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Urban Environment and Structure of Lithuanian Cities: Their Assessment in the Context of Climate Change and Other Potential Threats

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Abstract

The negative consequences of climate change—such as heatwaves, storms, and floods—together with emerging threats including war, radiation, and pandemics, are increasingly affecting human health, ecosystems, economic stability, and the overall living environment. Consequently, enhancing preparedness has become a key task in shaping the spatial structure of cities. However, despite the growing negative impact and increasing frequency of climate change consequences, along with the prevailing risk of other threats, Lithuania is still not adequately prepared. The article examines the urban environment of Lithuanian cities and its local climatic assessment, aiming to develop proposals to enhance the sustainability and resilience of this environment in addressing the negative consequences of these threats. Three main climatic regions of the country were selected for the research, represented by cities: Klaipėda, Kaunas, and Vilnius. Urban and local climatic research was carried out in the selected cities to assess their spatial structure and environment and identify for microclimatic research the unified morphostructure types commonly used in the country. Accordingly, to selected morphotypes, correlations of the relationship between development density, building height, and the area of impervious surfaces with air and surface temperatures were carried. The most favourable microclimatic conditions were identified in morphotypes characterised by lower development density, more abundant green spaces, and a more open development pattern. Such characteristics of urban morphostructures, considering additional factors of land use such as land saving and the efficient functioning of the city, form the basis for developing the spatial structure of sustainable urban residential areas.

Keywords: urban structure; climate change; air temperature; urban heat island; urban morphostructure

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1. Introduction

The rising ambient air temperature results in unavoidable global warming and other consequences of climate change such as storms, floods, and heatwaves. These climatic phenomena affect the urban environment and have a significant impact on quality of life, public health, and the social situation [1–3]. For the second consecutive year, a record global near-surface air temperature has been recorded worldwide in 2024 [4–6]. In addition to climate change, other emerging threats—such as pandemics and the risks associated with armed conflict—also have significant implications for urban areas. These phenomena, by their very nature, can be catastrophic, affecting both public health and the physical fabric of cities [7,8].

To reduce the adverse impacts of climate change and other threats, it is essential to anticipate their potential consequences and adapt cities and their environments accordingly. Although these threats differ in origin, their effects often overlap; therefore, a comprehensive assessment of all relevant threats is necessary to determine the appropriate level of preparedness, alongside the adaptation of the city's spatial structure and its safety and engineering infrastructure.

The aim of this article is to identify potential measures for adapting to the consequences of emerging threats by conducting urban studies of Lithuanian cities, highlighting the microclimatic aspect, linking urban and microclimatic features, and evaluating the most suitable characteristics of urban morphostructure influencing the formation of the most favourable microclimatic environment. Microclimatic research is currently being carried out in Lithuania; however, large-scale studies focusing on urban microclimatic structures are still limited. Such research has mainly been conducted by scholars at Vilnius University, whose work examines the impact of meteorological processes on pollutant dispersion in Vilnius [9], the challenges of quantitatively assessing technogenic landscapes [10], the intensity of the urban heat island effect in Vilnius, [11,12], and the role of urban green infrastructure in advancing climate change adaptation strategies [13], etc. However, these studies are not fully integrated with urban structures or the functional characteristics of cities. As a result, there remains a lack of comprehensive climate-related research linked to urban planning in the country. To outline the current state of this research field, the literature could be reviewed with regard to climate change impacts, urban local microclimate studies, and multi-threat preparedness.

Climate change impacts. Globally, numerous studies are being conducted on the impact of climate change on urban areas [14–16]. Among these, research examining the formation of urban heat islands and their relationship with urban structure is particularly prominent. To that end, evaluations of urban structures are conducted to explore the correlations between development density and microclimatic air temperature—evaluating materiality, parameters of the physical environment that may result in higher or lower microclimatic air temperatures, and other related analyses [17–19].

Urban local microclimate research. Among the early international studies, notable ones investigated how air temperature in urban spaces depends on city size, development density, and the extent of impervious surfaces [20], etc. Among ongoing research efforts, those aiming to establish a classification system for urban structures based on microclimatic features defined by specific morphological elements stand out [21–27]. The most systematised result of urban structure microclimatic research, currently widely applied by researchers worldwide, is the local climate zone classification developed by Stewart and Oke (local climate zones) [28]. This framework enables the differentiation of urban structures based on distinct physical characteristics, allowing for a clearer understanding of their relationship with microclimatic parameters. The standard local climate zones (LCZ) system proposed by the authors, composed of ten built-environment types (LCZs 1–10) and seven land-cover types (LCZs A–G), is widely applied in the areas of urban structure analysis and modelling [29–31].

Multi-threat preparedness. Preparedness for emerging threats of various kinds is one of the fundamental social objectives in every country. Among the countries paying the most attention to various threats are those that have themselves experienced or been affected by certain threats, such as Finland, which faced a significant threat of war [32], as well as others that recognised the significance of climate change and other threats earlier than others, for example, Denmark, Sweden, and Chile among others [33]. However, as demonstrated by the experience of Lithuania, insufficient attention is still given to this issue. Therefore, for the effective adaptation and preparedness of cities, a comprehensive assessment of urban structures is particularly relevant.

Foreign researchers have prepared a significant number of studies aimed at assessing and analysing the consequences caused by ongoing threats, and urban and natural changes, as well as possible measures to mitigate negative impacts and adapt to them [1,34–37]. However, only some countries have well-developed civil safety infrastructure, and only a few place greater emphasis on preparing for various emergency situations. Many countries, including Lithuania, have not yet achieved a high level of preparedness in responding to emerging threats related to climate change and other risks [8,38–41]. So microclimatic studies still remain actual and should be further developed by taking into account the specific urban characteristics of each country, national legal frameworks, and natural and climatic conditions.

The studies on climate change and other threats are becoming increasingly relevant, as global air temperatures continue to rise, geopolitical tensions persist, and the risk of other dangers remains present. Therefore, in light of these emerging challenges posed by multiple threats, this article aims to provide a more detailed assessment of the country's national characteristics in the studied field—specifically, the nature of urban structures in cities, their suitability for preparing for potential threats, and the identification of the most appropriate directions for urban development that could enhance the resilience of the living environment to various potential threats.

2. Indications of Climate Change Threats in Lithuania and the Prevention of the Dangers They Pose

2.1. Climate Change Threats—Such as Heatwaves, Floods, and Storms—And the Forecasting of Their Future Development

In Lithuania, the greatest threats to the living environment, human well-being, the economy, and ecosystems are associated with the following climate change trends: rapidly rising air temperatures across all months, increasing sea levels of the Baltic Sea, and an increasing frequency and intensity of heatwaves, droughts, and other hazardous, extreme, and catastrophic hydrometeorological events [38,42]. Over a period of 64 years (1961–2024), the average annual air temperature in Lithuania has reached 7.5 °C, representing an increase of 1.3 °C—an average of 0.2 °C per decade (for comparison, at the global scale, in 2024 the average air temperature exceeded pre-industrial levels by 1.5 ± 0.13 °C [5,6]). There have already been years in which the annual average air temperature exceeded 9 °C (notably in 2020 and 2024). The most significant increases in temperature have occurred during January–April and July–August (1.4–2.2 °C). In other months, the temperature during the analysed period increased by 1.3–0.1 °C (with the smallest changes occurring in October). The average annual precipitation has increased by only 3% since 1961; however, monthly variations in precipitation have been considerable. For example, in April, September, and November, the amount of precipitation decreased by an average of 12%, while in January and February, it increased by 26% and 43%, respectively. It was also found that in Lithuania, there was a 12% increase in heavy precipitation events ($\geq$20 mm per day), a 32% increase in the number of hot days (maximum daily temperature $\geq$ 25 °C), a 25% average decrease in the number of days with snow cover, a 16-day reduction in the length of the meteorological winter, and a 13-day increase in the length of the meteorological summer. Between 2017 and 2024, as many as seven droughts were recorded in different parts of Lithuania.

The consequences of climate change are most costly in regions with high population density and where infrastructure is highly sensitive to climate impacts. In this context, cities and urbanised areas are especially vulnerable, as the effects of climate change can significantly increase the costs of essential urban services and raise overall living expenses. Compared to rural landscapes, densely built-up urban areas develop into urban heat islands, where residents are exposed to higher-than-background levels of heat stress, particularly during summer periods characterised by anticyclonic circulation and reduced air exchange between the city centre and its periphery. For example, in the central part of Vilnius, during the summer of 2022, the number of days when the maximum air temperature reached 30 °C or more accounted for 30%, while in the suburbs it was only 16%; during the summer of 2023, such days accounted for 20% and 7%, respectively. In the central part of Vilnius, the average daily maximum air temperature during heatwaves was 3.2 °C higher than in the suburbs. It was also observed that tropical nights—defined as nights when the minimum daily air temperature does not drop below 20 °C—occurred more frequently in Vilnius city compared to its suburbs.

According to the RCP4.5 and RCP8.5 scenarios (Representative Concentration Pathway), it is estimated that by the end of the 21st century, the average annual air temperature in Lithuania compared to the current 1991–2020 period, should rise by 1.2–1.3 °C under RCP4.5 and by 2.6–2.9 °C under RCP8.5 [38]. Consequently, the risk of heatwaves and droughts will continue to rise, leading to increasingly severe impacts on human health, ecosystems, and the economy. The number of cold days per year (with a daily minimum temperature $\leq$ 15 °C) is expected to decrease by more than half by the end of the century according to both RCP scenarios; the heating season will shorten, while the number of cooling days will increase. Such climate change trends highlight the need to radically reduce the impact of human activity on the climate and to implement climate change adaptation objectives, reduce the current and projected vulnerability of natural ecosystems and economic sectors, and maintain and strengthen resilience to climate change to ensure favourable conditions for society and sustainable economic activity.

Urban living environments are heavily influenced by increasing development density, the fragmentation of green infrastructure, declining vegetation and natural surface cover, and development in flood-prone zones, among other factors. To improve the resilience of urban environments, greater emphasis should be placed on mitigating the urban heat island effect and, more broadly, on assessing how urban design influences the local microclimate. Global experience shows that the design of an urban neighbourhood can have a significant influence on the surrounding local microclimate under varying climatic conditions [18,19,43]. Not only the type of urban development but also the thermal properties of buildings and artificial surfaces play a role in shaping the local microclimate. For instance, studies conducted in Switzerland and Greece have shown that changes in neighbourhood morphology can lead to increases in local air temperature of up to 2.5 °C [44], while the use of materials with high solar reflectance (i.e., high albedo) can lower local air temperature by approximately 0.7 °C [45]. In turn, the local microclimate can also significantly affect the operational performance of buildings—for instance, as air temperature rises, energy consumption for cooling can increase substantially [46–48].

2.2. Other Potential Threats—War, Radiation, Pandemics, and Similar Risks—And Efforts to Mitigate and Eliminate Them

In addition to the growing negative impacts of climate change, other non-climatic threats—including armed conflict, radiation exposure, and pandemics—remain equally pressing. Ongoing threats related to war and radiation pose a risk of human casualties, destruction of cities and natural environments, trigger migration waves, and have a major impact on the ecological situation [2,49]. Moreover, such threats demand not only extensive resources for the production of military equipment and reconstruction of damage done but also accelerates adverse climate change [50–52]. The pandemic period also brought about major challenges, during which many countries worldwide experienced profound changes in social life and the functioning of urban systems [40,53]. Although these natural and anthropogenic threats differ in origin, they are interconnected, affecting public health and altering the conditions of both the built and natural environments. In terms of risk, they often overlap as they can occur simultaneously and intensify each other's effects; therefore, their cumulative impact must be assessed and addressed comprehensively through the implementation of integrated protective structures and associated infrastructure.

One of the primary measures for preparing cities against war-related threats is the development of essential civil safety infrastructure. This infrastructure primarily includes shelters and bunkers, which provide people with the possibility to protect themselves from bombings and shelling. However, as shown by the analysis of civil protection infrastructure, the current state of preparedness in this area is poor. In the country, only collective protection buildings and designated shelters are officially registered, while the broader development of suitable protective infrastructure remains largely neglected. According to 2024 data from the Fire and Rescue Department under the Ministry of the Interior, there were 3448 shelters nationwide, capable of accommodating 934,939 people, or approximately 32% of the population [54]. However, this figure falls short of the required standards, as urban shelters should accommodate at least 60% of the population, and rural shelters at least 40% [55]. The situation worsens further when considering that shelters intended for long-term protection are entirely absent in many areas. During the pandemic, the importance of public spaces and green areas became especially apparent, as locations that helped alleviate overcrowding and supported minimal social interaction within urban environments. Furthermore, many parts of public parks and open spaces were repurposed to accommodate temporary healthcare facilities. Despite the clear need for and benefits of such spaces, the country still lacks a clear direction for the formation of a green space system, and the existing undeveloped areas important to the green and public space system are often not properly assessed or protected. This is evidenced by initiatives from various interest groups to reduce the required area of green spaces, occupy green areas, and increase development density [56,57].

To mitigate and prevent the negative consequences of these threats, it is crucial to conduct a comprehensive assessment and planning of urban structure in relation to these risks. A key measure in adapting to these threats involves the appropriate evaluation and reservation of internal urban spaces for protective, functional, and environmental purposes. These spaces represent one of the primary resources for establishing areas of special use, safety infrastructure, and other social and engineering facilities that may be essential in responding to emerging threats.

3. Selection of Lithuanian Cities for Urban and Local Climate Research, and Application of Corresponding Research Methodologies

For the research caring methodological scheme is prepared. Methodology combines selection of research subjects (Section 3.1), their urban (Section 3.2) and microclimatic (Section 3.3) research and results summary (Section 3.4). General workflow chart is presented in Figure 1.

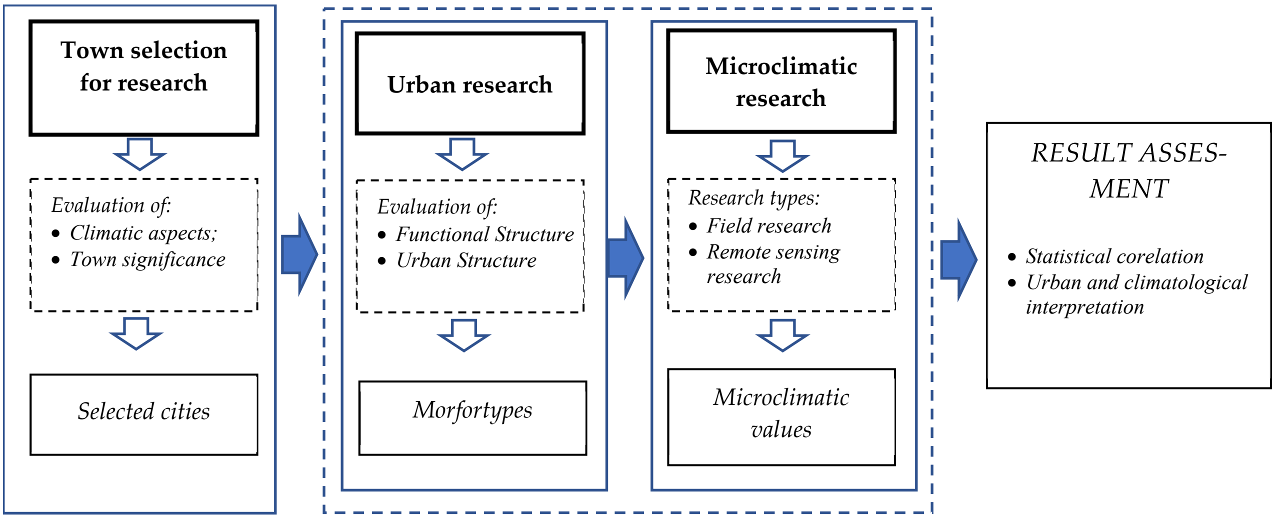


Figure 1. Methodological research flow chart.

3.1. Selection of Research Subjects

The study presented in this article encompasses urban and climatic analyses of cities within the country. To implement these analyses, an assessment of residential areas across Lithuania was conducted, based on which specific cities were selected for detailed investigation (see Table 1). Cities were chosen according to the three main climatic regions of the country: coastal, central lowland, and southeastern upland. The coastal region refers to the part of the country adjacent to the Baltic Sea, including coastal lowlands and the western uplands, which are characterised by relatively higher forest coverage. The central lowland region covers the central part of the country extending in a north–south direction and is defined by flat terrain and predominantly agricultural land with less forest cover. The southeastern upland region features a hillier landscape and is distinguished by the highest degree of forest coverage in the country.

Table 1. List of cities selected for research by climatic region and their main natural features.

No	Cities Representing Main Climatic Regions	Climatic Subregion	Natural Conditions		
			Lake	River	Forests, Fields
1	2	3	4	5	6
	Coastal climatic region *				
1	Klaipėda	Sea coast	Baltic Sea		Forests, fields
2	Šilutė	Coastal lowlands		Šyša	Forests, fields
3	Telšiai	Žemaitija Highlands	Lake Mastis		Forests, fields
4	Rietavas	Žemaitija Highlands			Forests
5	Mažeikiai	Middle reaches of the Venta lowlands		Venta	Fields
	Central lowland climatic region				
6	Šiauliai	Mūša–Nevėžis	Lakes Rėkyva, Talkša		Fields
7	Panevėžys	Mūša–Nevėžis		Nevėžis	Fields
8	Kaunas	Lower reaches of the Nemunas	Kaunas Lagoon	Nemunas	Forests, fields
9	Marijampolė	Lower reaches of the Nemunas		Šešupė	Fields
10	Tauragė	Lower reaches of the Nemunas		Sea	Forests, fields
	Southeastern upland climatic region				
11	Vilnius	Aukštaitija		Neris	Forests, fields

Table 1. *Cont.*

No	Cities Representing Main Climatic Regions	Climatic Subregion	Natural Conditions		
			Lake	River	Forests, Fields
12	Elektrėnai	Aukštaitija	Elektrėnai Reservoir		Forests, fields
13	Utena	Aukštaitija			Forests, fields
14	Varėna	Dzūkija			Forests

* The coastal climatic region includes the Pajūris and Žemaitija climatic subregions, located in the western part of the country and grouped into a single climatic region due to their shared proximity to the Baltic Sea. The other regions correspond, respectively, to the climatic subregions of the central lowland and the southeastern upland.

Within each studied climatic region, cities were selected based on their location within distinct climatic subregions and differing natural conditions, such as proximity to water bodies (rivers, lakes), forests, or open agrarian landscapes (Table 1, Figure 2). In the first studied region—the coastal region one major city, (Klaipėda), two medium-sized cities (Mažeikiai and Telšiai), and two small cities (Šilutė and Rietavas) were identified. In the second region—the central lowland climatic region—two major cities (Kaunas and Šiauliai), and three medium-sized cities (Panevėžys, Marijampolė, and Tauragė). In the third region—the southeastern upland climatic region—one major city (Vilnius), two medium-sized cities (Elektrėnai and Utena), and one small city (Varėna).

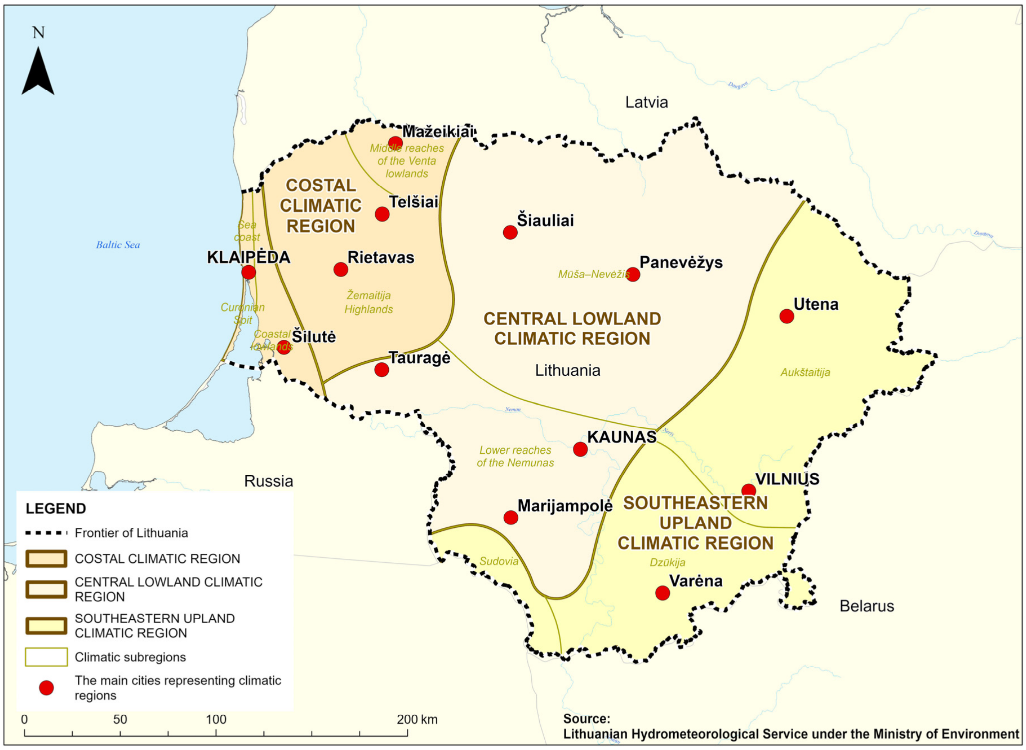


Figure 2. Climatic regions of Lithuania and cities selected for climate research (based on data from the Lithuanian Hydrometeorological Service under the Ministry of Environment) [58]).

It is expected that climatic zones, according to their peculiarity (differences in annual and seasonal temperatures, wind speed and others), can lead to microclimatic variations in corresponding urban structure.

3.2. Methodology of Conducting Urban Research

From an urbanistic perspective, the evaluation of cities was carried out by analysing the overall functional and urban structure of each city.

Evaluation of the Functional Structure. In reviewing the functional structure of cities, residential and industrial areas were examined in terms of their internal composition, spatial distribution, mutual relationships, and integration with the surrounding natural environment. Within these functional zones, green spaces and public areas were also identified and assessed. The evaluation of functional zones was conducted through urban analysis, incorporating geoinformation and orthophotography data alongside field observations. GIS software was used to support this analytical process. Based on the identified functional units, an analysis of the urban structure was carried out, identifying the main types of urban morphostructure relevant for microclimatic research.

Evaluation of Urban Structure. Types of urban morphostructure were defined based on the country's Territorial Planning Standards, which already classify specific development types. Based on national legislation, the following development types were distinguished: detached, single-family terraced, perimeter, open layout, industrial and infrastructure, and open space detached buildings [59]. Considering the objectives of the study, these development types were further supplemented with a mixed development type and structures representing non-built-up areas of green spaces. These structural elements of built-up and non-built-up areas are collectively referred to as urban morphostructure types. They are categorised into morphotypes of built-up areas (including residential and industrial area morphotypes) and morphotypes of greenery and open spaces (Table 2).

The identified morphostructure types are applied in climatic research. Depending on the morphostructure type, general microclimatic parameters corresponding to the areas are determined (based on Stewart and Oke, when the areas are larger than 0.4 km in diameter [28]). In addition, supplementary microclimatic parameters are determined when smaller distinctive urban elements are present within larger morphostructures, such as open space detached buildings with squares or public gardens. Though these urban morphotypes are specific and represents only a very small part of the urban environment, they are important from a social point—these places are central for people gathering and represents key urban spaces.

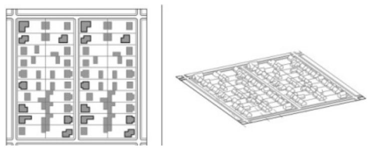
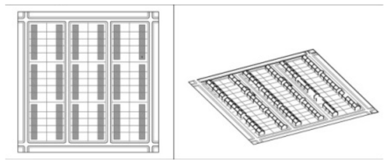
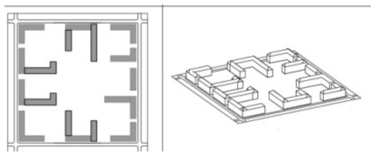
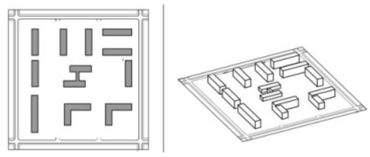
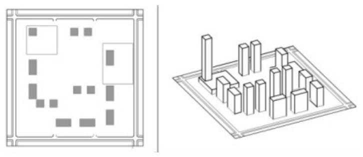
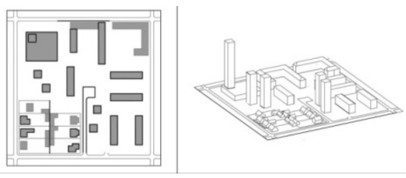
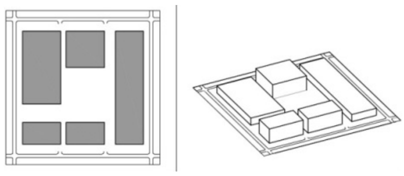
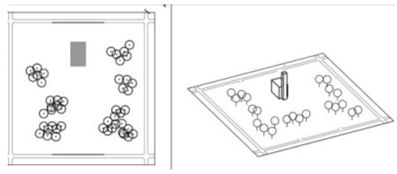
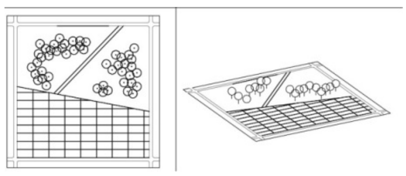
3.3. Methodology for Conducting Climatic Research

Urban microclimatic research was carried out across various types of urban morphostructures in selected cities, identified based on prior urban research. Microclimatic research was conducted using the following methods:

- field research: on-site measurement of microclimatic conditions, including air temperature, humidity, and wind speed
- remote satellite assessment: remote interpretation of surface temperature data obtained via satellites, covering different land-cover types such as soil, vegetation, impervious surfaces, building roofs, and other surface elements.

Field research was conducted only at selected locations within city morphostructures; therefore, to provide a broader assessment of the overall microclimatic conditions across entire cities, satellite-based land surface temperature data were also used, covering the full urban territory. According to research conducted by various authors, surface temperature measurements partially allow for the evaluation of the microclimate in inner urban spaces [60–66]. The general urban microclimatic situation was assessed by comparing deviations in air condition indicators (temperature, wind speed, humidity), identified through both surface and field measurements, relative to reference values obtained from rural meteorological stations.

Table 2. Development types and their application in local climate research.

Territory Type	No of Development Type, Name, and Description		Block Development Type Plan Scheme/Development Type Spatial Structure Scheme
Areas under development	Residential areas		
	Low-rise residential development area	1. Detached development (morph. 1—detached) Extensive low-rise detached development of residential areas where one- to three-storey buildings intended for one or two families, along with auxiliary structures, are constructed on individual plots.	
		2. Terraced development (morph. 2—terraced) Development of residential areas where three or more single-family, one- to three-storey buildings are terraced and placed either on separate plots or within a single plot, as well as low-rise detached housing of very high density which are included in this type.	
	Multistorey residential development area	3. Perimeter development (morph. 3—perimeter) An urban structure with a regular layout that is fully or partially enclosed along the block's outer perimeter, formed by terracing buildings along streets at plot boundaries. Usually used two- to five-storey buildings.	
		4. Open layout development (morph. 4—open layout) Buildings or building groups are arranged according to a flexible compositional principle, without forming the structured streets or spaces typical of perimeter development. Usually used five- to nine-storey buildings.	
		5. High-rise development (morph. 5—high-rise)—development composed of tall buildings (exceeding 30 m in height), typically of tower-type configuration.	
		6. Mixed development (morph. 6—mixed) A single block contains multiple development types—used in more intensively developed residential areas—combining quarters of both single-family and multi-family housing.	
	Industrial areas		
	7. Development of industrial and engineering infrastructure areas (morph. 7—industrial) Characterised by the presence of industrial and warehouse buildings, shaped by production and technological needs.		
Open space areas	Green areas, public open space areas		
	8. Open space detached buildings (morph. 8—open space det.) Development consisting of separately (freely) standing buildings with a distinct function in public space, which dominate the surrounding area (such as town halls and similar significant structures)		
	9. Greenery—parks, public spaces (morph. 9—green spaces)		

Field Research. Microclimatic research was carried out in the urbanised areas of Lithuania's major cities—Vilnius, Kaunas, and Klaipėda—between May and September during the years 2023–2024. The sites selected for microclimatic measurements were determined based on the defined morphological types of the urban structure, and were located in representative and characteristic positions, enabling a more precise description of the microclimatic parameters associated with each morphological type. Automatic mobile meteorological stations (MS) of the Portlog type (6 units) and Sencor SWS type (9 units) were used for the measurements, and their measurement results were compared with readings from automated meteorological stations (AMS) of LHMT located in rural or suburban areas (Vilnius AMS, Kaunas AMS, and Klaipėda coastal AMS). These three AMS are referred to as baseline MS. Since wind speed is measured at a height of 10 m at these baseline stations, a recalculation of wind speed to a height of 2 m was carried out for comparison with microclimatic measurements taken at that height. The research also utilised measurement data from Vilnius University's stationary automatic MS located in the Naujamiestis district of Vilnius. Before the beginning of each measurement season, mobile MS were calibrated and inspected annually. Measurements using mobile MS were conducted between 9:00 and 18:00. The research used recorded values of air temperature, relative humidity, and wind speed. Deviations in air temperature and relative humidity (dT and df) from the baseline MS were calculated. Measured wind speed was analysed, calculating relative differences Kv between wind speed at the measurement point and wind speed at the baseline MS. This calculation can be illustrated by the formula:

$$Kv = Vn/Va, \quad (1)$$

where Vn is the average wind speed at the measurement point, Va is the average wind speed at the baseline MS.

The deviations of the microclimatic parameters in this paper are presented as the final results of the microclimatic measurements.

Remote sensing assessment. Remote sensing assessment was conducted using land surface temperature data collected by satellites equipped with thermal sensors. The publicly available land surface temperature (LST) data was delivered from Landsat 8 and Landsat 9 satellites. It was downscaled using Sentinel 2 data for greater spatial resolution (10 m × 10 m) [67–69].

Satellite data were processed using the method developed by Onačillová and implemented through the Google Earth Engine tool used in her research [70]. This addressed LST influencing factors, such as atmospheric conditions [71] and urban structure characteristics [72].

The revisit time of Landsat 8/9 satellites over the same location is every 16 days [68], while for Sentinel 2 is every five days [67]. Therefore, only those Landsat 8/9 and Sentinel 2 images were selected for the analysis, that best aligned with the dates of the field measurements. Data with minimal atmospheric interference—particularly cloud cover—were prioritised in order that none of the field measurement point would be covered by cloud mask. The revisit time of both satellite systems over the territory of the Republic of Lithuania is approximately 11:30 local time (EEST) [67,68].

Since LST data were collected on different dates, average (median) surface temperature values were calculated for different morphotypes across the studied cities. For this purpose, the GIS-based zonal statistics and statistical-spatial analysis methods were applied.

3.4. Methodology for Research Results Assessment

For research results assessment, the relation between microclimatic conditions and urban indicators was analysed. For this analysis, the urbanistic and climatological interpretation was carried out and statistical correlations were calculated. Urbanistic and climatological interpretation was carried out using graphs of climatic parameters and statistical tables of urban indicators. Statistical calculations of correlations were performed with specific software, IBM SPSS Statistics (Version 30.0.0.0 (172)). Considering the limited measurement data, the Pearson's and Spearman's coefficients were used. The significance of correlations was assessed using p-values, and the strength of the relationships was further evaluated through the interpretation of R^2 coefficients.

4. Research of Cities in the Coastal Climatic Region

4.1. Description of the Region and Selection of Klaipėda City for Research

The coastal climatic region includes both the coastal and Žemaitija (Samogitia) climatic districts. It covers the western part of the country, comprising the coastal lowlands and the elevated areas located inland from the coast. The coastal and Samogitia climatic districts are composed of distinct climatic subdistricts: Curonian Spit, Sea Coast, coastal lowlands, Samogitian Highlands, and Venta midstream lowlands. In the coastal climatic zone, cities were selected by evaluating the main climatic subdistricts located in the inland areas. Within the sea coast climatic subdistrict of the coastal climatic district, the city of Klaipėda—situated along the Baltic Sea—is distinguished. In the coastal lowlands climatic subdistrict, Šilutė, located further inland, is selected for research. In the Samogitian Highlands subdistrict of the Samogitian climatic district, Telšiai—positioned near the large Lake Mastis—is identified as a representative city. Within the same subdistrict, Rietavas is also selected due to its particularly forested surroundings. In the Venta midstream lowlands climatic subdistrict of this district, located in the northern part of the country, Mažeikiai is distinguished.

Of all the selected cities representing different climatic subdistricts and similarity of their seasonal (summer) temperature (see Table 3), Klaipėda city is chosen for detailed analysis. It is the largest city in the coastal climatic region, located closest to the sea, and best reflects the microclimatic features associated with the urban structure of this region. Other regional cities (as well concerning further described regions) will be subject to additional comparative analysis at later stages of the study which will be presented in other publications.

Table 3. Average air temperature in selected cities of the Coastal climatic region for 1991–2020 (°C) (LHMT, 2025 [73]).

No	Cities	Climatic Subregion	Air Temperature		
			Annual	Summer	Winter
1	2	3	4	5	6
1	Klaipėda	Sea coast	8.2	17.3	−0.2
2	Šilutė	Coastal lowlands	7.9	17.3	−1.1
3	Telšiai	Žemaitija Highlands	7.2	16.9	−2.0
4	Rietavas	Žemaitija Highlands	6.7	16.3	−2.5
5	Mažeikiai	Middle reaches of the Venta lowlands	7.8	17.2	−1.7

Klaipėda is the third-largest city in Lithuania, serves as a county administrative centre, and hosts one of the most important ports on the Baltic Sea. The city is known for shipbuilding, maritime activities, scientific development, and growing industrial sectors. It currently has a population of approximately 159,400 [74]. Historical records mention Klaipėda as early as 1413. The city was founded near the site of a castle belonging to the Livonian Order, on the location of an ancient Curonian settlement. Its growth was historically driven by maritime trade [75]. During the 15th and 16th centuries, the Old Town developed near the Danė River with a characteristic perimeter development urban structure; in the 17th and 18th centuries, new districts with buildings of 2–4 storeys emerged. From the mid-20th century onwards, open layout districts and industrial zones expanded across the city [76]. Adjacent to these areas, low-rise detached and individual residential quarters were developed, with the seaport playing a particularly prominent role in shaping the urban fabric. Changes in the city's spatial structure are marked by increasing densification of existing urban areas, the construction of individual high-rise buildings (up to 20 storeys), and the development of large commercial and industrial facilities.

Klaipėda is situated in a unique geographical location in Lithuania, on the coast of the Baltic Sea and near the Curonian Lagoon, with the Danė River flowing through its territory. A part of the city extends into the Curonian Spit, a narrow sand peninsula formed by coastal accumulation processes. The city lies within the coastal lowlands and is characterised by a relatively flat terrain with no significant elevation changes. Forests are predominantly found in the Curonian Spit and the northern continental part of the city.

4.2. Urban and Microclimatic Research of Klaipėda City

To assess Klaipėda's preparedness for potential threats and to identify suitable locations for microclimatic measurements, an analysis of the city's functional zones was conducted, focusing on low-rise and high-rise residential areas, industrial zones, and green spaces (Figure 3, Table 4).

Table 4. Urban morphostructure types in Klaipėda city and their main indicators.

Main Functional Zones	Morphostructure Types	Area			Population Density (Inhab./ha)	Development Density %	Development Intensity	Proportion of Impervious Surfaces, %	Area Within 300 m Distance to Green Spaces	
		ha	%	%					ha	%
Low-rise residential	Detached	620	6.5		20	16	0.2	26.00	300	48
	Terraced	30	0.5		89	23	0.5	44.00	5	17
High-rise residential	Perimeter	160	1.5	18	77	29	0.9	63.25	115	72
	Open layout	620	6.5		155	18	0.9	36.00	360	58
	High-rise	90	1		258	22	2	41.50	16	18
	Mixed	190	2		70	20	0.6	39.00	90	47
Industrial	Industrial	1350	14	14	-	21	0.7	60.00	-	
Greenery	Open space detached	70	1		-	7	0.1	13.90	-	
	Green spaces	220	2		-	-	-	-	-	
	Forests, other green areas	2015	20		-	-	0.1	-	-	
	Water bodies	1075	11		-	-	-	-	-	
Other	Agricultural, other land, roads	3355	34	34	-	0.5	-	-	-	
	Total:	9795	100	100	20	-	0	-	-	

Urban research. The total area of residential territories in Klaipėda is approximately 1710 hectares, accounting for about 18% of the city's total area [77]. The predominant types of residential development include multistorey free style and low-rise detached layouts, each occupying approximately 7% of the city area. The most densely built-up areas are found in the central Old Town and in the New Town perimeter developments, where development density reaches around 31%. However, in terms of population density, the highest values are observed in open layout areas (175 inhabitants per hectare), whereas low-rise detached developments are the least dense, with approximately 20 inhabitants per hectare. Industrial land in Klaipėda covers approximately 1350 hectares, representing about 14% of the city's territory. Major industrial zones are concentrated around the Klaipėda Seaport and in the southeastern part of the city. Based on the analysis of orthophotography data, it was determined that the total area of green spaces, including water bodies, in Klaipėda amounts to approximately 3380 hectares (34% of the city's area), excluding agricultural and undeveloped land. Among these green areas, the most significant are the green space territories—coastal forests in the northern part of the city along the Baltic Sea and within the Curonian Spit territory.

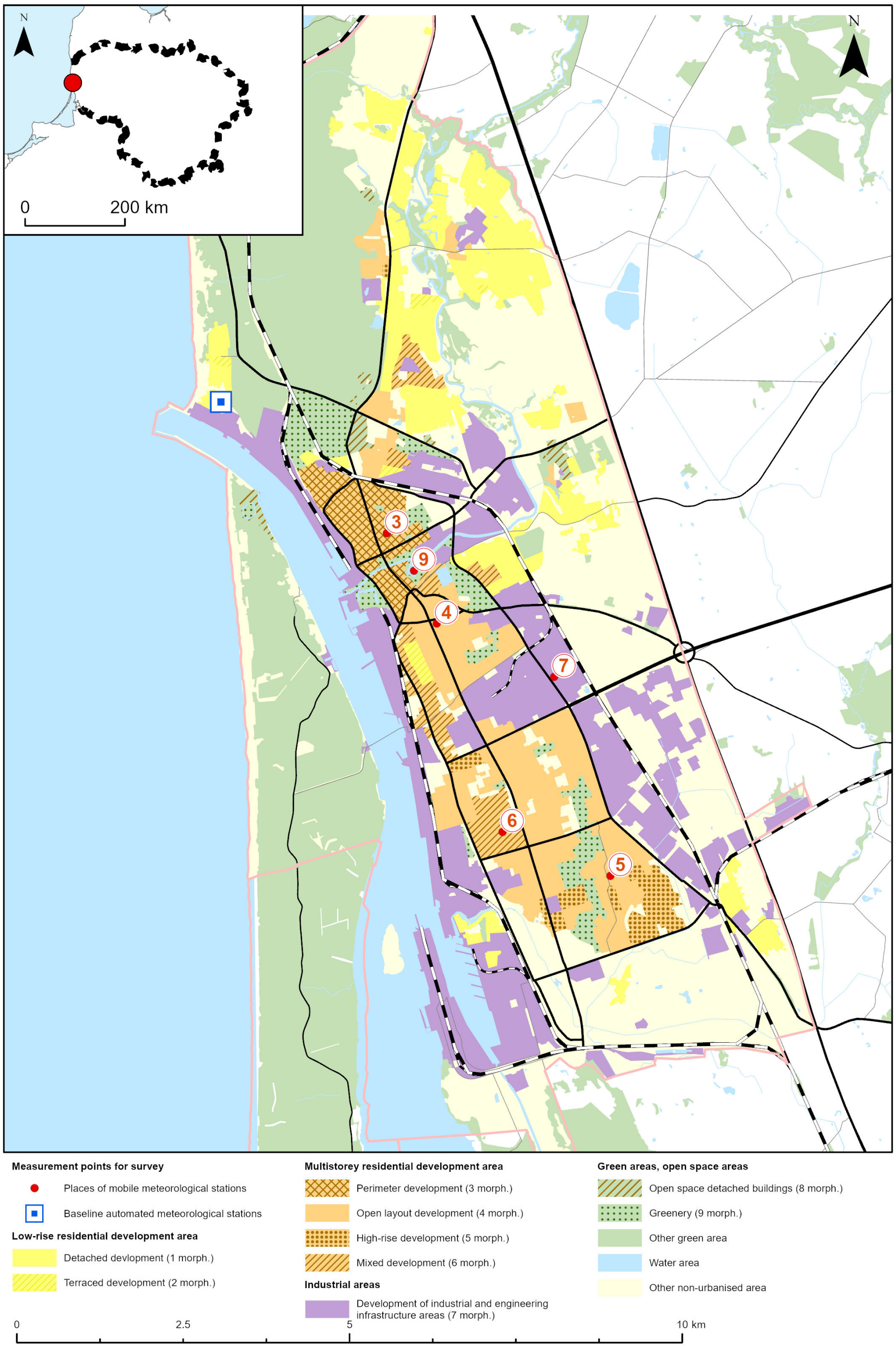


Figure 3. Klaipėda city and its territory division according to morphostructure types and the placement of research locations. Note: the number of the morphotype (morph.) is indicated at each measurement point.

In terms of preparedness for potential threats, the main civil protection infrastructure in Klaipėda consists of shelters and collective protection structures. There are currently no bunkers [54]. According to 2024 data, Klaipėda had a total of 79 shelters with a combined capacity of 28,239 residents (17.7% of the population), which falls significantly short of the normative requirement of providing shelter for at least 60% of the population. Additionally, the city has 83 collective protection structures with a total capacity of 40,655 residents, meeting the established need of accommodating 25% of the population. To assess the potential for developing new safety infrastructure, open layout residential areas stand out due to their lower development density and preserved green spaces, offering opportunities for the development of green infrastructure and other safety facilities. Conversely, newly developing expansion areas no longer possess such territorial resources to the same extent.

Microclimatic research. Considering the morphostructure characteristics of Klaipėda city, specific measurement points were selected in districts or block groups representing different morphostructure types. for microclimatic analysis, field research points were specifically chosen within perimeter, open layout, high-rise, industrial, mixed development types, and green space territories (Figure 3). Microclimatic research was carried out at selected locations across Klaipėda city (Figure 3). Air temperature and wind speed measurements were recorded at designated points. Land surface temperature indices were calculated based on satellite data (see Table 5, Figure 4).

Table 5. Microclimatic research in Klaipėda city.

No	Climatic Indicators	Deviations of Microclimatic Indicators (Air dT, Surface dT, Wind Kv) from Baseline MS Values in Selected Morphotypes								
		Morph. 1 Detached	**Morph. 2 Terraced**	**Morph. 3 Perimeter**	**Morph. 4 Open Layout**	**Morph. 5 High-Rise**	**Morph. 6 Mixed**	**Morph. 7 Indus-trial**	**Morph. 8 Open Space Det.**	**Morph. 9 Green Spaces**
Field research										
1	Air dT, °C	-	-	0.5	0.2	0.2	0.8	0.3	-	0.0
2	Wind Kv	-	-	0.6	0.6	1.0	0.7	1.1	-	0.8
Remote sensing research										
3	Surface dT, °C *	0.2	1.7	2.6	1.2	1.3	1.1	1.9	0.5	−0.2

* Remark: satellite land surface data used, recorded on 6 September 2024 at 11:00.

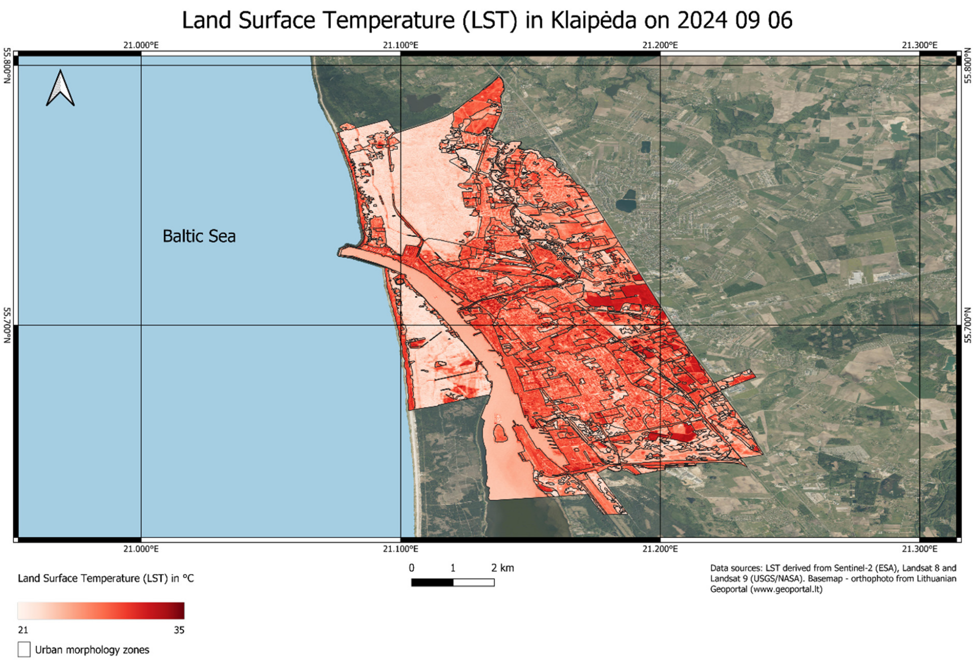


Figure 4. Land surface temperature in Klaipėda city based on satellite data.

The research revealed that the highest positive air temperature deviations compared to the baseline Klaipėda MS were observed in mixed development morphotypes (morph. 6) (0.8 °C) (morph. 6), while the lowest deviations were recorded in industrial (morph. 7) and green space (morph. 9) morphotypes (0.0–0.3 °C). Wind speed in various development morphotypes across Klaipėda city was found to be 20–40% lower than in the baseline Klaipėda MS with the exception of morphotype 7—representing industrial and engineering infrastructure development with large distances between buildings—where wind speed was 10% higher compared to the baseline MS (see Figures 5 and 6).

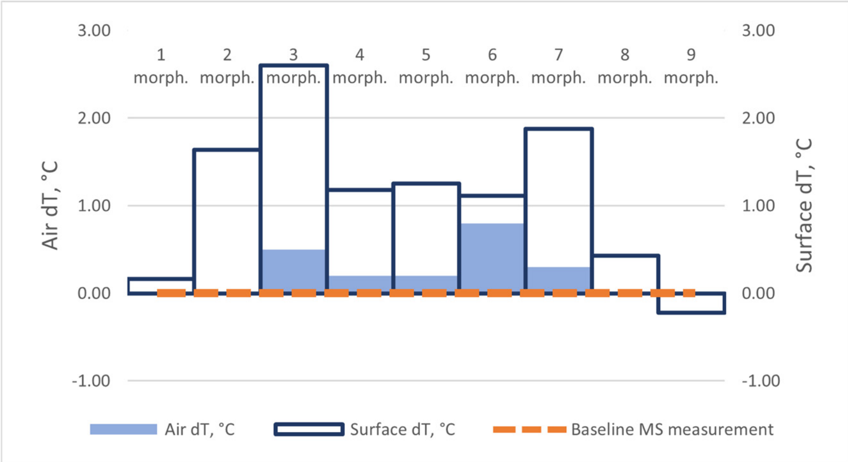


Figure 5. Deviations of climatic indicators (dT) from the baseline Klaipėda MS in different morphotypes (the vertical axis represents Air dT, °C).

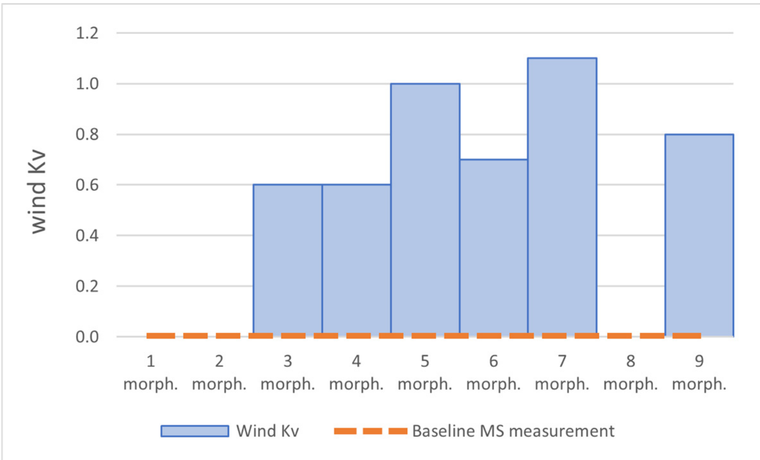


Figure 6. Relative wind speed difference (Kv) compared to the baseline Klaipėda MS across morphotypes.

Satellite-based land surface temperature analysis revealed that all types of developed urban territories experienced higher surface temperatures than the baseline Klaipėda MS environment (see Figure 6). Only green space territories (morph. 9) recorded lower surface temperatures. Among developed areas, the highest surface temperatures were observed in terraced (morph. 2), perimeter (morph. 3), and industrial and engineering infrastructure (morph. 7) development types. Detached (morph. 1) and open space detached buildings (morph. 8) development areas showed relatively lower surface heating.

5. Research of Cities in the Central Lowland Climatic Region

5.1. Description of the Region and Selection of Kaunas City for Research

The central lowland climatic region is situated in the central part of Lithuania, extending in a south–north direction. It is the largest of the country's climatic regions and comprises the Mūša, Nevėžis, and Nemunas River lowland subregions. Within this climatic zone, five cities were selected as representative: Šiauliai and Panevėžys in the Mūša and Nevėžis lowlands, and Tauragė, Marijampolė, and Kaunas in the Nemunas lowland subregion. Šiauliai and Panevėžys are the fourth and fifth biggest cities of Lithuania. Kaunas is the second largest city situated near the longest rivers of Lithunia—Nemunas and Neris. Tauragė is town of Lithuania with rivers, forests, and open agrarian suroundings, while Marijampolė is mainly surrounded by open agrarian areas. Among all the selected cities representing different climatic subregions as well as similarity in annual and seasonal temperature patterns (see Table 6), Kaunas was chosen for detailed investigation.

Table 6. Average air temperature in selected cities of the central lowland region, 1991–2020 (°C) (LHMT, 2025) [73].

No	Cities	Climatic Subregion	Air Temperature		
			Annual	Summer	Winter
1	2	3	4	5	6
1	Šiauliai	Mūša–Nevėžis	7.2	17.2	−2.3
2	Panevėžys	Mūša–Nevėžis	7.4	17.5	−2.5
3	Kaunas	Lower reaches of the Nemunas	7.5	17.6	−2.2
4	Marijampolė	Lower reaches of the Nemunas	7.9	17.5	−1.9
5	Tauragė	Lower reaches of the Nemunas	7.3	17.0	−1.9

Kaunas is the second-largest city in Lithuania by population and area. It serves as a regional and county administrative centre and plays a significant role in culture, industry, and higher education. Currently, approximately 293,200 residents live in Kaunas [74]. The residential area of Kaunas is mentioned in historical sources dating back to 1361, but the city began to develop significantly during the 14th and 15th centuries [78]. From the beginning of this period onwards, Kaunas experienced rapid growth and urban transformation, leading to changes in land use, development patterns, building heights, construction materials, and architectural styles. During this historical development phase, different types of urban structures emerged—starting with the castle and the Old Town as the historic core, followed by the formation of perimeter development residential quarters in the 18th and 19th centuries, and later (late 19th to early 20th century) the establishment of modern residential districts forming the New Town [76]. Urban development underwent a major shift with the onset of large-scale district construction in the second half of the 20th century, which introduced multistorey buildings that increased urban density and altered previous development configurations.

Kaunas city has a distinct natural setting. It is situated at the confluence of Lithuania's two largest rivers—the Nemunas and the Neris—and is surrounded by their green slopes and forested areas. Furthermore, on the eastern side of the city, the construction of the Kaunas Hydroelectric Power Plant and the damming of the Nemunas created one of the largest artificial water bodies in Lithuania, the Kaunas Lagoon. These geographical features contribute to favourable climatic conditions in the city.

Generally, Kaunas is a very important logistical, transport hub—important highways and railways cross the city, and there is an international airport not far from the city.

5.2. Urban and Climatic Research of Kaunas City

To assess Kaunas city's preparedness for potential threats and identify suitable locations for microclimatic measurements, an analysis of its functional zones was conducted, focusing on low-rise and multistorey residential areas, industrial zones, and green spaces (Figure 7, Table 7).

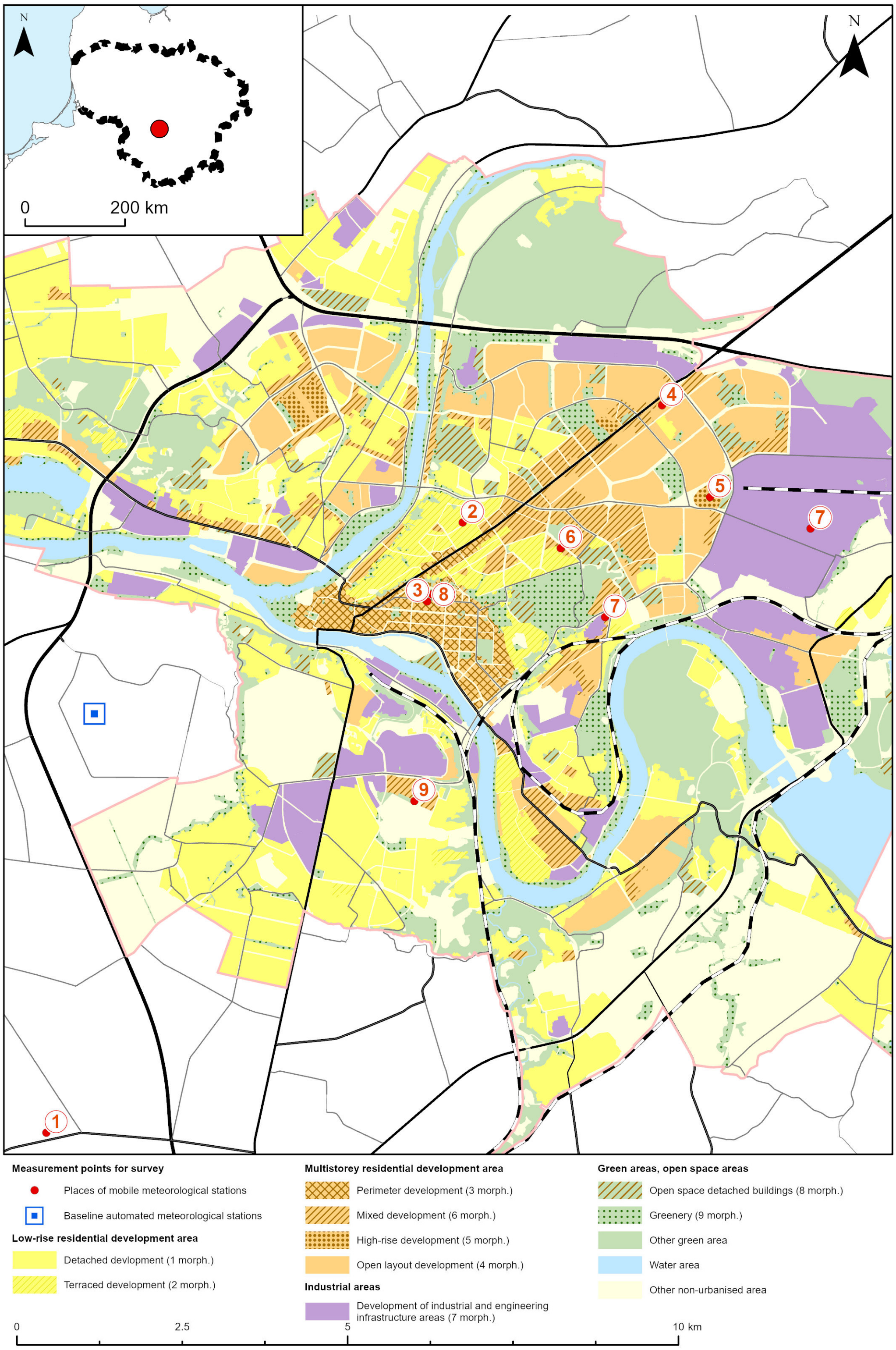


Figure 7. Kaunas city and its territorial division according to morphostructure types. Note: the number of the morphotype (morph.) is indicated at each measurement point.

Table 7. Urban morphostructure types in Kaunas city and their main indicators.

Main Functional Zones	Morphostructure Types	Area			Population Density (inhab./ha)	Development Density, %	Development Intensity	Proportion of Impervious Surfaces, %	Area Within 300 m Distance to Green Spaces	
		ha	%	%					ha	%
Low-rise residential	Detached	2770	18%	30	23	15	0.15	18	1500	54
	Terraced	380	2.5%		52	24	0.5	34	280	74
High-rise residential	Perimeter	220	1.5%		58	43	1.3	59	160	73
	Open layout	950	6%		151	19	0.9	26	550	58
	High-rise	50	0.5%		191	19	1.8	38.5	25	50
	Mixed	570	3.5%		81	26	0.8	38	430	75
Industrial	Industrial	1600	10%	10	-	22	0.7	44	-	
Greenery	Open space det.	250	1.5%	33	-	21	0.4	39	-	
	Green space territories	637	4%		-	-	-	-	-	
	Other green areas	2604	16.5%		-	-	-	-	-	
	Water bodies	1325	8.5%		-	-	-	-	-	
Other	Agricultural, other land, roads	4332	27.5%	27	-	-	-	-	-	
	Total:	15,688	100	100	23	-	-	-	-	

Urban research. The residential areas of Kaunas are spread across three main parts of the city, separated by the Nemunas and Neris rivers. Some residential zones are located within the river valleys, while others are situated on the upper terraces of the river slopes, rising approximately 40 metres above the valley floors. The total area of residential territories in Kaunas covers approximately 5020 hectares, accounting for about 33% of the city's total area [77]. The central zone of the city is characterised by the densest perimeter development (44%), with buildings typically ranging from 3 to 5 storeys in height. Near the central zone older suburbs have formed. They are marked by fine-grained, densely built, often terraced or semi-detached 2–3-storey buildings, sometimes arranged in closed blocks. Next to older suburbs, the main multistorey residential districts have developed, dominated by open layout development with 5-storey buildings, complemented by clusters of taller buildings reaching 9, 12, and 16 storeys. They are surrounded by extensive detached-style suburban areas. These development structures constitute the main low-rise and multistorey residential zones, within which research sites were selected. The total area of industrial territories in Kaunas is estimated at around 1600 hectares, accounting for about 10% of the city's total area. The main and largest industrial zone is located in a designated industrial district in the eastern part of the city. The total area covered by greenery in Kaunas reaches approximately 4736 hectares (30% of the city's territory). The most significant are green space territories, which include forest parks located in the peripheral parts of the city. In addition, important green areas are found in the central districts, along the slopes of the Nemunas and Neris Rivers.

The city has only limited safety infrastructure. Identified protective structures include shelters and collective protection buildings, but no bunkers. According to 2024 data from Kaunas, there were 286 shelters providing protection for 101,637 residents (33.4%), which remain below the required capacity of accommodating 60% of the population. Also, the city has 219 collective protection structures capable of accommodating 150,005 residents (51%). Considering the absence of dedicated safety facilities such as bunkers and shelters in the city, the adaptation of existing public spaces and the preservation of necessary territorial reserves become particularly relevant.

Microclimatic research. Microclimatic research was carried out at selected measurement points representing different morphotypes (Figure 7). As well as land surface, temperature was assessed (Figure 8). In Kaunas, air temperature deviations are more pronounced than in Klaipėda. Compared to the baseline Kaunas MS, terraced, mixed, and open space detached building morphotypes (morph. 2, 6, and 8) highlight positive deviations of 1.7–1.9 °C, while other morphotypes show deviations ranging from 0.6 to 1.5 °C (Table 8, Figure 9). Wind speed in Kaunas decreases more significantly compared to Klaipėda; measured values are 2–5 times lower than those recorded at the baseline MS (Table 8, Figure 10).

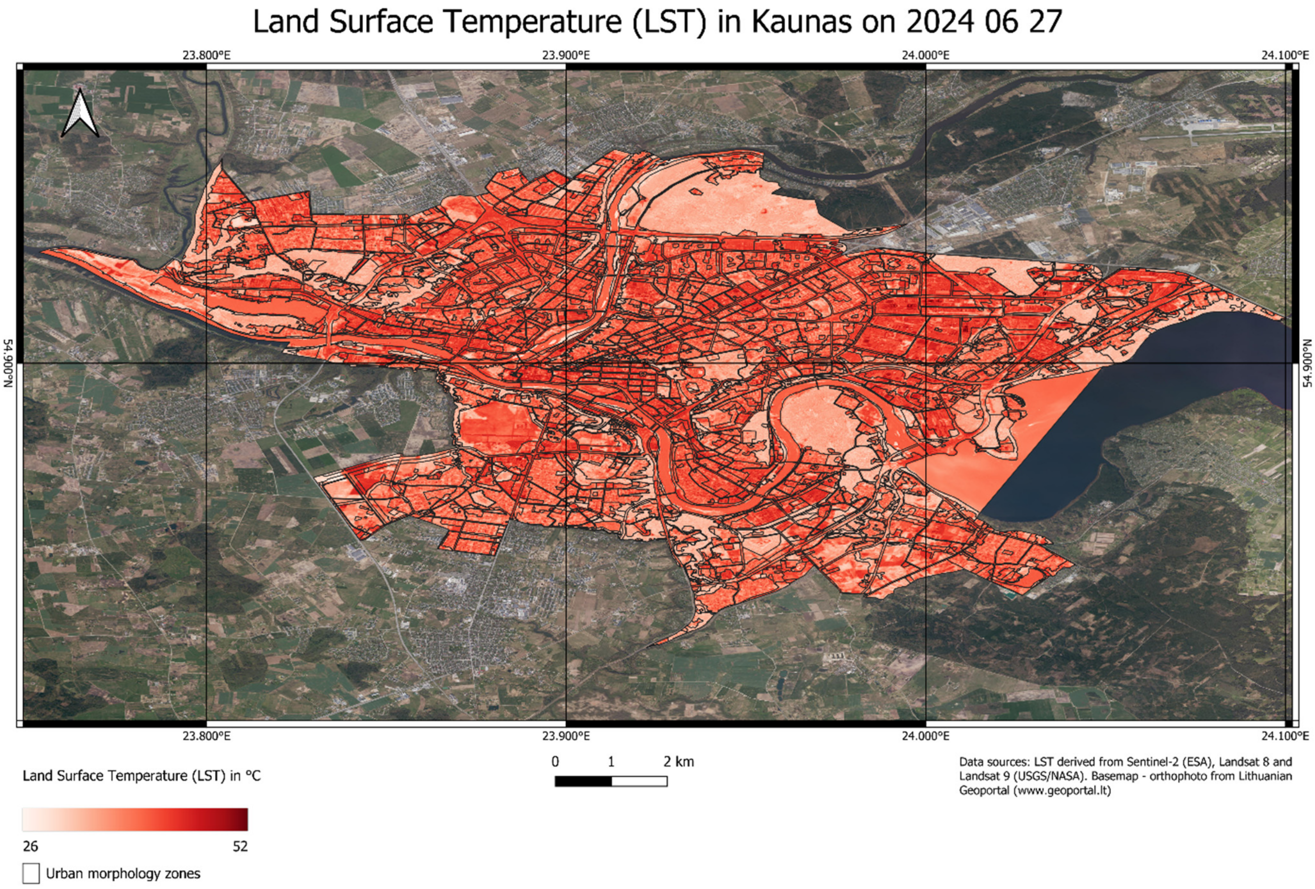


Figure 8. Land surface temperatures in Kaunas city based on satellite data.

Table 8. Microclimatic research in Kaunas city.

No	Climatic Indicators	Deviations of Microclimatic Indicators (Air dT, Surface dT, Wind, Kv) from Baseline MS Values in Selected Morphotypes								
		Morph. 1 Detached	Morph. 2 Terraced	Morph. 3 Perimeter	Morph. 4 Open Layout	Morph. 5 High-Rise	Morph. 6 Mixed	Morph. 7 Industrial	Morph. 8 Open Space Det.	Morph. 9 Green Spaces
Field research										
1	Air dT, °C	0.8	1.7	1.5	1.3	1.0	1.8	1.4	1.9	0.6
2	Wind Kv	0.5	0.3	0.2	0.4	0.2	0.2	0.5	0.7	0.2
Remote sensing research										
3	Surface dT, °C	4.5	5.3	7.1	5.7	6.1	6.7	7.3	6.1	0.4

Remark: Satellite land surface data recorded on 27 June 2024 were used. 11:00.

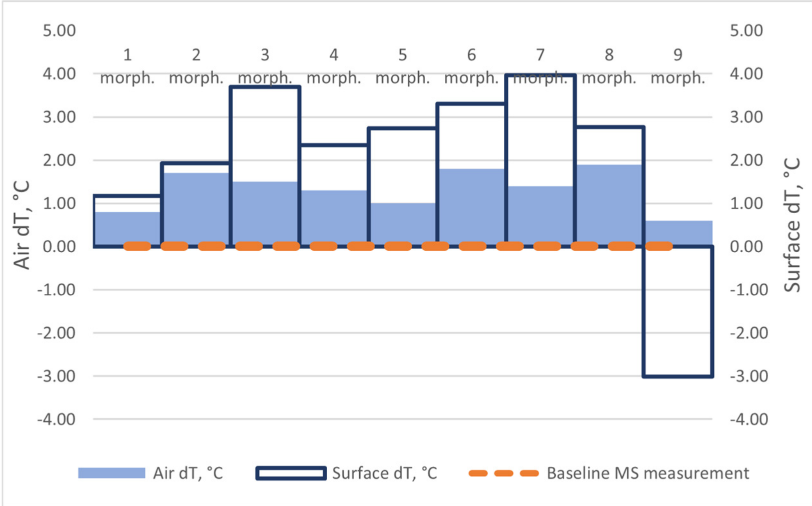


Figure 9. Deviations of climatic indicators (dT) from the baseline Kaunas MS across different morphotypes are presented with reference to the vertical axis, which includes air temperature dT, °C.

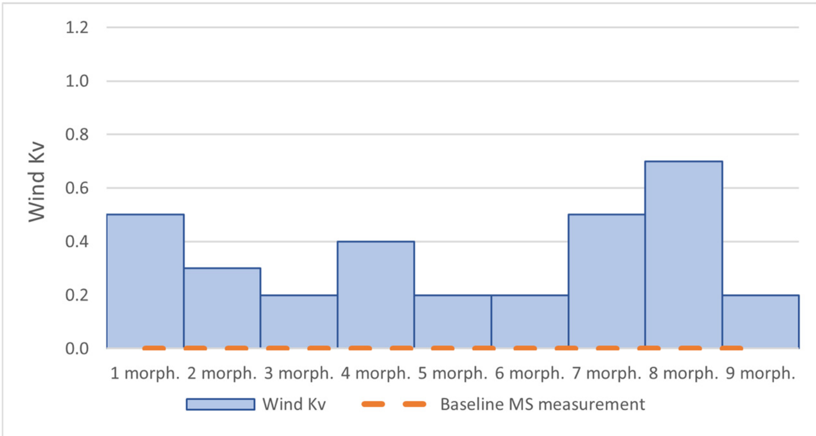


Figure 10. Relative wind speed difference (Kv) in different morphotypes.

Surface temperatures of built-up and impervious surface development types recorded on 27 June showed significant variation compared to green spaces- surface temperature was 3.01 °C lower than in the baseline Kaunas MS environment, whereas in industrial areas (morph. 7), it was 2.77 °C higher. Lower surface temperatures were recorded primarily in detached (morph. 1) and terraced development (morph. 2) areas. In open layout and high-rise morphotypes (morph. 3, 4, 5), surface temperatures were higher than in the terraced development morphotype (morph. 2), although air temperatures in these morphotypes were relatively lower (Table 8, Figures 8 and 9).

6. Research of Cities in the Southeastern Highlands Climatic Region

6.1. Description of the Region and Selection of Vilnius City for Research

The southeastern highlands climatic region is located on the eastern and southern peripheries of Lithuania. This climatic region consists of three subregions: Aukštaitija, Dzūkija, and Sudovia. Four cities were selected as representative of this climatic zone: Vilnius and Utena from the Aukštaitija subregion, and Elektrėnai and Varėna from the Dzūkija subregion. Vilnius is the largest city bounded by forests and agrarian spaces; Utena is an industrial town with lakes and agrarian surroundings. Elektrėnai is a new town with a power station near a big lake, and Varena is a town in the largest forest area of Lithuania.

From the selected cities, Vilnius was chosen for detailed investigation, as it represents regional climatic conditions (see Table 9).

Table 9. Average air temperature in the selected cities of the southeastern highlands climatic region for 1991–2020 (°C) (LHMT, 2025) [73].

No	Cities	Climatic Subregion	Air Temperature		
			Annual	Summer	Winter
1	2	3	4	5	6
1	Vilnius	Aukštaitija	7.2	17.5	−2.9
2	Elektrėnai	Aukštaitija	7.3	17.6	−2.2
3	Utena	Aukštaitija	7.0	17.1	−2.8
4	Varėna	Dzūkija	7.2	17.4	−2.6

Vilnius is the capital of Lithuania. It serves as a regional and county administrative centre and plays a central role in governance, culture, business, industry, and higher education. Currently, it has a population of approximately 605,300 [74]. The city has an international airport, a well-developed railway and road network, and established industrial districts. The residential area of Vilnius is mentioned in historical sources dating back to 1323. Urban development began near the historic castle hill as early as the 5th–9th centuries, and by the 14th century, the city had developed a distinct radial urban structure. Additional historic suburbs emerged by the 16th century [79]. In the 19th and 20th centuries, like other major Lithuanian cities, Vilnius underwent significant spatial transformation, expanding rapidly with the introduction of large-scale district construction in the second half of the 20th century. Currently, ongoing densification processes are taking place within existing urban areas, accompanied by rapid suburban expansion through the development of low-rise detached-style housing and multistorey apartment housing in separate blocks [76].

Vilnius city features a distinctive natural environment. Situated at the confluence of the Neris and Vilnia rivers, the city is characterised by a hilly landscape interspersed with extensive forested areas. Due to its topographical and ecological features, the urban structure of Vilnius is more fragmented compared to other Lithuanian cities, consisting of compact built-up zones separated by forested or otherwise undeveloped spaces that form the backbone of the city's natural framework. These spatial characteristics are considered particularly significant in shaping the quality of the urban residential environment.

6.2. Urban and Climatic Research of Vilnius City

To assess Vilnius city's preparedness for potential threats and to identify suitable locations for microclimatic research, an analysis of key urban functional zones was conducted, focusing on low-rise and high-rise residential areas, industrial zones, and green spaces (Figure 11, Table 10).

Urban research. Residential areas in Vilnius, like other built-up zones, are distributed across various parts of the city, often divided by the Neris River and forested territories. The oldest residential areas developed along the Neris and Vilnia rivers, in the hilly terrain forms the primary perimeter development zone, dominated by buildings ranging from 3 to 6 storey in height. The largest residential districts consist of open layouts featuring predominantly 5-storey development, with clusters of taller buildings reaching 9, 12, and 16 storeys. Besides these development types, high-rise building development represents a distinct and increasingly visible form of contemporary urban construction in Vilnius. Such structures are large-scale, often occupying a significant portion of the block and reaching densities of 40–60%. Overall, the total area of residential territories in Vilnius city amounts to 9402 hectares, accounting for approximately 24% of the city's total area [77]. The majority of the city's built-up area consists of low-rise detached developments and multistorey open layout residential districts.

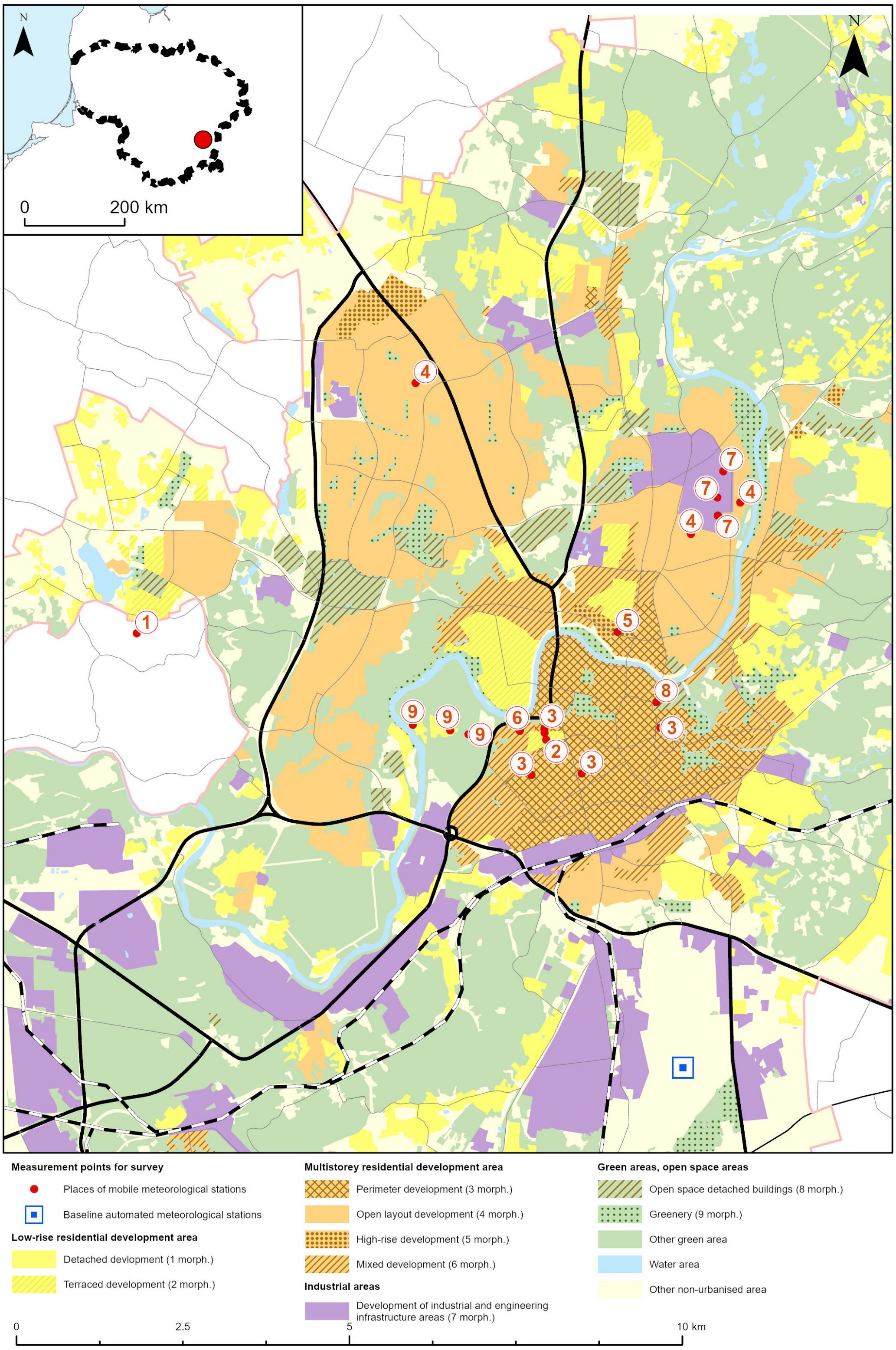


Figure 11. Vilnius city and its territorial division according to morphostructure types. Note: the number of the morphotype (morph.) is indicated at each measurement point.

Table 10. Types of urban morphostructure in Vilnius city and their main indicators.

Main Functional Zones	Morphostructure Types	Area			Population Density (inhab./ha)	Development Density, %	Development Intensity	Proportion of Impervious Surfaces, %	Area within 300 m Distance to Green Spaces	
		ha	%	%					ha	%
Residential	Detached	5880	15	23.8	17	13	0.2	12.84	4550	77
	Terraced	240	0.6		75	25	0.5	43.68	25	10
	Perimeter	580	1.5		87	37	1.5	56.15	218	37
	Open layout	2060	5		174	19	0.9	36.72	1900	92
	High-rise	92	0.2		142	25	3	50.25	32	35
	Mixed	550	1.5		115	22	0.9	33.62	450	82
Industrial	Industrial	1820	4.5	4.5	-	26	1	52.33	-	
Greenery	Open space det.	200	0.5	39.7	-	23	0.5	53.72	-	
	Green spaces	500	1.2		-	-	-	3.91	-	
	Forests, other green areas	14,227	36		-	-	-	-	-	
	Water bodies	845	2		-	-	-	-	-	
Other	Agricultural, other land, roads	13,050	32	32	-	-	-	-	-	
	Total:	40,044	100	100	18	-	-	-	-	

Industrial development in Vilnius was historically planned as separate, isolated zones, often separated from residential areas by forests or green buffers. However, recent trends show that this separation is gradually diminishing, with new industrial facilities being established closer to residential neighbourhoods. Although the industrial zones in Vilnius are generally smaller than those in Kaunas or Klaipėda, their number is greater. In total, industrial territories occupy about 1820 hectares, representing roughly 5% of the city's total area.

The total area of green spaces in Vilnius is estimated at approximately 15,772 hectares, or 39% of the city's territory, excluding agricultural and other undeveloped land. Vilnius stands out for its large forested areas, which are predominantly located on the hilly terrain surrounding the Neris River and its tributaries. Among the green spaces, forest parks integrated within residential areas are especially notable, as are green corridors along riverbanks, slopes, and within open layout residential districts. The most significant shortage of green spaces is observed in densely developed detached housing zones.

The city has only limited safety infrastructure; it has shelters and collective protection structures but, similar to other cities in Lithuania, it lacks bunkers. According to 2024 data from Vilnius, there were 653 shelters accommodating a total of 291,322 residents (49%), which remains below the required capacity of providing shelter for 60% of the population. Also, the city has 235 collective protection structures capable of accommodating 245,202 residents (41%). Notably, Vilnius is located approximately 30 km away from the recently constructed Astravets nuclear power plant in Belarus. Therefore, the city's preparedness for potential nuclear-related risks is of particular importance.

Microclimatic Research. The main microclimatic research in Vilnius has been carried out using data from a stationary university MS, supplemented by measurements taken at multiple selected points (Figure 11). In the analysed Vilnius city, air humidity indicators were additionally assessed. The highest positive deviations in air temperature (1.9–2.2 °C) compared to the baseline Vilnius MS were recorded in terraced, perimeter, and open space detached building morphotypes (morph. 2, 3, and 8), whereas the smallest deviations (0.3 °C) were observed in mixed and industrial morphotypes (6 and 7). Relative air humidity in Vilnius was found to be 1–7 percentage points lower than at the baseline station, with the smallest deviation recorded in detached development (morph. 1). Wind speed in two morphotypes—high-rise development and open space detached buildings (morph. 5, 8)—was 10–30% higher than at the baseline station. In all other morphotypes, wind speed decreased, with the relative wind speed coefficient (Kv) ranging between 0.3 and 0.9 (Table 11).

Table 11. Microclimatic research in Vilnius city.

No	Climatic Indicators	Deviations of Microclimatic Indicators (Air dT, Surface dT, Humidity df, Wind Kv) from Baseline MS Values Across Individual Morphotypes								
		Morph. 1 Detached	**Morph. 2 Terraced**	**Morph. 3 Perimeter**	**Morph. 4 Open Layout**	**Morph. 5 High-Rise**	**Morph. 6 Mixed**	**Morph. 7 Industrial**	**Morph. 8 Open Space Det.**	**Morph. 9 Green Spaces**
						Field research				
1	Air dT, °C	0.8	2.0	2.2	0.8	1.4	0.3	0.3	1.9	0.7
2	Air df, %	−1.0	−5.6	−3.4	−4.0	−6.0	−6.6	−4.3	−7.0	−5.5
3	Wind Kv	0.7	0.3	0.5	0.6	1.3	0.9	0.9	1.1	1.0
						Remote sensing research				
4	Surface dT, °C *	0.4	2.6	3.1	1.9	2.1	1.4	3.5	3.3	−0.8

* Note: satellite land surface data recorded on 7 July 2024 were used 11:00.

Surface temperature changes follow a pattern similar to air temperature, with the exception of industrial and green area morphotypes (morph. 7 and 9). The industrial and engineering infrastructure development type (morph. 7) is characterised by significantly higher surface temperatures and relatively lower air temperatures. This contrast in temperature can be attributed to the high proportion of impervious surfaces in industrial zones, while the lower air temperature may result from stronger wind flow and the spatial openness of these areas. High surface and air temperatures are observed in open space detached building spaces (morph. 8), which in Vilnius were analysed in areas with a particularly high share of paved surfaces (Figures 12–14).

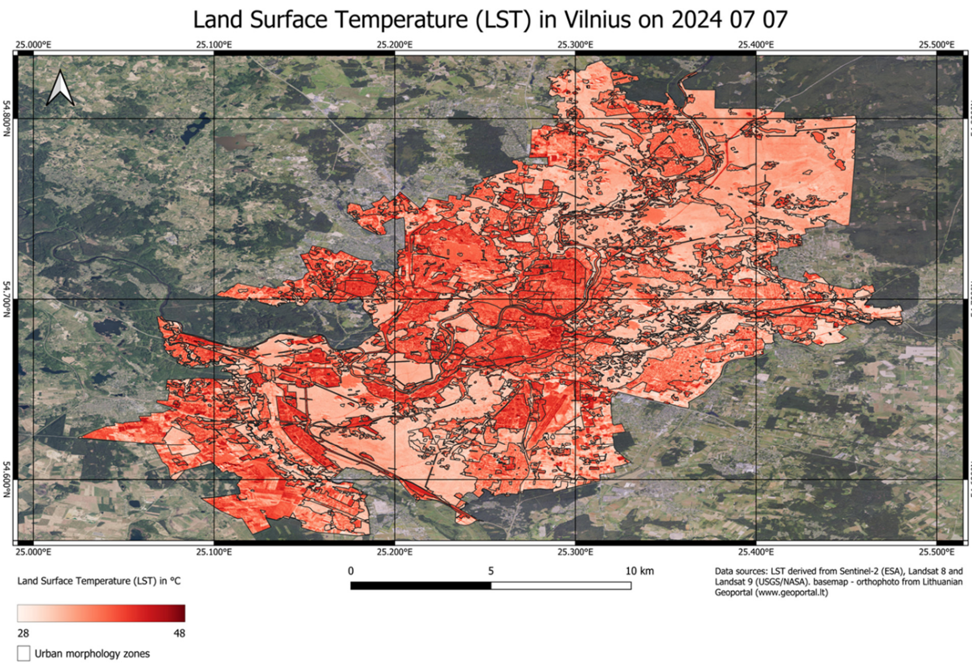


Figure 12. Land surface temperature in Vilnius city based on satellite data.

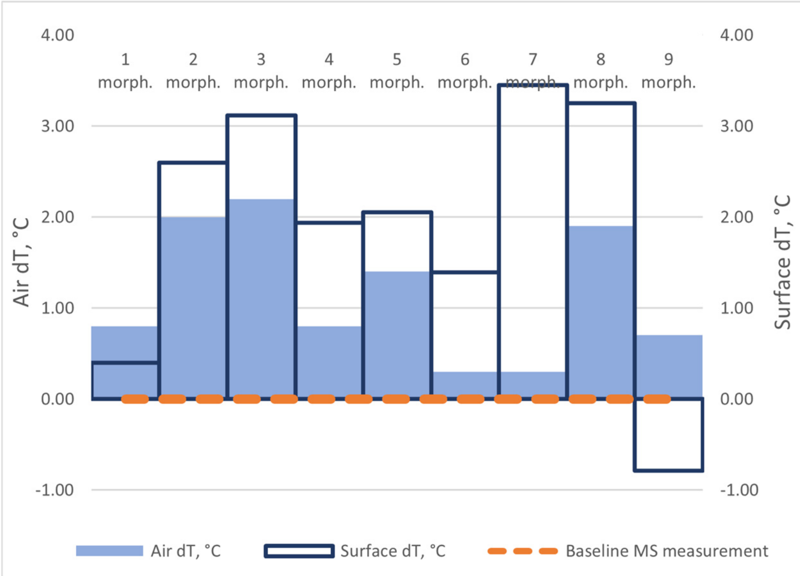


Figure 13. Deviations of climatic indicators (dT) from the baseline Vilnius MS in different morphotypes. The vertical axis represents air dT °C.

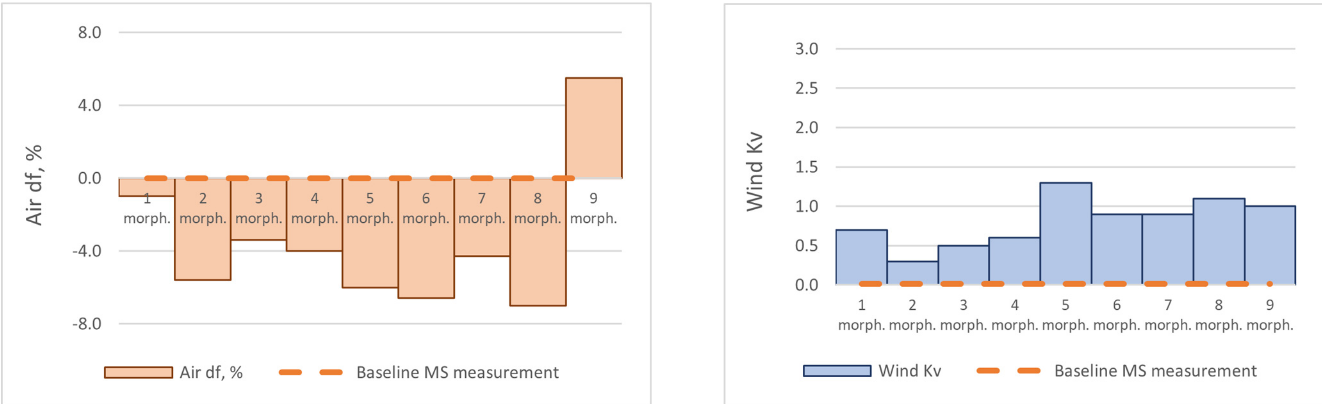


Figure 14. Relative wind speed difference (Kv) and air humidity deviation (df) compared to the baseline Vilnius MS across various morphotypes.

7. Summary of Urban and Climatic Research in the Cities of Lithuania and Their Application in Forming New and Sustainable Urban Structures

7.1. Urban Preparedness of Cities for Emerging Threats

The studied cities show similarities in functional composition but differ in urban structure, which cause different conditions of preparedness for challenging threats. As a basic indicator of preparedness—urban compactness could be distinguished. It shows land use efficiency, as well as the need for green area amount, safety infrastructure intensity. Regarding population density, Klaipėda has the most compact residential zones (92 inhabitants per hectare, calculated based on residential area), followed by Vilnius (63 inhabitants per hectare) and Kaunas (59 inhabitants per hectare).

Cities have retained considerable open and green spaces, which present an opportunity for adapting to the negative impacts of emerging threats through measures such as increasing vegetation cover, purposeful design of public spaces, and the establishment of safety infrastructure. Among them, Kaunas is the most urbanised, having the least amount of green and undeveloped land (see Table 12). In contrast, Vilnius is the most spacious, with the largest share of green infrastructure. On average, green areas account for 34% of Klaipėda, 30% of Kaunas, and 39% of Vilnius. Despite the quantity of green area, as well the system of area distribution and accessibility should be concerned. Green space territories are accessible within a regulated radius of 300 metres to approximately 53% in Klaipėda, 60% in Kaunas, and 76% in Vilnius of residential territories. And this shows that a considerable part of residential territories is too far from essential green territories. And especially this could be seen in suburban areas. This shortage is primarily due to construction practices focused on land use efficiency, underutilisation of territorial reserves, and the prioritisation of short-term economic gains over long-term environmental sustainability. As a result, new green areas are not being developed in expanding urban territories, and previously designated green spaces are being reduced with the aim of maximising land use intensity. New residential buildings and industrial objects often encroach upon the environment of existing neighbourhoods, physically separating them from larger open green spaces.

Table 12. Indicators for assessing urban structure.

No	Cities, Climatic Districts	Total City Area, ha	Population, 2024, Thousands	Main Functional Areas							
				Residential Area		Green Areas and Greenery		Industrial Area		Other Areas	
				ha	%	ha	%	ha	%	ha	%
1	Klaipėda	9795	159.4	1720	18	3288	34	1350	14	3355	34
2	Kaunas	15,688	298.9	5020	33	4736	30	1600	10	4332	27
3	Vilnius	40,044	606.6	9642	24	15,532	39	1820	5	13,050	32

The analysis also revealed that cities lack adequately developed safety infrastructure; there are no bunkers, and the number of shelters is insufficient. However, during the management and redevelopment of public spaces—such as the reconstruction of urban squares, renovation of public buildings, or construction of underground garages—these spaces are generally not adapted for potential safety-related functions. Moreover, the increasing densification of built-up areas often fails to preserve significant non-built-up green spaces, which could be used for safety infrastructure. It is also important to note that natural conditions present an increased flood risk, due to heavy rainfall events, seasonal spring floods (as well in Kaunas exists potential failure of the Kaunas Lagoon dam). Despite these risks, new major public buildings and other infrastructure continue to be constructed along riverbanks, indicating that urban development frequently proceeds without adequate consideration of emerging threats and territorial preservation needs.

Considering the overall urban preparedness of cities for emerging threats, it can be concluded that they remain largely unprepared. Therefore, significant efforts must be directed towards achieving the necessary level of urban functional structure resilience to the impacts of climate change and other potential threats. In addition to the preparedness of the functional urban structure, no less important are the initial capabilities of the urban morphostructure for climatic adaptation—either by mitigating or intensifying thermal and other climatic impacts. This could further be observed in relation to climatic regions and different types of morphotypes.

7.2. Specifics in Climatic Regions

Comparing the studied climatic regions, it can be observed that the central lowland and southeastern highlands climatic regions show the greatest relevance in terms of urban heat island formation, where more pronounced temperature contrasts between individual urban morphotypes were identified. In Klaipėda, representing the coastal climatic region, smaller temperature differences were recorded: air temperature deviations up to 0.5 °C and surface temperature deviations up to 2.6 °C. In contrast, higher deviations were observed in Kaunas, representing the central Lithuania region, and Vilnius, representing the southeastern highlands climatic region. In these cities, air temperature deviations reached up to 2.7 °C and surface temperature deviations up to 3.7 °C (see Figures 15 and 16). Contrary wind speed differences were also observed (Figure 17). In the coastal region, microclimatic characteristics are strongly influenced by the proximity of the Baltic Sea and higher wind exposure. As a result, the frequency of urban heat island formation in this region's cities is expected to be lower.

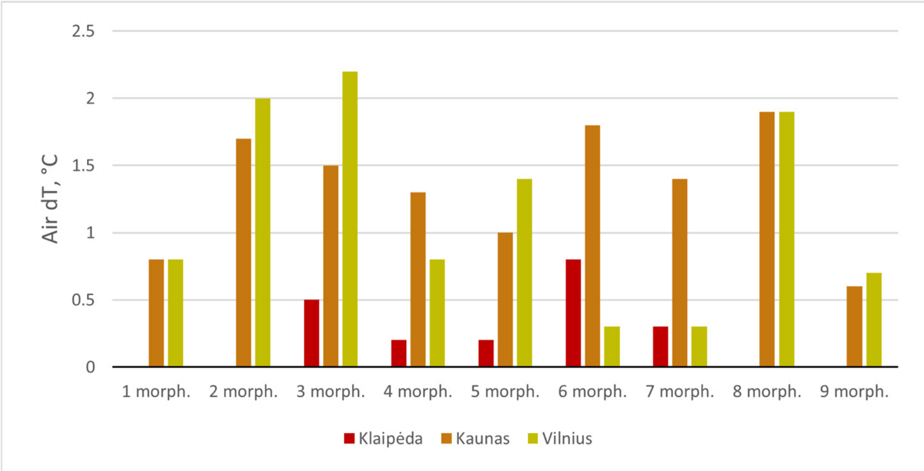


Figure 15. Air temperature deviations from baseline MS in analysed 1–9 morphotypes: comparison across individual cities.

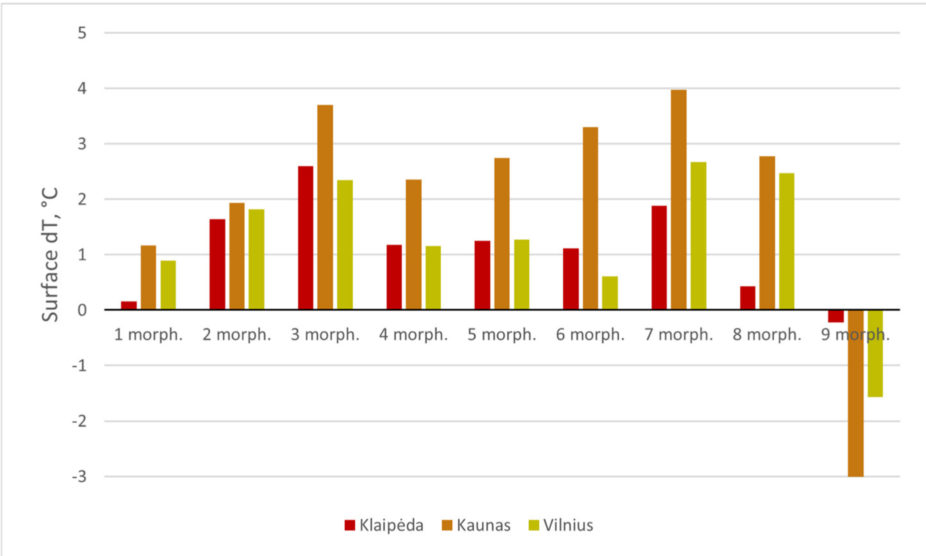


Figure 16. Surface temperature deviations from baseline MS in analysed 1–9 morphotypes: comparison across individual cities.

7.3. Temperature Deviations and Heat Islands in the Cities

Based on the consolidated results of microclimatic research conducted in Klaipėda, Kaunas, and Vilnius, built-up urban areas in Lithuanian cities create conditions where temperatures are 1.0–2.5 °C higher than those recorded at baseline city MS, contributing to the formation of localised urban heat islands (see Table 13).

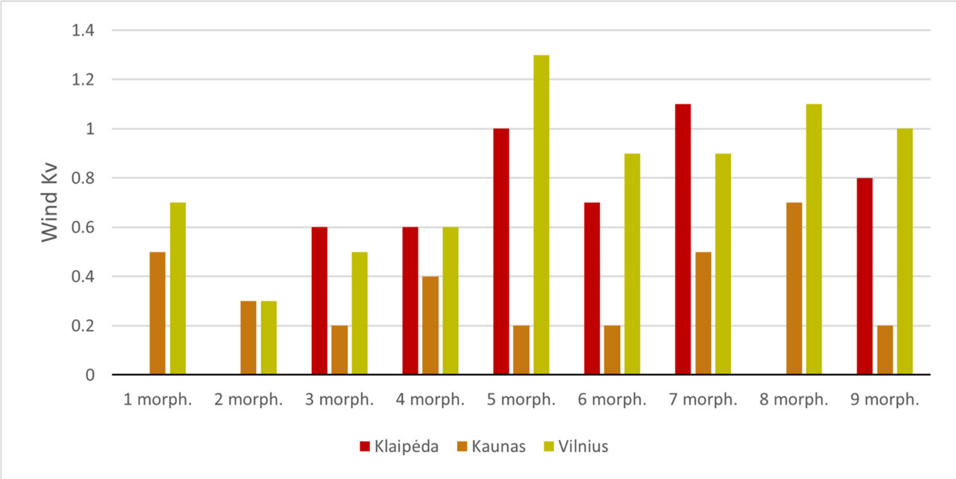


Figure 17. Relative wind speed difference (Kv) compared to baseline MS in analysed 1–9 morphotypes: comparison across individual cities.

Table 13. Summary of characteristics of urban morphostructure types based on microclimatic and urban indicators in Klaipėda, Kaunas, and Vilnius cities.

No	Type of Urban Morphostructure	Air Temperature Deviations, dT, °C	Surface Temperature Deviations dT, °C	Wind Deviations Kv	Development Density % (Development Area, m^2/Territorial Area, m^2)	Impervious Surface Area, % (Impervious Surface Area, m^2/Territorial Area, m^2)	Development Intensity, Total Development Area, m^2/Territory Area m^2
1	Morph. 1—detached	0.0–1.0	0.0–1.5	0.5–0.7	15–20	15–25	0.15–0.2
2	Morph. 2—terraced	1.5–2.0	1.5–2.0	0.3	23–25	35–45	0.5
3	Morph. 3—perimeter	0.5–2.5	2.0–4.0	0.2–0.6	30–45	55–65	1–1.5
4	Morph. 4—open layout	0.0–1.5	1.0–2.5	0.4–0.6	18–20	25–35	1
5	Morph. 5—high-rise	0.0–1.5	1.0–3.0	0.2–1.3	20–25	30–40	2–3
6	Morph. 6—mixed	0.5–2.0	0.5–3.5	0.2–0.9	20–25	35–40	0.5–1
7	Morph. 7—industrial	0.0–1.5	1.5–4.0	0.5–1.1	20–25	45–60	0.5–1
8	Morph. 8—open space det.	1.5–2.0	0.5–3.0	0.7–1.1	7–20	15–60	0.1–0.5
9	Morph. 9—green spaces	0.0–1.0	−3.0–0.0	0.2–1	-	-	-

Note: Deviations compared with meteorological indicators of baseline measurement stations in the analysed cities: Klaipėda, Kaunas, and Vilnius.

Evaluating the consolidated microclimatic indicators of urban morphostructure (Table 13), it was found that low-rise, low-density detached development (morph. 1) exhibits microclimatic conditions and deviations that are largely comparable to those of the cities' baseline MS, with temperature deviations typically ranging around 0–1 °C. In contrast, dense and enclosed development structures show significantly higher temperature deviations. This is evident in denser terraced development structures (morph. 2), where temperature deviations reach up to 1.5–2.0 °C, and perimeter structures (morph. 3), where deviations range between 0.5 and 2.5 °C. These development areas are characterised by closed or highly compact urban block configurations, often reinforced by plot fencing, which contributes to increased thermal retention. Mixed-use development structures (morph. 6) also exhibit higher temperatures, with readings 0.5–2.0 °C higher than those recorded at the baseline MS. Compared to open layout development types (morph. 4), this type shows slightly higher temperatures, influenced by greater development density, primarily due to the presence of low-rise infill within multistorey open layout developments. In industrial and engineering infrastructure territories (morph. 7), temperature deviations reach approximately 0–1.5 °C. These areas are distinguished by a high proportion of impervious surfaces, resulting in surface temperatures up to 4.0 °C higher than in the baseline MS environment. However, due to their relatively open spatial structure, these areas experience greater wind flow, which partially offsets temperature increases.

Among the analysed morphotypes, the distinctiveness of open space detached building development located in open spaces (morph. 8) should be highlighted. This type was used for the evaluation of the main urban public spaces, where it was established that the analysed central public spaces—squares with open hard—impervious surface pavements—exhibit higher temperatures than the environment of the cities' baseline MS (approximately 2.0 °C). Given the open nature of these spaces, temperatures may decrease under windy conditions but rise considerably during calm weather.

The conducted research confirmed the critical role of green areas in mitigating urban heat. In the analysed green space structures (morph. 9), surface temperatures across all cities were consistently lower than those recorded at the baseline MS, with differences ranging from 0.2 to 3.0 °C (see Tables 12 and 13). Accordingly, air temperature in green areas was also recorded as lower compared to other built-up morphotypes, showing deviations of up to approximately 1.0 °C higher or even equivalent to the baseline MS values of the cities.

Development types characterised by higher air temperatures are considered the most sensitive to climate change processes. These morphotypes exhibit the highest likelihood of urban heat island formation when compared to other urban structures. Therefore, for cities to be adequately prepared for the impacts of climate change, the preservation of green spaces, the restoration of natural surfaces, and the expansion of urban greening measures remain highly relevant. From a functional urban planning perspective, the spatial organisation of industrial territories becomes increasingly important, as their intensively developed environments—marked by high development density and extensive impervious surfaces—can significantly influence temperature levels in adjacent residential areas. To mitigate this effect, the placement of industrial zones on the leeward side of residential areas should be considered, along with their separation by green buffer zones and increased spatial distancing.

7.4. Relation Between Microclimatic Conditions and Urban Indicators

An analysis of the established relationship between air and surface temperatures of morphotypes and urban indicators reveals a clear linear dependence of both temperatures on the proportion of impervous surfaces and development density. This is most clearly demonstrated by the increase in surface and air temperatures of low-rise development morphotypes 1–2, as well as multistorey development morphotypes 3–4. In low-rise detached (morph. 1) and terraced (morph. 2) development types, temperature increases with rising impervious surface coverage and development density: air temperature deviations from the cities' baseline MS reach up to 1.0 °C in detached housing and up to 2.0 °C in block development types. Similarly, increasing development density and impervious surface coverage in multistorey development structures leads to higher temperatures: in more open layout development (morph. 4) areas, deviations reach up to 1.5 °C, while in dense perimeter development (morph. 3) structures, deviations reach up to 2.5 °C. Strong correlations were found between air temperature and environmental indicators in the city of Kaunas, with correlation coefficients of 0.687 for impervious surface area; the relationships between air and surface temperatures were also strong, showing coefficients of 0.694 in Kaunas (see Tables 14 and 15)

Table 14. Correlation coefficients of the relationship between measured field air temperature and environmental indicators.

Assessed Environmental Components	Cities	Used Coefficient for Correlation Calculation	Compared Environmental Components			
			Surface Temperature	Development Density	Development Intensity	Proportion of Impervious Surfaces
Correlations of air temperature (T)—relationship with other environmental component indicators	Klaipėda	Pearson's	0.486 (R^2 Linear—0.236)	0.596	0.022 (R^2 Quadr.—0.350)	0.517
		Spearman's	0.406	0.154	−0.763	0.308
	Kaunas	Pearson's	0.694 * (R^2 Linear—0.482)	0.653 *	0.165 (R^2 Quadr.—0.621)	0.687 *
		Spearman's	0.536	0.683	−0.167	0.405
	Vilnius	Pearson's	0.449 (R^2 Linear—0.202)	0.510	0.205 (R^2 Quadr.—0.043)	0.499
		Spearman's	0.336	0.430	0.153	0.555

Remarks: Reliable correlations are marked with an asterisk: *—correlation is significant at the 0.05 level (two-tailed). Coefficients between 0 and 0.4 indicate weak correlations, those between 0.4 and 0.7 indicate moderate correlations, and those between 0.7 and 1.0 indicate strong correlations.

Table 15. Correlation coefficients of the relationship between measured field surface temperature and environmental indicators.

Assessed Environmental Components	Cities	Used Coefficient for Correlation Calculation	Compared Environmental Components			
			Air Temperature	Development Density	Development Intensity	Proportion of Impervious Surfaces
Correlations of surface temperature (T)—relationship with other environmental component indicators	Klaipėda	Pearson's	0.486 (R^2 Linear—0.236)	0.888	0.517 (R^2 Quadr.—0.759)	0.949 (R^2 Linear—0.635)
		Spearman's	0.406	0.881 **	0.599	0.952 **
	Kaunas	Pearson's	0.694 * (R^2 Linear—0.482)	0.815 **	0.607 (R^2 Quadr.—0.767)	0.908 ** (R^2 Linear—0.824)
		Spearman's	0.536	0.620	0.455	0.874 **
	Vilnius	Pearson's	0.449 (R^2 Linear—0.202)	0.870 **	0.396 (R^2 Quadr.—0.602)	0.972 ** (R^2 Linear—0.944)
		Spearman's	0.336	0.845 **	0.529	0.917 **

Remarks: Reliable correlations are marked with an asterisk: *—correlation is significant at the 0.05 level (two-tailed); **—at the 0.01 level (two-tailed). Coefficients between 0 and 0.4 indicate weak correlations, those between 0.4 and 0.7 indicate moderate correlations, and those between 0.7 and 1.0 indicate strong correlations.

Within the scope of the research, an increase in development density and impervious surface coverage showed a direct linear impact on microclimatic conditions. However, such a linear relationship does not apply to development intensity, which incorporates building height as an additional variable. Assessing morphotype development intensity and its relationship with air and surface temperatures revealed no consistent linear correlation. This is exemplified by high-rise development (morph. 5) structures, which are often denser and more intensive than perimeter (morph. 3) and open layout (morph. 4) development types. Yet, in high-rise development areas, temperature deviations from baseline MS were recorded at up to 1.5 °C, considerably lower than those observed in perimeter development areas (morph. 3), and comparable to deviations recorded in less intensive open layout (morph. 4) structures. This suggests that factors beyond development density and surface sealing—such as building height and vertical structure—also influence the microclimatic situation (correlation analyses conducted in the analysed cities confirmed the absence of a linear relationship between air and surface temperatures and development intensity; for example, in Kaunas, the quadratic R^2 coefficient reaches up to—0.621).

7.5. Preconditions for Sustainable Morphotypes

The obtained research results and their interrelations support the conclusion that the most thermally favourable residential environments—characterised by lower summer temperatures—are found in detached development (morph. 1) structures. In these areas, air temperature deviations from the cities' baseline MS range from 0 to 1 °C, while surface temperature increases by approximately 1.5 °C. Relatively small deviations from the baseline MS are also observed in the open layout morphotype (4), where air temperature deviations reach 0–1.5 °C and surface temperature deviations range from 1 to 2.5 °C, as well as in high-rise development (morph. 5) structures, where air temperature deviations range from 0 to 1.5 °C and surface temperature deviations reach 1–3.0 °C.

These development types exhibit fairly similar microclimatic conditions but differ significantly in terms of spatial organisation and urban function. For example, in terms of residential density, open layout territories accommodate a larger number of residents—reaching population densities of 150–175 inhabitants per hectare—compared to detached housing development areas, which have much lower densities of 17–23 inhabitants per hectare. Additionally, these morphotypes differ in development intensity, density parameters, functional layout, and other urban characteristics. Therefore, it is evident that microclimatic indicators alone cannot determine the optimal development type for achieving a balanced and sustainable urban structure.

To support the development of new, sustainable cities, it is necessary to consider not only microclimatic factors but also broader urbanistic aspects. This includes saving territorial reserves, promoting compact urban development—aligned with the principles outlined in international environmental frameworks [80,81]—and enhancing the vitality of spatial structures through contemporary urban planning concepts such as the 15 min city model and related approaches [82,83]. Therefore, when shaping sustainable urban structures, priority should be given to development types that not only exhibit the most favourable microclimatic indicators but also allow for more efficient land use. These types should integrate their spatial structure with functional development and provide convenient, attractive environments for residents.

8. Discussion

The discussion could first be raised concerning the relationship between climatic and other threats. Of course, the aim of the paper is not to find a direct relationship, but to maintain the basis of infrastructure that could both serve to mitigate negative climate impact and as well be used for safety infrastructure if other threats such as war, radiation will emerge. If Lithuania still pay insufficient attention to the preparedness of cities for climate change and other potential threats, then in contrast, international practices demonstrate a higher level of complex preparedness; countries such as Finland and Sweden actively plan for heatwaves, floods, storms, public health crises, and even radiation and war-related hazards [32,34,84–86]. One of the main reasons for such insufficient attention in Lithuania is the liberalisation of urban management, which primarily addresses short-term economic goals (resulting in urban sprawl, densification at the expense of green structures, and similar outcomes). International experience shows only the consistent integration of urban development with strategic issues and a progressive socio-political perspective can lead to positive results. Strategic goals, implemented through active social policy, could help to evaluate the importance of open and green spaces, reserve them for future public needs, and as well implement the infrastructure necessary to mitigate the negative impacts of potential multi-threats.

The combined evaluation of urbanistic and microclimatic factors complements previous work by other authors and aligns in principle with methodologies applied internationally. However, some methodological differences become apparent [28,72,87,88], when comparing the results of this study with those of foreign researchers. In this study, the assessment of development structures is based on morphostructure types that are legally binding in Lithuania, making direct comparisons with foreign development morphotypes challenging. For example, while certain development types such as detached housing can be roughly equated to Stewart and Oke's [28] low-rise LCZ-1 category, and industrial structures to LCZ-6, others show more complex relationships. The open layout development type corresponds partially to both LCZ-1 and LCZ-2, while mixed development structures resemble combinations of LCZ-1 and LCZ-4, among others. This tailored morphotype classification allows for a more principal evaluation of local development characteristics and enables a more context-specific analysis of urban structures within Lithuania.

Despite mentioned differences between selected morphotypes used in this study and local climate zones (LCZs) defined by other authors, the microclimatic results can be compared. For example, in Lithuania an analysis of dense urban structures and green areas revealed air temperature differences of up to 2–2.5 °C and surface temperature of 4–7 °C (Table 13). Steward and Oke argue that air temperature differences between classes with significant contrasts in geometry and land cover can often exceed about 5 °C. Other research in Australia has indicated surface temperature differences of up to 10 °C between LCZ1 (compact high-rise) and LCZ9 (sparsely built) [89]. Rural-urban temperature differences during intense heating events were recorded at approximately 6 °C in Taiwan and in Japan, and around 10 °C in The Netherlands [90]. These variations largely depend on differences in urban structures and climatic conditions. To evaluate more precisely the relationship between urban indicators and microclimatic conditions across different countries, more detailed research is required. Nevertheless, in this study, selected morphotypes and their microclimatic characteristics may be applied to neighbouring countries such as Latvia, Poland, and others, which were affected by the intense urbanisation of the socialistic period and urban structures of similar morphotypes were created. In particular, morphotypes such as open layout, low-rise detached, and industrial areas may be directly compared.

When interpreting the research findings, it is important to note inverse correlations between land surface temperature and development height, which have been identified in studies by foreign researchers [72,91–94]. Such complex relationships were also observed in this study. Based on the regularities of the relationships between development characteristics and microclimatic conditions, foreign researchers have highlighted dense, low-rise development areas as particularly vulnerable; these are often characterised by limited open space, reduced vegetation cover, and raised microclimatic temperatures. Conversely, the authors propose that such territories should be developed with higher-rise residential structures, which can accommodate more residents while preserving open spaces and incorporating more green infrastructure [72,87].

These findings, together with those of other researchers, indicate that to develop a city morphostructure resilient to negative temperature impacts, it is essential to assess built-environment parameters that influence the ecological quality of the residential environment, including development density, extent of impervious surfaces, surface material properties, building height, spatial layout, and the provision of green space areas. However, for sustainable urban development and preparedness against broader threat scenarios, additional environmental and economic factors must also be considered, such as land use conservation and efficiency, residential density indicators, and functional accessibility.

These aspects are addressed in various contemporary urban planning frameworks, including new urbanism, the 15 min city concept, and the principle of zero land take. In light of these considerations, further research will aim to elaborate on potential strategies for improving development structures within the broader scope of ongoing studies. As further research, it is planned to analyse variations in different urban structures of higher intensity, including both individual blocks and blocks groups, that could better adapt to the negative impacts of climate change and also integrate safety infrastructure against other threats.

9. Conclusions

1. Climate change projections increasingly point to more severe consequences of global warming. According to RCP4.5 and RCP8.5 scenario-based forecasts, the frequency and intensity of heatwaves and droughts are expected to rise, leading to greater impacts on human health, ecosystems, and agricultural productivity. Equally pressing remain threats such as war, radiation exposure, pandemics, and other potential hazards. The risks associated with these threats underline the urgent need to significantly reduce human impact on the climate system, as well as to immediately strengthen efforts in adaptation and preparedness for the adverse effects of emerging threats.

2. An analysis of the general urban characteristics of the studied cities—Klaipėda, Kaunas, and Vilnius—reveals that urban development continues in a largely similar manner across all three, without adequate consideration of climate change or other potential threats. Construction is often carried out in a fragmented way, on individual plots, with insufficient integration of green spaces or public areas. Existing green spaces, coastal flood-prone areas, and other open territories are increasingly being repurposed for construction. It was also found that the urban residential environment is neither currently prepared nor being developed to mitigate the negative impacts of climate change. Of particular importance in preventing the effects of these threats are civil safety facilities, which at present only nominally exist in the form of limited-capacity shelters, with no bunkers available at all. This indicates that the cities under study are not adequately prepared to address the consequences of climate change and other emerging threats.

3. Comparing the climatic regions of the country, it was determined that the central lowlands and southeastern uplands climatic regions show the greatest urgency in addressing the effects of urban heat island, as larger temperature deviations from baseline measurement stations were recorded in their urban structures. In the central Lithuania and southeastern uplands climatic regions, air temperature deviations reached up to 2.7 °C and surface temperature deviations up to 3.7 °C. In contrast, in the coastal region, air temperature deviations were significantly lower—up to 0.5 °C—while surface temperature deviations reached up to 2.6 °C.

4. Based on urban and microclimatic analysis, distinct microclimatic indicators were identified for different morphostructure types (nine in total) representing both built-up and open spaces. The morphostructure type with the lowest development intensity—detached housing (morph. 1), as well more intense development of open layout (morph. 4)—compared to other development types, shows the smallest deviation in air temperature compared to the baseline MS readings across the studied cities (air dT—0–2 °C). Morphotypes with higher development density—classified as terraced (morph. 2) and perimeter (morph. 3) development—exhibit more pronounced microclimatic differences from the baseline MS (air dT −0.5–2.5 °C).

5. Discussing the results of local climatic analysis of morphotypes in the selected cities, it can be concluded that morphotype characteristics are closely correlated with and influenced by factors such as development character, building height, density, vegetation cover, and other urban features. Based on the analysis of identified morphostructure

types, it was determined that low-rise areas with lower development density (morph. 1) exhibit more favourable air conditions, characterised by lower temperatures. In multistorey development areas, air temperature conditions also depend on building height: lower structures (morph. 3) show greater overheating, while taller buildings (morph. 4 and 5) exhibit relatively lower temperature increases. Similarly, the spatial arrangement of buildings and open spaces significantly affects microclimatic conditions. Open layouts (morph. 4) of detached buildings and open space structures (morph. 1 and 9) contribute to more favourable microclimatic conditions, whereas enclosed or compact development forms (morph. 2 and 3) tend to create less favourable thermal environments.

6. When planning urban expansion and selecting morphotypes for shaping future city structures, it is essential —as previously noted—to evaluate not only climatic performance but also a range of other considerations. These include land saving, development compacting, city size, green and public space effectiveness. Therefore, in the search for optimal morphotypes, more intensive development types should be prioritised.

7. A general evaluation of emerging threats, combined with the complex use of territorial elements aimed at preventing these threats, can effectively support adaptation to climate challenges and the development of adequate safety infrastructure. Based on these principles, further research will focus on the detailed resilience of urban morphotypes and on ways to integrate safety infrastructure into green and open spaces.

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Data Availability Statement: During this research, no database was created. The LHMS and FRD datasets used in this study were used as third-party data, which were obtained from third parties (LHMS, FRD) and were available to the authors with the permission of these third parties (LHMS, FRD). The datasets for the urban area analysis used in this study are available from the Public Institution Construction Sector Development Agency. These data were derived from the following resource and are available in the public domain: https://www.geoportal.lt/geoportal/ (accessed on 20 November 2024). The data for surface temperature analysis Landsat 8 and Landsat 9 satellites data as well Sentinel 2 data were used. Data was obtained from the following resource and are available in the public domains: https://docs.sentinel-hub.com/api/latest/data/landsat-8/; https://sentiwiki.copernicus.eu/web/s2-mission (accessed on 10 April 2025).

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Abbreviations

LCZ	local climate zones
LST	Land surface temperature
RCP	Representative Concentration Pathway
LHMS	Lithuanian Hydrometeorological Service
FRD	Fire Rescue Department under the Ministry of the Interior of the Republic of Lithuania
MS	meteorological stations
UNESCO	United Nations Educational, Scientific and Cultural Organization

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