Chapter 11
Urban Heat Island and Bioclimatic Comfort in Warsaw

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Abstract This chapter will introduce the UHI phenomena in Warsaw, in particular after a the definition of the pilot area, experimental microclimatic measurements were made in two housing estates, Koło and Włodarzewska, located at a similar distance from the city centre and from the city limits but different in terms of building periods and materials. A specific analysis of vegetation is provided to put in relationship UHI effects and allergenic factors. The case is completed by some solutions in terms of mitigation and adaptation to reduce urban warming impact.

Keywords Microclimate • Urban spatial organization • Green areas • Mitigation

11.1 Introduction – UHI as an Effect of Spatial Organization of the City

Warsaw is the largest city in Poland. Its area of almost 515 km^2 has significant differentiation of land use. Currently about 248 km^2 is built-up area (48 %). Within this the greatest part (about 57 km^2) is covered by industry, trade units and transport systems. Forests make up about 15 % of the city. Urban parks and other recreational green areas cover 10 %. 12 % of the city territory is used as arable land, for crops and pasture. The category "heterogeneous agricultural areas" includes sparsely built areas and allotment gardens – 11.3 % (Table 11.1). With 1.7 million residents and

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Table 11.1 The land use types in Warsaw, according to Corine Land Cover 2006 (EEA 2007)

Land use	Area [km^2]	Area [%]
Urban fabric	191.0	37.1
Industrial. commercial and transport units	56.9	11.1
Construction sites	3.3	0.6
Artificial. non-agricultural vegetated areas	53.4	10.4
Arable land	40.0	7.8
Permanent crops	0.5	0.1
Pastures	21.2	4.1
Heterogeneous agricultural areas	58.3	11.3
Forests	77.8	15.1
Scrub and/or herbaceous vegetation	0.6	0.1
Open spaces with little or no vegetation	1.6	0.3
Inland wetlands	0.2	0.0
Inland waters	9.9	1.9
Total	514.6	100.0

over 3.2 million residents of the greater agglomeration area, it has become the 10th most populous city in the European Union (Eurostat 2014). After the Second World War, the area of Warsaw increased gradually; small villages and rural areas as well as natural forests were included into the city.

During the last 20 years, many fields, pastures and meadows were adapted for residential districts.

The recent tendency in city development is to build dense settled residential districts (both, small single family buildings and 4–6 floor blocks) as well as to insert new buildings into free spaces in the city centre (which was dramatically destroyed during the II World War). At the administration level of Warsaw there is not one single vision for city development. For the whole city there is only a general overview of investment intentions (Studium… 2010).

The shape of UHI in Warsaw resembles a diamond and reflects the distribution of the densest built area. The mean yearly intensity of the UHI-index (difference of the minimum daily temperature for the considered site to the value of the minimum daily temperature for Warszawa-Okęcie station) reaches over 2 °C in the city centre. On the outskirts and in the forest area in south-east Warsaw, the UHI-index is from 0.5 to 1.0 °C lower than at the airport station. During spring and summer, the intensity of UHI is comparable to the average. The most intensive UHI is to be observed in autumn. The very centre of the city is warmer in the night by 2.5 °C comparing to Okęcie station. The lowest UHI-index occurs in winter – only 1.5 °C, but then the spatial extent of UHI is greater than in other seasons. This situation is associated

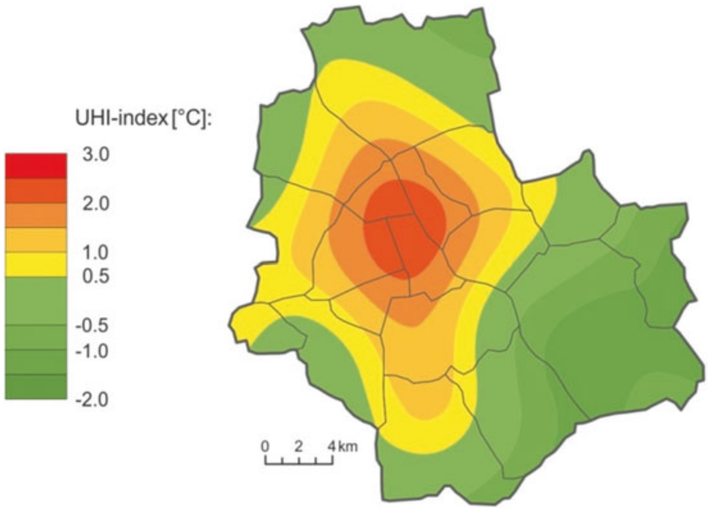

Fig. 11.1 Spatial distribution of UHI-index in Warsaw, mean values for the years 2011–2012

with the usage of house heating stoves in places not connected to central heating plants (Fig. 11.1).

Thus, the general idea of pilot studies in Warsaw was: (1) to verify how the varying structures of space organization and land cover of selected residential districts influence UHI intensity and perceptible thermal conditions, and (2) how architectural solutions (e.g. planting additional lawns and trees, organizing green roofs) can minimise UHI and affect perceptible thermal conditions.

An additional aspect of the pilot studies was to assess the allergenic potential of plant cover (trees and bushes) growing inside the studied residential districts. It allows the validation of the health impact of vegetation and consequently, to give recommendations regarding plant composition which would be more friendly for the local population.

11.2 Pilot Areas Methodology

The pilot studies were designed on the basis of a network of microclimatic measurements in Warsaw and its surroundings, working since 2006 as part of climate research carried out in IGSO PAS (Kuchcik et al. 2008; Błażejczyk et al. 2013b).

To cope with the aims of research, three small areas in Warsaw were chosen: Twarda (in the centre of the city) as well as Koło and Włodarzewska housing estates (in the western part of the city). As a reference site, representing outside rural conditions, the station situated in the Botanical Garden in Powsin was chosen (Fig. 11.2). For each area a detailed inventory of the greenery, type of surfaces, heights of buildings and horizon limitations was made.

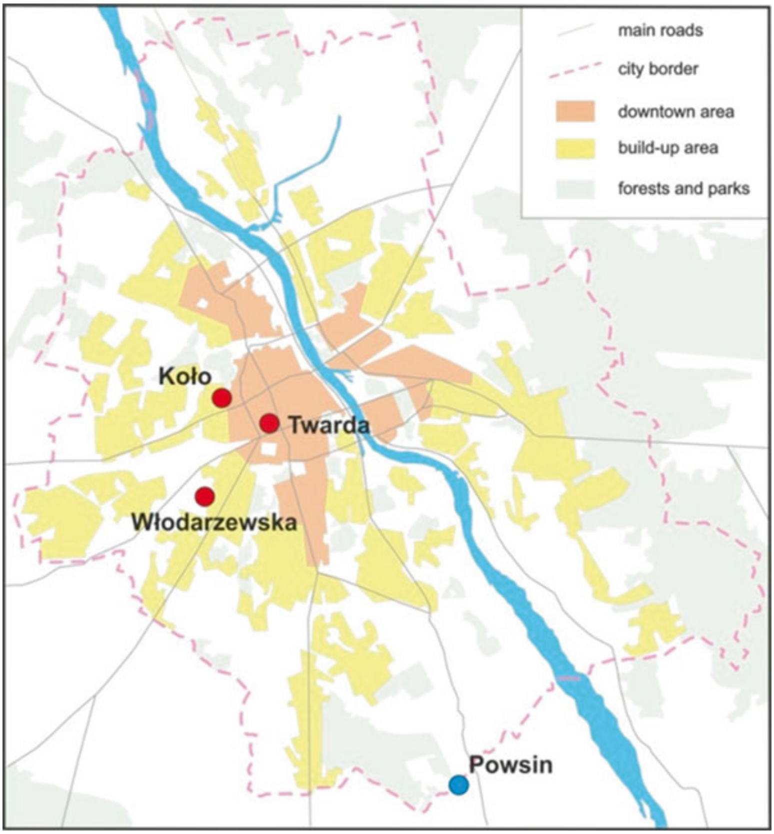

Fig. 11.2 Location of the pilot study areas (Twarda, Koło, Włodarzewska) and peripheral reference station (Powsin)

The Koło estate was established about 50 years ago (in the 1960s). The 4–5 floor buildings are built in low density and the majority are built from clay bricks. Few parking places are located inside the estate. Wide spaces between buildings are covered by lawns and tall, mature, deciduous trees. The RBVA (Ratio of Biologically Vital Areas), i.e. the ratio of areas covered by vegetation or open water (not sealed areas) in the plot size (according to Szulczewska et al. 2014) is 54.3 % and FAR (Floor Area Ratio)[1] is 0.8 (Fig. 11.3a).

The Włodarzewska estate was built about 15 years ago (1995–2000) and is surrounded by many open spaces and a park, but arranged in a way which effectively precludes the entrance of air from the outside. It is characterized by compact development. The 4–5 floor blocks are very densely built up. They are constructed mostly from concrete and include underground car parks. Parking places are also organized along communication roads inside the estate. Many small flowerbeds and lawns

[1] Floor Area Ratio, is calculated as the area of all building contours (Barea) multiplied by the number of floors (fn) and divided by the total area of the plot (Tarea), FAR = Barea·fn/Tarea.

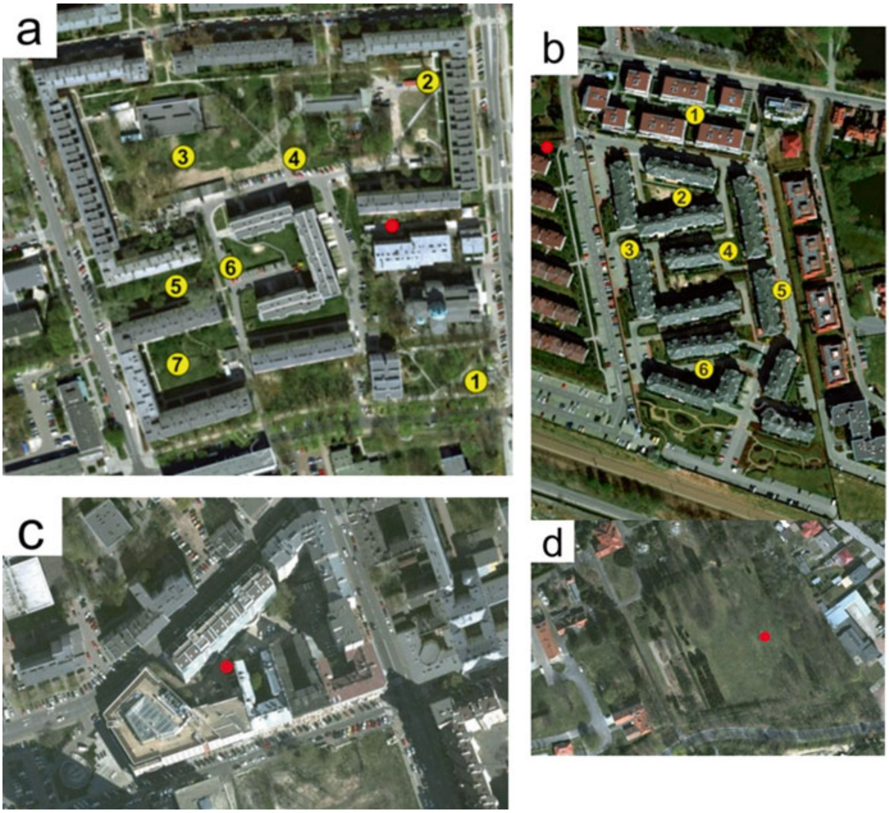

Fig. 11.3 Aerial view of pilot areas: Koło housing estate (**a**), Włodarzewska housing estate (**b**), Twarda district (**c**) and Powsin reference station (**d**); *yellow points* indicate sites of microclimatic measurements, the *red points* indicate sites of permanent microclimatic measurements

with coniferous shrubs grow between the buildings. Only a few young deciduous trees grow there. RBVA is 40.7 % and FAR is 1.25 (Fig. 11.3b).

The Twarda district is located in the city centre. It consists of a mixture of 80-year old buildings (from clay bricks), which were not destroyed during II World War as well as of newly constructed compartments (from concrete). 6–7 floor buildings predominate. Vegetation cover is very poor and only few trees and lawns can be found at the bottom of deep courtyards. Almost all the space between buildings is used as parking places. The area is surrounded by streets without any vegetation. The RBVA for this area is only 4 % and the FAR index is 2.74 (Fig. 11.3c).

The characteristics of UHI and perceptible thermal conditions in each of the selected studied areas were compared with air temperature (Ta) and Universal Thermal Climate Index (UTCI) values observed at the peripheral reference station in Powsin. The station is situated in the Botanical Garden and represents open area conditions with ground covered by grass. Horizon shading is about 10 % and the station is exposed to sunbeams almost the whole day (Fig. 11.3d).

11.3 Methods

The pilot studies in Warsaw have been composed of two steps. In the first step, experimental microclimatic measurements were made in two housing estates, Koło and Włodarzewska. They are located a similar distance from the city centre and from the city limits. However, they differ in type, density and age of buildings as well as in composition of green areas and the percentage of biologically vital area. The aim of the microclimatic measurements was to assess influence of local space organization on differences of UHI and perceptible thermal conditions. The results of the measurements were compared both with the Powsin reference station and with the city centre represented by Twarda district.

During the microclimatic research on 21 and 22 May 2013, the air temperature and humidity, wind speed and global solar radiation were measured in two periods of the day: early morning (5–7 a.m.) and at midday (12 p.m.–2 p.m.). The posts were situated in various micro structures of the housing estates (Fig. 11.3a, b). The perceptible thermal conditions were assessed with the use of the Universal Thermal Climate Index UTCI (Błażejczyk 2011; Bröde et al. 2012; Błażejczyk et al. 2013a, b). The index assesses heat stress in man caused by a complex outdoor environment (air temperature and humidity, solar radiation and wind speed). The spatial variability (in early morning and midday hours) of air temperature and UTCI and differences between microclimatic posts and the reference peripheral station were analysed.

As a result of the greenery inventory, all plant species have been divided into four classes according their allergenic potential. The classification was evaluated according to the Polish Society of Allergology guidelines for diagnosis and management of allergic diseases supported additionally by local allergists' experience.

Class 3 – great allergenicity, frequently sensitizing species (Alder, Birch, Hazel)
Class 2 – moderate allergenicity, rare sensitizing species (Poplar, Elm, Willow, Beech, Oak, Plane, Ash, Linden)
Class 1 – slight allergenicity, very rare sensitizing species or isolated case reports only (Acacia, Hornbeam, Maple, Elder, Spruce, Pine, Jasmine, Ambrosia, Olive)
Class 0 – no allergenicity, species with no or unknown allergenic potential (female cultivars of dioeciously plants from higher classes were also included in this class due to no pollen production).

If a plant species was not mentioned in any guidelines or local allergists' statement, the EBSCO scientific journal database was used to determine the potential allergenicity of the plant. If, during the last 15 years, there had been three or more cases or scientific reports published on the possibility of respiratory tract allergy induction, the plant was classified as Class 1; otherwise it was classified as Class 0.

Microclimatic measurements became the basis for the second, simulation step of the pilot studies. In this step a few scenarios of possible changes in land cover in Włodarzewska and Twarda, which could reduce UHI, were considered. The simulations of air temperature for 4 days a year representing spring, summer, autumn and winter were made with the use of ENVI-Met software in the Vienna University of Technology, Department of Building Physics and Building Ecology, Institute of Architectural Sciences.

11.4 The Role of Urban Vegetation in Reduction of UHI – The Results of Microclimatic Research

The variation of air temperature (Ta) and heat stress (UTCI) inside residential districts was examined on two sunny days, 21–22 May 2013, in two housing estates, Koło and Włodarzewska, which differ in the provision of green areas as well as in the arrangement of buildings (Fig. 11.3a, b). On the measuring days, the wind was weak (<2 $m \cdot s^{-1}$), the mornings had clear sky, *Cumulus* clouds were created during the day and a short 10-min shower occurred on 22 May. Global solar radiation in Koło was more differentiated inside the estate than in Włodarzewska, which significantly influenced the calculated UTCI values. The air temperatures in the housing estates and in the reference station (Powsin) fluctuated between 8 and 15 °C in the mornings and 20 and 23 °C during the middle of the day.

The differences in air temperature in various micro structures inside both housing estates ranged from 2.5 to 2.8 °C in the early morning to 3.3 to 3.5 °C at noon, reaching higher values in Włodarzewska. At midday, the spatial differences in air temperature increased due to an increase in solar radiation (up to about 600–800 $W \cdot m^{-2}$). The warmest air was above artificial surfaces (asphalt, concrete), at well insulated sites and the coldest air was found over natural, shaded surfaces (lawns under trees). The wind tunnel effect was clearly seen at post 2 (close to the tunnel under the block of flats) and 5 (between two buildings) in Koło, and at post 5 (on a street along a long block of flats) in Włodarzewska.

The spread of UTCI values inside the analysed estates was 3 times greater than that of air temperature, though they mostly fall within one heat stress category, named "no thermal stress". In the Koło estate, the differences in UTCI values between posts at individual points in time reached 10.5 °C in the morning. The coldest was recorded on a vast lawn in the centre of the estate, surrounded by high trees and buildings (post 3), and the UTCI values indicated "slight cold stress" there. The warmest was a calm site under a canopy of high trees (post 1), where, at midday, the differences in UTCI reached 10.4 °C. The coldest was a shaded site under a tree canopy (post 1) and the warmest – an asphalt surfaced parking area (post 6), where moderate heat stress was noted.

In the Włodarzewska estate, the differences in UTCI values were much smaller and they reached only 6.7 °C in the morning. The coldest were pavements next to a block of flats, the windiest in the estate (post 5), and the warmest – a calm and sunny square between buildings (post 6). At midday, the spread of UTCI values was up to 6.8 °C. The warmest was a small lawn with young trees, squeezed between blocks of flats (post 4).

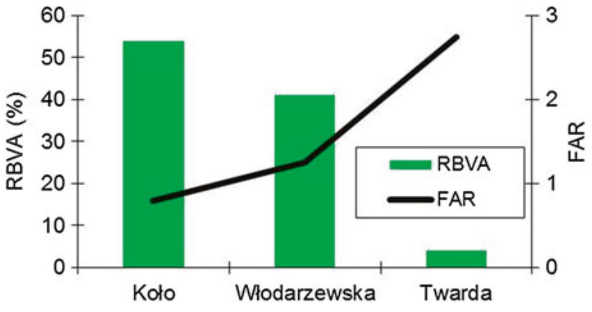

Fig. 11.4 The Ratio of Biologically Vital Areas (RBVA) and the Floor Area Ratio (FAR) of the pilot areas

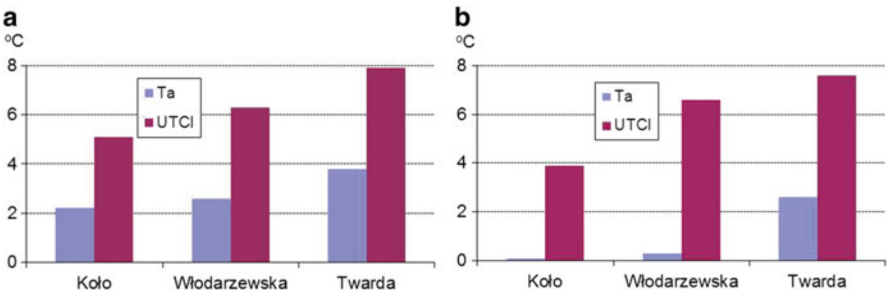

Fig. 11.5 The difference of the air temperature (Ta) and heat stress index (UTCI) between pilot areas and the Powsin reference point (**a** – morning hours, **b** – midday hours)

Concluding, green areas, including both lawns, bushes and trees, play an important role in creating urban heat stress. The results of experimental research revealed a bigger variation of Ta and UTCI inside a housing estate with higher RBVA and lower FAR (Fig. 11.4). Significant differences were found when Ta and UTCI values observed inside pilot areas were compared with the peripheral part of Warsaw (Powsin). In early morning (which represents the classical definition of UHI), the greatest Ta differences were observed in the city center and the smallest – in the Koło area. Similar relations of Ta were found for the midday hours, though Koło was characterized by the same temperature as the peripheral station and Włodarzewska was little warmer. The differences between the studied areas in comparison to the peripheral reference station (Powsin) were even greater when considering the perceptible thermal conditions represented by UTCI. The Koło estate has UTCI values that are, on average, 4–5 °C higher than at the periphery station, though in the Twarda district (city center), UTCI is 7.5–8 °C higher. The reason for such good thermal conditions in Koło is the presence of well-developed vegetation with predominantly high, leafy trees which cause many places in the Koło estate to be as cool as is observed in the botanical garden (Fig. 11.5). The UTCI is very sensitive to even small changes in the meteorological variables induced by different urban structures on a very detailed scale. The comparison of two housing estates with different structures shows that low density settlements with a great portion of biologically vital surfaces and trees can create relatively mild biothermal conditions.

11.4.1 Allergenic Potential of Vegetation

In the ecophysiographic description of three pilot study areas (in this case vegetation was also analysed for the southern part of the Włodarzewska estate where microclimatic conditions were not considered), a total of 97 different plant species have been described (see Table 11.2). Table 11.3 contains the general evidence of allergenicity in classes of plants in the studied pilot areas.

It is generally recognised that the Urban Heat Island (UHI) phenomenon has a detrimental impact on the health of populations that live under its influence. This phenomenon can act as an amplifier to heat wave events, mainly due to a lack of night-time thermal body regeneration. It can cause thermal stress through heat accumulation during consecutive days. Such conditions affect a certain population of city dwellers known to be at risk of developing heat-related illnesses. This population comprises subjects with chronic pulmonary and cardio- or cerebrovascular disorders, elderly people, young children and the disabled (Basu 2009). It is indisputable that phenomenon such as UHI need to be counteracted by launching various mitigation and adaptation strategies. One must remember that some of those strategies involve introduction of a new plant species into an urban area. It can mitigate the UHI phenomenon quite efficiently, but simultaneously can give rise to another major health problem. Improper plant choice may cause people who are susceptible to seasonal airborne allergens to develop symptoms of asthma, rhino conjunctivitis or urticaria/dermatitis. It is essential for mitigation and adaptation strategies to select appropriate plant species that do not aggravate the symptoms of airborne allergies. Although the definite impact of the UHI phenomenon on the allergenic activity of plants has never been described or proven before, there is some evidence supporting the hypothesis that such phenomena can alter plant physiology, causing them to be more allergy-aggressive. It has been proved in many studies, that in warmer climate plants can produce larger amounts of pollens when compared to those in cooler regions. An increase in carbon dioxide level has a similar impact (Cecchi et al. 2010). Factors typical for urbanized UHI areas such as: elevated ambient temperature, elevated carbon dioxide levels, increase in concentration of anthropic pollutants, i.e. sulphur dioxide, nitrogen dioxide, carbon monoxide, ozone and airborne particulate matter (PM) affect plant physiology causing an increase in allergen production. Pollen grains released in such an environment contain more allergen proteins on their external surfaces than they do in cooler settings (Todea et al. 2013; Beck et al. 2013). Typical pollen grain diameters range from 15 to 40 μm. Such a diameter allows pollen grains to reach only the upper region of the respiratory tract to trigger rhinoconjunctival symptoms. Only particles smaller than 10 μm can penetrate the respiratory tract down to its deeper structures to provoke asthma seizures. Pollen grains are extremely resistant to fragmentation, however, allergens can easily be transferred from pollen onto smaller particles (PM_{10}, $PM_{2.5}$) and, in this way, easily reach every compartment of the respiratory tract. Therefore, increased plant allergenic activity and air pollutants can act synergistically and thus dramatically reduce the quality of life of subjects susceptible to airborne allergens.

Table 11.2 Plant species recognised in three pilot study areas (Latin names in alphabetical order)

Abies concolor	*Cotoneaster horizontalis*	*Mahonia aquifolium*	*Rhus typhina*
Abies koreana	*Cotoneaster lucidus*	*Malus purpurea*	*Ribes alpinum*
Acer campestre	*Crataegus monogyna*	*Malus spMorus alba*	*Robinia pseudoacacia*
Acer negundo	*Crataegus xmedia*	*Parthenocissus quinquefolia*	*Rosa sp.*
Acer platanoides	*Daphne mezereum*	*Philadelphus sp.*	*Salix alba*
Acer platanoides	*Deutzia scabra*	*Physocarpus opulifolius*	*Salix babylonica*
Acer pseudpolatanus	*Elaeagnus angustifolia*	*Picea abies*	*Salix caprea*
Acer saccharinum	*Euonymus fortunei*	*Picea pungens*	*Salix caprea 'Klimanrock'*
Aesculus hippocastanum	*Fagus sylvatica*	*Pinus mugo*	*Salix fragilis*
Alnus glutinosa	*Forsythia xintermedia*	*Pinus sylvestris*	*Sambucus nigra*
Berberis thunbergii	*Fraxinus excelsior*	*Platanus xhispanica*	*Sorbus aria*
Betula pendula	*Hedera helix*	*Populus alba*	*Sorbus aucuparia*
Buxus sempervirens	*Hydrangea sp.*	*Populus nigra*	*Spiraea 'Grefsheim'*
Caragana arborescens	*Ilex aquifolium*	*Populus simonii*	*Spiraea japonica*
Carpinus betulus	*Juglans nigra*	*Potentilla fruticosa*	*Spiraea xvanhouttei*
Catapla bignonioides	*Juniperus 'Blue Carpet*	*Prunus avium*	*Symphoricarpos albus*
Cercidiphyllum japonicum	*Juniperus sabina*	*Prunus cerasifera*	*Syringa vulgaris*
Chaenomeles japonica	*Juniperus sp.*	*Prunus domestica subsp. syriaca*	*Tamarix sp.*
Chamaecyparis pisifera	*Juniperus virginiana*	*Pyracantha coccinea*	*Taxus baccata*
Chamaecyparis sp.	*Juniperus xmedia*	*Pyrus pyraster*	*Thuja occidentalis*
Cornus alba	*Larix decidua*	*Quercus robur*	*Tilia cordata*
Corylus colurna	*Ligustrum vulgare*	*Quercus rubra*	*Tilia platyphyllos*
Cotinus coggygria	*Lonicera maackii*	*Reynoutria sachalinensis*	*Viburnum opulus*
Cotoneaster dammeri	*Lonicera xylosteum*		*Weigela florida*
	Magnolia sp.		*Wisteria sp.*

Table 11.3 Numbers of tree and shrub specimens with different allergenicity in compared housing estates

Pilot area	Allergenicity			
	No (class 0)	Slight (class 1)	Moderate (class 3)	Great (class 4)
Koło (469)	134 (28.6 %)	273 (58.2 %)	54 (11.5 %)	8 (1.7 %)
Class 2&3 together			62 (13.2 %)	
Włodarzewska (619)	302 (48.8 %)	276 (44.6 %)	15 (2.4 %)	26 (4 2 %)
Class 2&3 together			41 (6.6 %)	
Włodarzewska-south (101)	49 (48.5 %)	39 (38.6 %)	9 (8.9 %)	4 (4 %)
Class 2&3 together			13 (12.9 %)	

It is also hypothesized that combinations of those factors, in addition to triggering respiratory tract allergy symptoms, can also promote allergisation in the portion of the population so far unaffected by allergies, by facilitation of allergen penetration into the respiratory tract (Lovasi et al. 2013). The deeper the allergen can reach into the respiratory tract, the greater area of mucosa is affected and the longer the allergen stays inside the organism, the more severe allergy symptoms can be triggered as well as easier allergisation. Air pollution itself also facilitates allergisation. It can irritate respiratory tract mucosa, thus causing it to be more easily penetrated by allergen proteins. Another factor that can affect people susceptible to seasonal airborne allergens is the elongation of the pollen season (Bielory et al. 2012). In a warmer climate, plants start to pollinate earlier and continue to release pollens for longer periods. It causes the anti-allergic pharmacology therapy schedule and specific immunotherapy calendar to require additional modification (early implementation, prolonged administration). All facts described above indicate that suitable plant selection is essential for successful implementation of various greenery-related UHI adaptation and mitigation strategies. It is also important to remember that all plant allergenicity assessment is local-specific. The set of allergy patterns is different for various geographic regions. The best example is the allergy to olive trees, which is known to be a frequent allergy in the Mediterranean region but not in north of Europe. Therefore, for performing such an assessment, the cooperation of local urbanists, botanists and allergists is needed to develop a suiTab. model of plant cover for UHI mitigation and adaptation strategies.

The prevalence of plant species considered to be a recognizable hazard to people with seasonal airborne allergies (Class 2 and 3) ranged from 6.6 to 13.3 %. The prevalence of Class 3 plants alone, known to cause the greatest allergological risk, range from 1.7 % (Koło area) up to 4.2 % (Włodarzewska area). Although Class 2 and Class 3 plants are almost evenly scattered throughout the pilot areas, there are two spots of Class 3 plant compaction close together. First, the spot at the south east corner of the Koło area contains six Class 3 plants. The second spot, at the north east corner of the Włodarzewska area, contains seven Class 3 plants. These spots are recommended for immediate remodeling. This limited intervention will allow the reduction of Class 3 prevalence to 0.4 % in Koło and 3.4 % in the Włodarzewska area.

11.5 Possibility of Reducing UHI Intensity

For the calculations of the scenarios of the possible UHI reduction, two areas were chosen – Włodarzewska and Twarda (very city centre). Koło was eliminated because there was nothing to change and the existing thermal conditions were friendly for humans.

Looking for the benefits from trees and the non-dense locations of buildings, a reduction in the number of buildings (pulling down 2 of them) and an increase in the number of lawns and trees (in the places of 2 new empty parcels) (Fig. 11.6) was proposed for the Włodarzewska estate. For the Twarda district, the possible effects of two scenarios were verified. In the 1st scenario, planting an additional lawn area and deciduous trees inside court yards and along streets was proposed. In the 2nd scenario all roofs were additionally covered by vegetation (Fig. 11.7).

Four characteristics of the urban heat island for 4 days of the year were analysed: maximum UHI, i.e. the highest daily urban to rural air temperature difference (dTa), minimum UHI, i.e. minimum daily dTa value, average dTa value for night hours (9 p.m.–7 a.m.) and average dTa value for day-time hours (10 a.m.–4 p.m.).

Simulations of air temperature for the Włodarzewska housing estate showed that the replacement of some buildings by lawns and trees could lead to a significant

Fig. 11.6 Land cover of Włodarzewska housing estate: (**a**) – the present state, (**b**) – changes in land cover proposed in scenario 1 (replacing 2 buildings by lawns and trees)

Fig. 11.7 Land cover of the Twarda district; (**a**) – present state, (**b**) – changes in land cover proposed in scenario 1 (additional trees and permeable surfaces), (**c**) – changes in land use proposed in scenario 2 (additional trees, permeable surfaces and green roofs)

reduction of UHI (Fig. 11.8). Maximum and minimum UHI values in spring, summer and autumn could be lowered by about 0.5 °C, and in winter up to 1 °C. The proposed land use changes would also cause a reduction of average UHI values, greater at night than during day-time hours.

For the Twarda district, simulations have verified that the 1st scenario of land cover changes (additional lawns and trees) would result in no significant changes of UHI intensity. Some lower values could occur, especially in summer, but in autumn, values of minimum UHI and midday hours UHI can be higher than in the present state. A more positive effect was obtained when the 2nd scenario (additional green roofs) was applied. Lower values of UHI occurred in spring and summer but in autumn and winter no changes were observed.

11.5.1 Assessment of Mitigation Measures

Simulations showed that increasing the number of lawns and trees as well as implementing green roofs in Warsaw city centre cause only small changes in the intensity of the urban heat island. To make a significant improvement, some radical action is needed, involving the reorganization of the existing built-up area. In places where it is possible some buildings should be pulled down and replaced by lawns and trees.

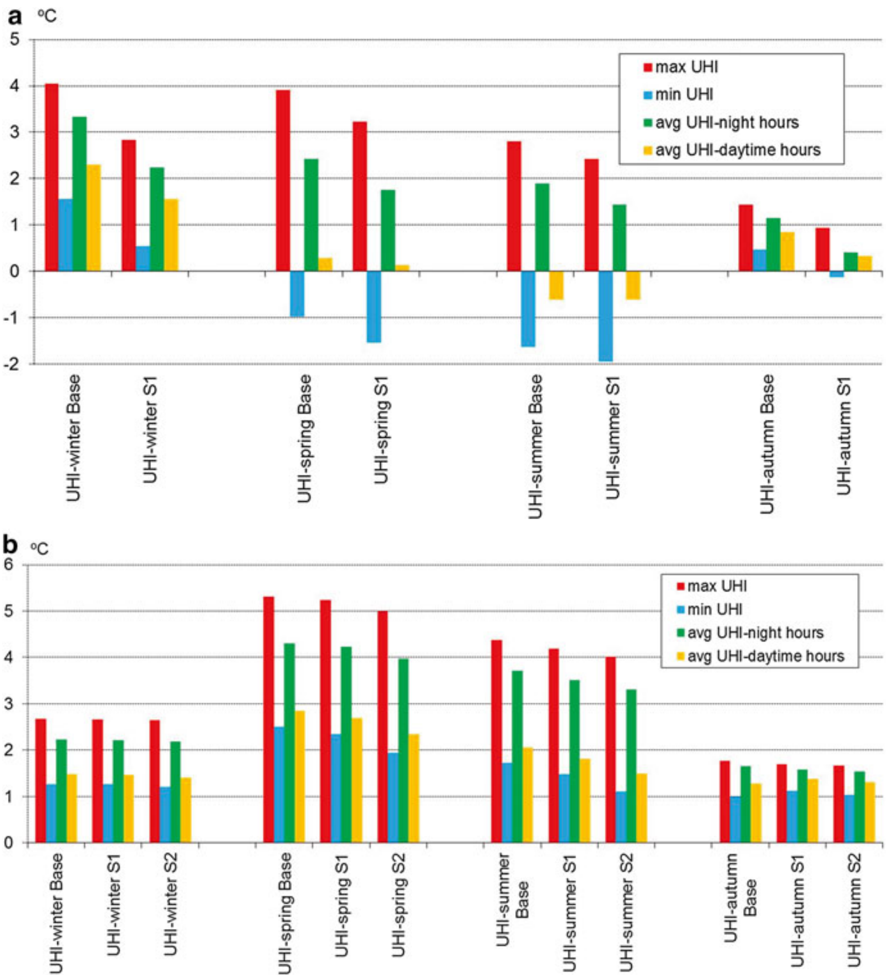

Fig. 11.8 Simulations of UHI-index (°C) made by ENVI-Met software for 4 days of a year representing winter, spring, summer and autumn for Włodarzewska housing estate (**a**) and Twarda district (**b**)

It is also advisable to forbid compaction of downtown and to take special care of present green areas.

There are many indications when designing new housing estates which could clearly mitigate UHI effects: applying a building layout which does not close the interiors of the housing estates but open them to the neighbouring green areas, using openwork metallic fencing was much more conducive to ventilation than high brick walls, which did not allow infiltration of the air from the outside.

Mitigation of the urban heat island in areas located at a greater distance from the city centre is easier. Small measures, e.g. planting deciduous trees, planting flowerbeds or reducing artificial surfaces can clearly mitigate UHI. Summarising, the following mitigation actions should be undertaken on all planning levels: (1) protection within the city structure of open spaces which can intensify air movement and remove heat, (2) protection of all existing green areas inside the city which can reduce air temperature and heat stress as well as allow to the human organism to recuperate during hot episodes, (3) when planning new estates and compartments the urbanists and decision makers must remember about green areas and sufficient open space between buildings, (4) planting tree belts along streets to reduce surface heating, (5) planting trees on squares and play areas for children and the elderly, (6) increase the number of green roofs, terraces, balconies and facades, especially in the city centre.

However, when planning new plants, the appropriate composition of species must be considered. All plants of great allergernicity (Class 3) should be removed as soon as possible and plants of moderate allergenicity (Class 2) are recommended to be removed during the soonest area greenery remodelling and replaced with low- or non-allergenic species (Class 0 or Class 1).

Examples of plant species suitable for greenery related UHI mitigation and adaptation strategies in Warsaw:

Trees Maple, Hornbeam, Elder, Horse chestnut, Rowan, Acacia, Cherry plum, Mountain pine, Spruce, Fir, European larch, female cultivars of Poplar, Ash and Willow

Shrubs and Bushes Hedge cotoneaster, Boxwood, White dogwood, English dogwood, Border forsythia, Old-fashioned weigela, Staghorn sumac, Japanese quince, Red barberry, Common hawthorn.

Climbing Plants (suitable for Green Facades) Common ivy, Five-leaved ivy, Russian vine.

11.6 Adaptation Strategies

It is not possible to abolish the Urban Heat Island, and society must adapt to its occurrence. In 2013, the Polish Ministry of Environment published a strategic adaptation agenda for climate change in Poland to the year 2020 (Ministerstwo Środowiska 2013). There are several links to Urban Heat Island phenomenon when considering adaptation of cities to climate change. Several adaptation actions were also defined in the area of human health. Some of them refer to increased air temperature as well as to the increasing risk of allergies.

Taking into consideration action proposed in the adaptation agenda and the results obtained within UHI project, the following adaptation activities are recommended in Warsaw and should be implemented by city authorities: (1) education of all groups of society (city officers and decision makers, planners, architects, teachers and general population) about UHI phenomenon, its influence on quality of life and mitigation possibilities, (2) incorporation of UHI monitoring and information systems about UHI intensity and extension, (3) installing air conditioning in public buildings, (4) supporting air conditioning in private buildings and apartments, (5) incorporating a warning system of cardiovascular disorders, asthma and allergenic risks, (6) incorporating a system supporting elderly and disable people during episodes of extreme heat waves and intensive Urban Heat Island.

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