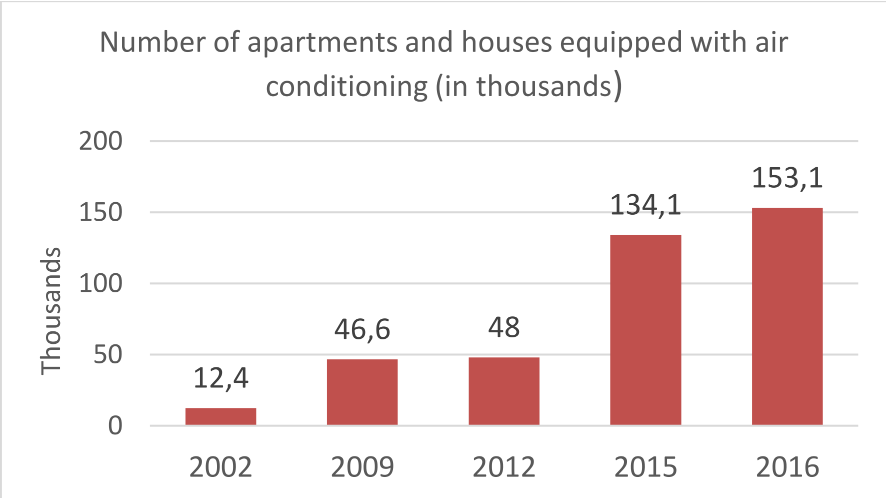


Fig. 2. Data on the number of houses and apartments equipped with air conditioning in Poland from 2002 to 20016,based on the data of the Central Statistical Office, Poland; source: https://www.muratorplus.pl/biznes/wiesci-z-rynku/juz-150-tys-polskich-domow-i-mieszkan-ma-klimatyzacje-aa-Gd7W-12pg-H7Am.html

1.3 The impact of buildings and their surroundings on thermal comfort phenomena

Buildings and their surrounding spaces influence the thermal comfort experienced by people, as they exert a direct impact on environmental factors mentioned above and shown in Fig. 1. Solar radiation is partly reflected and partly absorbed by building solids and the surrounding surfaces (hardened or green). The proportion of absorbed radiation depends on the color and materials of the surface. Buildings and pavements absorb more solar radiation due to their dark colors. Furthermore, increased water evaporation due to higher temperatures increases air humidity. When wind collides with buildings, its direction, velocity and pressure undergo dynamic changes and lead to various aerodynamic effects. The microclimate around buildings, therefore, consists of a system of complex phenomena. At a relatively small area, a variety of thermal, humidity and wind conditions may be present simultaneously (Fig. 3). These conditions are of direct importance in the view to the comfort of citizens in the vicinity of buildings (in public spaces, neighborhood spaces, private gardens, etc.). Moreover, environmental conditions indirectly influence the physical environment inside the buildings themselves, as these factors constitute the onset of the building's energy system.

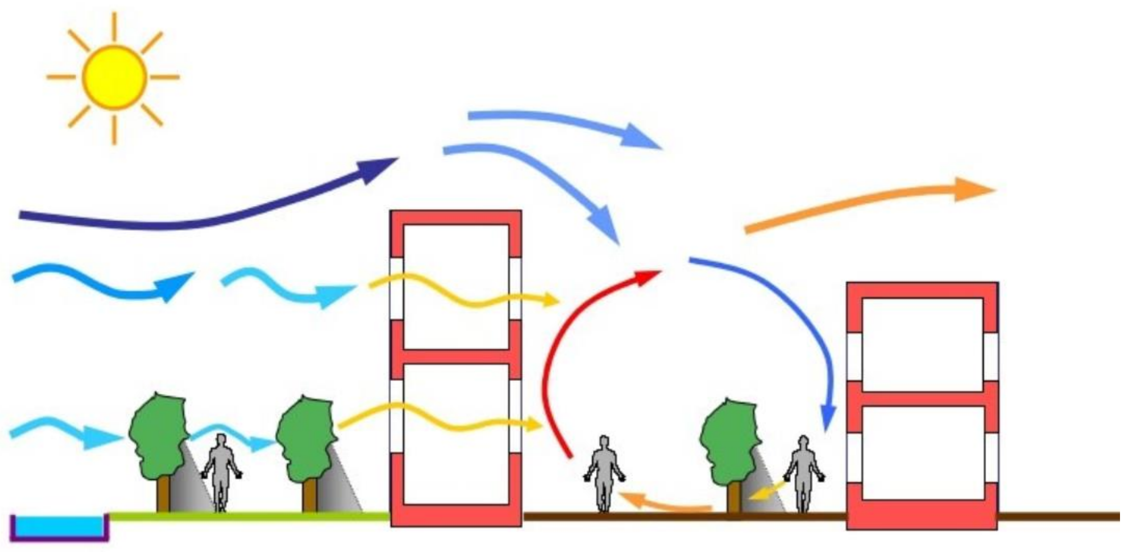


Fig. 3. Diagram of microclimatic phenomena around buildings on the example of street space; source: Carmeliet J. [23].

The interior of a building also constitutes an environment where complex thermal, humidity and aerodynamic processes occur. The course of these processes is heavily influenced by architectural and construction-related solutions (Fig. 4). Source literature on the topic provides the opinion that the building, and especially its facades, serve as the "third skin" of humans [1]. The primary skin is the natural one, clothing is believed to be the second skin, whereas the exterior of the building provides the third skin, as it separates human interior from its surroundings

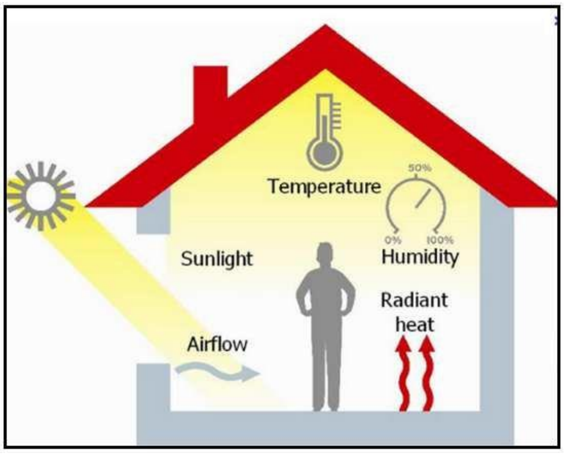


Fig.4. Diagram of microclimatic phenomena inside the building that affect the thermal comfort; source: Alwetaishi M. [22]

In contemporary architecture, two opposite approaches: technological and bioclimatic can be distinguished to the perception of the relationship between the interior climate of a building and external factors. In the 20th century, a technological approach emerged and was consolidated. The application of technology rendered the interior climate independent from natural conditions. The development of installation technologies made it possible to create the interior physical environment in an almost fully artificial way. In the case of this approach, architectural decisions regarding the building space, its location with reference to the surroundings and construction solutions applied fail to be climate-optimized, whereas the building envelope is constructed as a tight layer which blocks access to external factors. The comfort of the interior environment, including thermal comfort, relies entirely on installation systems (the so-called HVAC installations- heating, cooling, air condition). Such solutions are characteristic of buildings developed in the 70s, 80s and 90s of the 20th century.

The energy crisis that revealed itself in the 1970s, together with numerous problems related to the condition of the natural environment, as well as psychophysical condition of city dwellers resulted in a revision of this approach in favor of a stronger connection between building interiors and their surroundings and natural conditions. The so-called bioclimatic approach emerged as the concept that implements these connections to the fullest. According to the principles of the approach, the building interior microclimate should rely, as much as possible, on the potential of natural climatic factors (e.g., natural lighting, natural ventilation, use of solar energy gains, shading in heat seasons), whereas installations supplied by non-renewable energy that artificially create interior microclimate should be of limited use (Fig. 5). Thus, the external envelope of the building should be designed in such a way as to enable efficient use of favorable climatic factors and to provide protection against unfavorable conditions. This approach was characteristic of traditional architecture before the industrialization period, when humanity was much more closely associated with the natural environment. Nowadays, in order for this approach to be implemented, new solutions adapted to standards in force are required, as well as a larger scale of buildings and their increased complexity.

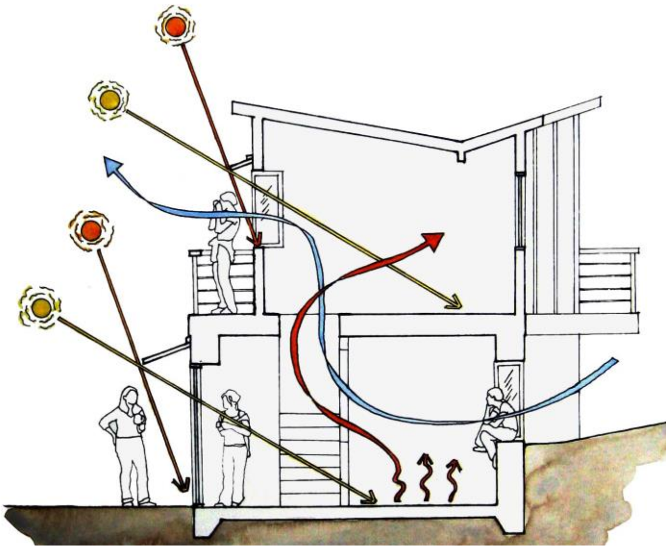


Fig. 5. An example of the bioclimatic approach in the selection of architectural solutions to ensure proper use of solar energy (warmth gains in cold periods, protection against overheating in hot periods) and natural cross-ventilation; source: https://ecocentricdesign.wordpress.com/2009/10/24/passive-solar-design/

Innovative research possibilities offer a better recognition of physical phenomena that occur on the scale of building development complexes and urban districts (Fig. 6). Correlations between smaller elements (such as buildings and their surroundings) and larger areas (including housing estates, districts) are becoming increasingly visible and tangible. Thus, the smaller components can be seen as part of the urban system that exerts influence on the city's climate and vice versa –is subject to climatic conditions characteristic for parts of the city, in which they are located [3]. Thus, the bioclimatic approach extends to the concepts of designing building development layouts and developing public spaces that surround them.

Perhaps, to use the abovementioned analogy to the successive "skins" that protect humans against external factors, the urban structure in which the building is located can be treated as the "fourth skin". Similar conclusions are formulated by Jan Carmeliet [23]. He points to the differences between the traditional building physics related to the physical phenomena (including thermal phenomena) that occur within the building boundaries and the multiscale building physics related to building blocks, entire districts, and cities (Fig.7). The latter aspect is more complex and, thus, has been much less recognized. However, its importance is becoming obvious regarding measures to improve city climate and life quality for inhabitants.

Implementing the bioclimatic design approach on an urban scale remains rather uncommon. Such an approach requires considering various previously overlooked criteria. Moreover, developing new planning procedures and principles for cooperation between participants in investment processes is essential. Such attempts have been observed in countries most focused on ecological goals and sustainable development (e.g., the Netherlands, Denmark, Germany). In Poland, the bioclimatic approach is being signaled by means of various postulates and programs, but so far, it has not been applied in practice.

Fig. 6. Diagram of a bioclimatic approach to designing a city district; source: Raven J. [3].

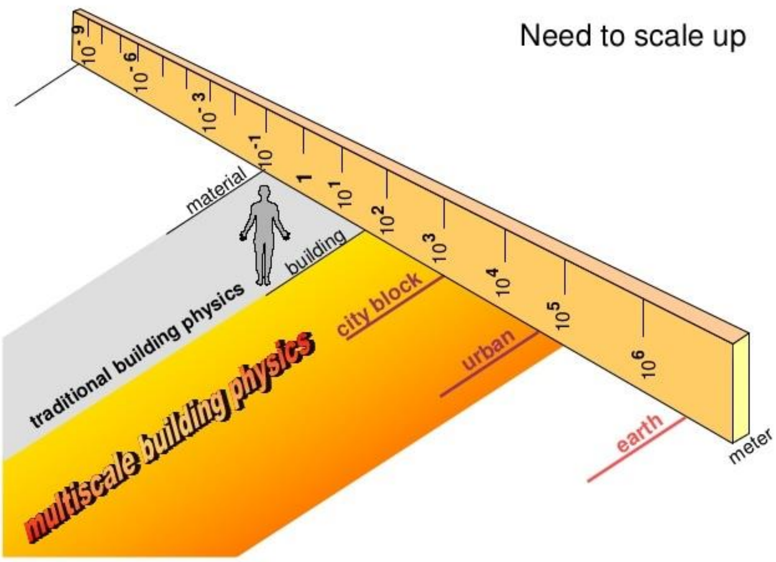


Fig. 7. Multiscale building physics as a need for modern climate science; source: Carmeliet J. [23].

1.4 Urban and architectural factors that influence thermal comfort

Urban and architectural factors that affect thermal comfort of building interiors and urban spaces can be divided according to the scale of design activities - from the most general ones, that is those concerning the scale of the entire city, to the most detailed ones related to construction solutions applied in buildings. This is due to the differentiation of 3 scales of the city climate [4]: mesoclimate, local climate and microclimate (Fig. 8).

On the basis of the above, it is possible to determine the dependencies between climate scales, starting with the climatic zone, through individual levels to the building indoor climate. Furthermore, it is possible to assign various types of design to these climate scales - from spatial planning of larger areas, through urban and architectural design, to interior design (Fig. 9). Each of these design scales corresponds to specific groups of solutions which result in the phenomena that shape thermal comfort inside buildings and in the vicinity thereof.

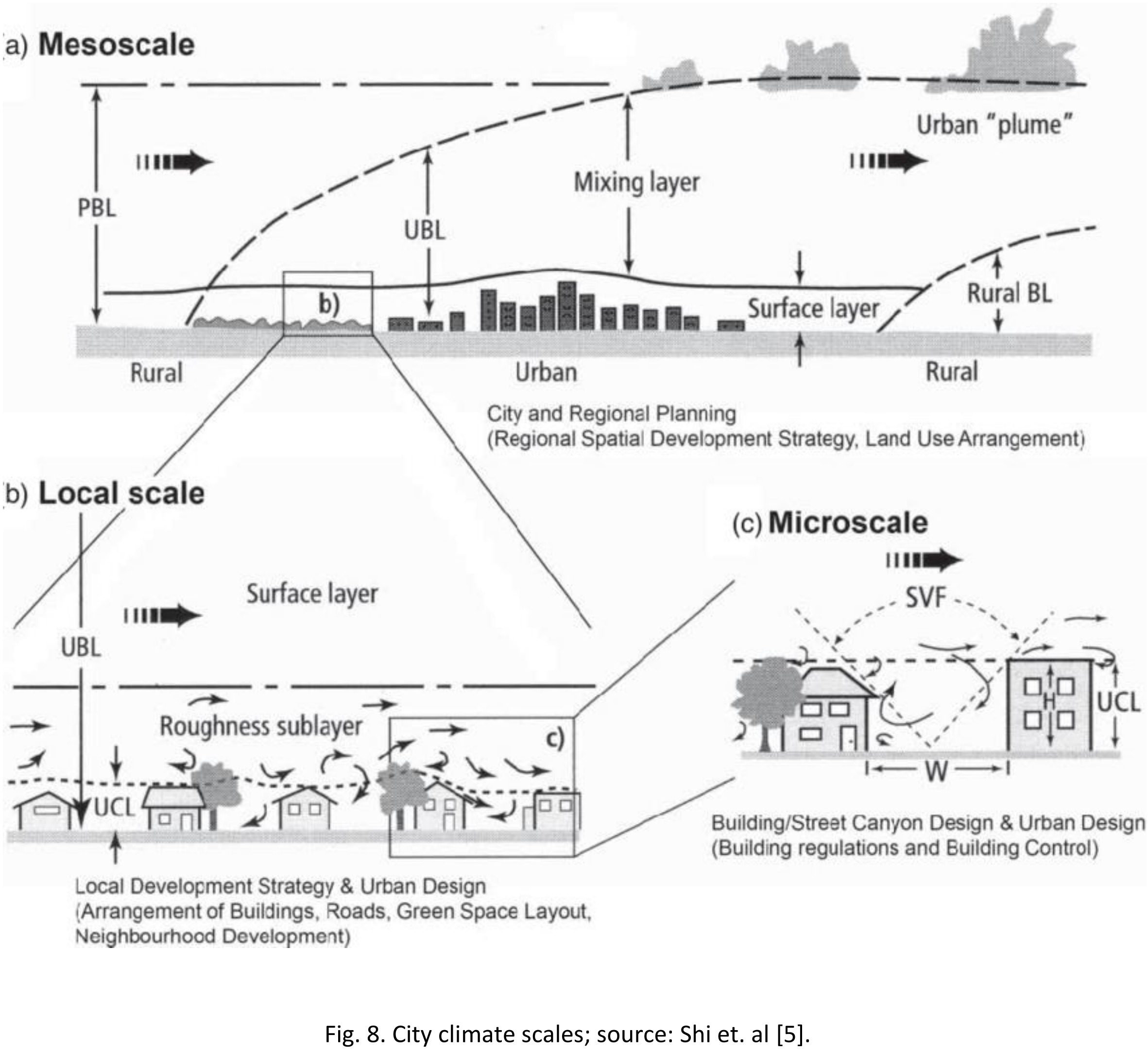


Fig. 8. City climate scales; source: Shi et. al [5].

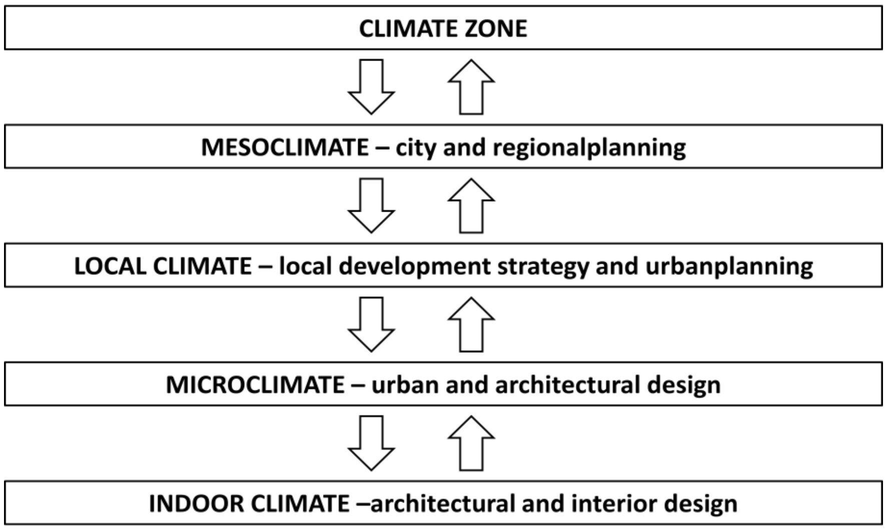


Fig. 9. Climate scales and respective scopes of urban and architectural design; author's own study.

1.4.1 City mesoclimate scale

Among the factors that influence energy flow (including thermal phenomena) on the scale of the city as a whole are, the following should be mentioned:

1. City size and population – densely populated cities that occupy large areas are energy-intensive and emit relatively substantial pollution and waste. Moreover, significant amounts of thermal energy are generated by them.
2. Traffic intensity and industry – these two city structure elements play a significant part in pollutant and heat emission. In the early twentieth century and mid-twentieth century, the industrial sector was more harmful than it is currently. Transport began to contribute more to the climatic problems of urbanized zones owing to the transformation of industry (lighter technology, increased pollution reduction requirements), together with the expansion of cities and the increase in their populations at the end of the 20th century.
3. Amount and layout of water and wind permeable areas and greenery – these undeveloped and biologically active areas balance the overheating, insufficient ventilation, and the accumulation of pollutants in urban areas. Their effectiveness depends on the share of biologically active areas in relation to built-up ones (the higher the ratio, the more effective such zones are). The geometric layout of biologically active areas also impacts their effectiveness. They must form a continuous, uninterrupted system; the layout should be distributed fairly evenly throughout the city, with account to the prevailing wind directions.
4. Building development density – the more buildings, the higher and closer to each other, the greater pollution and heat emission per unit area. A reduction in air movement occurs in such areas. Moreover, densely built-up areas lack space for greenery and water-permeable areas. It is also more difficult to provide buildings with natural sunlight. In general, a simple correlation can be noted between building development density and the urban heat island effect intensity.

In the case of Warsaw, criteria 1, 2, and 4 pose threats related to the city climate quality, also regarding thermal stress. The share of built-up areas in the central zone of the city amounts to 75-100%; in the case of the western peripheral districts, the ratio equals 60-75%, whereas, in the northern, eastern, and southern Warsaw, built-up areas cover 30-60% of the total (Fig. 10,11). However, the city has a great advantage in the fulfillment (although not to the full extent) of criterion 3. Warsaw is one of the few large Polish cities equipped with a clear system of open spaces that act as aeration corridors. The concept of a system of aeration corridors, created in 1916, is an example of a design decision on the city's mesoclimate scale. The corridors are of fundamental importance for the climate of Warsaw. The concept was initiated by Tadeusz Tołwiński as part of *Szkic Planu Regulacyjnego Warszawy /the Draft Regulatory Plan of Warsaw* [24]. At that time, Warsaw was much smaller in territory than it is nowadays; the Draft was created when the need to develop new districts emerged, whereas the city's territorial expansion began. The Draft contained a concept for the spatial development of Warsaw for the following decades. The system of corridors was intended to separate new districts from each other, thereby creating recreational facilities for their inhabitants. The natural topography (including the Vistula riverbed) and naturally valuable areas were incorporated into the concept (Fig. 12,13).

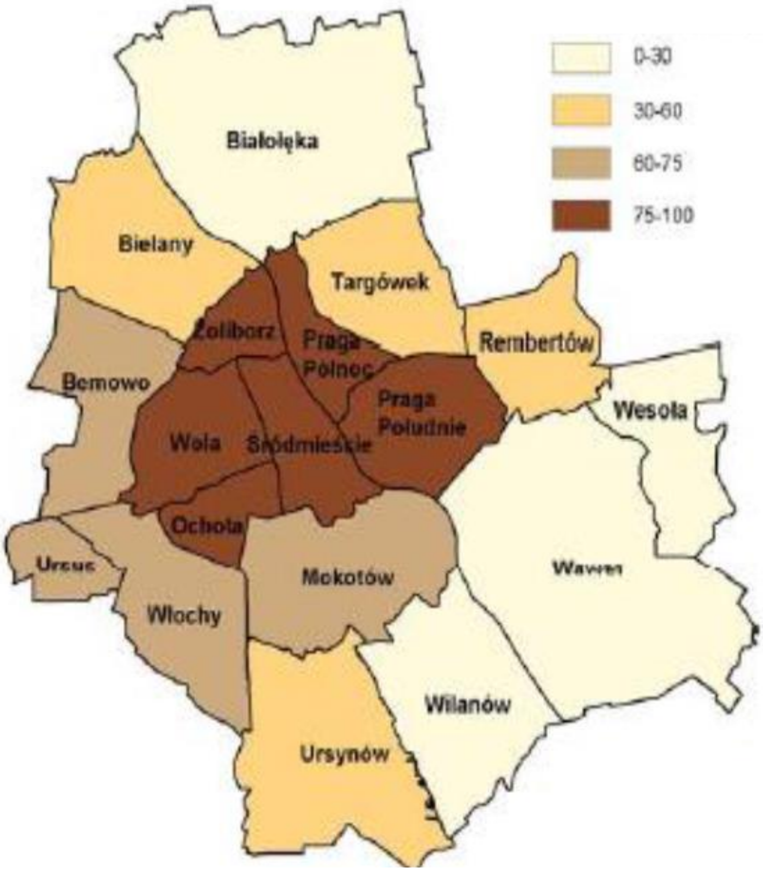


Fig. 10. Built-up and paved areas in Warsaw given in% in relation to the total area of districts; source: [9].

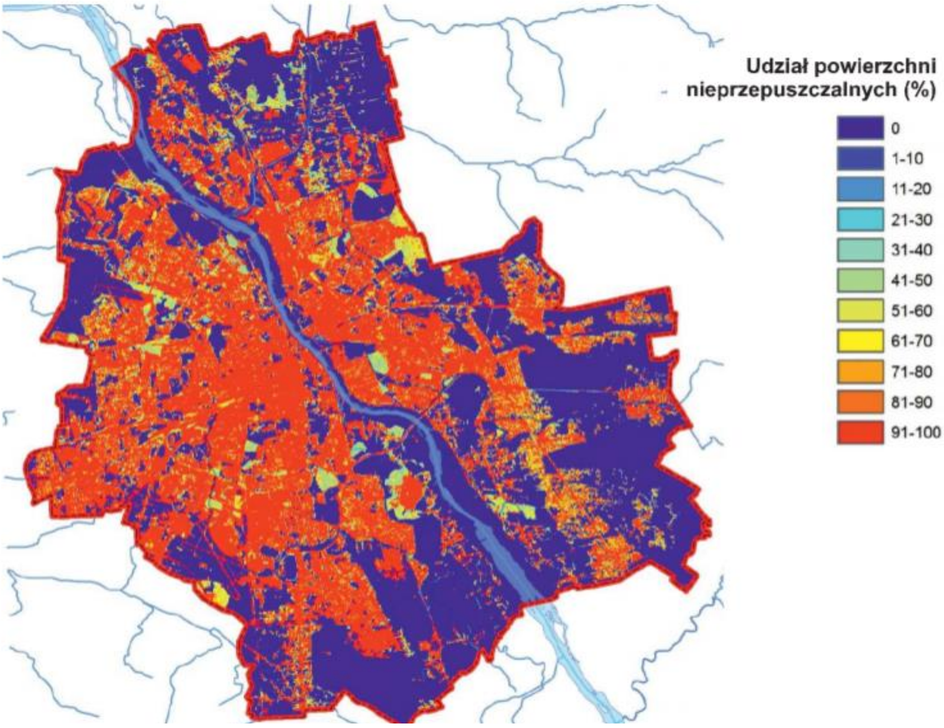


Fig. 11. Water impermeable areas in Warsaw given in%; source: [11].

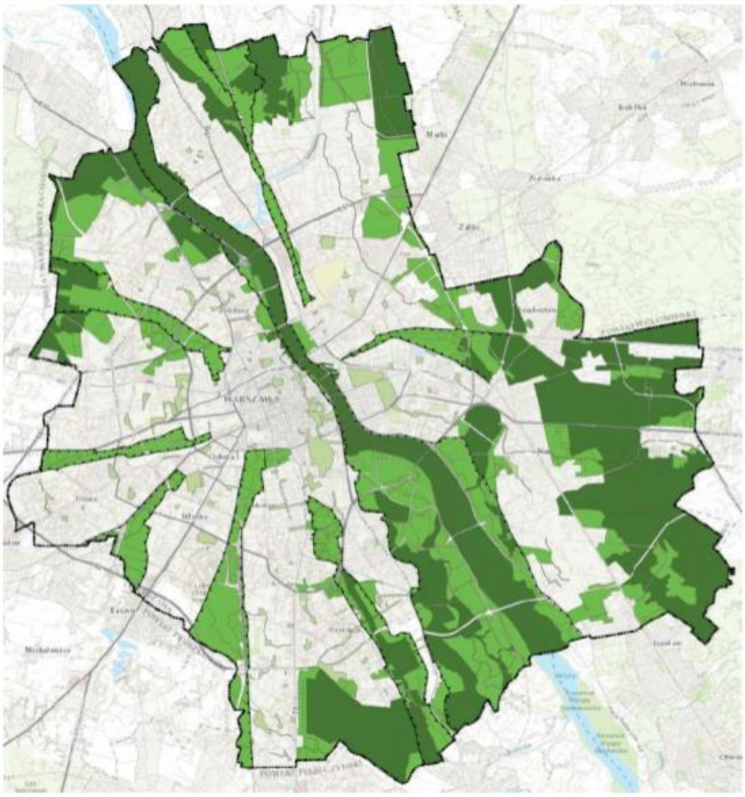


Fig. 12. The layout of the main green area system in Warsaw (dark green: basic areas, light green: supporting areas); source: [11].

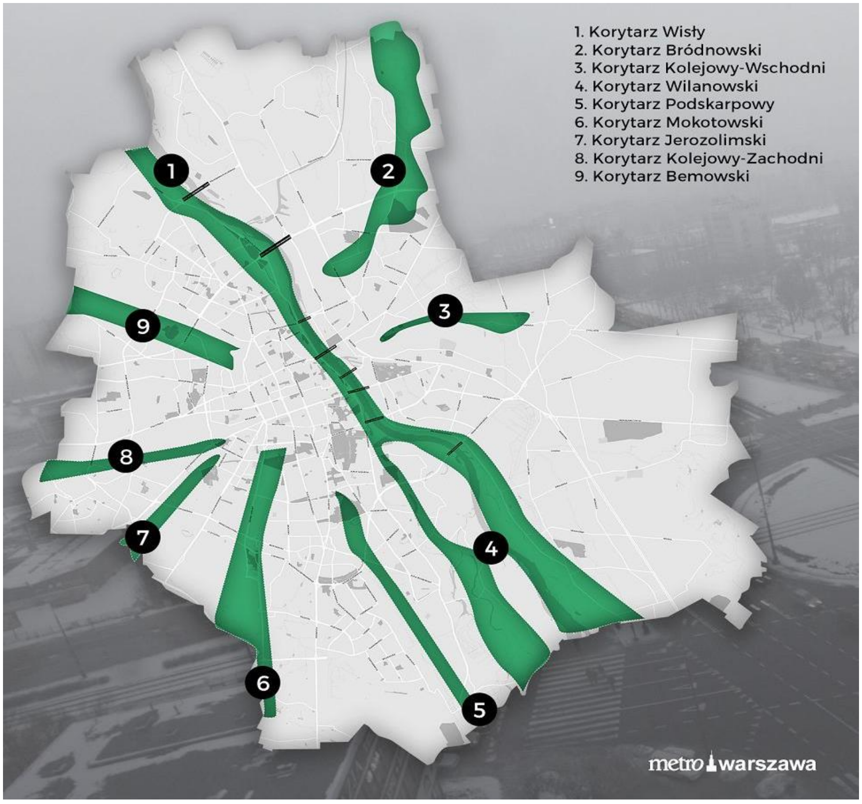


Fig. 13. System of aeration corridors in Warsaw; 1 - Vistula Corridor, 2 Bródno Corridor, 3 - Eastern Railway Corridor, 4 – Wilanów Corridor, 5 - Under Escarpment Corridor, 6 - Mokotów Corridor, 7 – Jerozolimski Corridor, 8 - Western Railway Corridor, 9 – Bemowo Corridor; source: https://www.google.com/search?q=korytarze+napowietrzaj%C4%85ce+warszawy+metrowarszawa&client

For climatic reasons, the geometric layout of this system is characteristic and highly favorable. The pattern of radially arranged undeveloped areas of greenery provides a path for air inflow from the outer areas to the center. It is caused by local winds or, on windless days, by urban breezes (the period of winds at low velocities and atmospheric stillness in Warsaw reaches up to 1/3 of the year).

In the 1990s, the aeration corridors were freed from administrative protection of agricultural land. Since then, they have become the most attractive locations for housing investments. Discussions have been ongoing on the actual effectiveness of aeration corridors and possibilities of limiting it. The system, although already depleted, is still protected by *Studium uwarunkowań i kierunków zagospodarowania przestrzennego Warszawy* / *the Study of the Conditions and Directions of Spatial Development in Warsaw* and remains the main system of open areas of natural value (Fig. 9).

1.4.2 Local climate area

Factors that influence energy flows (including thermal phenomena) on the scale of local climate (e.g., parts of the city, districts or housing estates) include:

1. Distance from the center and suburbs – the city center tends to be the area with the highest pollutant and heat emission; it is the most densely developed, with limited biologically active areas. Therefore, the phenomena related to the urban heat island are intensified there. Suburban areas are much cooler, better ventilated, and less exposed to air pollution. Thus, the closer to downtown, the greater the risk of poor local climate quality.
2. Distance from large green spaces or water reservoirs – such areas heat up much slower than densely developed and paved ones; therefore, they act as a local cooling system for the surrounding areas in the hot seasons. The larger the green area or the water reservoir, the stronger the local balancing effect regarding the urban heat island phenomenon.
3. Building development density, type of buildings (function, shape, height), and geometry of their configuration – in densely built-up areas, greater problems with heat accumulation during hot periods occur. This is especially visible when a large share of the building development comprises high thermal load buildings, which results from their function (e.g., service and industrial buildings belong to this group; energy-intensive buildings emit large amounts of heat). The shape of building development is also important. Even at a similar intensity, the building geometry may be favorable to a greater or lesser extent due to the ventilation possibility (e.g., closed building development layouts are problematic in this respect).
4. Amount and type of greenery (trees or lawns) – as in the case of the mesoclimate, greenery positively balances climatic phenomena on a local scale. Generally, the larger the greenery-covered area, the greater its effectiveness in this respect. However, the type of greenery is also important. Tall greenery in the form of large, mature trees proves more beneficial, especially in terms of mitigating thermal stress, than low greenery, e.g., in the form of lawns or flower beds.
5. Balance of hardened and water-permeable surfaces – hardened surfaces, e.g., roadways, pavements, squares, especially those fully covered with asphalt or dark-colored concrete materials, accumulate thermal energy. Thus, they contribute to the intensification of the urban heat island phenomenon. In addition, such paving completely blocks the water penetration. Not only does this aspect hinder proper water circulation in the city, but it also indirectly aggravates the thermal stress issue. Thus, the more space unoccupied by buildings that remain unpaved, the more advantageous the situation is to protect against excess heat.

The differences in these elements of the city structure are visible in the photos from the Google Maps portal. The photographs present parts of two Warsaw districts, namely Mokotów and Śródmieście (Fig.14). Mokotów is located in the vicinity of open greenery areas (part of the aeration corridor system), the building development is of medium intensity and is composed of a system of simple solids open to wind flow. The city downtown is almost devoid of greenery and unpaved areas. The building development is very compact, formed into layouts with internal courtyards closed to the airflow. Therefore, Mokotów is provided with much more favorable urban conditions that may likely influence the urban heat island phenomenon intensity and the risk of thermal stress. The significance of the abovementioned factors is confirmed by studies on individual districts of Warsaw described in [6] and [7].

Fig. 14. Elements of the urban structure of the Mokotów and Śródmieście districts; source: Google Maps

1.4.3 Micro-climate scale

Among the factors that influence energy flow (including thermal phenomena) on the scale of micro-climate, the following should be mentioned

1. Building Form and their geometric correlation with each other and with the Sunpath – the geometry of buildings influences the solar radiation distribution. Certain parts of the ground wall surfaces remain in the shade, whereas others are exposed to the sun. Thus, different parts of the same area heat up differently within the same period. Furthermore, building geometry plays a vital role in the wind flow. The areas that are excessively wind-protected by buildings tend to be poorly ventilated and prone to overheating.
2. Greenery areas and water reservoirs in the vicinity of buildings (also green roofs and vertical gardens) – even small greenery areas and water reservoirs prove advantageous for microclimate improvement. Especially valuable elements include trees located at favourable distances from buildings and places where people stay outside (trees shade buildings in summer; whereas in winter, when the leaves have fallen, trees do not obstruct solar radiation access). Green roofs or facades are justified in case of no space for greenery on the ground.
3. Type of surface around the building (hardened or permeable to water, greenery) – regarding the thermal stress issue, hardened surfaces close to the building, and especially nearby the windows, are less advantageous than greenery-covered surfaces. This happens due to the high heat accumulation capacity of hardened surfaces. Hardened surfaces near the windows reduce the building's natural ventilation effectiveness.
4. Color of walls and pavements and their ability to reflect and absorb solar radiation – in general, light colors in finishing materials are preferable due to their lower energy absorption properties. Also, highly reflective materials should be avoided.

Microclimatic phenomena occur in the immediate vicinity of buildings and are among the strongest factors that impact the physical environment in building interiors. Phenomena that emerge in tight and spatially complex building development layouts are multifaceted and, as such, pose the greatest difficulty to predict. Particularly in the case of dense building development (Fig.15), local situations when overheating occurs can be expected, e.g., excessive wind exposure or a negative greenery balance.

Fig. 15. A part of a new housing estate implemented by the developer in the Mokotów district,; high intensity of building development and partially closed layout, not very favorable from the point of view of smooth ventilation, source Google Earth.

1.4.4 The scale of the building interior climate

Among the factors that influence energy flow (including thermal phenomena) between the building and its surroundings, the following should be mentioned:

1. The building form and its solar exposure – depending on the building's shape and arrangement regarding the directions of the world, its different zones heat up and cool down differently at different times of the year and day. Generally, in Polish climatic conditions, compact building forms that open to sunny sides are more favourable (they cool down less during heating seasons). Such forms minimize heat loss, although the risk of overheating in summer occurs. It is, thus, advisable that seasonally shading elements are introduced to the building.

2. Spatial layout inside the building, layout of rooms designated for various purposes, area and height of the rooms – according to the principles of bioclimatic design, the rooms should be grouped into zones. Moreover, they ought to be properly located in relation to the directions of the world. Rooms that require considerable amounts of daylight and heat (e.g., living rooms in flats) should be exposed to the south or a similar direction. In contrast, rooms that demand less demanding daylight (e.g., bathrooms, wardrobes) or emit heat (e.g., kitchens) should be implemented towards the north or a similar direction. It is also more advantageous when rooms with larger surfaces and heights have better solar exposure (during heating seasons, they are heated up by solar energy; however, in the summer, the process of overheating may pose difficulties). Small and low rooms should not be exposed to the sun due to the high risk of overheating.

3. Building technology (material and thickness of the walls and slabs – thermal mass) – thermal mass) - buildings erected in heavy technologies (e.g., made of brick or concrete) are

characterised by high heat accumulation capacity. Therefore, they heat up slower than those in light technologies (e.g., steel or wooden frame).

4. Thermal insulation of building envelope – the thermal insulation coefficient for external walls and roofs U [W/m2K] is important in protecting the building against energy loss during heating seasons and summer overheating. In Poland, the value of this ratio is regulated by law. To meet modern requirements, adding a layer of thermally insulating material (e.g., polystyrene, mineral wool) to the structural wall (e.g., brick or concrete) is necessary.

5. Internal thermal loads - various rooms in a building can heat up to various extents because of the heat emitted inside them. Rooms with large thermal loads include those with heat emitting devices (e.g., kitchens) or those in which people are physically active (e.g., sports rooms).

6. Windows area and solar exposure thereof – solar energy penetrates through glazed surfaces differently than through solid walls. Windows have worse thermal insulation parameters than a wall, so the more passages in a building, the greater the heat loss in heating seasons (it is particularly unfavourable to locate large glazing from the north). At the same time, the greenhouse effect makes it possible to obtain thermal energy from the sun, which can compensate for heat losses in the transitional seasons (given the windows have proper solar exposure). In summer, the greenhouse effect can, in turn, lead to room overheating.

7. Glazing parameters – by selecting these parameters carefully, it is possible to vary the amount of total solar radiation energy to the interior or to select specific ranges of this radiation (for example, the thermal radiation inflow may be reduced without losing the inflow of light energy).

8. Sunshading elements - they protect buildings against excess heat, especially in the case of glazing. External environmental elements (e.g., trees, other buildings), the building's elements (e.g., balconies, galleries, strongly protruding roof eaves), or specially designed systems installed outside the building (e.g., blinds, roller blinds, awnings) can serve sun shading purpose.

9. Ventilation efficiency – in residential buildings, rooms are ventilated through windows and ducts of gravity vent chimneys. In the case of high-rise buildings, they need to be supported with mechanical systems. Well-ventilated apartments, i.e., those with windows on different building walls (rather than one side only), are less prone to overheating. In their case, the heated air in the summer may be removed by opening the windows "wide open" at night when the outside temperature is lower.

10. Cooling devices – these are applied to cool rooms down. However, the more susceptible the room is to overheating (e.g., a kitchen with large windows not sheltered from the sun), the more energy is needed to cool it down. As a rule, residential buildings are not equipped with cooling installations (unlike, e.g., office buildings, commercial buildings, sports buildings, i.e., those with higher thermal loads). However, apartment users often install such devices at their own expense to improve thermal comfort in summer.

In conclusion, the group of factors that influence thermal conditions inside buildings and in their surroundings (including the issue of overheating) comprises numerous issues and is subject to various design decisions at all design stages. These can be divided into:

1. urban planning solutions –the following elements are subject to optimization with the view to thermal phenomena: spatial layout of building complexes and their orientation in relation to the surroundings, building development intensity, proportions between developed and open areas, distribution and selection of greenery, ratio of water-permeable areas, surface hardening materials;

2. architectural solutions - the following elements are subject to optimization with the view to thermal phenomena: the building form and its orientation in relation to the surroundings, the distribution of functions within the building, the layout of internal spaces (depths of utility routes, atriums, solar chimneys), the ratio of glazing and its location on the facades, elements of the surroundings around the building (hardened surfaces, greenery, shading installations), colors

3. construction-related solutions - the following elements are subject to optimization with the view to thermal phenomena: materials used in building the construction (e.g., their heat accumulation properties) and internal and external building finishing elements (color; properties in terms of solar radiation reflection and absorption), thermal insulation materials, glazing parameters.

4. installation-related solutions – such solutions can support natural phenomena that take part in regulating the interior climate (e.g., hybrid ventilation) or can create the climate in an artificial way (e.g., mechanical ventilation, air conditioning).

In order to apply the pro-ecological approach, it is required to compare the effectiveness of individual solutions, together with the assessment of their ecological footprint. According to this approach, the potential of passive, simple solutions (e.g., rational spatial design, materials and solutions with a low share of advanced technologies) should be used in the first place, and supplemented with more advanced or active systems (e.g., air-conditioning).

The above division into groups concerning project activities on many different scales suggests a model to achieve sustainable solutions (beneficial to the users, economical, and with the smallest possible environmental footprint). This model is commenced at an urban-planning scale; it leads through an architectural design level to the construction and installation solutions (from general to detail). However, in practice, implementing such a model is extremely difficult. It may even be deemed impossible for various reasons (e.g., the possibilities to modify the urban tissue are limited; the investors' interests fail to account for all environmentally and socially important issues; planning procedures are not adapted to such a model). The most common response to environmental problems is sought by reaching for easily-implemented solutions. These usually include installation solutions, i.e., the ones included in the final design phase (4). In the case of the room overheating issue, the installation of cooling devices may be seen as such a solution (the effect is achieved immediately). Installation of cooling devices is the least environmentally appropriate solution. Meanwhile, in well-designed housing estates and well-designed (or modernized) houses, overheating might not occur at all.

It is uncommon nowadays to implement the abovementioned solutions to their full scale and, importantly, to such a systematic combination of these solutions that they complement each other. In this respect, the greatest achievements have been made by countries that focus on environmental goals (e.g., Denmark, The Netherlands, Germany). These countries comprise examples of new or modernized districts and housing estates where a wide range of pro-ecological solutions have been implemented from an urban-planning level to a technological scale. In large Polish cities, including Warsaw, modern buildings (erected towards the end of the 20th century), installation, and construction solutions are well implemented. However, architectural solutions are given much less thought, whereas the urban-planning scale solutions are implemented poorly. In buildings from the second half of the 20th century, architectural and urban-planning solutions are introduced to a far more advantageous extent. This is due to the emphasis on the "healthy" city concept. At the time of their erection, the idea constituted the prevailing doctrine of modernism that the communist authorities supported (as a reaction to the poor health conditions of early industrial cities in the early 20th century). However, the technical quality of these buildings (including, for example, thermal insulation of walls, glazing parameters) proves far worse than that of currently-erected buildings. Concerning overheating in multi-family buildings in Warsaw, these issues are further developed in the following chapter.

Chapter 2- Typology of residential buildings in Warsaw. Overheating risk aspect

2.1 Basic criteria

The present study is primarily intended to create an appropriate typology of multi-family building development in Warsaw, in terms of assessing the risk of overheating building interior and their immediate surroundings. With account to the overview of factors that influence thermal issues presented in the previous chapter, basic criteria for this typology have been selected. These include as follows:

• building's parameters in terms of thermal insulation for external partitions.

• building technology and selected architectural solutions thereof.

These factors are among the issues that most strongly influence thermal processes inside buildings. This provides the focus of the EmCliC research project. At the same time, these factors allow for the identification of coherent features of the structure and their arrangement into groups in a comprehensible manner.

2.1.1 Thermal insulation properties

In accordance with legal regulations in force in Poland, thermal insulation of building partitions is expressed with the U-value (thermal transmittance) parameter. The U-value for walls and roofs [W/m2K] measures the efficiency of a material as a thermal insulator. The lower the U-value, the greater the capacity of a wall (or roof) to limit heat flow between the inside and outside of the building. This feature proves to be of particular importance in order to provide a building with protection against heat loss during heating periods (as mentioned above, in Polish climatic conditions the feature is an important goal).However, as evidenced by numerous studies, thermal insulation of partitions also protects the interior against excess heat. In Poland, the requirements for the U-value have changed over time. They were first introduced in 1967.Since then, along with the development of the ecological approach, the requirements have gradually been strengthened (Tab. 1).

Tab. 1. The progression of the regulations concerning U-value in Poland

	Period	**U [**W/m2K]
1	Prior to 1967	no requirements (1,16-1,4)
2	1967-1985	1,16
3	1986-1992	0,75
4	1993- 2002	0,55
5	2003-2013	0,3
6	2014-2017	0,25
7	2017- 2020	0,23
8	2017- 2020	0,2

It should be taken into account that the dates provided above represent the year in which the provisions to regulate the U coefficient requirements entered into force. This means that after that date, all projects submitted to the office with a view to obtaining building permit were expected to meet the above-defined requirements. The actual building commissioning date was set at a later due date. For multi-family buildings, the difference between the two terms can be estimated at 2 years. This means that, for example, a building erected in 2003 meets the U-value requirements that were in force two years earlier, i.e., in 2001. Therefore, the U-value of its walls is 0.55, rather than 0.3 W/M2K.

The dynamics of changes introduced to the U-value requirements is shown in the diagram, Fig. 16 (the aforementioned difference resulting from the duration of the construction process was excluded). It can be assumed that the requirement coincides with the tendency of room overheating risk in these buildings. Yet, the requirement should be adjusted on the basis of additional criteria, as described further in the present study.

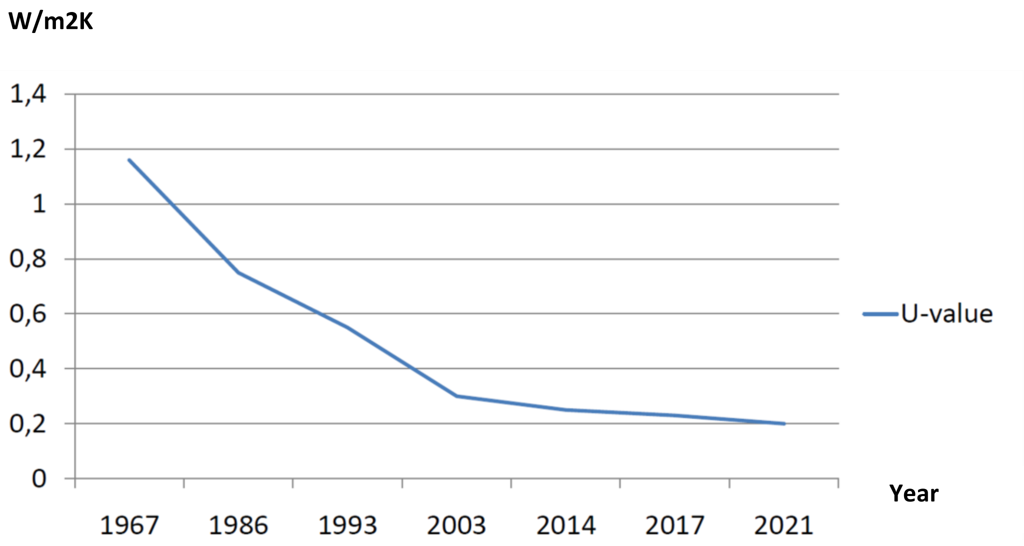


Fig. 16. U-value requirements in Poland; source: [8].

Notably, it must be mentioned that some of the buildings have been subject to thermal modernization by having a layer of thermal insulation added on the walls and roofs. In the case of masonry walls and reinforced concrete flat roofs, fixing a layer of expanded polystyrene on the outside of the building proves the most popular insulation method (Fig. 17). In the case of wooden roofs, mineral wool is placed between the beams and below them.

Due to the above dynamics of changes in the U-value requirements, it is impossible to assume that all thermally insulated buildings meet the same requirements in this respect. For example, the walls of buildings modernized in the 1990s (the first wave of thermal insulation to the walls of existing buildings) are characterized by U = 55 W/M2K, which is much weaker than the currently required ratio. The walls of modern buildings should be adapted to the requirements of U = 0.2 W/M2K.

Fig. 17. The most popular method for wall thermal modernization in multi-family buildings in Poland.

2.1.2 Construction technology

Building technologies have been developed over time. In the history of construction in Poland, breakthrough technological changes may be specified, which have constituted milestones in development. 5 groups of multi-family buildings with different construction technologies may be distinguished. In addition, features related to architecture and urban-planning characteristic of the given period, as well as the requirements for maximum U-values for external walls were correlated with the 5 selected groups. A similar typology can be found in the study prepared by Narodowa Agencja Poszanowania Energii [the National Energy Conservation Agency], in 2011, as part of the Tabula project co-financed by Intelligent Energy Europe. The study is entitled *Podręcznik typologii budynków mieszkalnych z przykładami działań mających na celu zmniejszenie ich energochłonności* / *Typology of residential buildings with examples of measures to improve energy consumption* [8]. The typology proposed in the abovementioned study is of more complex nature, whereas it only includes technological aspects. For the purposes of the EmCliC project, a simpler division has been suggested. The latter differentiation seems more appropriate as the basis for a typology with which the inclusion of other aspects important for the project could be made. The provided dates should be treated as approximate. These include:

1. until 1945 – historical architecture - historical technologies, massive brick walls, no thermal insulation requirements, wooden roofs with non-residential attics, no large windows, high ceilings (Fig. 18)

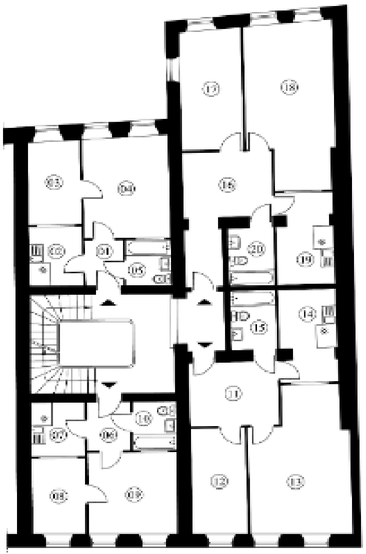
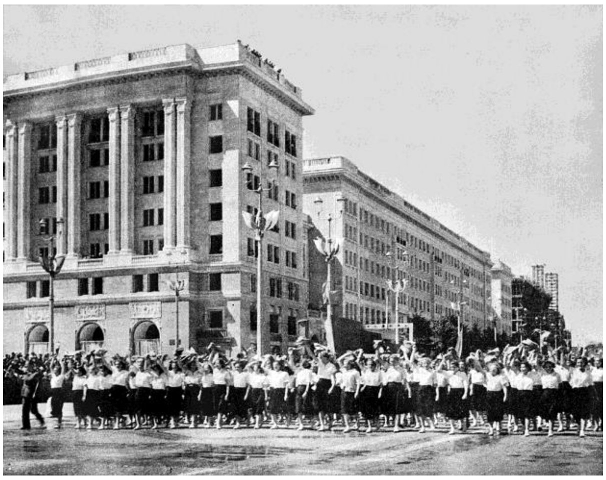


Fig. 18. View and layout of a historical tenement house, Piwna street, Old Town, Warsaw

As a rule, buildings that originate in this period fail to be modernized in terms of wall insulation, owing to their historical value. An additional outer layer of insulation would cover the decorative elements of the facade, which is rendered impossible by the heritage conservator. Such buildings are marked with high level of energy consumption during heating seasons. Regardless, it is difficult to obtain thermal comfort in them during this time. However, they prove resistant to overheating in summer due to the high thermal mass of the walls, considerable room heights and relatively small windows. The risk of overheating may affect loft appartments that have been adapted for residential purposes in the second half of the 20th century. Thermal insulation of the roof was fitted from the inside of the rooms; thus, the thinnest possible layers were aimed at in order not to lower the room heights. The surroundings of the buildings may also prove problematic. Historic streets tend to be rather narrow, fully paved and devoid of greenery. Therefore, surfaces receive considerable amounts of heat during hot days, which intensifies the urban heat island phenomenon.

Typical Warsaw buildings of historical value are located mainly in the Old Town, as well as in other parts of Śródmieście, but also in the oldest parts of Wola, Ochota and Praga districts. Original buildings constitute a small part of these constructions, especially in the Old Town which had been destroyed in World War II and rebuilt immediately afterwards. The structures maintain their historical features, also in terms of technology.

2. 1946 ~ 1966- reconstruction of war damages and new estates with the use of demolition bricks, cheap, economical construction, not as massive as historical technologies had been, no thermal insulation requirements, larger windows, lower ceilings, smaller apartments (fig. 19).



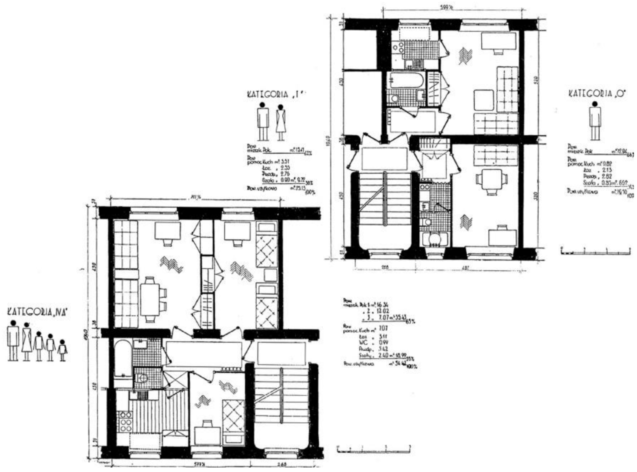


Fig. 19. On the left - the socialist-realist MDM housing estate (Śródmieście), on the right - typical schemes of apartments from 50ths

Buildings constructed in that period come in the form of socialist-realist and modernist housing estates. As in the case of historical buildings, these estates also largely fall under protection of the heritage conservator. Thus, it is difficult to provide them with thermal modernization. In terms of heating, socialist-realist buildings are mainly energy-intensive. In terms of thermal comfort in summer, they prove unfavorable, as their structures entail the risk of overheating. This results from the fact that the structures of that period are less massive than historic buildings. However, buildings of both periods are alike in that they lack thermal insulation.

Buildings erected in the socialist period are located mainly in Śródmieście (socialist realism). Thevurban context in their case is rather unfavorable in terms of microclimatic conditions, due to the high intensity of building development and a very low ratio of unpaved, biologically active areas. Buildings that originate in this period are also located in the districts surrounding Śródmieście, e.g., in SaskaKępa (PragaPołudnie), Żoliborz, Bielany, Mokotów (the modernist style predominate among them). In these areas, however, the development enjoys a slightly better urban situation.

3. 1967 ~ 1989- prefabricated, large-panel prefabricated construction, walls of concrete or porous concrete (15-20cm thick), simple blocks, large windows, balconies, low ceilings (2,4m), small rooms, low quality of technology, especially connections between prefabricated elements, external walls with poor thermal insulation (U = 1, 16 and 0,75 from 1986), (Fig. 20).

The abovementioned dates are of approximate nature. The beginnings of prefabricated construction date back to the first half of 1960s, but it evidently thrived in the second half of this decade. Prefabricated buildings (mostly assembled of large-panel prefabricated structures, although prefabrications of smaller elements or mixing prefabricated elements with brick masonry technology were also used) fail to be very resistant to overheating in summer. Their structural elements are thin, not too massive, whereas the cubature of the rooms is small. Owing to these factors, such buildings heat up rapidly. This problem may apply, in particular, to flats that face intense solar radiation (on western, but also on southern facade) and flats on the top floor (due to poor thermal insulation of the roof). The advantage of this type of buildings lies in the fact that, being simple solids with no additional details, they can be relatively easily modernized. A large part of the housing stock from this period has already been subjected to renovation. The cost of the works is borne by housing cooperatives, so poorer association may not able to undertake such activities.

While the construction technology in which these buildings were erected is assessed critically in retrospect (not only with reference to overheating), their urban-planning context offers numerous advantages, also from the point of view of thermal comfort. In housing estates built in that period, the distances between individual buildings are usually quite large, which favors efficient air exchange by means of winds. Moreover, those estates tend to be accompanied by vast areas of greenery, which favorably influence the microclimate around the buildings.

In the 1960s, 1970s and 1980s, a large part of housing estates was erected in Warsaw. Some of these complexes were built in the close vicinity of Śródmieście as buildings to supplement the existing building development (Żoliborz, Wola, Ochota, Mokotów, Praga, Targówek), whereas other estates emerged as large new residential districts (Ursynów, Włochy, Ursus, Bemowo, Bielany, Rembertów, Wawer) that occupy Warsaw outskirts.



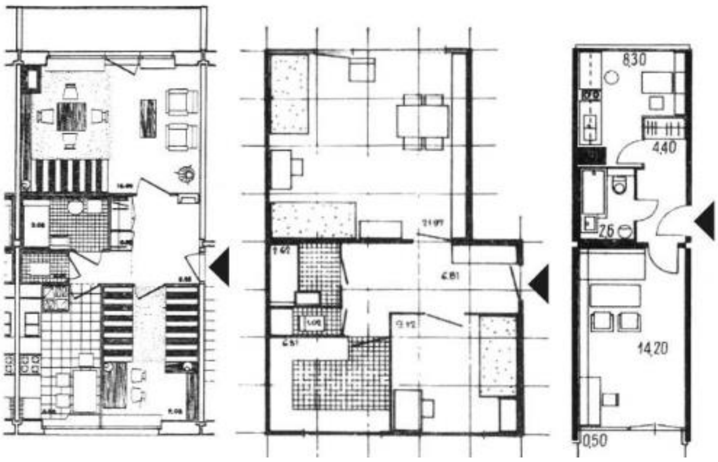


Fig. 20. On the left - the construction of prefabricated buildings, on the right - Jelonki housing estate (Bemowo district), at the bottom - typical layouts of flats from the 1970s

4. 1990 ~ 2002 –more diverse technologies, rather than prefabrication, walls made of ceramic and porous concrete blocks with thermal insulation, large windows, balconies, higher ceilings (2,5-2,7m), larger rooms, more complex forms, requirements for thermal insulation – U = 0,55 W/m2K (Fig. 21)

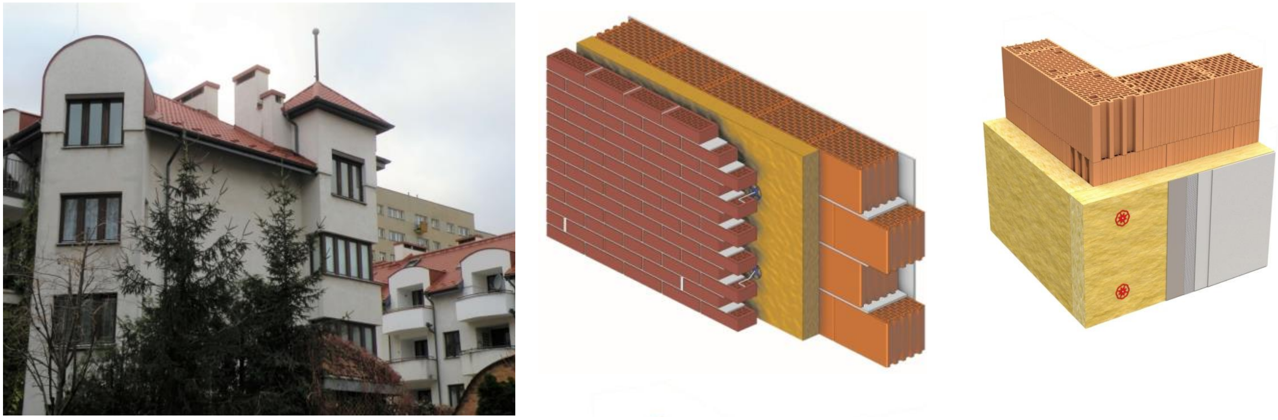


Fig. 21. On the left - an example of a multi-family building erected in the early 1990's, postmodern style, on the right - diagrams of a wall structure with three-tier and two-tier thermal insulation.

In the 1990s, the political system transformation in Poland began, which turned Poland from a socialist country to a democratic free market economy. Large housing cooperatives that used to erect new housing estates began to disappear in favor of development investments. Prefabricated technologies were eventually abandoned in favor of the masonry wall technology. Owing to the regulations in force with regards to the U value, building walls needed to be thermally insulated. However, in comparison to the current regulations, provisions applicable over the 1990s still defined a rather low U value. Buildings erected in that period are definitely less prone to overheating than the prefabricated ones built in former decades. However, if compared to modern buildings, they demonstrate worse parameters in this respect.

Housing estate projects with which to supplement gaps in the existing building development of Śródmieście and neighboring districts are characteristic for this period, as well as housing estates erected on the outskirts of large districts that had emerged in previous decades (e.g.,at that time, two major districts developed significantly, namely Ursynów-due to the construction of the underground that connects it with Warsaw downtown, and Białołęka-owing to emerging road systems)

5. after 2002- stronger than before emphasis on thermal insulation and energy efficiency, improvement in technology, ceramic, porous concrete or silicate blocks, two- or three-layers walls with thermal insulation (thicker layers), other energy-efficient technologies, requirements for thermal insulation – U = 0,3 - 0,2 W/m2K, requirements for energy efficiency (the need to reduce the demand for cooling as well as heating) (Fig. 22).

By increasing the requirements for thermal insulation of partitions to the above specified values, buildings are protected against the risk of overheating. However, buildings with large ratio of glazing with no sufficient protection by means of shading systems from the sides exposed to solar radiation may prove disadvantageous. The trend towards the use of large glazed surfaces, observable in building construction since the beginning of the 21st century, is also noticeable in the case of multi-family housing. Therefore, the problem of overheating may manifest itself.


Fig. 22. New housing estates in Warsaw, in the Wola district, on the right the district of Dzielnica 19 built in 2010, on the left the district of Odolany, currently under construction.

Urban-planning conditions may also be very unfavorable. Business mechanisms related to the development market result in the desire for increasingly intensive land use, as well as reduction of all investment elements that are deemed unnecessary. Therefore, no greenery or elements of land development are introduced. Individual buildings are located very close to each other and create layouts unfavorable with a view to ventilation. Thus, the problem of overheating arises in spaces around buildings on the scale of microclimate, which exerts an impact on the thermal comfort in the interior.

New housing estates are being built to supplement the ever-smaller reserves in the city's central zones, in areas freed of previous functions, for example, post-industrial, post-rail areas (e.g., in Wola, Praga) and on the outskirts of the entire outer perimeter, as well as in suburban areas.

2.2 Types of building and risk of overheating

The presented division of multi-family buildings in Warsaw into 5 groups can be used for a preliminary evaluation with regards to the risk of overheating. These include as follows

1. buildings erected prior to 1945 – generally, marked with a low risk of interior overheating due to high thermal mass of walls (possible overheating in apartments located in adapted attics), high risk of overheating with regards to spaces around buildings

2. 1946 - 1966 – generally, at an average risk of overheating (in apartments exposed to more solar radiation, in buildings of a lower standard, where economical technologies were used);

3. 1967 - 1989 – generally, at a high risk of room overheating, due to low thermal mass of walls, lack of thermal insulation and small rooms with low ceilings (the situation can be significantly improved if thermal modernization is implemented), low risk of overheating spaces around buildings;

4. 1990 - 2002 – generally, at a low and medium risk of overheating, technologies similar to modern ones, less restrictive in terms of thermal insulation of walls;

5. following 2002 – generally, at a low risk of room overheating, owing to high standard of thermal insulation of walls (except for premises with large glazing ratio and locations exposed to solar radiation), high risk of overheating spaces around the buildings (dense building development, little greenery, obstructed wind flow); in some cases, unfavorable microclimate of the environment with regards to thermal properties may significantly reduce thermal comfort of rooms.

The general distribution by districts of the 5 types of multi-family housing described above is shown in Fig. 23.

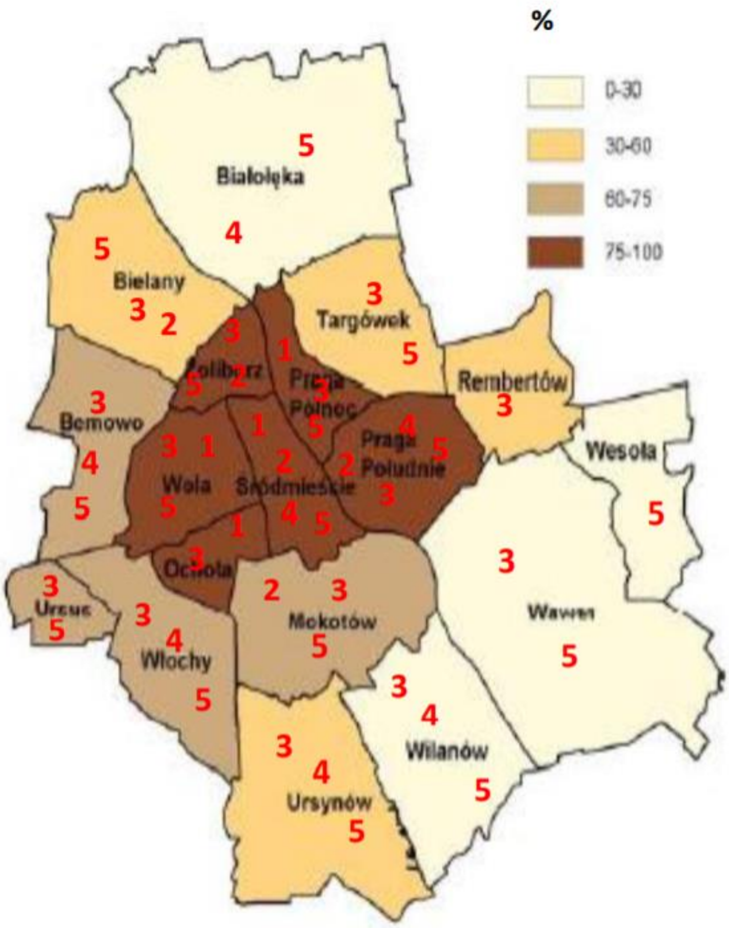


Fig. 23 . Map of built-up areas in Warsaw given in% in relation to the total area of districts (marked by colours) with different types of multi-family buildings (marked by numbers); 1: buildings erected prior to 1945, 2: 1946 -1966, 3: 1967 – 1989, 4: 1990 – 2002, 5: following 2002; author's own study.

Unfortunately, no publicly available maps exist that would fully show the distribution of multi-family housing in Warsaw, divided by the period of their creation. Maps that picture the location of all residential buildings and estates according to the construction period can be found in *Studium uwarunkowań i kierunków rozwoju Miasta Stołecznego Warszawy / Study of conditions and directions of development of the Capital City of Warsaw* [9]. The document shows the distribution of all housing resources in Warsaw, whereas housing estates were divided into those erected prior to 1939, housing estates in traditional technology of 1945-70, housing estates in prefabricated technology of 1945-70 and housing estates in prefabricated technology following 1970 (Fig. 24). Clearly, newer housing estates tend not to have been included in this division. However, the ones that have been taken into account were divided according to criteria other than those adopted in the present study (although some similarities can be found). Insufficiency of the available maps concerning the distribution of multi-family buildings in Warsaw results in the lack of information on the technical condition of these structures, including whether and to what extent they have been modernized. This information is important for the EmCliC project. Data on this subject have not been made available in any integrated form accessible by the public. An interactive version of the maps of Polish cities, including the map of Warsaw, can be found on the e-map portal. These maps include information on the functions of buildings, which makes it possible to distinguish multi-family buildings into high-rise and low buildings. The maps lack information on the period of construction (perhaps it is possible to attain such data, because some of the information is not clearly presented).

In his article entitled *Zróżnicowania społeczno-przestrzenne Warszawy – inercja, czy metamorfoza struktury miasta ?/ Social - spatial variances in Warsaw - inertia or metamorphosis of the city's structure?,* Maciej Smętkowski [10] proposed an interesting typological classification. In one typology, he combined the simplified division of buildings, with regards to the period of construction, with the social-material status of the inhabitants, dividing each building type into "superior" and "inferior" in terms of this status (Fig. 25). Although, as in the case of the abovementioned map, the division according to the period of creation differs slightly from the one proposed in the present study, certain similarities are visible. The "superior" and "inferior" status of building inhabitants in a given group may correlate well with the risk of overheating, as the buildings classified as "inferior" usually represented a lower technological standard. Moreover, a large part of them has not undergone thermal modernization.

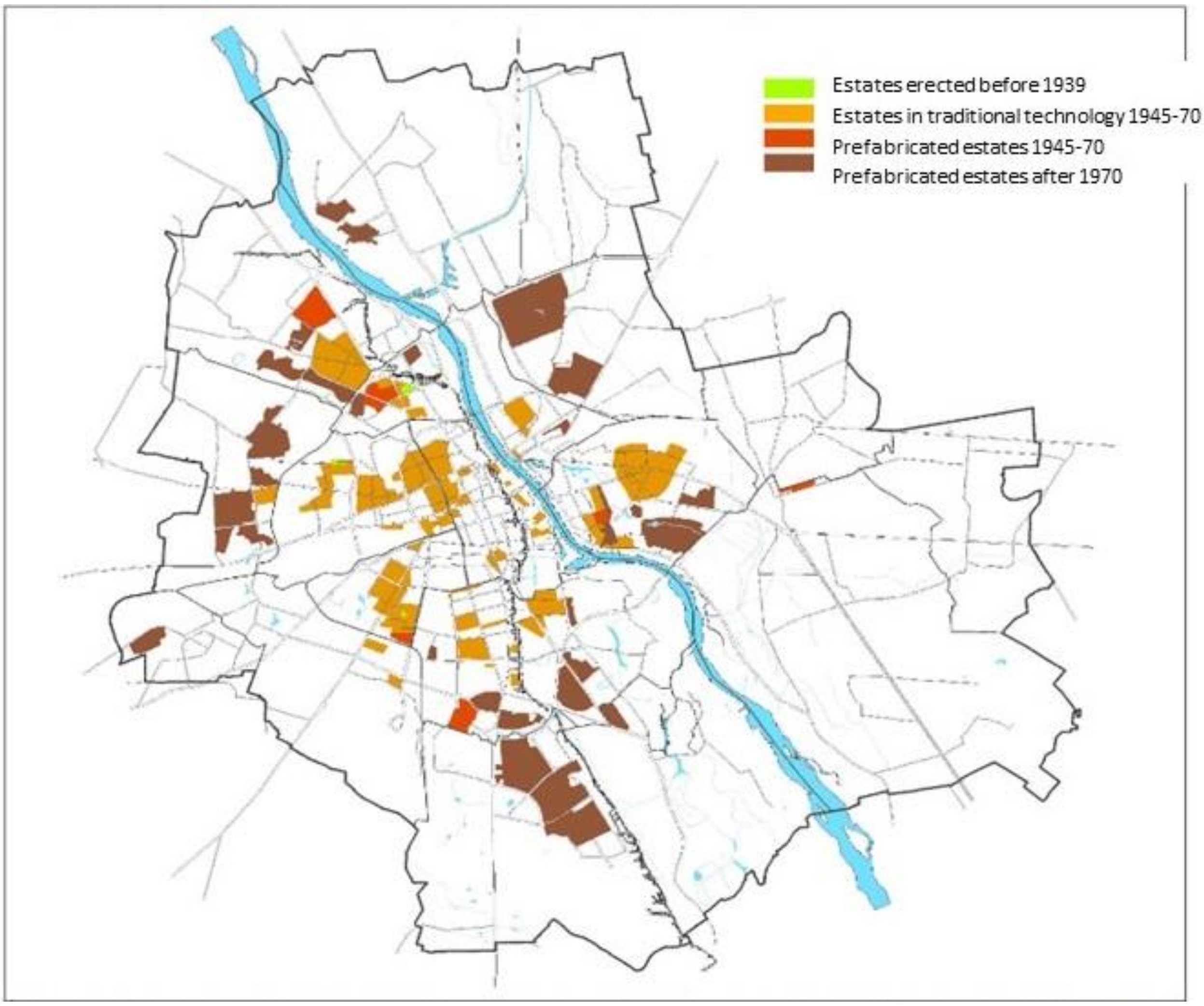


Fig. 24. Distribution of housing estates in Warsaw by the time of construction according to [9].

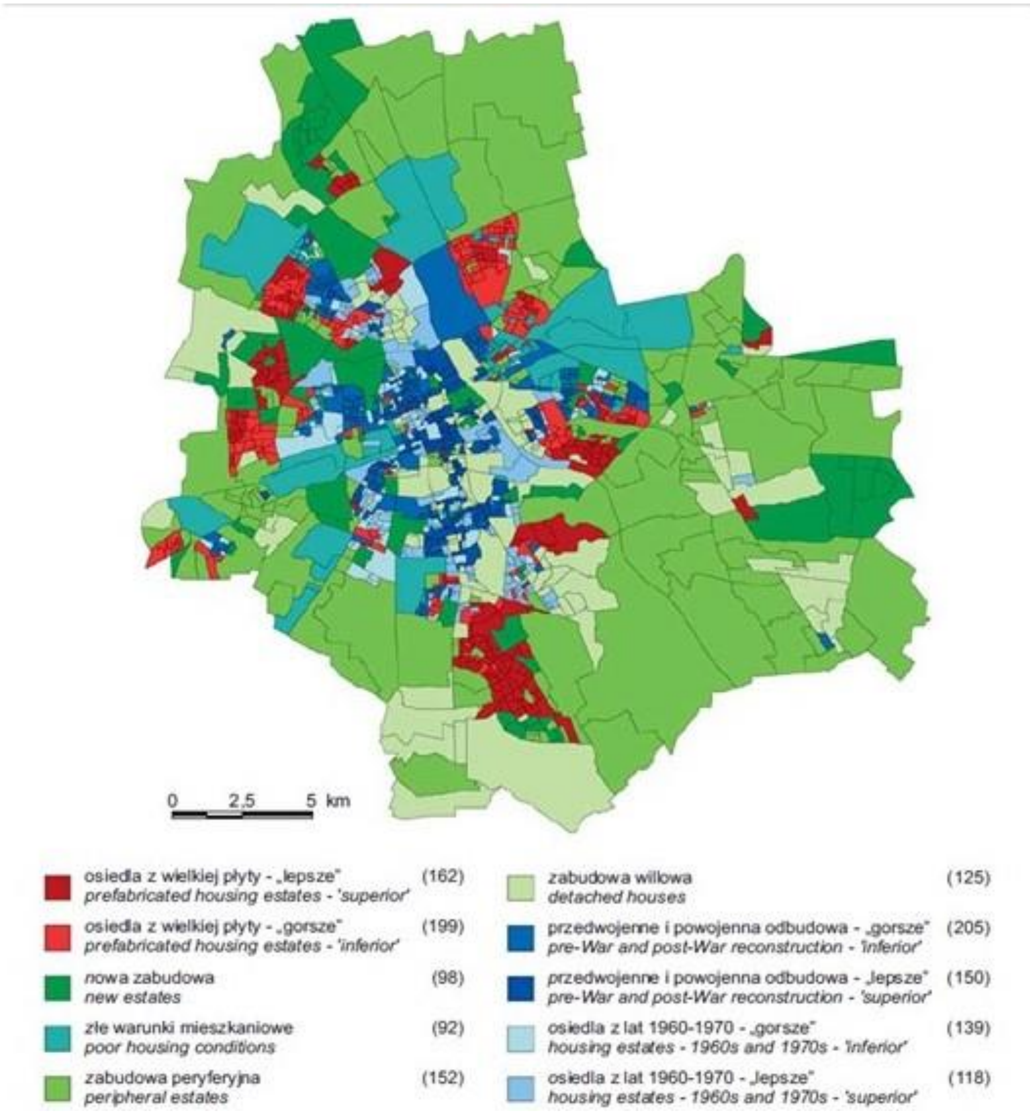


Fig. 25. Distribution of housing estates in Warsaw, according to the time of construction and the social status of residents according to [10].

In order to thoroughly evaluate the risk of overheating, it is necessary to correlate the typology developed in the present study with the location within the city and the related urban heat island characteristics. The data included in the study *Miejska wyspa ciepła w Warszawie. Uwarunkowania klimatyczne i urbanistyczne / Urban Heat Island in Warsaw. Climatic and urban conditions* [6] and Mapy klimatyczne Warszawy / *Warsaw Climate Maps*, which were prepared as part of the ADAPTCITY project and constitute part of the preparation of *Strategia Adaptacji do zmian klimatu dla Warszawy* / *Strategy for Adaptation to Climate Change for Warsaw* by the Capital City of Warsaw and Instytut na rzecz Ekorozwoju/ *Institute for Sustainable Development* [11]. An interactive version of climate maps is available on the Internet https://mapa.um.warszawa.pl/mapaApp1/mapa?service=adaptcity. With the use of it, it is possible to superimpose climate data on an interactive map of Warsaw with data, such as the street layouts and names (Fig. 26). Therefore, if a properly prepared map of individual types of buildings in Warsaw was available, it would be possible to correlate it with climate data.

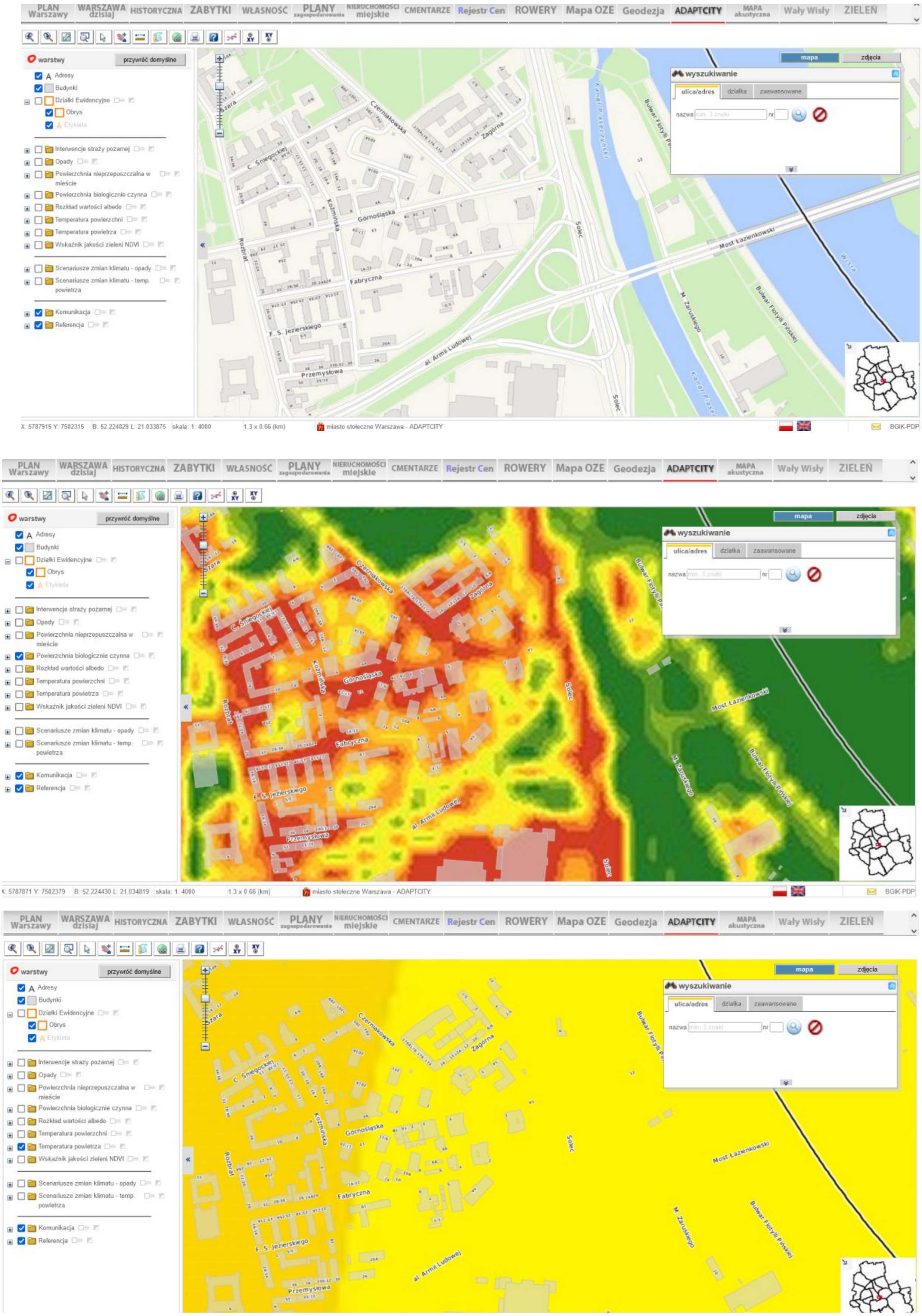


Fig. 26. Printscreens of interactive map of Warsaw, part of Powiśle district: basic plan (on the bottom), plan with biologically active areas (in the middle) , plan with the average annual air temperature (in the bottom); https://mapa.um.warszawa.pl/mapaApp1/mapa?service=adaptcity.

Surveys with residents' participation may be useful in diagnosing the location and types of residential buildings affected by thermal stress. For such surveys to be effective, the questions must be simple and understandable to people unfamiliar with construction and building physics. It is not possible to obtain conclusive information in this way, yet the following questions may be asked to help elicit the information:

6. What type of a building do you live in? In a tenement house, in a block of flats of concrete prefabricated slabs, in a block of flats, in an apartment complex?
7. What is the shape of the roof? Pitched or flat?
8. Do you know when the building was erected?
9. Do you know if the walls/roof have ever been insulated? When was it?
10. What storey (in relation to all storeys of the building) do you live on, on which side of the world are the external walls?
11. What is the thickness of the outer walls? 20, 30, 40, 50, more?
12. What are the approximate dimensions of the largest window in your apartment and what side of the world does it face?
13. Are there any shading elements for windows in your apartment? Balconies/loggia, external blinds, blinds, awnings, etc.
14. Do you have the opportunity to ventilate your apartment through?
15. Are the walls of your apartment cold or warm when touched in winter?
16. Do you feel the air movement in winter while sitting by the window?
17. Are the windows tight and do they open well?
18. Is there more greenery or paved areas in the vicinity where you live?

Chapter 3 - Adaptive experiences to thermal stress – Warsaw context

3.1 City-wide strategies

Adaptation of a large city to climate change consists of initiating and coordinating activities on various scales, namely the city as a whole, districts and housing estates, individual buildings and their surroundings, and individual apartments. The scale of the city as a whole constitutes the most general scale.

3.1.1 General characteristics of the spatial arrangement of Warsaw in the context of urban heat island (UHI)

Warsaw is a city with a central layout, whose area is separated by the Vistula River into two parts of a similar range, but with a "qualitative" advantage of the west-bank part (where Śródmieście is located). The historical building development of Warsaw consisted of a gradual increase of city peripheries (Fig. 27). Currently, Warsaw is divided into 18 districts (Fig. 27). It covers an area of 517 km2 and is inhabited by 1,800,000 people.

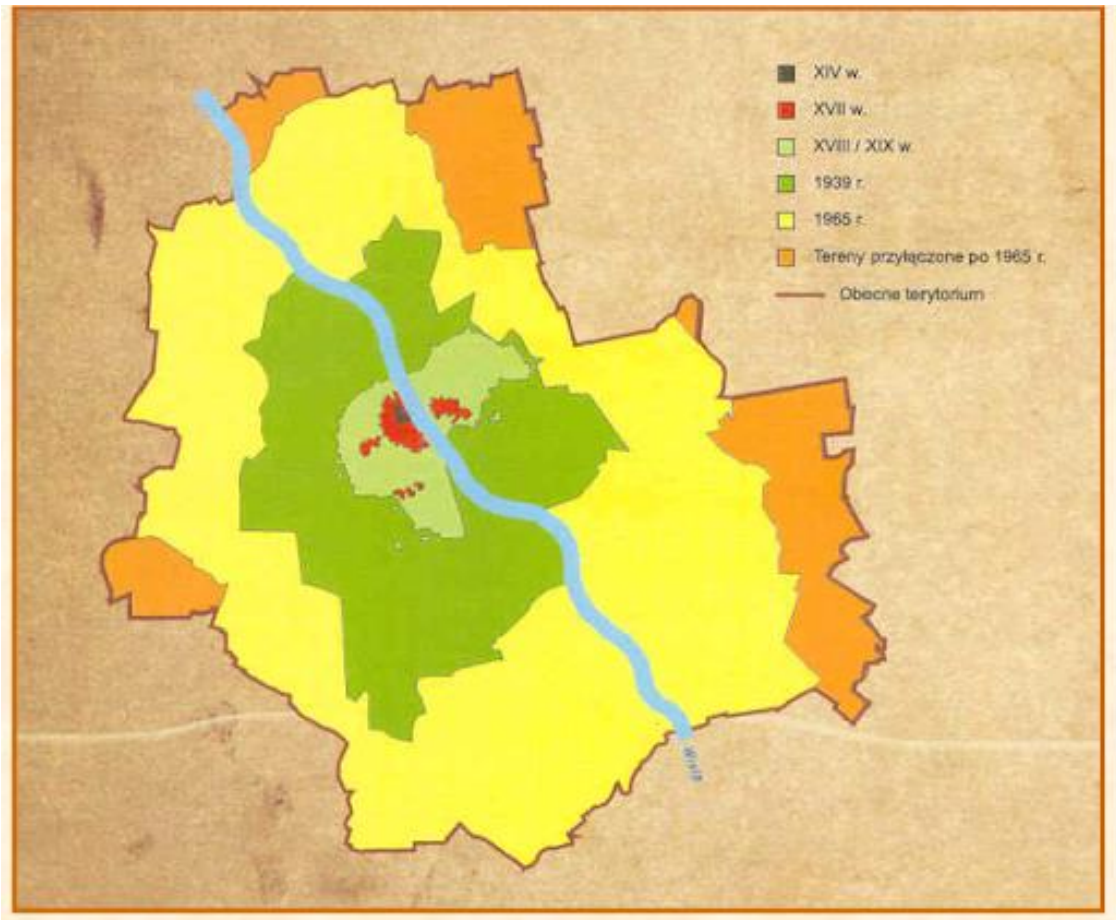


Fig. 27. Territorial development of Warsaw; source: http://radnawilanow.pl/wp-content/uploads/2016/05/Mapka-Warszawa-Feniksem-XX-w.png

Fig. 28. Administrative division of Warsaw; source: https://warszawa.wikia.org/wiki/Dzielnice

Like many other large cities, Warsaw is affected by the urban heat island phenomenon. In 1981-2014 an increase in the average annual air temperature in the city area was noted; it amounted to 0.02-0.04°C per year (Fig. 29) [25]. In 1976–2011, the urban heat island phenomenon occurred in Warsaw for almost 87% of the year (from 80% of days in winter to over 94% in summer) [6].

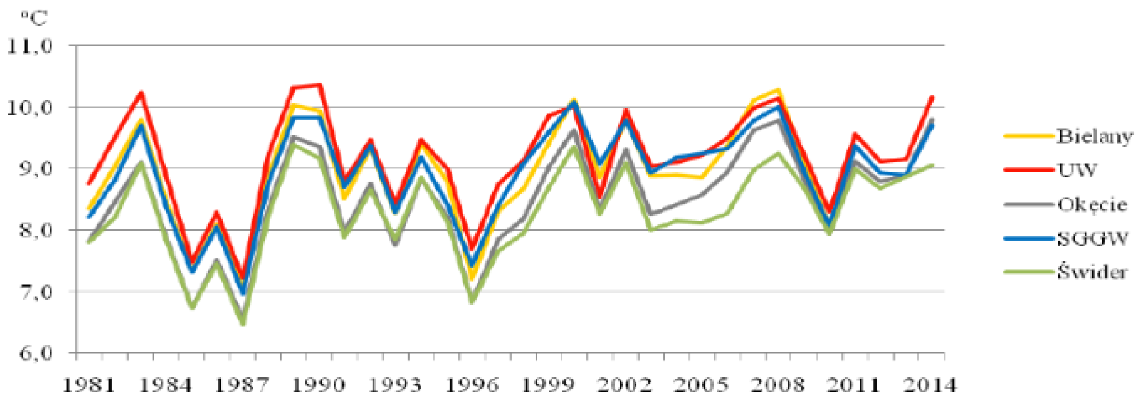


Fig. 29. The long-term average annual air temperature in Warsaw according to data from various meteorological stations; source [25].

In the area of Warsaw, the average annual air temperature values range from about 8.5°C in the eastern part of the city, in the Kampinos Forest and the Łomianki commune adjacent to Warsaw (the Białołęka area is also relatively cool) to almost 10°C in the central parts of Warsaw and the Praga district. A significant increase in the summer air temperature was observed in 1981-2014, including a significant upsurge in the maximum temperature by 0.04-0.08°C. The maximum temperatures in Warsaw reach 37 ° C. The number of very warm nights (the minimum temperature does not fall below 18°C) amounts to around 40 per year. These phenomena occur mainly in central districts - Sródmieście Ochota, a part of Wola, upper Mokotów. The amount of hot tropical nights (the minimum temperature does not fall below 20°C) equals 5-7 a year and applies to the regions mentioned above. Moreover, heat waves are observed in Warsaw (minimum 3 consecutive days with temperatures above 30°C) and hot periods (minimum 5 consecutive days with a temperature greater than 25 ° C). In 2008-2014, the number of heatwaves and heat periods noted in the city centre was 11-12 each [25].

In 1981-2014, the average wind velocity at the Warszawa Okęcie station was 3.8 m/s. It is observed that the number of days with wind velocities greater than 10 m/s decreased by 0.67. However, it is not certain whether the maximum wind values have not increased or will not do so [25].

Due to natural and historical conditions, Warsaw displays a dense central layout. The greatest intensification of building development and technical infrastructure occurs in an almost geometric centre of the city. This is reflected in the thermal phenomena observed throughout Warsaw. According to the abovementioned *Mapa Klimatyczna Warszawy / Climate Map of Warsaw*, both the distribution of average annual air temperatures (Fig. 30) and the average number of very warm nights on annual basis (Fig. 31) show the highest values in the centre of the layout and their gradual decrease towards the outskirts.

The map presents the cooling effect exerted by the Vistula River and the biologically active Skarpa Wiślna (e.g., local lowering of air temperature in the central city part) and the correlation between air temperature and the intensity of building development. The highest temperatures occur in the districts shown in chapter 1.4, Fig. 10, as most densely developed, i.e., Śródmieście, Żoliborz, Wola, Ochota, Praga. Moreover, the western districts of Mokotów, Włochy, Ursus, and Bemowo are warmer than the eastern, less urbanized ones. A more detailed distribution of data on the intensity of urban heat islands in Warsaw in 2010 is presented in Fig. 32.

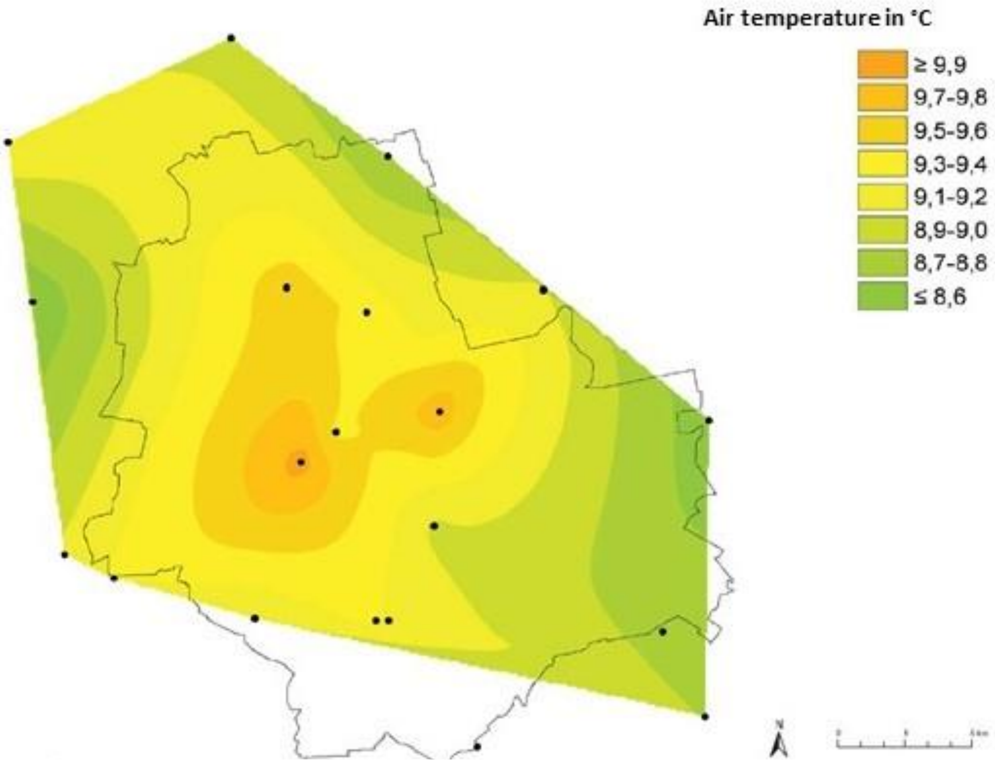


Fig. 30. Distribution of average annual air temperatures in Warsaw in 2008-2014: source [26].

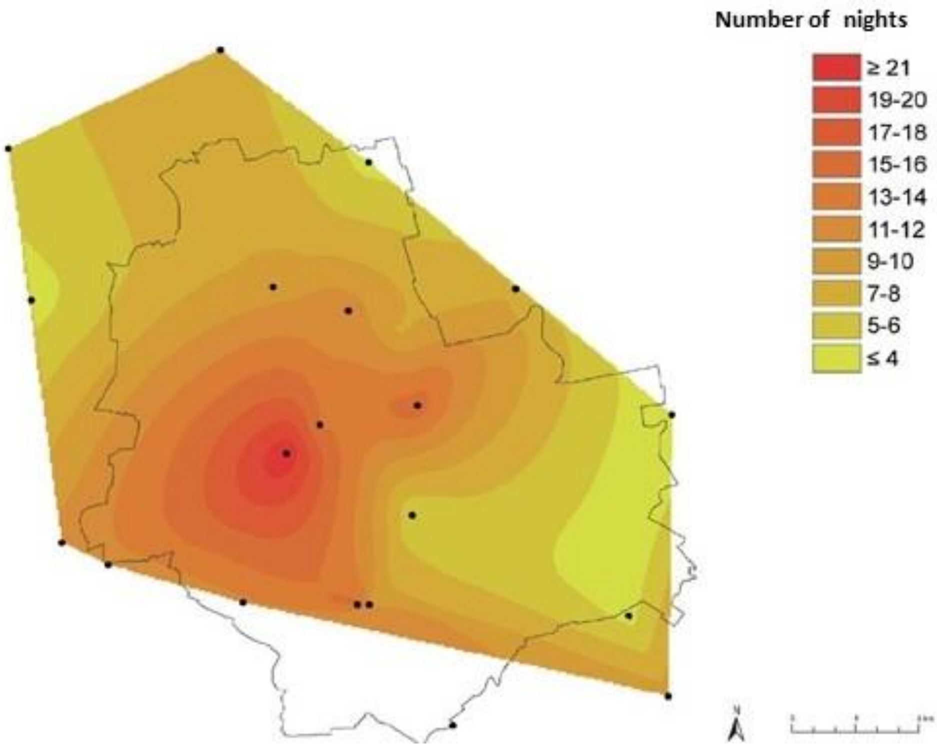


Fig. 31. Distribution of average number of very hot nights in Warsaw in 2008-2014; source [26].

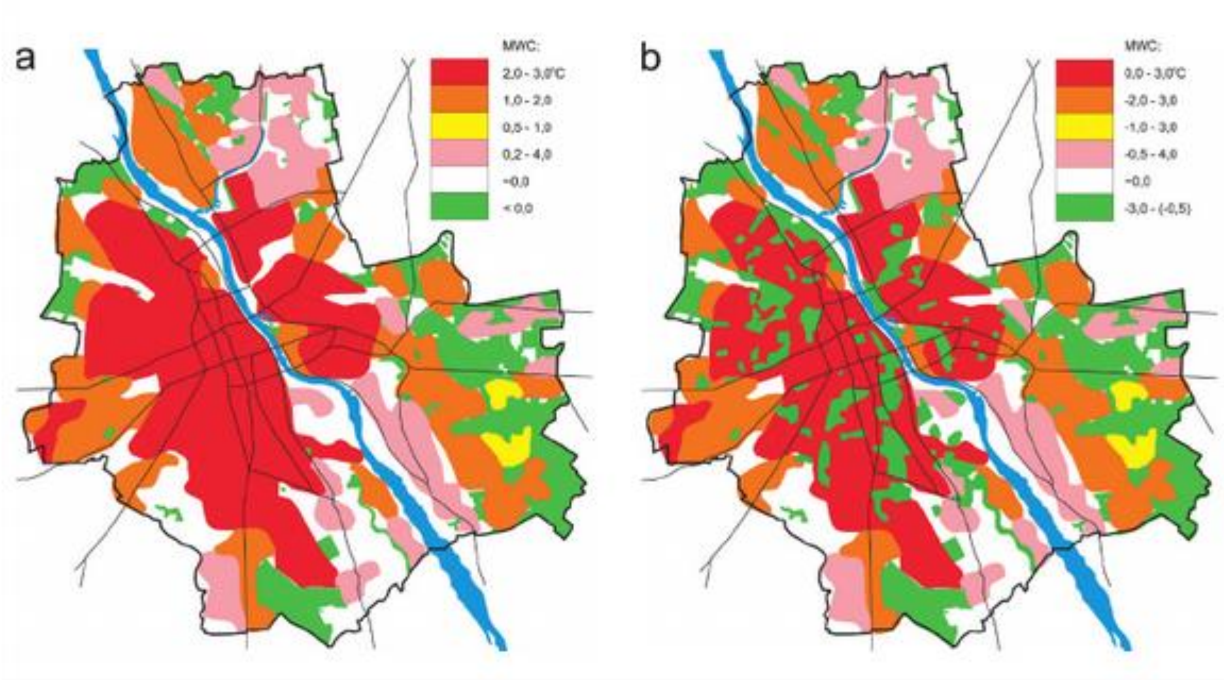


Fig. 32. Distribution of various categories of the urban heat island in Warsaw given the current land development (2010); night (a), day (b); source [6].

Implementing the construction investments planned for 2070 will significantly modify the spatial distribution of the urban heat island in Warsaw. Not only will it increase the areas where the highest intensity of the phenomenon occurs, but also areas where the UHI is not extremely intense (1-2 ° C) will grow. Areas with no urban heat island will be limited. Various scenarios for the development of UHI for Warsaw have been developed. They present unambiguous, though unequal, dynamics of changes in climatic factors, e.g., an increase in temperature values (Fig. 33) and the number of tropical nights (Fig. 34) [33]. The climatic situation of Warsaw was analyzed and summarized in the paper *Miejska wyspa ciepła w Warszawie*. *Uwarunkowania klimatyczne i urbanistyczne [Urban heat island in Warsaw. Climatic and urban conditions]* [6].

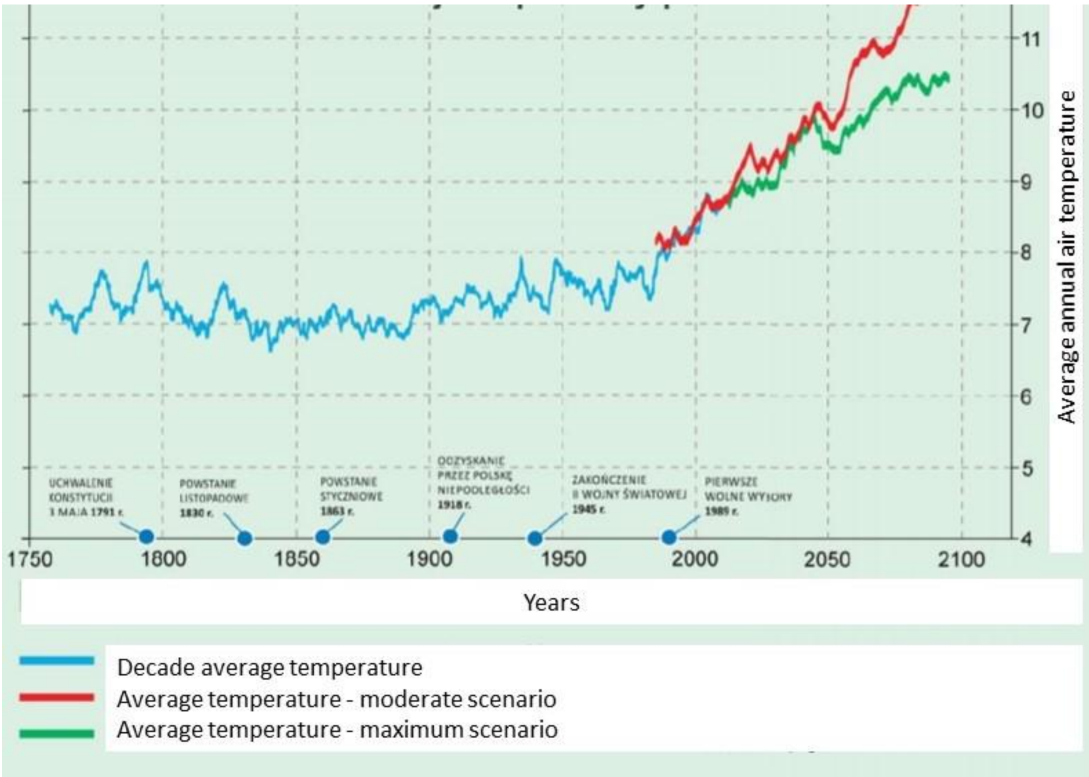


Fig. 33. Projected changes in the temperature values in Warsaw; source [11].

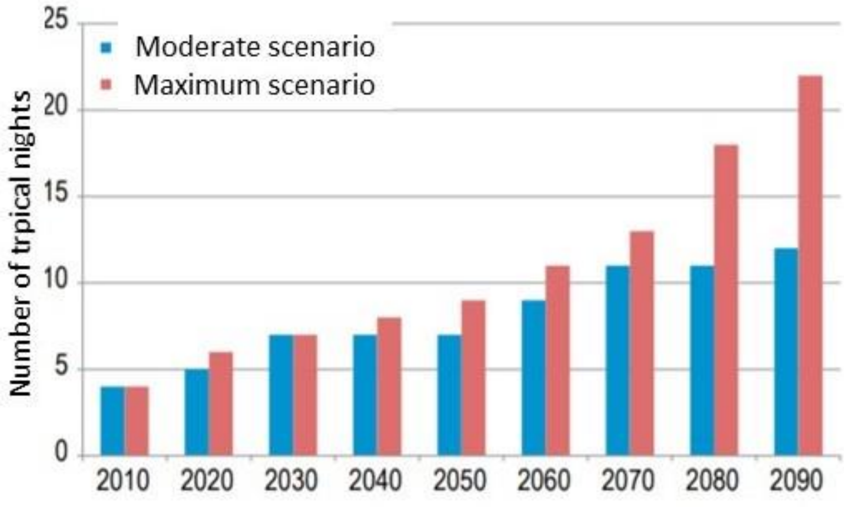


Fig. 34. Projected changes in the number of tropical nights in Warsaw; source [11].

3.1.2 Aeration corridor system

To improve climate quality, a reduction in the emission of heat and pollutants (also those produced by buildings) is required. In this context, strict requirements on energy efficiency for newly erected buildings and eco-modernization of the existing building development should provide the goal of a coherent strategy on a city scale. However, in the context of climate quality, it should be equally important for urban planners to balance built-up and open-air areas and control the intensity of building development. In the case of Warsaw, the aeration corridor system mentioned in Chapter 1 is the key to achieving the above goals while creating the basic structure for the city's natural system. The main advantage of the aeration corridor system lies in its radial layout (in line with the natural movement of the so-called urban breeze) and its continuity. Within 100 years since their implementation, the system has only been disturbed in its central zone. Following 1990, the corridor area was reduced by new investments, yet the corridors remain effective in the majority of areas. This is demonstrated, among other studies, by the research cited in the report entitled *Potencjał do kształtowania warunków klimatycznych – w tym wymiany I regeneracjipowietrza w Warszawie / Potential for shaping climatic conditions - including air exchange and air regeneration in Warsaw* prepared in 2017 at the request of Biuro Architektury I Planowania Przestrzennego / Architecture and Spatial Planning Office at the Capital City of Warsaw Hall [12]. According to this report, protection of aeration corridor system areas and control over intensity and shape of newly erected buildings on the city's outskirts and the corridors themselves, to allow smooth ventilation, constitutes one of the main priorities of the pro-climate strategy. The existing corridor system is protected by local law but not sufficiently so. No complete ban on building within the corridors has been introduced yet; new investments are allowed, as long as architects prove that the investment will not disturb the airflow.

Meanwhile, it seems reasonable that the corridor areas remain undeveloped and that it is only possible to develop them as biologically active zones filled with greenery. Such development would positively regulate air temperature, while appropriately selected greenery would intensify air exchange locally. In such cases, the temperature within the aeration corridors is lower than the temperature of the surroundings. Therefore, a pressure difference occurs, prompting lateral air movements towards built-up areas.

Another issue refers to the need to ensure maintenance of the corridors in places where they have lost their continuity, i.e., in the city downtown. Directing the air is possible by using street spaces and the system of open areas such as green squares, parks, and garden squares. Issues to be analysed include the extent to which the existing spatial structure of buildings allows for undisturbed airflow, which areas that have not been built up so far should remain undeveloped, how to supplement the existing building development and how new investments can improve the situation. For instance, properly located buildings of significant height in comparison to their surroundings can enhance vertical ventilation.

Protection of open spaces in cities should be closely connected with greenery protection. The existing large green spaces of Warsaw, such as Pola Mokotowskie, Park Skaryszewski, or Natolin, reduce the air temperature in adjacent areas, which is confirmed by research, as evidenced in [6,7]. Therefore, it is necessary to protect the areas already developed with greenery and allocate sites for new ones, for example, in areas freed from previous functions, such as industry or railways.

3.2 Local strategies

3.2.1 Shape and intensity of building development

Control over the intensity of building development provides an important issue. This applies to newly designed housing estates and buildings erected to supplement the existing development. The criterion of taking action for climate quality, also in minimizing the risk of overheating, consists of the optimization of two major factors. On the one hand, intensive land use should be pursued to prevent uncontrolled urban development (the so-called urban sprawl). On the other hand, building development design should render the structure properly exposed to sunlight and open to wind flow. For these factors to be accounted for, it is necessary to supplement the existing parameters that regulate building shapes in the local law's provisions and introduce additional criteria to characterize these very issues. While the insolation criteria are regulated to some extent, however insufficiently, the ventilation issues of urban spaces are almost completely overlooked. The issue is complex, while contemporary science fails to provide unequivocal answers concerning most appropriate parameters to be applied. Such research, however, is underway worldwide, and it would be advisable to implement it for Polish conditions [13]. Generally, it is known that closed building development layouts, for example, urban blocks with internal courtyards, are not ventilated well. It may be expected that the compaction of building development shaped similarly will result in air stagnation, less efficient ventilation, and, as a result, intensification of the urban heat island phenomenon [14].

Research on airflow conducted by the author of the present study in cooperation with researchers from Wydział Mechaniczny Energetyki I Lotnictwa/Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, proved the risk of air stagnation in a multi-family building development quarter erected recently in the Wola district, Warsaw (Fig. 35).

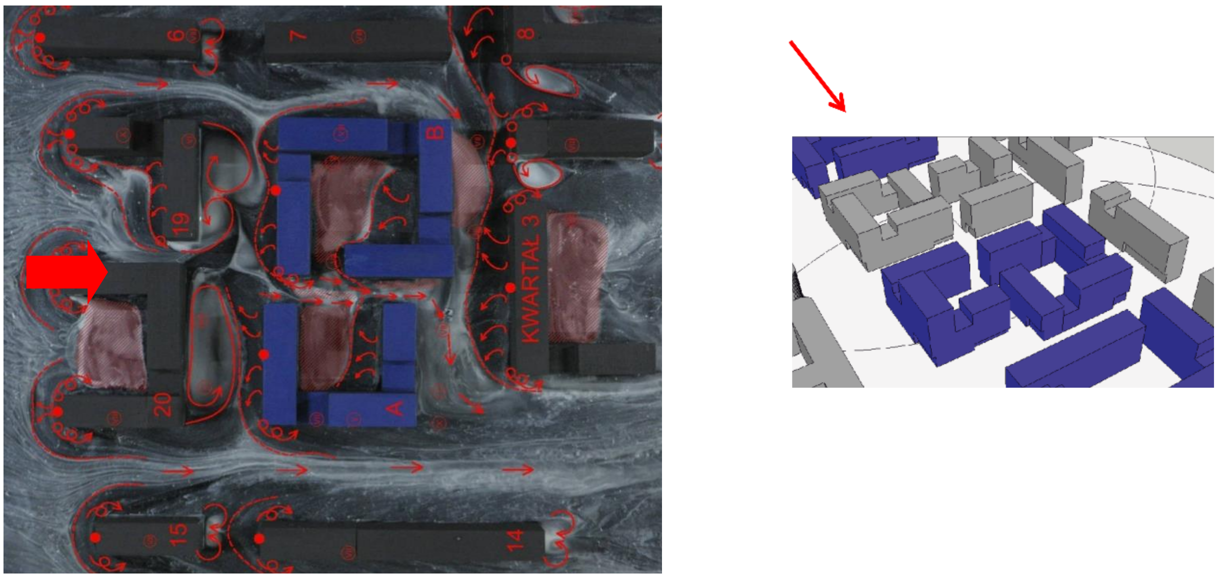


Fig. 35. An example of a closed-plan urban block in Warsaw erected in 2010 - wind tests have shown space stagnation inside the courtyards (white areas); author's study.

The design is an award-winning project that has been highly appraised as compared to other housing development projects across Warsaw. This means that legal provisions in force in Poland allow for the construction of buildings that are unfavourable to wind flow. The issue remains very poorly understood and seems overlooked even by the most acclaimed teams of Polish architects.

3.2.2 Green infrastructure

The positive impact of greenery on the climate in urbanized spaces is well-established and has been confirmed in scientific research. Greenery, especially trees, absorb carbon dioxide and other pollutants; they provide shade, regulate humidity, do not accumulate heat energy. Thus, greenery contributes to reducing the urban heat island phenomenon. Generally, the larger the green area, the greater its effect in this respect. Green areas that form continuous systems offer the greatest advantage in climate-regulating value for the city. Such greenery systems are formed when large greenery areas are connected with each other and with smaller green spaces by biologically active corridors free from building development. In the case of Warsaw, the above-described system of aeration corridors acts as such a system. Smaller layouts of greenery, street-lining tree rows, green roofs, or green façade play a less significant role in creating climate. However, they are locally important if no place can be devoted to greenery on the ground. The share of greenery areas in various districts of Warsaw is shown in Fig. 36.

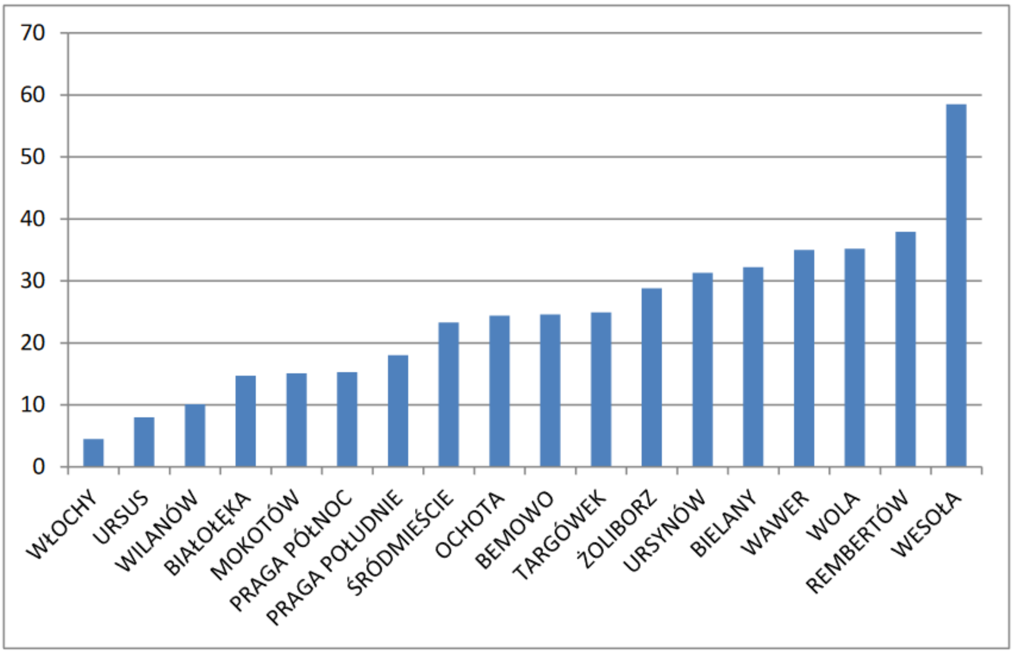


Fig. 36. The share of green areas and forests in% in individual districts of Warsaw; source [26].

Warsaw was classified as a city with a favourable geographical location, which stems from its location in the valley of a large river and the direct connection to large forest complexes. In an intensely urbanized large city, green areas are arranged in such forms as city parks. Detailed data on the share of individual greenery forms in Warsaw was collected and compiled in [6]. Despite the good general situation, the lack of green areas is observable in most urbanized districts. The gradual thickening of building development results in losses of the existing greenery resources.

Intensification of green areas and replacement of damaged areas with biologically active, water-permeable surfaces constitutes yet another element of pro-climate local strategies. Such actions offer numerous advantages, including lowering air temperature during hot periods. When comparing the surroundings of a given building as of several decades ago to the ones nowadays, a definite increase in the number of hardened surfaces around them can be observed. Plac Teatralny [the Theatre Square] in Warsaw offers a remarkable example of this situation. In the centre of the square, i.e., Teatr Wielki [the Grand Theatre], a green, tree-covered foreground is visible in the archival photographs. Today, however, the building is surrounded only by streets, pavements, and car parks (Fig. 37).

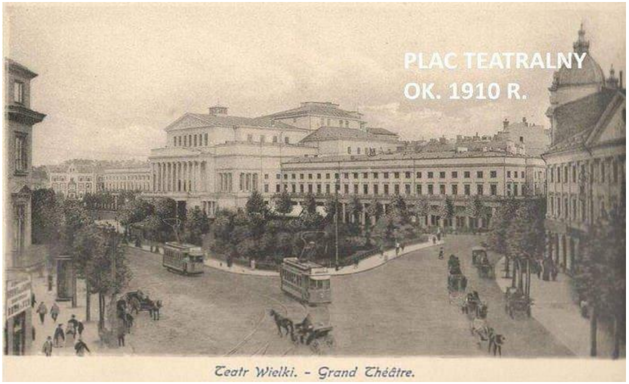


Fig. 37. Plac Teatralny/Theatre Square in Warsaw at the beginning of the 20th century and today; source:https://opinie.olsztyn.pl/spoleczenstwo/betonoza-piotra-grzymowicza/#.YOire0wwhEY

It is contemptible that numerous examples of public spaces in Polish cities have lost their valuable, mature greenery during the recent modernization processes (often small-town squares), to implement a parking lot, commercial spaces, or with no clear cause in mind. Meanwhile, precisely the opposite actions, i.e., replacing paved areas with green-covered ones, are postulated in studies on climate improvement [15], also those with regards to Warsaw [6, 11, 12]. Moreover, examples of the practical application of solutions to increase the share of greenery in the surroundings of buildings as elements for the environmental and social revitalization of degraded neighbourhoods can be found (case studies such as Vancouver, Philadelphia have been well described). Synergistic actions are required in the scope of reducing road communication spaces and parking lots in the immediate vicinity of buildings. Then, all areas whose surfaces need not be paved for utility reasons should be developed with appropriately selected greenery. An additional possibility is created by building roofs and walls. In their case, however, a greater technological effort is required than in the case of greenery on the ground, whereas environmental benefits are less significant. Nevertheless, for intensively built-up areas, where no reserves for greenery exist on the ground, green roofs and walls covered with greenery offer a very valuable ecological potential.

Interesting research on the impact of an increased share of green areas on the urban heat island effect is presented in [6]. The situation observed in various buildings development quarters in

Warsaw was compared to two scenarios of supplementing these areas with greenery. The building development quarter with a very low share of biologically active area (4%), located in ul. Twarda [Twarda Street], Śródmieście, proved the most interesting case. The first scenario assumed the introduction of high and low greenery in the inner courtyard and areas free from communication around the perimeter of the quarter. However, the second scenario accounted for the entire roof area of the building development quarter and the neighbouring buildings to be additionally covered with greenery. These changes (especially the second scenario) led to air temperature reduction and the urban heat island effect in summer and spring (Fig. 38). At the same time, in the case of this quarter, the best results were yielded in comparison to other quarters under study, especially with regards to areas located further away from the city centre and with a better initial situation in terms of biologically active areas. Therefore, major transformation strategies in buildings' surroundings consist of replacing paved surfaces with greenery (with attention to planting mature trees and replacing existing roofs with green ones). Such actions have the greatest justification in densely built-up downtown areas.

High, mature trees play a particularly valuable role in cities. Apart from numerous other benefits, such trees can protect lower parts of buildings' facades, as well as surrounding areas of buildings, from excessive exposure to solar radiation. Therefore, such plants can be used to regulate the interior climate of buildings and the microclimate around them. On arid days, cooler enclaves are created by the shadow cast by the treetops on the surface and the buildings.

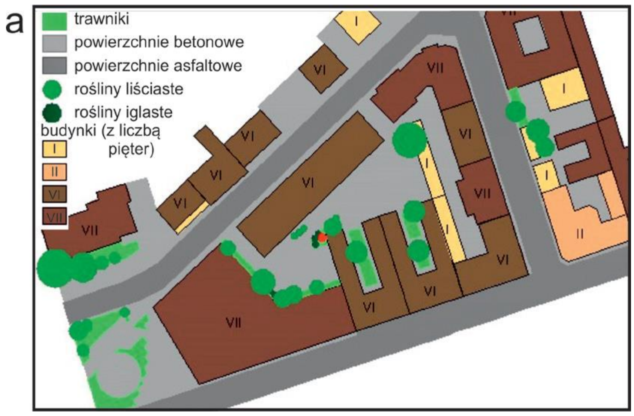
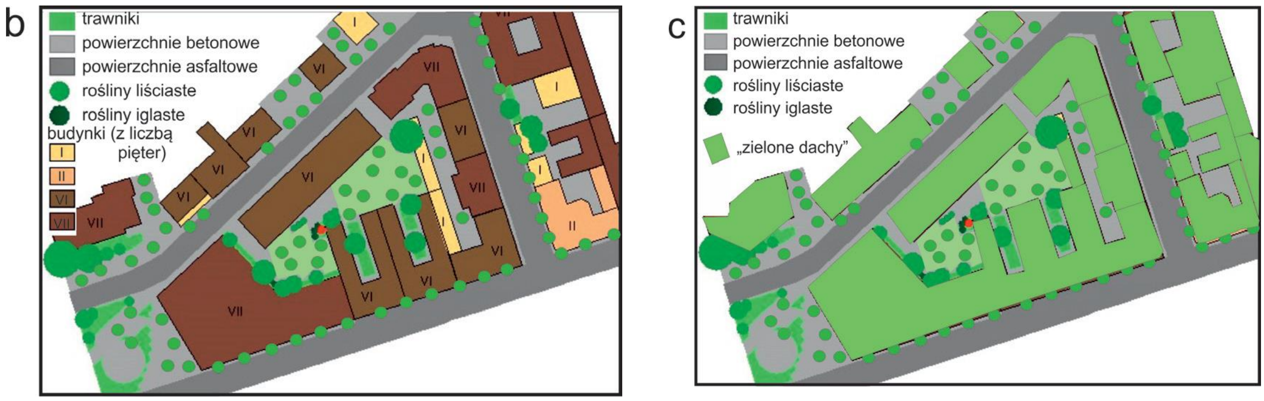
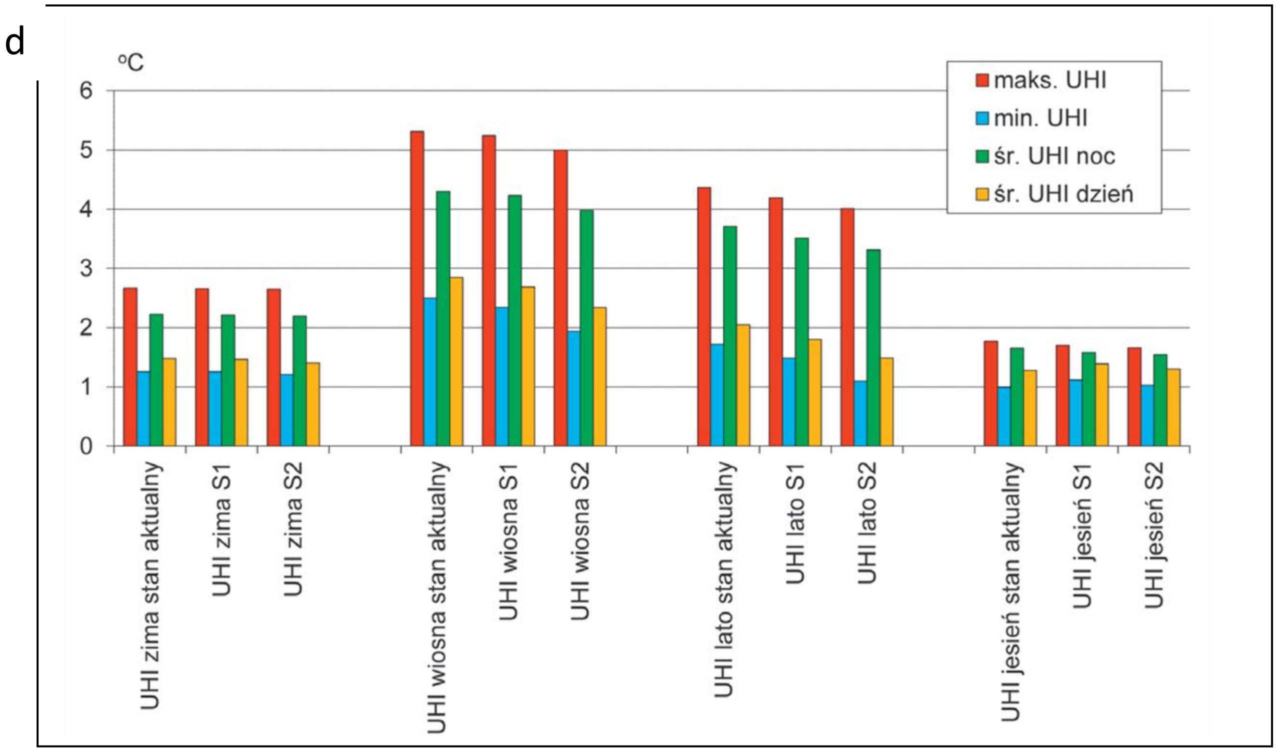


Fig. 38. A building development quarter on ul. Twarda [Twarda Street], Warsaw – (a) the current condition and scenarios for supplementing it with greenery S1 - greenery on the ground (b), S2 additionally, green roofs (c); below, the results of research on the impact of both scenarios on the reduction of the UHI effect (on the left) in winter, spring, summer and autumn (d); on the basis of [6].





It is important to protect the existing trees in cities, use their full potential, and introduce new greenery. The selection of plants and their location in relation to buildings and technical infrastructure should be well planned. It is reasonable to plant trees as mature as possible to provide shade in urban spaces. An example of street revitalization with the use of trees as elements to regulate street microclimate is the development of ul. Daszyńskiego [Daszyńskiego Street], Wrocław. It was implemented as part of a project conducted by The City of Wrocław, financed by the European Union "Horizon 2020" framework program (Fig. 39).

Fig. 39. Above - plan of the street fragment prior to its modification (on the left) and after the changes (on the right), at the bottom - a view of a place to sit under a tree and a row of trees along the pedestrian route; source: https://tecla.pl/portfolio/grow-green-2/

In this project implementation, the car park area was reduced on behalf of greenery, especially trees. Tree lanes were introduced along the streets as an element to separate the pavement from the road and shade most sun-exposed parts of the street. Places to sit, located underneath the trees, away from car traffic zones and car parks provide a valuable street design element. Owing to the introduction thereof, the street may likely become a social space friendly to all users, also those of more limited physical mobility, the elderly and adults with small children. These kinds of places can also help reduce thermal stress on hot days.

Therefore, street greenery should be treated as an integral element of the urban system. This applies even to the smallest forms of vegetation that cover less spacious parts of the city surface, as green elements are indispensable to creating quality city spaces. This can be achieved by the implementation of urban planning guidelines that account for the specificity of particular cities, such as *Gdański Standard Ulicy Miejskiej* [*The Gdansk Standard for City Street]* [15], in which the potential for comprehensive street development in possible variants is presented (Fig. 40). Tree lanes and clusters of greenery are given a specific place according to the norm, whereas the criterion of shade provided by trees in summer was also considered.

Fig. 40. Examples of street development schemes with various building developments, functions, and proportions, with the account to high greenery according to the Gdański Standard Ulicy Miejskiej [*The Gdansk Standard for City Stree]t* [15].

3.2.3 Blue infrastructure

The city's blue infrastructure covers the system of groundwater, water reservoirs, and water that circulates as rainfall. It is closely related to the greenery system, which is why both systems are often referred to as blue-green infrastructure. The role of water reservoirs as elements that regulate the air temperature is vital from the point of view of temperature perception. The water heats up and cools much slower than the air or the ground; thus, it has cooling properties in the hot seasons. This cooling effect depends on the size of the water reservoir. Seas or vast rivers and lakes exert an impact of a climatic significance on the scale of an urban mesoclimate. In the case of Warsaw, the Vistula and the Skarpa Wislana [Vistula Embankment] assume such a function; so does the unregulated, valuable natural coastal zone on the eastern side of the city. Small water reservoirs, including retention reservoirs, play an important role in rainwater management and greenery maintenance. Therefore, they may be important for the local climate and the microclimate.

The percentage share of surface reservoirs in Warsaw is relatively small, i.e., 3%. However, it is estimated that as much as 67% of Warsaw areas have a natural potential to become part of the blue-green infrastructure. Such areas include forests, agricultural land, arranged greenery, recreational zones, cemeteries, allotment gardens, as well as built-up areas with a large share of greenery. Hence, new housing estates should be designed, and the existing ones should be modernized so that the areas surrounding the development are included in the city's blue-green infrastructure. This is important both for the general water balance and the microclimate, as well as for the temperature perceived by the inhabitants during hot seasons.

Hardening of a large area of cities surfaces in the last decades has resulted not only in reduction of greenery but also in disruption of natural water circulation processes. A significant part of rainwater is prevented from soaking into the ground. Instead, it is discharged into rainwater drainage systems. Drainage systems also receive water removed from building roofs. In total, during heavy rains, a very large amount of water needs to be drained away fast. This leads to several negative consequences, such as deterioration of plant growth, lower quality of water to which sewage is discharged, or decreased flood safety.

Therefore, it is important to ensure that as much of the city surface as possible is permeable to water and to create various types of retention reservoirs that regulate water levels. In this respect, a comprehensive set of solutions can be found in the publicly available study entitled *Katalog dobrych praktyk, cz. II. Zasady zrównoważonego gospodarowania wodami opadowymina obszarze zabudowanym/Catalogue of goodpractices, part II. Principles for sustainable rainwater management in built-up areas* [16] prepared by experts from the University of Life Sciences, Wrocław, and commissioned by the city authorities. The catalogue comprises various solutions intended for specific situations. The surroundings of building development, typical in the case of buildings with residential functions, were also considered in the catalogue (Fig. 41). The concept of water retention is closely related to the greenery in order to create a self-sufficient natural system whose microclimate is favourable to people. At the same time, the system designed in such a way offers places conducive to rest, recreation and neighbourhood integration. Such an approach, as evidenced by the revitalization of ul. Daszyńskiego [Daszynskiego Street], Wrocław, is especially appreciated by the elderly who need places to spend time close to their apartments, places conducive to meetings with neighbours, places resistant to overheating from high temperatures during summer. The environment associated with greenery and water provides such opportunities, although it should be remembered that excess moisture is not beneficial in terms of experiencing high temperatures.

Fig. 41. Water retention, rainwater recovery as a system to cooperating with greenery. An example of a residential area included in the catalogue of good practices for water retention developed for Wrocław [16].

Other methods to use water as a solution to protect against heat effects include various types of water fountains and curtains. Such installations are increasingly often fitted in public spaces in Polish cities, as they work well as a temporary solution and are usually well received by residents and tourists. This solution is categorized as the so-called active solution that requires water and energy. Yet, it serves a relatively large group of people. Water installations of that kind usually emerge in the busiest parts of cities, in the main public spaces. Installations of that sort could be considered a solution to be implemented in housing estates to serve people who spend a large part of their daily time in the surroundings. Drinking water intakes could be of similar use.

3.2.4 Shading elements

Looking for a shade in hot seasons is the natural behaviour of humans and animals alike. Therefore, creating shaded spots in public spaces, including in housing estates, is justified. As mentioned above, trees are very efficient in fulfilling the role of shading elements. A similar function may be performed by specially designed shading systems, such as roofs, canopies, umbrellas (Fig. 42). In climatic conditions in Poland, it is advisable to use seasonal elements in order not to limit the possibility of solar gains during heating periods and to provide protection against excessive heat when it is most needed. In the shade of elements, places for sitting, playgrounds, and recreation areas, as well as drinking water intakes should be located.

Fig. 42. An example of spontaneous actions taken by the inhabitants of Cairo to shade the street (left) and designed sunscreens in Gdynia; source [17]

3.2.5 Material solutions for pavements and wall finishing of buildings

Material properties in terms of accumulating and reflecting solar radiation are significant for temperature distribution in urban spaces. The albedo coefficient is used to characterize the ability of a material to reflect radiation, as it expresses the ratio of the amount of radiation reflected in all directions to the amount of radiation incident on a given surface. In general, the city as a whole is marked with a low albedo coefficient and high thermal accumulation due to a large share of dark materials used on surfaces, such as bituminous waterproofing or asphalt (low albedo) and massive heat accumulation materials, such as concrete hardened surfaces or ceramic coverings (roof tiles, tiles). The best way to balance these parameters is the above-described replacement of hardened surfaces with greenery or other porous materials and the introduction of green roofs. However, it is obvious that the possibilities in this respect are limited. In the immediate vicinity of buildings, it is advisable to avoid materials with high thermal mass, e.g., hardened concrete surfaces and dark-coloured materials. If it is made possible by building use, wood (e.g., on terraces) or wood-plastic composites can be applied (this is shown in Fig. 39 bottom left).

It is also more advantageous to introduce light colours on walls and roofs. Roof finishing materials in the form of bituminous roof waterproofing, typical for flat roofs on multi-family buildings (characteristic of large-panel prefabricated blocks of flats), should be replaced with more modern materials, e.g., membranes based on light-coloured plastics.

Furthermore, unfavourable phenomena tend to arise in the vicinity of buildings with a large glazing ratio. Large panes of glass act as lenses; they focus and reflect radiation, which leads to many nuisances in the surroundings of buildings, primarily to glare and overheating. Typically, multi-family buildings are not fitted with a high share of glazing in the external walls. However, if residential development is located near such buildings, it may be exposed to similar phenomena. In the surroundings of such buildings, greenery and surfaces should be designed with particular care to counteract adverse effects.

3.3 Individual solutions

Individual solutions for ensuring thermal comfort in buildings during hot seasons are related to the architecture and technology applied in the case of individual buildings and apartments, as well as to the habits of users. While designing new buildings, the principles formulated on behalf of ecological construction, aimed at saving natural resources, including energy, and providing people with healthy living conditions, should be observed. An extensive body of literature on this issue [18, 19] may be consulted. Indeed, this approach is not yet well-established in Poland, but its spread is dynamic, especially in the field of energy efficiency. Since 2021, regulations have entered into force, according to which all newly designed buildings are required to meet quite restrictive regulations regarding the consumption of non-renewable energy. Thus, it is obligatory that the problem of optimizing energy flow (including phenomena related to overheating) is minimized at the architectural design level. Therefore, the main issue concerns the existing buildings and the possibility of their modernization with regards to high temperatures. Hence, the present article focuses on showing the possibilities in this aspect.

Individual solutions can be divided into 5 groups of activities discussed below.

1. Large-scale building renovation

As part of these solutions, the most important aspect lies in thermal modernization of the building by thermal insulation of walls and roof, and replacement of windows. In certain cases, it may be justified to reduce the area of glazing, but this only applies to over-glazed buildings. Such amendments constitute a major renovation that must be performed on the building as a whole, especially in terms of thermal insulation of the walls.

2. Medium-scale building renovation

As part of these solutions, external shading systems can be introduced for windows located on the sides exposed to solar radiation (especially towards the south and west), and not shaded by high greenery. Such systems include, for instance, protruding horizontal elements (balconies, loggias, protruding cornices, canopies) in the case of southern walls or sliding blinds, awnings, roller blinds, shutters in the case of west, south-west, east, south-east orientations (Fig. 43).

Fig. 43. Examples of various external shading systems to be applied over glazing in buildings; source [19].

The main principle of designing such systems in climatic conditions in Poland should rely on the possibility of providing penetration of solar radiation into the interior during heating seasons and in transition seasons. At the same time, the systems ought to protect against solar radiation in summer periods, but with the least possible limitation of natural light and view to the outside.

It may also be beneficial to arrange a balcony or terrace properly, as such building elements constitute an external space related to the apartment's interior. In the case of inhabitants who spend a large amount of their time at home or do not leave their apartments at all, this solution may provide the primary possibility of communicating with the building's spatial surroundings.

To balance the temperature in summer, it is beneficial to finish the balcony or terrace surface in relatively bright colours and with coverings of a low heat-accumulating degree (e.g., wood, wood-based, and plastic composite materials). Moreover, shading the balcony space from the summer sun and introducing vegetation may also be helpful.

Such modifications can be introduced individually by the apartment owners, although some of them require the consent of the building managers. Coordinated measures to prevent excessive differentiation of solutions provide significantly better aesthetic effects for the external image of the building.

3. Small-scale building renovation

As part of these solutions, shading systems mounted on the inside of the windows can be introduced. These include curtains, internal blinds, and shades. Such a solution may be much less effective than the external ones in terms of protection against overheating, but their advantage stems from the easiness of implementation.

4. Installation equipment

Individual air conditioning units are becoming an increasingly popular method to protect apartment interiors from overheating. The cost per unit of such a device is quite substantial but affordable to middle-income households. Such a device offers a high degree of effectiveness, which can be additionally controlled. However, the solution triggers numerous disadvantages. From an ecological point of view, it is an energy-consuming device that requires highly processed technological elements and emits heat to the outside. It may be estimated that within approximately 15 years, the devices will become waste, difficult to recycle. Air conditioning units also require the installation of condensers outside the building, which disfigures the facades. This aspect would be especially visible if every apartment in the building were to be equipped with an air conditioning unit. In addition, the solution is far from healthy to humans, which is confirmed by several studies that point to a correlation between the greater infection rate among people who stay in air-conditioned rooms. It also seems unfavourable to older adults, susceptible to colds, who may experience additional problems with the operation of the device and its proper adjustment.

Another possibility is to install ceiling-mounted or free-standing fans. These devices are much simpler than air conditioning units, but their effectiveness is low.

5. User habits

The proper behaviour of apartment users may impact the air temperature prevailing inside their dwellings. In this case, it is important to close the windows and cover them when the outside temperature is at its highest. In turn, at night, ventilation should be intensified in the apartment in order to replace the air indoors, if possible. For this purpose, the apartment should be ventilated throughout by opening windows on opposite walls simultaneously. If the surroundings of the building are not adequately ventilated and air stagnation occurs in the vicinity of windows, such action will be ineffective.

To sum up, the range of solutions applied in order to adapt buildings to high temperatures is very wide and concerns various design scales. Individual residents themselves can take only a small part of these actions. Even if undertaken in the best possible way, their actions will bring little benefit if no higher order solutions are applied on the building scale, in housing estates, and in the form of comprehensive urban-planning activities. In Warsaw, installing air-conditioning units in apartments solves the problem of experiencing high temperatures only seemingly and temporarily, as it fails to eliminate the causes of the problem.

It is impossible to make a reliable comparative assessment of individual solutions, as their actual effectiveness can only be measured concerning specific conditions (location of a given housing estate within the city, the location of a building in relation to other buildings, etc.). When assessing them, other criteria should also be considered, e.g., their environmental cost, availability or friendliness to humans in other aspects than thermal comfort only.

The only correct assumption is to treat the above solutions as a system of complementary, synergistic elements. The system should consist of solutions undertaken on various scales - from the most general ones to those related to individual decisions made by the inhabitants themselves. It is necessary to develop strategies based, as much as possible, on passive, simple solutions that fulfil a variety of tasks.

The needs of older adults result in special conditions to introduce solutions dedicated to them. From their point of view, the following issues prove of particular importance:

- avoiding elements that require control, regular maintenance, or equipment prone to failures, creating simple solutions that require little operation and technological knowledge, the advantage of passive solutions over active ones (e.g., external shading systems with a simple structure, not limiting the view from the outside)
- creating solutions that encourage people to leave the house, spend time outside, ensure thermal comfort in the immediate vicinity, and allow the elderly to stay in touch (e.g., a place to sit for recreation, greenery, water, shaded places),
- providing places for resting along pedestrian routes (benches in the shade, the possibility to drink water),
- development of balconies and terraces as sheltered spaces, smallest possible share of easily heated elements, arranged with greenery.

Chapter 4 – Administrative and legal conditions

4.1 Basic legal mechanisms concerning construction investments in Poland

Legal regulations concerning the pro-ecological approach to urban and architectural issues result from the directives adopted by the European Union. Directive (EU) 2018/844 on the energy efficiency of buildings has exerted the greatest impact on actual amendments to Polish law regarding thermal issues. The document includes such aspects as the definition of "nearly zero energy building" (nZEB), a strategy to gradually reduce the energy consumption of buildings by 2050, modernization strategies, a methodology applied to calculate the energy balance of buildings. The provisions of the directive have resulted in the following changes to the regulations in force in Poland:

1. system of energy performance certificates - a mandatory document for buildings or parts of buildings sold or rented and for public buildings (over 250 sq.m.)

2. national plan to increase the number of nZEB - a series of various documents - not merged, some of them consist of legal acts, other ones are recommendations with no legal force

3. energy audit - an expert opinion to determine ways of building modernization so as to reduce its energy demand. It indicates the most optimal solutions, both in terms of implementation costs and energy savings – not mandatory for residential buildings.

Each investment process in Poland related to buildings development and its plan is subject to various regulations adopted at various administrative levels. The system of documents applied for spatial planning and urban design is presented in Fig. 44 below.

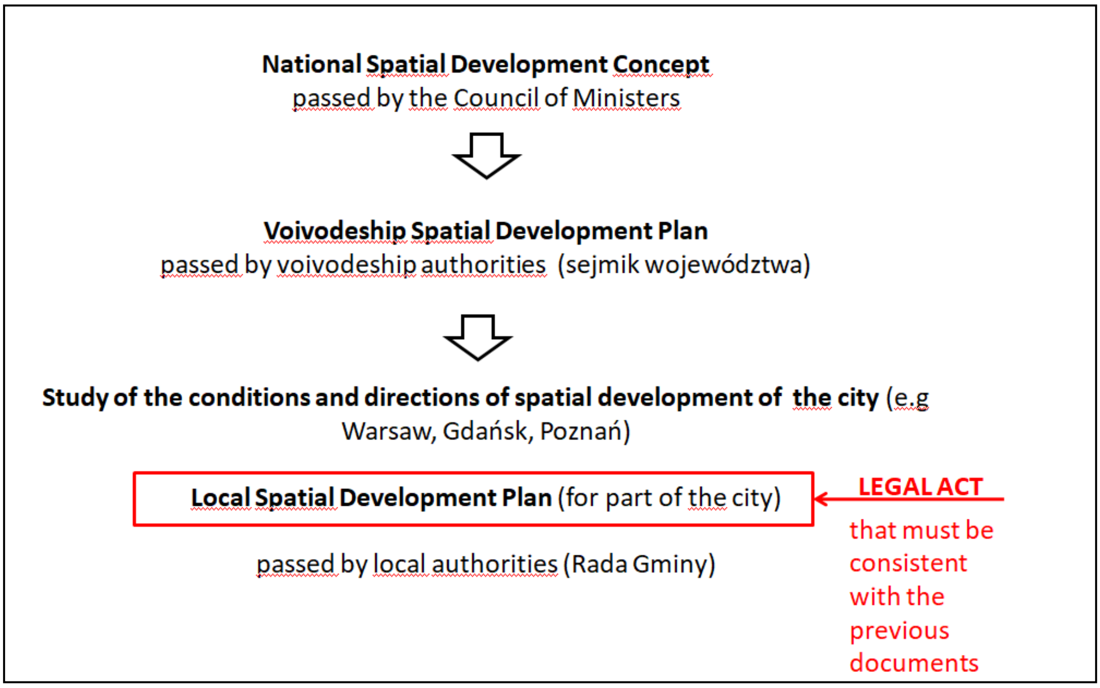


Fig. 44. System of documents that regulate spatial planning and urban design in Poland, Author's study, based on [20].

Documents that constitute the basis for activities adopted across the city of Warsaw include *StudiumuwarunkowańikierunkówzagospodarowaniaprzestrzennegoWarszawy/Study of conditions and directions for the spatial development of Warsaw* [9] and *Lokalne Plany Zagrospodarowania Przestrzennego/Local Spatial Development Plans*. The first of the two documents concerns the city as a whole and must be consistent with *Plan Zagospodarowania Województwa / Voivodship Development Plan*. The document is not binding in legal terms, but *Local Spatial Development Plans* (LSDP) are developed on the basis thereof. LSDP covers larger or smaller parts of the city (e.g., part of a district, housing estate, or building development quarter). LSDP comprises a legal act binding on the users of a given area. Each building erected in a given area or undergoing modernization must meet the requirements indicated in the plan. The investor who implements this type of investment must submit a project to the city hall, in order to demonstrate its compliance with the provisions of LSDP as well as with other applicable regulations. On this basis, a construction permit is issued, which conditions the commencement of construction works.

4.2 Regulations on thermal phenomena in urban spaces and buildings

On the scale of urban planning, the following documents can be listed:

1. *Studium uwarunkowań I kierunków zagospodarowania przestrzennego Warszawy/ Study of conditions and directions for spatial development of Warsaw* [9] contains an analysis and description of the existing condition and defines development assumptions of greatest priority. Provisions with regards to aeration corridors and the city's natural system are contained in the document. These specifications define which areas within aeration corridors are excluded from building development, and which are granted permission to be developed and under what conditions.

2. Programs and strategies prepared by local authorities – city guidelines and recommendations, e.g., for Warsaw:

3. *Strategia adaptacji do zmian klimatu dla m.st. Warszawy do 2030 r. z prognozą do 2050 r. Miejski plan adaptacyjny/Strategy for adaptation to climate change for the Capital City of Warsaw until 2030 with forecast until 2050. Urban adaptation plan,* 2019 [11],

4. *Klimat Warszawy/Warsaw Climate,* 2017 [12],

5. documents related to the housing policy of Warsaw– *Warszawski standard mieszkaniowy, Mieszkania 2030, Mieszkania 2030 standardy modernizacji I remontów/Warsaw housing standard, Apartments 2030, Apartments 2030 standards for modernization and renovation,* 2017.

The abovementioned documents comprise recommendations as to standards and solutions for new investments, as well as modernization policy. These recommendations are applied in investments conducted by city authorities, mostly in the case of public utility buildings rather than multi-family building development. It is impossible to enforce the implementation of the recommendations above for development investments, as the documents have no legal force. Nevertheless, they present educational value, raise public awareness and can be helpful as general design guidelines. They include solutions aimed at minimizing thermal stress, e.g., regarding water retention, development of green areas, improvement of the energy efficiency of buildings.

6. *Lokalny Plan Zagospodarowania Przestrzennego/Local Spatial Development Plan* covers requirements concerning building development height and density (floor area ratio - FAR), amount of biologically active areas, including green roofs, amount and type of car parks, greenery to be preserved. The LSDP specifies a rather limited number of parameters to determine building development shapes and the structure of greenery. Despite the broadening knowledge on the relationship between building geometry and energy phenomena in the city spaces, the number of parameters defined in LSDP and their type has not been amended almost at all in recent decades. None of the parameters provided in the document directly refer to the issues of local ventilation. As a matter of novelty, the provisions on the necessity to install green roofs in certain cases have appeared. In contrast, the rules for determining the required parking spaces have also changed in favour of environmental terms. Until recently, the minimum range of car parks was specified (i.e., if the investor could not provide the specified number of places per usable area, they could not implement the investment). Nowadays, however, the maximum number of parking spaces is often defined, i.e., those amounts cannot be exceeded. Thus, certain changes are visible in the approach to preparing local plans. These adjustments, however, are not sufficient. The problem is highly important, as the LSDP constitutes virtually the only document that directly affects the way land is developed in general, including solutions that influence the quality of microclimate.

On an architectural design scale, the following documents can be specified:

1. *Prawo budowlane/Construction law* - design procedures, determine which works require a construction permit, what qualifications should architects have;

2. *Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawiewarunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie/Ordinance of the Minister of Infrastructure of April 12, 2002 on technical conditions to be met by buildings and their location*– contains maximum values for energy consumption, minimum requirements for thermal insulation of external partitions, requirements for technical equipment (also requirements concerning facilities for the disabled);

3. *Rozporządzenie Ministra Transportu, Budownictwa I Gospodarki Morskiej z dnia 21czerwca 2013 r. w sprawieszczegółowego zakresu I formy projektu budowlanego/Regulation of the Minister of Transport, Construction and Maritime Economy of June 21, 2013, on the detailed scope and form of a construction design*–includes the requirement to perform an analysis of the possibilities of various energy-saving solutions based on renewable energy sources;

4. *Rozporządzenie Ministra Infrastruktury I Rozwoju z dnia 27 lutego 2015 r. w sprawiemetodologiiwyznaczaniacharakterystykienergetycznejbudynkulubczęścibudynkuorazświadectwcharakterystykienergetycznej/Regulation of the Minister of Infrastructure and Development of February 27, 2015, on the methodology for determining the energy performance of a building or part of a building and energy performance certificates*

4.3 Social Participation

The forms of social participation are not particularly well developed in Poland when it comes to the emergence of new investments in cities or revitalization processes. Immediately after the change of the political system in the 1990s, social participation was far from popular owing to a strong association with forced social gatherings remembered from the socialist times. Over time, the need to hold such meetings occurred. By following the model established in countries whose inhabitants developed this form of social involvement, various participation forms gradually emerged. One of such forms of social participation activities results from the provisions of law [20] and constitutes an element of the process towards the adoption of LSDP. City authorities, to whose order the plan is prepared, are obliged to publish the draft plan for a specified period and accept residents' comments. An open meeting with representatives of the authorities and architects is organized. Comments are considered but need not be complied with.

Other forms of participation are also organized as non-obligatory initiatives to accompany controversial investments, development concepts for completely new areas in the city, or district revitalization programs. During these meetings, residents gather and participate in workshops to express their needs or evaluate individual solutions. Charette workshops, that is intensive sessions attended by all stakeholders of a given investment, offer an interesting form of participation.

City authorities usually undertake participatory initiatives in the cases of investments financed with public funds. These tend to exclude multi-family housing. Development companies that have captured the multi-family housing market do not launch such initiatives. Apart from not being obliged to organize participation actions, they take little interest in them, as their involvement in the investment ends as soon as the apartments are sold. Moreover, development companies typically design housing estates for an "anonymous client" who only appears once the project is fully implemented. Therefore, creating participatory models makes little sense.

It is difficult to assess the effects of participation based on the experience in Poland as of today. Firstly, residents tend not to demonstrate a lively interest in such actions. A surprisingly small part of the society is active enough and takes sufficient interest in the events that happen in their environment to join in participation projects. The low degree of interest may also result from a feeling of helplessness. Inhabitants fail to believe that they are likely to influence any decisions made at the government level. Drawing on their experience, they believe that even if they are heard, the investor will be the one to decide anyway, while the business goals will outweigh the social ones. Conducting interviews with residents as part of participatory meetings is far from an easy task. People seem unable to define their needs and have problems with the imagination of space and multi-criteria evaluation. The most active participants usually include protesters concerned about the adverse effects of a given investment (for example, they will lose an open view from a window or a parking space close to their house). Situations in which it is impossible to reach a compromise are commonplace. Nevertheless, it is worth making such attempts, developing various models of social participation, and encouraging residents to participate in these actions.

The city should improve communication with its citizens on planned developments and renovations. Announcements concerning the publication of the LSDP project are usually made available at the City Hall, on the website of the municipal office and, optionally, in the local press or via municipal social networks. It seems that a more effective method accessible to people of all ages would be to follow the British tradition. Invariably since historical times, advertisements have been hung on trees, fences, and poles in British streets inhabited by the residents concerned. The form in which the provisions of LSDP appear poses problems as well. The textual and graphic planning documents are hardly understandable to people not professionally related to urban planning, architecture, or construction. It is necessary to make the information contained in the draft clearer to discuss it more widely.

Social activation of the elderly stands chances of success, as these members of society usually have a lot of time, want to feel needed, and are willing to act for the benefit of others. Reaching them is possible through, for example, Senior Clubs, highly popular Universities of the Third Age, or traditional high-visibility advertisements posted in neighbourhoods.

4.4 Participation of scientific and professional communities

In addition to the abovementioned methods of influencing design decisions that affect thermal phenomena in the field of architecture and urban planning, it is worth emphasizing the importance of scientific and professional circles.

The scientific community is of great importance to educational processes. Scientific circles educate new professionals who will face the growing climate problems in the decades to come. In turn, by taking the educational mission beyond the students' environment, it is possible to develop social awareness of wider groups. Such measures are taken at Polish universities, but this potential is not entirely fulfiled. These efforts fail to be particularly appreciated (remuneration received by academic staff is not high compared to the national average salary, whereas the evaluation of their activity is based mainly on the scores for publications in scientific journals). Therefore, actions towards raising awareness thrive only when passionate scientists and academics with a sense of mission cooperate. It is not enough to achieve impressive results, despite students demonstrating substantial, ever-growing interest in the subject. A shortage is observed in workshops and qualified staff to teach students issues, such as numerical methods for simulating energy phenomena, working with new building materials (low-tech materials, smart materials), and organizing forms of social participation.

Similarly, the translation of scientific achievements in the above-discussed fields into practical activities is not fully utilized. A lack of cooperation between researchers and decision-makers, investors, and prospective users can be seen. Architecture and urban planning as a scientific discipline have an unfavourable position in grant proceedings, compared to other technical disciplines under which it belongs. For example, no separate panel for this discipline at the National Science Centre has been formed, which means that the research results achieved in architecture and urban-planning compete with other more technical fields of science focused on tangible effects expressed in quantitative research. Moreover, the orientation of university evaluation is not conducive to research projects on the local scale, as international importance cannot be ascribed to them. All of the abovementioned issues create a situation in which research, even if organized, is not used in practice. Developers, as a rule, are not interested in such studies, as they perceive architecture and urban-planning research as a potential complication to the investment process.

The few positive manifestations of cooperation between the scientific community and the environment are related to the development of documents in which analyses, recommendations, and lists of good practices are contained. City authorities most often commission these studies to academic teams. Unfortunately, research grants are still rarely obtained for purposes directly related to architecture, and urban-planning in Poland constitute another form of cooperation. One example of such a grant is *Miejski Budynek Jutra 2030/Urban Building of Tomorrow 2030*research project implemented by Mostostal Warszawa, financed by the Minister of Construction and Infrastructure in 2009-2013 as a goal-specific grant. Its purpose was to create a demonstration model of a multi-family building that meets the standards of a sustainable building, including energy-saving criteria, with high-quality thermal, light, and acoustic environment. The building was erected at the intersection of Krasińskiego and Burakowska Streets in Warsaw (Fig. 45); it was designed by Galicki Sypniewski Architekci company.

Fig. 45. View of a multi-family building in Warsaw, erected as a result of *Miejski Budynek Jutra 2030/Urban Building of Tomorrow 2030* research project, source: http://www.krasinskiego41.pl/Technology.aspx.

The construction team failed to implement all the assumptions made at the beginning of the project in this building. This resulted from the tight timeframe of the project and unforeseen investment difficulties during its course. It was impossible to achieve a situation when an architectural design of the building would be created in cooperation with a group of scientists. The scientific team only joined as consultants on a project that was ready to be approved for construction. Nevertheless, numerous ecological solutions were applied, including those intended to protect the interior against excessive solar radiation in the summer. Very good thermal insulation parameters of walls and windows were obtained, the shape and location of balconies were optimized in such a way as to shade the glazing, whereas an external shading system in the form of sliding panels with shutters was introduced.

Although *Miejski Budynek Jutra 2030/ Urban Building of Tomorrow 2030* cannot be considered an exemplary project, such initiatives should certainly be developed as consecutive steps on the way to developing model solutions. The process of designing a new district of Wrocław – Nowe Żerniki can be seen as a similar initiative that sets new standards. This time, however, the venture was undertaken on the scale of urban design. The process was initiated by the professional community of Wrocław architects who, having been informed that the city had planned to erect a new district, assembled to create a coherent vision of the district. They intended to protect the area from the mechanisms which offer the advantage of business goals over other results. Highly qualified architects embarked on developing a coherent plan for the entire district, reserving places for social investments (retirement homes, education, and recreation facilities) and for non-developer business models of building apartments (cooperatives). The plan served as the basis for the development of the LSDP, followed by requirements for individual designs to be selected through architectural competitions.

Another project, less advanced in implementation than Nowe Żerniki, is *Warszawska Dzielnica Społeczna/Warsaw Social District* concept, which is to be built as a stock of apartments erected by the city of Warsaw in the Wola district. As in the case of the Wrocław district, the starting point was a plan for the entire area prepared by the BBGK Architekci studio. Design assumptions include various solutions favourable to thermal comfort, for example: limiting car traffic and paved areas, a significant share of high-rise greenery and biologically active areas, green roofs, light colours of roofing, water retention, energy-saving solutions for buildings [21]. The project provides for staging investments and public consultations with future residents.

Although the experiences described above are limited and it is impossible to assess their effects fully, it seems proper to create model solutions in cooperation with local government and scientific and professional communities, with the most comprehensive approach to the issues of climate and quality of life within the housing environment. This applies to both newly designed housing estates and modernization of the existing ones. Such investments would provide conclusions on the effectiveness of individual solutions, the possibility of formulating appropriate requirements by the provisions of the LSDP, as well as to raise public awareness on standards to be expected from development investments.

4.5 Summary of the legal situation in Poland

Analysis of the current situation in Poland, specifically in Warsaw, in terms of regulations related to thermal comfort, proves several weaknesses. The shortcomings can be summarized as follows:

1. a large part of documents that regulate thermal issues is not binding in legal terms but are voluntary and, as such, fail to be respected by development companies that have captured the family housing construction market in Poland;
2. provisions of LSDP fail to guarantee the appropriate standard in terms of thermal comfort for newly designed, supplemented, or modernized buildings

3. lack of a comprehensive approach to the issue in legal regulations, provisions on energy issues are scattered across various legal documents;
4. the introduced changes organize certain issues but complicate other ones at the same time; new regulations are introduced quickly and chaotically
5. it is doubtful as to whether the fulfilment of the current regulations on energy phenomena and thermal comfort truly guarantees such comfort; for building design, the situation is fairly good but much worse in the case of urban design;
6. environmental issues are not highly valued in Poland; despite the verbal declarations of government representatives, climate action does not go beyond the necessary minimum dictated by the EU requirements

Despite the abovementioned criticism, it is important to appreciate the "promising symptoms" that mark the commencement of well-targeted actions such as:

1. formulation of urban-planning and architectural standards with the account to thermal comfort solutions by local authorities; although their scope in the field of developer construction is limited, their positive impact on the implementation of public buildings is visible;
2. attempts to create conditions for other forms of multi-family investments than the development model only; first attempts are made to create housing cooperatives that allow future residents to participate more in investment decisions
3. research projects involving numerous disciplines attempt to bring together issues so far considered in isolation and relate them to the local conditions of individual cities.

Supporting such activities by the authorities, both at the national and local level, as well as by scientific, social, and other institutions, may result in the development of permanent, sustainable mechanisms to guide the partial policy of cities.

Final conclusion

The problem of overheating buildings and urban spaces remains relatively unrecognized in Poland's urban-planning and architectural tradition. So far, climate conditions have mainly dictated the need to protect against the cold. Due to climate change and the urban heat island effect, the issue of interior overheating has recently become apparent in large cities. The emerging situation constitutes a new task for local authorities, urban planners, architects, investors, citizens, and other participants in construction investments.

For the EmCliC project, the taxonomy of residential buildings in Warsaw regarding their susceptibility to overheating was developed. The typological division was conducted by analyzing plentiful source literature on the topic. Five groups of multi-family buildings were distinguished according to construction time, following the erection technology criteria and thermal insulation parameters. The buildings include those erected:

- before 1945 - historical architecture - historical technologies, massive brick walls, no thermal insulation requirements;
- 1946 - 1966 - reconstruction of war damages and new estates with the use of demolition bricks, cheap, economical construction;
- 1967 - 1989 – prefabricated, large-panel prefabricated construction;
- 1990 ~ 2002 – more diverse technologies similar to modern ones but less restrictive in terms of thermal insulation of walls;
- following 2002 – stronger than before emphasis on thermal insulation and energy efficiency, improvement in technology.

The analysis of these groups prompts conclusions concerning the types of multi-family housing that are prone to overheating to a lesser and a greater degree. Buildings most exposed to the above problem (although to a different extent, as discussed in chapter 2.2) are the ones built by the 1990s that have not yet been subject to thermal modernization. Newer buildings, especially those erected after 2002, are marked with improved technological standards related to thermal comfort. Still, due to the high density of building development and the low share of greenery, the spaces around them may be at risk of overheating.

The issue of experiencing high temperatures in large cities is part of the broader and very complex problem of energy processes that occur in the city and the need to regulate them in accordance with the sustainable development principles. This requires the analysed problem to be approached on various scales - the city as a whole, parts of the city, buildings and their immediate vicinity, individual apartments, and the user habits. The solutions to promote thermal comfort in hot seasons presented in the study above have been arranged in this order. Therefore, thermal stress affects the processes of city spatial planning, urban design of districts, housing estates, building development quarters, architectural design of buildings and their surroundings (including landscape design), and interior design. The scale of activities is rather wide. Moreover, it comprises various regulations, which are improperly arranged in Polish law.

A clear need is noticeable for long-term, comprehensive development concepts that should be consistently implemented regardless of political conditions. The most important elements of such strategies should primarily include efforts to:

1. challenge the dominance of developer models for conducting housing investments

2. provide absolute protection of strategic areas in terms of nature, including the system of aeration corridors

3. exert control over building development intensity (according to [6] Warsaw development plans, to be implemented by 2070, will result in increasing the UHI problem by significantly densifying buildings and reducing the share of biologically active areas),

4. increase the effectiveness of *Local Spatial Development Plans* as legal instruments with which to impose high environmental and social standards,

5. increase design standards at the study1 and conceptual stage, and increase urban design rank (good practices show the utmost importance of the plan as a starting point for legal decisions concerning a given area).

Short-term actions should mainly concern the modernization of the existing housing development. The analysis conducted in the study above proved the necessity to analyse the building and its immediate surroundings as a whole, both with regards to designing new buildings and modernizations. Undoubtedly, thermal modernization of buildings, successively performed in housing estates that fail to meet modern energy standards, yields a satisfactory effect. Central or local authorities should better support such actions, but it is also necessary to:

1. update technologies and change them to more ecological ones (for example, the currently predominant polystyrene as a thermal insulation material should be replaced with other, more environmentally friendly materials),
2. extend the goals of thermal modernization - from the approach of protecting the building against heat loss to the approach of protecting it also against overheating the rooms during hot periods,
3. develop and promote appropriate solutions for buildings of historical value, where the facades should remain uncovered, so as not to lose valuable architectural details (a large part of buildings, also those not protected by the heritage conservator, is equipped with such elements).

Among the solutions described above which affect temperature balance in summer, a group of solutions can be distinguished that are likely to yield satisfactory results, are simple, and require little intervention. Their introduction is within the capabilities of housing associations or apartment owners (it is also worth co-financing them under municipal programs). In general, these solutions also fulfil many environmentally and socially valuable goals. These include:

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1. Currently, it is common that the preliminary concepts for the development of masterplan spaces, which are used to develop LSDP, are made by architects, for investors, for free, only on the vague promise that in the future they will be commissioned to design the entire investment.

1. external shading systems in the form of fittings, such as horizontal canopies, balconies, cornices on south-oriented facades and panels of blinds, roller shutters, vertical elements (blade-shaped) on the western, south-western, south-eastern facades; these elements should be carefully designed (in order not to restrict access to solar radiation during winter periods and not to limit natural light and view throughout the year); such renovations should be coordinated for the entire building,
2. biologically active surfaces, instead of hardened surfaces in the vicinity of the building,
3. tall trees in vicinity of buildings (their species, size, and location in relation to the building, roads, parking lots, and sidewalks is of importance)
4. shaded places in the vicinity of buildings as places to spend time at (trees, seasonal roofs), seasonal shading of balconies
5. green roofs and balconies
6. water retention, water reservoirs in neighbourhood recreational spaces, drinking water intakes, seasonal cooling water curtains

Installation of air conditioning units in individual apartments, although it seems an almost immediate solution and, in many respects, the simplest one, is unfavourable in terms of overall environmental and social assessment. Multiplied by the number of flats that require this sort of improvement, it may overall worsen the climatic situation of the city.

When it comes to practical measures that can bring favourable results, it is also worth considering support for urban planners, architects, engineers of various construction industries, and other participants in designing new buildings or modernizing the existing ones. Mastering such complex issues as urban microclimate requires advanced tools to simulate the effects of various design decisions and compare them. Although such tools exist and are constantly being developed, their implementation into the design process in practice is very difficult. Currently, only a few best-developed and specialized architectural studios in Poland can successfully master the issue. Design supporting tools, such as BIM (Building Information Management), parametric software, and simulation software stand a chance of becoming more popular than before. However, this can only happen if data is more accessible, including construction data (digital versions of technical documentation), climate data, especially on the microclimate scale around buildings, digital city maps, together with models that can be used directly to simulate the operation of designed buildings as elements of the environment as a whole.

Annex

Tips and guidelines on managing thermal stress from the perspective of architectural and urban solutions.

1. For individuals:
    - adapting one's own apartment by installing window shading elements (external ones have a greater effect than internal ones), covering a terrace or balcony floor with non-heating and light materials, introducing greenery and shading (e.g., with an awning or climbers);
    - user habits - closing and covering windows at high air temperatures, airing the apartment at night;
    - arrangement of the area in the building's proximity as unpaved, covered with greenery;
    - assembly of installation elements - fans or air conditioners, although the latter is not an environmentally friendly solution and should only be applied as a last resort.

2. For neighbourhood communities and housing associations:
    - modernization of buildings - thermal insulation of walls and roofs, replacing windows (better thermal insulation, selective transmission of solar radiation);
    - development of the area around the buildings with the least paving possible (without cars), with as much greenery as possible, including trees to shade the most sun-exposed walls of the building and to protect outdoor resting areas against excessive insolation, implementation of retention reservoirs, introducing benches, taps with drinking water and seasonal shading elements;
    - creating neighbourhood initiatives, dialogue with local city authorities to support building modernization and environmental initiatives.

3. For city authorities:
    - protection of the existing biologically active area systems, supplementing them with new ones, creating continuous systems by combining them with the existing ones;
    - controlling the building development intensity, increasing the parameters for regulating their shape according to pro-environmental criteria, e.g., the possibility of ventilating the space around them;
    - better support for thermal modernization of the existing buildings;
    - modernization of the city's public spaces by maximizing green spaces, introducing shaded areas to allow resting, seasonal water curtains, water intake points;
    - transforming planning procedures towards the obligation to prepare master plans for larger areas, and to prepare Local Development Plans only on the master plans,
    - seeking other methods to implement housing investments than the developer ones, placing greater demands on developers in terms of the urban quality of the erected housing estates.

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