A Comparative Analysis of Nature-Based Solutions for Heat Stress Reduction in Cities

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Degree of Master of Science

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ABSTRACT OF THESIS submitted by:
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Effects of climate change will be experienced the most in cities due to the considerable growth of human population in urban areas. City residents will become vulnerable to extreme weather events, especially heat waves that impose an additional threat to human health and well-being. Green spaces have a direct impact on microclimatic features of the urban environment, as the ambient temperature in parks is lower in comparison to areas with multi-story buildings. However, due to urbanization, there is a lack of free spaces for green infrastructure development, especially in city centers and new built-up subdivisions of the city. Thus, the research aims to study nature-based solutions (NBS) as an additional option to green spaces in urban areas and a response to negative effects of climate change. To obtain data, academic sources, policy documents and governmental web-sites as well as grey literature were examined and official requests on information were done. Through the content analysis, the status of nature-based solutions in Kyiv, Melbourne and Tianjin was explored with specific attention allocated to NBS for climate change adaptation, resilience and mitigation. Additionally, the main policy documents that ensure the development of green spaces and NBS in the cities of interest were studied. By using comparative analysis, the most effective examples of NBS for heat stress reduction and policy documents that support their development in Melbourne and Tianjin were applied to Kyiv case. The results acquired through this research showed that green roofs, walls and facades on buildings, indoor greening and community gardens, among others can be applicable in Kyiv. Ukrainian regulatory framework related to green infrastructure development in Kyiv must be improved with the specific focus on adaptation to climate change.

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Keywords: climate change, heat waves, heat stress, resilience, adaptation, human health, urban areas, green spaces, vegetation, nature-based solutions

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1. Introduction

1.1. Problem definition and background

Effects of climate change on nature and people are more intensively experienced in cities due to urbanization which is caused by population growth and high density of built infrastructure. Presently, about half of the human population globally lives in cities and this number is expected to further increase (Chapman *et al.* 2017). Urban areas already are and will increasingly become vulnerable to extreme weather events, floods and heat waves, which will impose an additional threat to population all over the world (White *et al.* 2005; McMichael *et al.* 2008). The ways in which cities respond and get ready to climate change implications will be consequential for urban sustainability, human health and well-being.

One of the significant impacts of climate change on cities is heat stress, mainly because of negative effects on human health that result in higher mortality and morbidity rates. Between 1991 and 2000 and 2001–2010 casualties from extreme temperature increased 2300% which represents the most significant climate-related disaster (WMO 2013). According to the Centre for Research on Epidemiology of Disasters (CRED), in 2015 approximately 4 out of 10 lethal disasters were caused by heat waves (Guha-Sapir *et al.* 2016).

During the last few decades, heat waves caused increased mortality rates, even in developed countries with good public health services. For instance, the heat wave in Chicago in 1995 caused 514 heat-related deaths (Withman *et al.* 1997), in August 2003 several European countries broke maximum temperature records: 38.5°C in England and Wales and 47°C in Portugal with more than 35 000 deaths (Poumadere *et al.* 2005) and in France during 11 extremely hot days in August 2003 this indicator reached 14 947 deaths (Poumadere *et al.* 2005).

During the last decade, the most significant heat wave in terms of mortality was in the Russian Federation in 2010, which caused 55 736 deaths (WMO 2014), followed by a heat wave during the summer of 2017 in Europe. There were also 3–4 exceptionally hot days in July 2019 in Western Europe (Vautard *et al.* 2019). This pervasive trend of heat wave events (Furrer *et al.* 2010) extends to the territory of Ukraine as well. Kyiv recorded 32 heat waves from 1911 to 2010 with an average interval of 10 years (Shevchenko 2013). Excess mortality in all cases was influenced predominantly by factors such as sex, age, marital status and degree of urbanization, among others. Potentially vulnerable groups were people over 55 years old and women over 75 who mainly lived in cities (Kovats and Hajat 2008; Grundy 2006; Borrell *et al.* 2006; Schwartz 2005).

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Adaptation to climate change is a growing priority for many countries as they try to reduce risks for the economy, environment and human. Cities can respond to heat stress in many ways: by using building materials that are heat tolerant, establishing cool pavements, increasing the number of vegetation, restricting the heat produced by vehicles, providing new bathing areas, temporary pools, etc.

One of the ways that is raising interest is the use of nature-based solutions (NBS). They refer to measures inspired and supported by or copied from nature that include multiple co-benefits for health, environment and economy (Cohen-Shacham *et al.* 2016; EC 2015). Nature-based solutions can mitigate the negative impact from climate change; influence the microclimate of the area, and create additional social benefits (Kabisch *et al.* 2016). They include traditional green parks and street trees as well as green roofs or vegetated building facades, among others.

Green space has a direct impact on microclimatic features of the urban environment. It has been found that the average monthly air temperature in large parks can be 0.3–1.1°C lower than around multi-story buildings (Bukharina and Dvoyeglazova 2010). During the summer, woody vegetation and lawns do not warm up to more than 25–30°C, while the asphalt's temperature can be 45°C and above (Kazantsev *et al.* 2016). In comparison with soil and paved areas, green spaces have a higher albedo value, which helps lower air temperature to create a more comfortable and healthy environment for residents.

In order for NBS to achieve significant impact, they need to be systematically implemented and managed as part of the urban fabric. However, presently, new construction projects in cities are happening at a cost to natural vegetation. According to recent studies, the level of vegetation in a number of new districts in Kyiv is very low and not regulated by the state building standards (Kazantsev *et al.* 2016). Moreover, green spaces are unevenly distributed across administrative districts (see **Appendix II**). The central focus should be done on better understanding of the role and potential of nature-based solutions in urban development.

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1.2. Research aim and questions

The ***main aim*** of the research is to explore the potential use of nature-based solutions in urban areas in order to minimize the negative effects of heat stress in the context of climate change.

This aim will be achieved through case study research, with primary focus on Kyiv. As comparative cases, two cities, namely Melbourne and Tianjin were chosen. Kyiv is lack of experience on implementation of nature-based solutions (Zinchenko 2015) as well as it has a problem with high density of built infrastructure in the central part of the city and in new sub-

divisions. Melbourne and Tianjin are partner cities in Naturvation project and have been successfully involved in the development of nature-based solutions. Additionally, I had an access to essential data provided by people who worked with NBS in Melbourne and Tianjin.

Research questions of the study are the following:

1. What is the present status of NBS in the cities of interest?
2. What policies and regulations affect the presence of green space and NBS in the cities of interest?
3. What types of nature-based solutions can be integrated in cities as a contribution to heat stress reduction?
4. Can these response measures be applicable to Kyiv and in what form?

1.3. Organizational structure

Chapter 1 of the thesis provides general information on the problem, defines the main aim and identifies specific research questions that the work will address. *Chapter 2* is literature review delineates the problem of climate change, particularly heat waves and urban heat island, its negative implications on human health and well-being. Nature-based solutions are identified as a response measure to climate change, discussing their types, effectiveness, potential barriers and opportunities. *Chapter* 3 introduces research methodology, such as case study methods, content analysis and comparative analysis. *Chapter 4* provides the main results and their discussion. Finally, conclusions and key findings of the thesis are presented in *Chapter 5*.

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2. Literature Review

This Chapter includes key findings on heat waves and urban heat island in the contex of climate change as well as describes nature-based solutions that relevant for heat stress reduction. Climate risks are especially tangible in urban areas due to growing urbanization and intensifying climate change. My initial interest was on heat stress reduction in cities that is more severe in the last couple of decades and results in high mortality and morbidity rates. I looked at two key problems in cities connected with climate change, specifically heat waves and heat island, and the possibilities to respond them. One of the ways that was of particular interest for me is the use of nature-based solutions that benefit environment and people in multiple ways. My focus was done on NBS that promote heat stress reduction, opportunities they can provide for environment and people as well as their potential barriers to implementation.

2.1. Implications from climate change in urban areas

Cities have the highest exposure to the effects of climate change as more than half (54%) of the human population globally lives in urban areas, a number that is expected to increase (Chapman *et al.* 2017). Urban land cover is estimated to grow to 1.2 million km^2 by 2030, caused mainly by migration (Seto *et al.* 2012). By 2050, more than 70% of the population is anticipated to live in urban areas (Cities and Climate Change 2014). Hence, the problem of climate change will bring new challenges and threats to human health and well-being, especially in cities. The most obvious risks come from raised water levels and floods due to the change in precipitation regime; extreme weather events such as hurricanes and rainstorms; high temperatures and heat stress; other health risks related to expansion of 'tropical' infectious disease vectors that adapt to urban conditions.

The way in which cities are functioning nowadays may exacerbate both direct and indirect impacts on human health from climate change. Such problems as reduction of vegetation level, creation of artificial impermeable surfaces and decrease in water sources will make city residents more vulnerable to extreme heat events. The focus of this research is done on heat waves as the frequency and intensity of these events has significantly changed over the last couple of decades, disturbing sustainability of urban settlements and leading to heat-related mortality.

2.1.1. Heat waves and their influence on human health

In accordance with the World Meteorological Organization, heat wave is defined as 'a period during which the daily maximum temperature exceeds for more than five consecutive days the maximum normal temperature by 9°F (5°C), the "normal" period being defined as 1961–1990'

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(Robinson 2001). However, there is no universal computational methodology and different approaches can vary depending on the region and data applied (Stefanon *et al.* 2012; Ding *et al.* 2010; De Boeck *et al.* 2010). Such characteristics as duration, intensity, frequency and daily temperatures are often taken into account (Furrer *et al.* 2010; Russo *et al.* 2014).

From the physical point of view, a heat wave occurs when there is a persistent anticyclone over a territory with high temperature for a prolonged period of time. So-called "atmospheric blocking" can cause abnormally hot, dry weather that endures for a period of time over large areas.

The problem of heat waves (HW) has become more urgent over the last few decades and attracts significant scientific interest for two main reasons. First, heat waves occurring today are becoming more frequent and intense in comparison with the past century due to climate change (Koffi and Koffi 2008; Lemonsu *et al.* 2014; Ouzeaua *et al.* 2016). Secondly, this phenomenon is highly dangerous for human health impact, resulting in higher mortality and morbidity rates.

Heat waves that occurred historically in Europe, the United States and Australia in fact led to higher levels of mortality in comparison to natural hazards such as floods, bushfires or storms (Changnon *et al.* 1996; Nairn and Fawcett 2014). They have a substantial impact and serious consequences for society, especially human health. Several European countries reached the highest temperature maximums in August 2003, from 38.5°C in England and Wales to 47°C in Portugal (Johnson *et al.* 2005). More than 35 000 people died as a result of abnormal heat wave in Europe during the summer period in 2003 (Rey *et al.* 2007). In particular, for the period of 11 extremely hot days in August 2003 this indicator reached 14 947 deaths all over the territory of France (Poumadere *et al.* 2005).

Every year heat waves are becoming more severe and breaking new records. Hence, the last week of July 2019 was also characterized by exceptionally high temperatures during 3–4 days, especially in Western Europe. The record of 2003 was broken in France on 25 July with the historical meaning that was measured in Paris were the temperature reached 42.6°C (Vautard 2019). At the same time, the Netherlands and Belgium fixed temperatures above 40°C for the first time during the whole period of observations.

The territory of Ukraine is also affected by climate change implications, particularly heat waves phenomena. From 1911 to 2010 Kyiv recorded 32 heat waves with the average interval in 10 years (Shevchenko 2013). According to Shevchenko *et al.* (2020), during the two decades between 1961 and 1980 the amount of heat waves was less in comparison to the decade 2001–2010. According to the data from Central Geophysical Observatory (2017) on 2 August 2017

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average daily temperature in Kyiv exceeded the previous temperature record by 0.6°C in 2010 and was 28.9°C.

The impact of heat waves on human health and mortality rate has been widely studied in the literature (Kovats and Hajat 2008; Canoui-Poitrine *et al.* 2006; Empereur-Bissonnet *et al.* 2006; Flynn *et al.* 2005; Fouillet *et al.* 2006; Hajat *et al.* 2007; Michelozzi *et al.* 2005; Stafoggia *et al.* 2006). There are several factors that can influence the level of vulnerability among population (see **Table 1**). Overall, the most vulnerable and exposed to heat stress group is elderly people (Flynn *et al.* 2005; Grundy 2006; Thomas and Soliman 2002). As the population structure is changing, proportion of elderly increases that may result into general growth of susceptibility to elevated temperatures. Additionally, some studies also report the stronger heat-related impacts on women than on men (Canoui-Poitrine *et al.* 2006; Burse 1979).

Table 1. Determinants of heat-related mortality and morbidity. Data source: Canoui-Poitrine *et al.* 2006; Michelozzi *et al.* 2005; Stafoggia *et al.* 2006; Kovats and Hajat 2008; Empereur-Bissonnet *et al.* 2006; Flynn *et al.* 2005; Fouillet *et al.* 2006; Hajat *et al.* 2007; Grundy 2006

Factor	Vulnerable groups
Age and Aging	• People over 50 years old • Child deaths from heat stroke were recorded in France during the heat waves in 2003 and 2006
Gender	• Women have higher risk than man • The heat risk increased for unmarried men during the studies in Paris • Elderly men were more at risk in the United States particularly due to the level of social isolation
Clinical or Pathophysiological Factors	• People with depression, diabetes, cardio-vascular and cerebrovascular conditions, have higher exposure to hear-related risk • Accompanying illnesses also have an impact on heat susceptibility
Living in institutions	• The mortality rate doubled for people over 75 years who were living in retirement homes in France • There is a higher heat risk for elderly persons in residential, nursing and care institutions in comparison to those who are living at home
Socioeconomic factors	• Deprivation was found as an important factor that increases heat-related vulnerability especially in the United States • Homeless people were also exposed to heat stroke during the heat wave in Pheonix in 2006 • One study in Italy reported a higher heat mortality risk in low-income groups

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High temperatures affect people in different ways. Some findings report that there is a strong relation between heat wave characteristics such as intensity, length, frequency and mortality rate (Kovats and Hajat 2008; Zacharias *et al.* 2015). Furthermore, the most vulnerable are groups of people with cardiovascular or respiratory diseases. Pre-existing chronic diseases such as heart, lung and kidney disease also have an influence on ability to tolerate the heat stress (Zacharias *et al.* 2015). However, in case of severe exposure to high temperatures, even healthy people may suffer from heat-related illnesses such as dehydration or heat stroke.

Heat-related vulnerability depends on inherent (age, accompanying illnesses) and external (housing, income) risk factors. They can operate throughout the causal chain starting from excessive heat and ending with death (see **Fig. 1**). Effective health protection measures can help to cope with high ambient temperature and decrease the level of vulnerability among population.

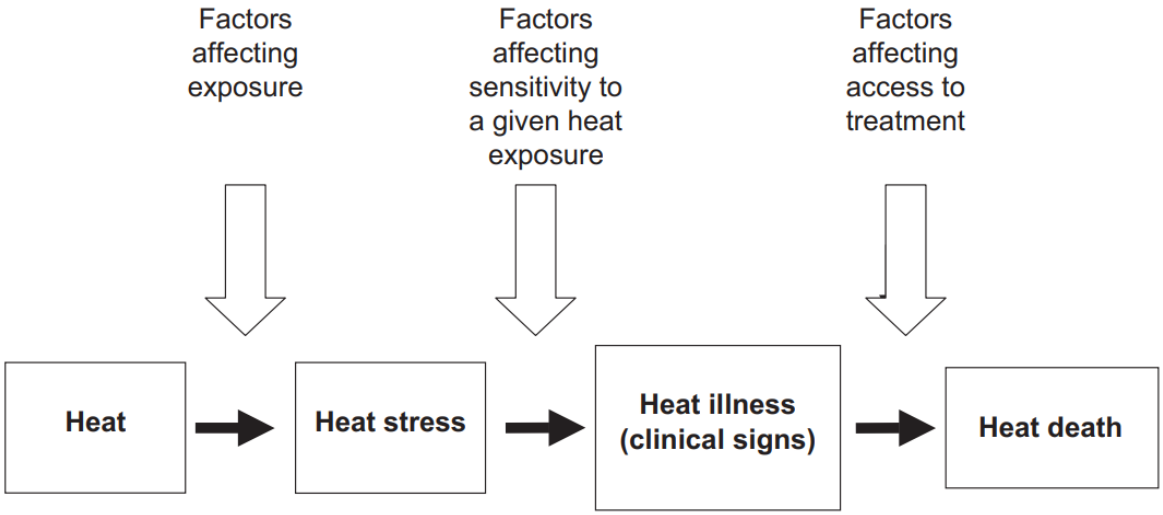

Fig. 1. From heat exposure to heat death. Source: Kovats and Hajat 2008

In comparison to the 2003 heat wave a lot of counties are becoming more prepared to extreme heat events by elaborating heat wave action plans and warning systems, anticipating accurate weather forecasts. Notorious experience of Europe during the heat wave in 2003 contributed to implementation of effective health measures. For instance, while more than 15 000 people died in France alone from severe heat wave in 2003, this amount decreased to 1500 in 2019 (Vautard 2019). Temperatures of 42–43°C in Paris were forecasted 3–4 days ahead by Météo-France.

To sum up, one of the most significant implications from climate change in future will be increase in heat wave frequency and intensity that will have an impact on public health and challenge for medical services.

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2.1.2. The Urban Heat Island effect in cities

Urban residents are more exposed to the risk of heat stress because of Urban Heat Island (UHI) effects, which occurs when the temperature in the city center is higher than its surroundings or the suburban area (Nuruzzaman 2015; Adinna *et al.* 2009; Synnefa *et al.* 2008). It appears in the air and on the surface, which causes discomfort to the city dwellers. The main reason for it is replacement of natural land with artificial surfaces that alters albedo by absorbing solar radiation and re-radiating it at night, reducing the rate of nocturnal cooling (Oke 1982). With the rapid development of urbanization, cities prone to decrease the level of green areas and substitute them with impervious surfaces that reduce the amount of evapotranspiration (Oke 1982). Weather can also be an important factor in formation of Urban Heat Island as the low wind movements and low cloud cover contribute to its development (Arnfield 2003).

The UHI can be regarded as an example of changes in land use that affect the local climatic conditions. In general, the difference between temperatures in city center and rural areas does not exceed 2°C (Chang *et al.* 2007), albeit it can reach up to 10–15°C under proper weather conditions (Oke 1982; Gedzelman *et al.* 2003; Arnfield 2003). Heat island may increase the vulnerability of city dwellers to temperature extremes that aggravated by climate change. Thus, heat wave 2006 in Amsterdam had urban temperatures 7–9°C higher than in rural surrounding, which imposed significant heat stress on city residents (Koomen and Diogo 2015). Urban growth of population will change the form and geometry of cities and lead to increase in temperatures, excessive heat and alteration of microclimatic conditions.

According to Akbari *et al.* (2001) and Santamouris *et al.* (2007) the UHI occurs due to the following causes:

- Low amount of evapotranspiration because of low vegetation
- Absorption of solar radiation due to low albedo
- High amount of anthropogenic heat release

During the summertime, the effect from urban heat island is devastating for people living in the city center. It has direct impact on their health, creates discomfort, and causes illness as well as death (see **Fig. 2**). City dwellers are becoming less capable to tolerate the heat stress. Moreover, cooling systems require more energy to be used. For instance, every 10°C increase demands growth in energy supply up to 2–4% during the summertime (Akbari *et al.* 2001). On the contrary, urban heat island during the winter season creates thermal comfort for city dwellers.

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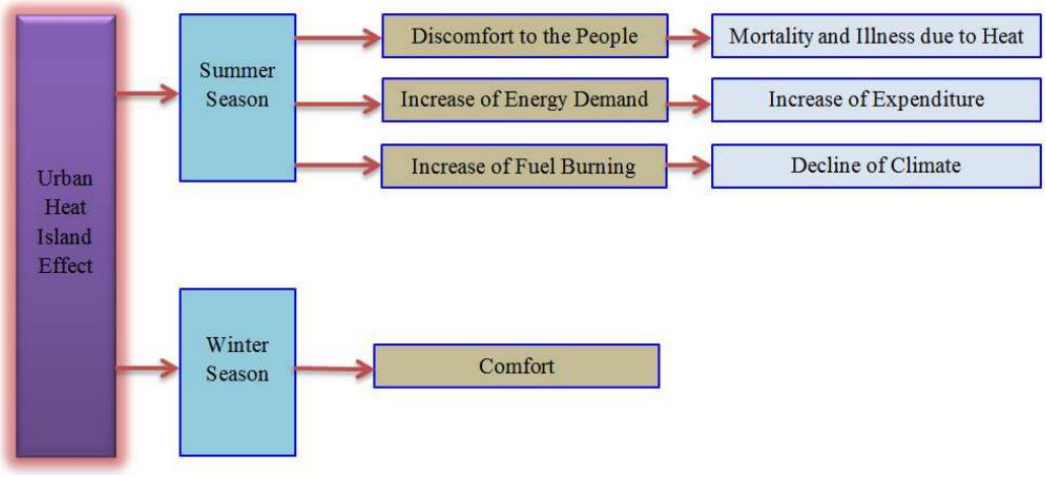

Fig. 2. Effects of Urban Heat Island formation. Source: Nuruzzaman 2015

To summarize, the growth of urban area is attributable to rapid urban development. In the densely built city centers, with a low level of vegetation, temperatures tend to be higher. This phenomenon is known as urban heat island. Owing to climate change, the temperature difference between city center and rural areas may become higher, which can lead to deterioration of thermal comfort of city dwellers and significant heat stress.

2.2. Nature-based solutions to climate change adaptation in urban areas

This section is related to nature-based solution as an additional option to green spaces in cities with particular focus on NBS for climate change adaptation. For many cities adaptation to climate change is a growing priority as it has considerable impact on the functioning of ecosystems as well as human well-being. Cities respond to climate change in numerous ways: through implementation of heat wave preparedness plans, introduction of warning systems, increase in the number of vegetation, establishment of cooling systems, air conditioners, temporary pools, etc. In the thesis I decided to focus on nature-based solutions approach as they can mitigate climate change implications, particularly heat wave problem, by taking into account the services provided by nature and implementing them in urban landscapes. For instance, green parks and street trees diminish elevated temperatures in cities or regulate air flows and wind velocity (Kabisch *et al.* 2017; Cohen-Shacham *et al.* 2016; EC 2015). At the same time, architectural solutions such as green roofs or vegetated building facades may influence the microclimate of the area, reduce temperature and save energy (Kabisch *et al.* 2016). The main goal of nature-based approach is to ensure sustainable transition and to create additional social and health benefits.

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2.2.1. General characteristics and typology of NBS

According to Cohen-Shacham *et al.* (2016) and EC (2015), nature-based solutions (NBS) can be defined as "actions inspired by, supported by, or copied from nature." These actions are aiming to develop natural features in a sustainable way; to depict the role of nature in urban, rural, and natural environments; to combine environmental, social and economic benefits by creating sustainable transition and resilience (Somarakis *et al.* 2019).

The term "nature-based solutions" appeared in the beginning of the 21st century and was approved by several worldwide institutions. Initially, the focus was done on biodiversity conservation and ecosystem management (Eggermont *et al.* 2015). However, later on economic and social components were gradually included, making emphases on ecosystem services. With the focus on economic growth and development, the role of nature in improving health and well-being was not taking into account and underestimated. Only in 2013 the term "nature-based solutions" was widely acknowledged and adopted in the EU Research and Innovation Policy agenda as it facilitates sustainable development and creates a link between social, economic and environmental pillars (Cohen-Shacham *et al.* 2019).

Nature-based solutions provide an overall multiple co-benefits, e.g. increase in climate change resilience, improving of air quality, biodiversity protection, sustainable resource use, disaster risk management and creation of additional recreational zones (EC 2015; Seddon *et al.* 2020). Nature-based approaches are often cost-efficient and can be adjusted to constantly changing climate risks (NBS for climate change mitigation and adaptation 2014). Generally, they are flexible in terms of implementation and follow multiple goals simultaneously. At the same time, it is possible to complement existing technical approaches or to create new (e.g. in the case of urban heat island mitigation) (Cohen-Shacham *et al.* 2019).

One of the leading projects that promote NBS development is "NATURVATION" that seeks to increase understanding of NBS benefits in cities and to build urban resilience. The Urban Nature Atlas provides 1000 examples of NBS in 100 European cities (Urban Nature Atlas 2017). NBS projects are systematized by countries and cities, challenges they address, urban setting, project cost, initiating organization, etc. Among the key challenges they address the most important ones for the thesis are climate action for adaptation, resilience and mitigation as well as health and well-being. In these categories 705 projects are presented that satisfy both criteria.

Nature-based solutions play an important role in human adaptation to climate change among other as they can decrease the level of socio-ecological vulnerability (Marshall *et al.* 2010;

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Thiault *et al.* 2017). The framework formalized by the IPCC integrates ecosystem and socio-economic aspects of the vulnerability (see **Fig. 3**).

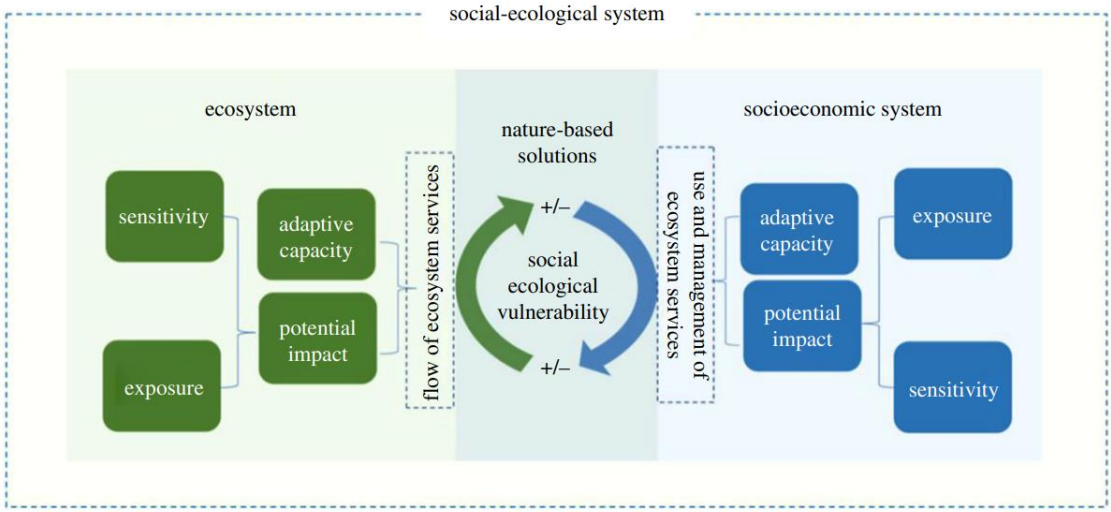

Fig. 3. Integration of NBS to climate change into socio-ecological vulnerability framework. Source: Seddon *et al.* 2020

Due to the **Fig. 3**, each ecosystem has three dimensions of vulnerability to climate change: exposure, sensitivity and adaptive capacity. The first one, exposure, is the extent to which ecosystem or region is influenced by climate change. It can be measured by the frequency, duration or intensity of events such as flood, drought, heat wave, etc. and capability to manage the repercussions from these events.

The second dimension is sensitivity that is the degree to which a system can be affected or changed as a result of perturbations. The last one is the adaptive capacity; in other words that is the ability of a system to adjust in response to changing conditions. In general, ecosystem vulnerability depends on a combination of potential implications from climate change and level of adaptive capacity.

Nature-based solutions can tolerate the degree of a socio-ecological system's exposure to impacts from climate change and to reduce the level of vulnerability. Owing to sustainable management, protection and restoration of ecosystems, nature-based solutions can positively influence all three dimensions of socioeconomic vulnerability (Seddon *et al.* 2020). Nature-based approaches are also known as "ecosystem-based approaches" (NBS for climate change mitigation and adaptation 2014).

There are two main types of nature-based solutions for climate change (NBS for climate change mitigation and adaptation 2014):

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- Nature-based climate change mitigation which is aiming to reduce the level of greenhouse gas emissions and to expand the utilization of carbon sinks;
- Nature-based climate adaptation seeks to decrease the level of vulnerability of a system to anticipated negative consequences from climate change (such as heat waves, extreme weather conditions, intense rainfall, more frequent floods).

Above-mentioned approaches are aiming to increase the resilience of ecosystems and to manage sustainable use of ecosystem services. In order to boost their resilience, it is necessary to increase stabilization within the ecosystem and to reinforce its functional relationships (NBS for climate change mitigation and adaptation 2014). This can be achieved in different ways, e.g. by protection and restoration of ecosystems. Successful case studies of nature-based solution can be applied at different levels in countries worldwide that facilitate the development of NBS-related experiences, information exchange and opportunities it might bring.

2.2.2. Indicators concerning the effectiveness of nature-based solutions

The effectiveness of nature-based solutions for climate change adaptation and mitigation can be measured by different targeted indicators. Indicators are based on the measure of verifiable data that conveys information (Haase *et al.* 2014). They are mainly used to estimate or analyze the information, conduct monitoring or communicate the results (Sparks *et al.* 2011). While estimating the effectiveness of NBS for climate change, it is necessary to include all benefits and shortfalls of the implementation progress, particularly for human well-being. At the same time, indicators can play an important role in decision-making process, by pointing out convincing arguments for NBS in budget allocations.

In accordance with Kabisch *et al.* (2016), there are four main groups of indicators that cover important aspects in the assessment of NBS:

1. indicators for integrated environmental performance;
2. indicators of human health and well-being;
3. indicators for citizen involvement;
4. indicators of transferability.

These 4 groups of indicators can be applied to comparative assessments of NBS for both: city level and between cities. The first group, environmental performance indicators, is closely connected with regulation of ecosystem services. Effectiveness in mitigation of climate change is measures in temperature and CO_2 reduction; richness of biodiversity in a number of green spaces created; air quality is defined through a decrease of air pollutants, etc. An important indicator

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that also should be taken into account is ecosystem disservices (Lyytimäki and Sipilä 2009; Von Döhren and Haase 2015). They represent dysfunctions in an ecosystem that negatively influence human well-being, e.g. increase in numbers of mosquitoes or allergic plants (Lyytimäki and Sipilä 2009).

The second group of indicators is related to human health and well-being. Physical and mental health can be defined through the decrease in number of people with respiratory diseases or obesity as well as through the number of citizens who takes part in outdoor sport activities. According to Hartig *et al.* (2014), residents who were living not far from the green spaces recorded health improvements. In addition, such benefit can lead to increases in land prices and rent as it has high social value. Simultaneously, mental health is proposed to measure through the level of satisfaction with quality of life (White *et al.* 2013, Carrus *et al.* 2015).

The third group of indicators is closely connected with the citizen's involvement into the process of managing NBS. It is represented by the number or percentage of residents that participate in NBS implementation projects and maintain the development of green and blue spaces in cities (Shandas and Messer 2008). With the help of this group of indicators, it is possible to track how the information is perceived and spread in the community.

The last group of indicators refers to the transfer of projects into practice and their monitoring. It takes into consideration nature-based solutions for decision-making process. In other words it measures the number of stakeholders from different sectors involved into implementation process as well as formation of policy discourse such as strategies, plans and agendas, regarding NBS (Kabisch *et al.* 2016). One of the aspects is monitoring which should be provided at the each stage of policy implementation. In terms of financial expenditures, it is necessary to take into account money allocated from a city's administrative budget for green space planning and its maintenance.

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2.2.3. Potential barriers and opportunities of NBS for climate change

According to Kabisch *et al.* (2016), there are 5 main categories of potential barriers to nature-based solutions as tools for climate change mitigation and adaption:

1. fear of the unknowns;
2. the disconnect between short-term actions and long-term goals;
3. the discontinuity between short-term actions and long-term plans;
4. sectoral silos;
5. the paradigm of growth.

The first group of barriers such as 'fear of the unknowns' includes uncertainties connected with risks of implementing NBS in cities as well as changes in city planning they might entail. Development of nature-based solutions requires special protocols and approaches for implementation and maintenance. There is a lack of information on assessment of NBS effectiveness in dealing with climate mitigation and adaptation. In addition, although a number of studies approve positive impact from green spaces on human health and well-being, there is still a gap in awareness among residents or policy makers about the benefits provided by green installations on roofs and walls (Kirkpatrick *et al.* 2013, Kronenberg 2015).

The second barrier is the disconnection between short-term actions and long-term goals. Implementation process and maintenance of NBS often require long-term planning, while most of city's administrations rely on short-term actions and results. It conceives a threat to long-term projects and imposes uncertainty on desired socioeconomic and environmental benefits. Comprehensive study done by Davies *et al.* (2015) shows that European projects concerning long-term implementation of green infrastructure require modification due to political changes in short-term prospective. Additionally, there is a need to include short-term actions into long-term plans and goals. The discontinuity here can be explained by absence of specific actions to maintain project and conduct monitoring over time. A number of nature-based solution projects exist only for a certain period of time, without any concern for further impacts on human-environment relationships (Kabisch *et al.* 2016).

Another barrier is 'sectoral silos' (Frantzeskaki and Tillie 2014, Hansen *et al.* 2015) that can be defined as a lack of cooperation in multidimensional projects such as NBS. Duties, established by city departments are restricted as they can be responsible only for specific sectors of influence. In order to overcome this barrier a city or municipality has to set up interactions with stakeholders in decision-making process and share responsibilities.

The last barrier is associated with the paradigm of growth. It has been proven that modern European cities face sharp decrease in number of green spaces, while the built-up area is tending to grow up (Kabisch and Haase 2013). Even though the population growth is not significant in these cities, there is a focus on economic growth-oriented issues. Money are allocated mainly for job creation, infrastructure development, etc. leaving behind the need in urban green spaces and associated with it nature-based solutions (Baur *et al.* 2013, Kabisch 2015).

In the concept of nature-based solutions a shift should be done from barriers towards opportunities that promote urban sustainability. There are 2 main opportunities which can facilitate the development of NBS in cities. The first one refers to exploitation of existing

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knowledge from researchers, citizens, policy makers, urban engineers about NBS in cities (Moseley *et al.* 2013). Experience gained from successful projects such as improving in climate change adaptation and mitigation, decrease in air pollution, etc. can be transferred and effectively implemented in urban planning.

The second opportunity proposes collaborative approach with multiple stakeholders such as businesses, residents, governmental authorities, NGOs, etc. in the development of NBS in cities. Cooperation with different actors may reduce barriers for adopting nature-based solutions in urban areas (Graham and Ernstson 2012). Such partnership should be based on principles of openness, transparency, and legitimacy and bring innovative approaches from concepts to actions.

To sum up, climate change nowadays progressively affects ecosystems and poses further threats to human health and well-being all over the world (Schröter *et al.* 2005, Grimm *et al.* 2008). It is expected that urban areas will suffer the most due to extreme weather events, heat waves and development of heat islands in the city centers (White *et al.* 2005, McMichael *et al.* 2008). In addition, urbanization process imposes extra pressure to urban ecosystems and produces a threat to ecosystem functionality and human well-being.

Taking all the mentioned above into account, green and blue spaces in urban areas are currently recognized as additional capacity that can establish social, economic and environmental benefits and significantly contribute to climate change adaptation and mitigation (Haase *et al.* 2014, Kabisch *et al.* 2015). Nature-based solutions produce multiple co-benefits in urban areas such as temperature reduction, improved air quality, biodiversity conservation, mental and physical health, etc. (Keniger *et al.* 2013, Hartig *et al.* 2014). They are considered to be worthy alternative to traditional approaches in terms of efficiency and cost (EC 2015).

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3. Research Methodology

This section of the thesis defines and characterizes the case study areas, methods of collecting and analyzing data as well as points out the main research limitations. The thesis aims to explore nature-based solutions in selected urban areas as part of a response strategy to the negative effects of climate change. The three cities included in the study are Kyiv in Ukraine, Melbourne in Australia and Tianjin in the People's Republic of China. The methodology includes three main components. First, data collection through literature review and corresponding official requests was done. Secondly, content analysis of the most effective nature-based solutions in the cities of interest was conducted as well as the main strategies, regulations and guidelines were studied. Finally, the three cases were analyzed through comparative analysis feeding into the discussion of results.

3.1. Case study selection

Kyiv, Melbourne and Tianjin were initially selected for the study as they are affected by increasing amount and frequency of heat waves that make their residents exposed and vulnerable to heat stress. Melbourne and Tianjin are widely implementing nature-based solutions, with particular focus on NBS to climate change adaptation. Moreover, they are partner cities in Naturvation project and I was able to receive essential data from people who worked with NBS in Melbourne and Tianjin.

Kyiv was selected as a main case study because there is limited awareness of the benefits of NBS and lack of experience on their implementation (Zinchenko 2015). Additionally, in the central part and in new developments of the city the problem with high density of built infrastructure exists, which can be solved with application of NBS. The city is exposed to climate change problems, particularly heat waves. The amount of heat waves in Kyiv increased during the decade 2001–2010 in comparison to the period of 1961–1980 (Shevchenko *et al.* 2020). Prolongation of the heat wave in 2010 was the longest and comprised of 18 days in total (Shevchenko 2013). However, due to increase in heat wave frequency and intensity this record was broken: the average daily temperature in Kyiv on 2 August 2017 exceeded the previous temperature record by 0.6°C in 2010 (Central Geophysical Observatory 2017).

Kyiv is located in north-central Ukraine. The permanent population of the city is 2 884 454 people (in 2017) and growing steadily (Population in Ukraine 2017). Kyiv has a warm-summer humid continental climate (Köppen climate classification); microclimatic features of the city are

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greatly influenced by presence of the Dnipro River. Western part of the city is surrounded by hills. The territory of the city also includes urban forest away from built-up areas.

The second city is Melbourne, the capital of the State of Victoria in Southeastern Australia. Melbourne has a temperate oceanic climate (Köppen climate classification) and it is expected that climate change will impose significant challenges for the city in future (Alexander and Arblaster 2009). For instance, more than 55% of natural disaster related deaths are caused by heat waves in Australia (Perkins-Kirkpatrick *et al.* 2015). It was recorded that over 370 people died in January 2009 due to Victorian heat wave (Alexander and Arblaster 2009). McMichael *et al.* (2003) has evaluated that heat waves nowadays are the reason of mortality among 1 000 people aged over 65 each year in Australia and this figure is expected to increase by 2050.

Melbourne is one of the cities with the fastest population growth in Australia. The number of residents is expected to double over the next 20 years from a 2018 base of 4 936 000 (Nature in the City: thriving biodiversity and healthy ecosystems 2017). Melbourne was chosen as a comparative case study as it has already implemented a number of nature-based solutions that facilitate mitigation of climate change. Additionally, the city has many policies that promote NBS.

The third city is Tianjin, coastal metropolis in Northern China that has an access to the Bohai Sea. It is a fast developing city with a population of 15.6 million (2016) that quadrupled in less than 40 years (Katona 2018). The area of the city consists of plains and lowlands and has a coastline area. Tianjin has hot summer continental climate (Köppen climate classification) and is also vulnerable to climate change (Zou and Li 2014). High temperatures in China were the cause of 5 758 heat wave related illnesses in 2013 (Gu *et al.* 2016). Moreover, in comparison to the recent 50 years, the summer of 2019 had in 3.1 more days with extreme temperatures (Zheng *et al.* 2020).

Tianjin has municipal policies encouraging the reforestation of abandoned territories and green development in new sub-devisions. It has succesfully implemented ‘Sino-Singapore Tianjin Eco-City’ with numerous examples of NBS that anticipate increase in green spaces and reduction of heat stress problem related to climate change (Katona 2018). The city is also a part of China’s national Sponge Cities Project (Zou and Li 2014).

3.2. Data collection and analysis

Firstly, data on projected average temperature increase and how it relates to the share of green space in Kyiv, Melbourne and Tianjin was studied. In this regard, supportive materials on green

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areas and average surface temperatures in the cities of interest were selected and classified by related topics. Using inventory materials on distribution and share of green zones of public usage in Kyiv by districts (see **Appendix II**), a bar chart was created.

Secondly, content analysis of main literature sources connected with nature-based solutions as an adaptation measure to climate change, particularly heat stress was undertaken. For this purpose, official governmental web-sites and academic sources as well as grey literature were examined in order to get information about existing NBS in the cities of interest. Each piece of literature was categorized according to the topic it is relevant for by using content analysis. Subsequently, examples of NBS that play a role in climate change adaptation, resilience and mitigation have been selected and classified according to Urban Nature Atlas (2017). Resulting tables consist of project description, environmental components, key challenges addressed by the NBS and their urban settings.

Content analysis was also applied to study NBS-related environmental legislative documents linked to green zones and nature-based solutions development. In Kyiv these included laws and other legal and regulatory instruments. Additionally, I submitted a formal request on public environmental information. The data I requested was connected with the area allocated for green zones in administrative districts of Kyiv. In this regard, I have used special official request form that is available on the website of the Ministry of Ecology and Natural Resources of Ukraine. The responses received are available for public access and can be found in **Appendix I** and **Appendix II**.

Official documentation that regulates the development of green infrastructure in Melbourne includes strategies, plans, regulations, and guidelines. Thus, among all these documents, the most relevant to the management of green zones and NBS in the city were examined. In case of Tianjin, as an example of green spaces and NBS development in new subdivisions of the city (Wuqing District), regulations at different levels and the main requirements related to greening standards such as the accessibility of green zones in new developments, the minimum amount of green spaces per capita, etc. were studied.

The final stage of the research included comparative analysis. Nature-based solutions that facilitate climate change adaptation, mitigation and resilience and are successfully implemented in Melbourne and Tianjin were discussed to be applied in Kyiv. In the same manner, advantages and drawbacks of legislative documentation in Kyiv, Melbourne and Tianjin were compared in order to find how Ukrainian laws and rules on management of green spaces can be improved.

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3.3. Study limitations

Thesis research has a number of limitations. The main obstacle was inability to collect primary data. It can be explained by strict COVID-related quarantine measures in countries worldwide that restricted personal contacts and access to printed documents, including official requests to governmental offices. The second limitation concerns information on green spaces in cities for adaptation to climate change. Data on the territories allocated for green spaces is not comparable, as in the work the urban tree cover in Melbourne was studied, while in case of Kyiv the shares of green space were presented, which may also include lawns, shrubs, gardens etc. The third limitation is related to the lack or inaccessibility of information on nature-based solutions in new subdivisions of the city. Although some general policy documents were available for research, this was not specific enough to study green area development and management in new urban districts. In the case of Melbourne, the only strategy document related to green spaces and NBS in built-up areas is the Victoria Planning Provisions. Simultaneously, a couple of strategies mention requirements on presence of green zones in residential areas, without any specific information. Tianjin, on the contrary, has an explicit example with integrated green and blue infrastructure in Wuqing District; however, all the supplementary documents and articles are in Chinese. Thus, results concerning green space and nature-based solutions in new subdivisions are fragmentary.

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4. Results and Discussion

This Chapter provides the key findings of my thesis and the discussion of the results. The findings address the goals of this thesis and are focused on the following topics: 1) the status of nature-based solutions in Kyiv, Melbourne and Tianjin; 2) main policy aspects and regulations related to green spaces and NBS in above-mentioned cities; 3) types of NBS that implemented in the cities of interest as a contribution to heat stress reduction; 4) discussion of results on how these response measures can be applicable to Kyiv and in what form.

4.1. Green spaces in cities as adaptation to climate change

In this section I conduct a research on adaptation of the selected cities to climate change with the help of green spaces. My goal was to assess the status of green spaces in Kyiv, Melbourne and Tianjin, their distribution across the city and influence on reducing climate change impacts.

Urban green space has a number of direct and indirect benefits for residents as well as for the environment. Georgi and Tzesouri (2008) argue that the average temperature in parks is 2℃ lower in comparison to the city center as well as relative humidity which is 4% higher. It is proven that people feel more "comfortable" within the green areas of the city, while trees can provide cooling effect on the surface temperature up to -12℃ (Radomska and Bogomazyuk 2017).

4.1.1. Green space and related heat stress reduction potential in Kyiv

In Ukraine, in accordance with 'Rules for the maintenance of green spaces in the settlements of Ukraine' (2006) green zones can be classified as follows:

- Green zones of public usage –parks, zoos and botanical gardens, city gardens and gardens of residential areas, public gardens, boulevards, etc. which are available for public access for residents with the purpose of recreation;
- Green zones for limited use – vegetation that belongs to residential areas and public buildings, industrial enterprises, educational centers, health care facilities, sanatoriums, etc.
- Green zones for special purposes – these are located along streets; within sanitary protection zones around industrial enterprises; can be used at cemeteries and crematoria, or as roadside green space within settlements.

Green zones for public use have direct significant impact on the state of the urban environment and can be regarded as places of recreation value for residents. According to official inventory

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data (see **Appendix II**), on 01.01.2018 the total area of green zones available for public use in built-up districts of Kyiv was 6,459.99 hectares. I also calculated the percentage of green areas of public use by administrative districts (see **Fig. 4**). Green public areas are subordinated to 'Kyivzelenbud'[1] and have a satisfactory condition, despite a number of problems typical for all green areas in the cities worldwide.

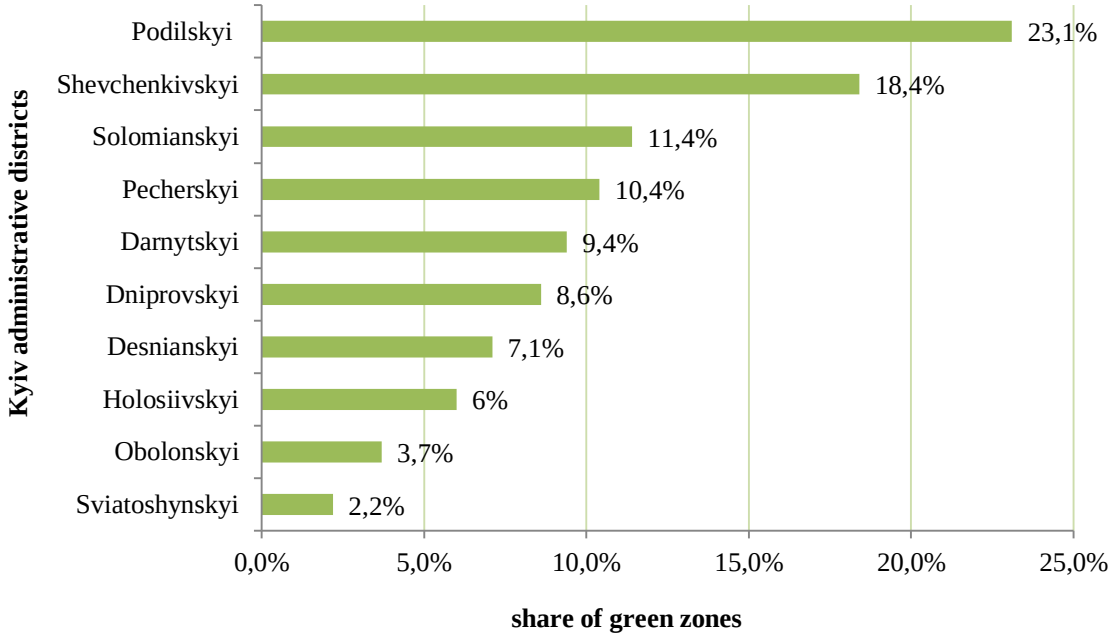

Fig. 4. Distribution and share of green zones of public usage in Kyiv by districts as of 01.01.2018. Data source: **Appendix II**

Green zones of limited usage and special purpose are in degraded, unsanitary state (Tkachenko *et al.* 2016). It can be explained by a number of economic, political and social reasons. Due to decrease of industrial production of Ukraine, a lot of enterprises and plants were closed that led to deterioration of the vegetation in these zones, absence of pest control, replacement of native trees, shrubs and plants by ruderal species (Tkachenko *et al.* 2016). All this alters the positive image of the city and negatively affects the health of citizens as most weeds cause allergic reactions.

Taking into account State building standards 'DBN B.2.2-12:2018' (1992) about 45–50% of Kyiv's territory must be allocated to green space. According to the Institute of Municipal Hygiene of Ukraine (Sholok 2014) this figure should be approximately 50–60%. The territory allocated for green spaces in Kyiv is at the level of 58.8% which is within statutory limits (Kazantsev *et al.* 2016); however, they are unevenly distributed across administrative districts.

[1] 'Kyivzelenbud' – is a local association that is responsible for maintenance of green spaces in Kyiv

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Additionally, one of the important indicators that influence public health is the area of green space per person. In European countries, this figure is 20 m^2/person (Kazantsev *et al.* 2016), while according to WHO (Sholok 2014) it must be 50 m^2/person and 300 m^2/person of suburban woodland parks in order to ensure adequate rates of oxygen for urban dwellers.

According to the Main Department of Statistics in Kyiv (Population in Ukraine 2017) on 01.01.2017, the permanent population of Kyiv is 2,884,454 people. The area of greenery within the city development on 01.01.2017 is 7,790.90 hectares (see **Appendix I**). Thus, the actual supply of greenery per person in Kyiv within the city development is 27 m^2/person, which is in conformity with internationally accepted standards.

Taking into account implications from climate change, in accordance with Kazantsev *et al.* (2016) the average surface temperature in Kyiv may increase to 31–38°C in summer (see **Fig. 5**). The areas with the highest average surface temperature during the summer are industrial districts and high density new neighborhoods in the Obolon massif: here the average summer surface temperature varies between 34–37°C. In Holosiivskyi district, Borshchahivka, Vidradny and Pechersk, the average surface temperatures do not exceed 33°C.

Fig. 5. Breakdown of average summer surface temperatures in Kyiv over 2013–2015 by micro-districts. (1) Obolon massif; (2) Holosiivskyi district; (3) Borshchahivka; (4) Vidradny; (5) Pechersk. Source: Kazantsev *et al.* 2016

The highest level of vegetation (35–40%) is observed in part of the quarters of Solomyansky and Holosiivskyi districts (see **Fig. 6**). At the same time, Obolon and Pechersk have an average level

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(15–20%). The share of green cover is lowest (0–10%) in the residential areas of Pozniaky and Troieschyna (Kazantsev *et al.* 2016).

Fig. 6. Percentage of green areas in micro-districts of Kyiv. (1) Solomyansky; (2) Holosiivskyi; (3) Obolon; (4) Pechersk; (5) Pozniaky; (6) Troieschyna. Source: Kazantsev *et al.* 2016

From **Fig. 5** and **Fig. 6** it is noticeable that the temperature in residential districts highly depends on the share of green areas. Most recently built-up areas (e.g. Pozniaky, Obolon, Troieschyna) do not follow building standards that prescribe the level of vegetation within residential territories. High temperatures during the summer period in these areas can lead to problems with health and social well-being, reinforced by climate change. It is expected that by 2030 the growth of the average annual temperature in Ukraine will not exceed 0.44°C (Ukraine's Fifth National Communication on Climate Change 2009) while Gorny *et al.* (2016) anticipate that by 2024 the average daytime temperature in Kyiv will increase by +1.3°C.

4.1.2. Green space and heat stress reduction potential in Melbourne

The climate in Melbourne has changed over the last couple of decades, becoming warmer and drier. It is anticipated that these changes will continue in future (Greater Melbourne 2015). Simultaneously, the city has been experiencing accelerated urban growth. Thus, it is increasingly important to implement actions that contribute to the health and well-being of residents.

Melbourne is one of the Australian cities with the fastest growth of the population. It is expected that over the next 20 years the number of residents (4 936 000 people in 2018) will double (Nature in the City: thriving biodiversity and healthy ecosystems 2017). Such a tendency may lead to a drop in the share of green space per resident in the city, involving difficulties with

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access, and consequently, disconnection from nature. One of the key policy priorities is to create healthy habitat with sufficient green space to meet the expectations of residents (Nature in the City: thriving biodiversity and healthy ecosystems 2017).

The distribution of green zones in Melbourne is unequal. Based on 2018 data, tree cover in Western region is 5.5%, while Inner South East has 17.4% (see **Fig. 7**). The overall urban tree canopy cover in metropolitan Melbourne is 15.3% (in 2018). Another example is Southbank where there are only 4.5 m^2 of green space per person, while on average this should be 56 m^2 per person (Nature in the City: thriving biodiversity and healthy ecosystems 2017). Particularly in these areas green space should be increased to ensure physical and mental health of the Melburnians.

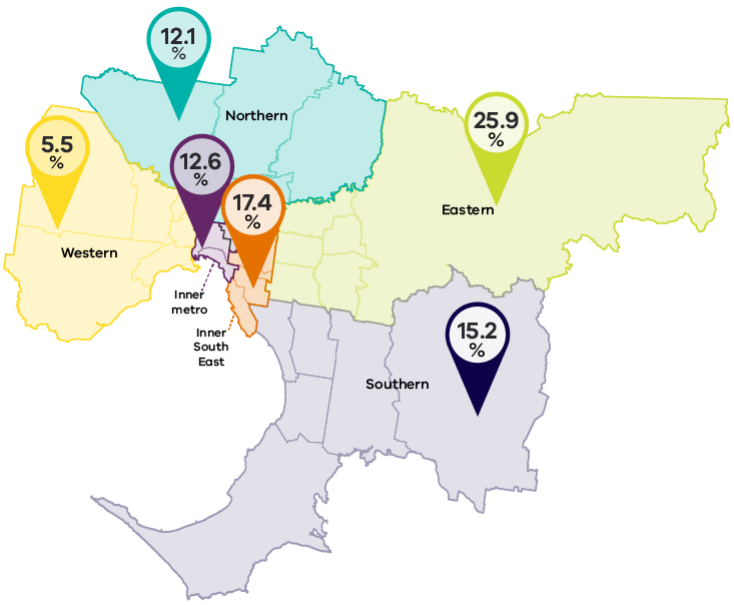

Fig. 7. Urban tree cover in Melbourne by region in 2018, %. Source: Clean Air and Urban Landscapes Hub 2018

Taking into account microclimatic conditions, the city has a clearly identifiable heat island in the center that creates an up to 7°C temperature difference with the surrounding rural area (Nature in the City: thriving biodiversity and healthy ecosystems 2017). It is anticipated that by 2070 temperature will rise by 3.4°C due to climate change, compared with business-as-usual scenarios (Greater Melbourne 2015). If the city continues to develop as business as usual, impervious surfaces may further increase surface temperature and heat stress.

In 2018 the Heat Vulnerability Index (HVI) was calculated for Melbourne. It indicates the level of population's vulnerability to heat stress and consists of three components including heat exposure, sensitivity to heat, and adaptive capability and scaled from 1 to 5 (where 1 is low

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vulnerability, 5 is high) (Sun *et al.* 2019). The research demonstrated that the districts with the highest HVI are Melton, Casey, Darebin, Wyndham, and Brimbank (**see Fig. 8**). Even though the urban heat island effect is lower in these areas, the meaning of HVI is still high due to the social profile of residents: many elderly people and children with a lower adaptive capacity to heat stress. In contrast, in Nillumbik and some parts of Manningham because of lower social vulnerability the impacts of heat stress are reduced.

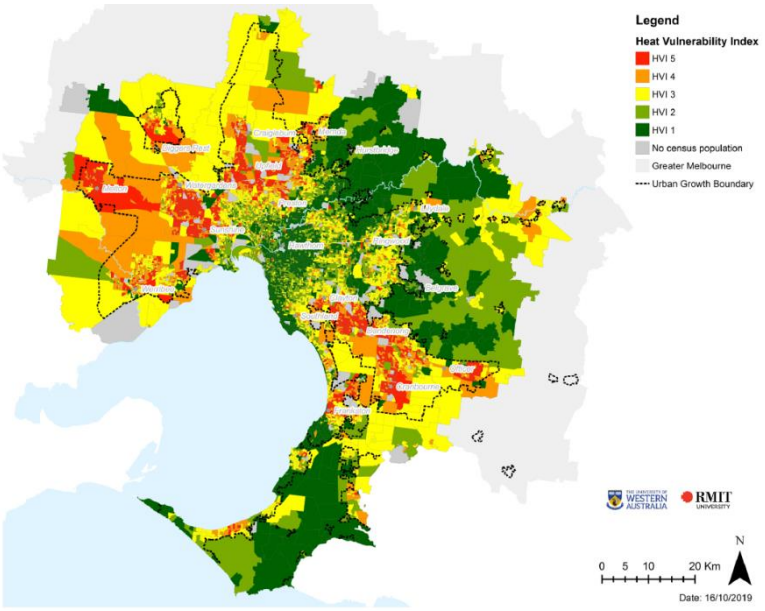

Fig. 8. Distribution of HVI across metropolitan Melbourne in 2018. Source: Sun *et al.* 2019

During more than ten years, initiatives at different levels were undertaken to increase Melbourne's green cover (Healthy and sustainable cities 2018). A wide range of stakeholders from green movements to local governments and state authorities were involved in the process. In order to mitigate the negative implications from climate change and to reduce heat stress, Melbourne has developed an Urban Forest Strategy, which is aiming to double canopy cover by 2040 and thereby to decrease summertime temperatures (Healthy and sustainable cities 2018). Meeting this target would also support biodiversity conservation and ecosystem restoration objectives.

4.1.3. The status of green zones in Tianjin

Climate in China has been also changing over the last couple of decades. In accordance with China Climate Bulletin the summer of 2019 had in 3.1 more days with high temperatures compared to the recent 50 years (Zheng *et al.* 2020). Additionally, the rapid process of urbanization influences the climate conditions in cities greatly and poses supplemental hazard in

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the form of heat waves, urban heat island, poor air quality, floods, etc. Gu *et al.* (2016) show that extreme temperatures were the cause of 5,758 heat wave related illnesses in China in 2013.

Tianjin is a city in coastal area of Nothern China. It has the population of 15.6 million (2016) that is continuing to grow (Katona 2018). By introducing 'Sino-Singapore Tianjin Eco-City' project the city targets to increase green spaces and implement reforestation program. It is also a part of China's national Sponge Cities Project and seeks to develop environmentally-friendly infrastructure that absorb, clean and reuse drain water.

Tianjin aims to increase green space per capita from 9.72 m^2 to 12 m^2 by 2025 (Katona 2018). The city has launched a reforestation program of low-productivity and abandoned agricultural land for all urban districts. During 2014–2016 the municipality planted vegetation on 96,866 hectares (Katona 2018). Another reforestation program on low quality agricultural land was launched in 2018 that connected two urban cores of Tianjin with 600 km^2 of forest called the 'Twins City Parks'. The main aim of this program was to reduce the level of air pollution in the city.

Protected areas also play a significant role in the city occupying about 3000 km^2 with 8 nature reserves, covering 13.66% of Tianjin's land (Katona 2018). The city is also a part of China's national Sponge Cities Project and it seeks to absorb minimum 75% of the rainfall. Water management related benefits of properly planned green space are another example of how NBS can have multiple benefits in addition to heat stress reduction (in this case related to water and specifically flood management). Tianjin is planning to transform and utilize parks and residential areas as well as to reach the 'sponge city' standard in 80% by 2030 (Katona 2018).

4.1.4. Discussion of heat stress and green space relationships in the three cities

Rapid urbanization in Kyiv, Melbourne, and Tianjin comes with a significant population growth that is not accompanied by a parallel increase in green space, which leads to higher physical density of both people and physical infrastructure and increased exposure to heat stress.

Green public space in Kyiv plays an important role in the state of the urban environment and provides recreation space for residents. However, their distribution in the city is uneven. **Fig. 4** showed that the ratio of green zones within the district varies from 23.1% in Podilskyi to only 2.2% in Sviatoshynskyi. There is a similar problem in Melbourne, where tree cover varies from 17.4% in Inner South East to 5.5% in the Western region (see **Fig. 7**). The amount of green space per person depends on location and as a result residents who live in areas with lower green cover are potentially more vulnerable to heat stress.

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Considering the projected impacts of climate change and continuing urbanization, one can see the need for increasing the amount of green space in cities to reduce heat stress related impacts and vulnerability. Melbourne has an Urban Forest Strategy that aims to double tree canopy cover by 2040 and to reduce summertime temperatures, among other positive effects associated with green cover. Tianjin also has a reforestation program targeting low-productive and abandoned agricultural lands through the 'Twins City Parks' in 2018 on approximately 600 km^2 (Katona 2018).

In comparison, recently developed subdivisions in Kyiv do not observe green space standards. As shown on **Fig. 5** and **6**, limited vegetation cover in these districts is accompanied by higher temperatures during the summer period, posing an increased threat to the health and well-being of inhabitants. One of the potential response decisions can be the development of nature-based solutions. Their forms, features, and benefits in each city, with emphasis on heat stress reduction will be discussed in the following section of the thesis.

4.2 The present status of nature-based solutions in the cities of interest

This section provides an analysis of nature-based solutions (NBS) in Kyiv, Melbourne and Tianjin. Following on the analysis in the previous chapter that established the general case for the status of green space and its potential relevance for the reduction of heat stress (among other positive impacts), the main aim of this chapter is to review the types of NBS present in the three cities as well as key challenges they address. Particular attention is paid to NBS that facilitate climate change adaptation, resilience and mitigation. The discussion part of the chapter reflects on the types of nature-based solutions and other green infrastructure approaches that can be implemented specifically in Kyiv.

4.2.1. The status of NBS in Kyiv

Green building standards in Ukraine are voluntary and there are no policy frameworks that may facilitate the development of NBS in the country (Zinchenko 2015). These standards are applicable not only to individual buildings but also districts and should include provisions about green space, both related directly to buildings or space around buildings. Among the main directions for Ukraine in terms of NBS development there are the following (Tkachenko *et al.* 2016):

- introduction of international experience in NBS development in Ukraine;
- certification of existing building areas for compliance with 'green' standards;

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- organization of conferences and workshops for environmentalists, builders, lawyers, investors, citizens, etc. that will promote the knowledge about NBS;
- popularization of nature-based solutions ideas.

The information on types of NBS implemented in Kyiv is very limited and concerns mainly limitations connected with their development. Thus, the present section on the status of NBS in Kyiv is different than the section on Melbourne and Tianjin.

Existing building standards (State Committee for Urban Development 1992) presuppose that in high-density areas vertical and rooftop gardens are possible. However, there are no specific regulations for the design and form of the roof landscapes. The majority of Ukrainian green roof design companies lack experience and technological background which results in the violation of technology and safety precautions, and the reduction in a life span of the object (Tkachenko *et al.* 2016). In contrast, international companies operating in the Ukrainian market apply European standards and technologies.

In high-density areas of Kyiv it is almost impossible to establish or expand green zones, especially in city center. However, it is feasible to create alternative smaller scale green spots such as green walls, roofs or parking areas. Presently, the structure of residential buildings is mainly occupied with balconies or intensive renovations such as murals, heat insulation, etc. Consequently, NBS such as green roofs attached to existing structures can be more realistic to address the relative lack of vegetation. Additionally, co-benefits from such structures include the retention and filtration of rainwater, production of oxygen, habitat for biological species and mitigation of heat island in city (Radomska and Bogomazyuk 2017).

Taking into account limited information on NBS implemented in Kyiv, it is impossible to further discuss benefits and shortfalls of existing projects. Thus, special emphasis in the work is done on Melbourne and Tianjin examples which will be described in the following sections.

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4.2.2. Types of NBS in Melbourne

Nature-based solutions in Melbourne were classified in accordance with the Urban Nature Atlas (2017) (see **Table 2**). Firstly, the types of NBS presented in Melbourne were studied based on materials from the Strategy 'Nature in the City: thriving biodiversity and healthy ecosystems' (2017). Secondly, supportive information from different printed sources as well as governmental web-sites was processed. Finally, each NBS project was classified due to key components of Urban Nature Atlas. Specific focus was on NBS for climate change adaptation, resilience and mitigation. Description of the project and environmental components were identified as well as

key challenges these NBS address and their urban settings (description of the signs is provided in **Appendix III**).

Table 2. Nature-based solutions in Melbourne

Name of NBS	Description	Environmental components
The Elizabeth Street pop-up park	The park was created with recreational purpose for residents over the summer period. The area of the park is 375 m^2. It was studied that up to 10 000 pedestrians and 73 cars passing it through every hour, especially during the AM peak. There is a need to decrease a number of cars and to turn this zone from grey to green with the help of more functional space.	The park is equipped with trees of different species, artificial turf, planter boxes, and moveable furniture.
Data source	City of Melbourne 2018	
Key challenges to address		
Urban setting		
Medibank Building	Madibank is a building that promotes healthy workplace and ecological wellbeing of the city. Vegetation on the building's facade and in the workplace contributes to stress reduction among workers, improves internal air quality, ensures aesthetic benefits from the view, and provides habitat for biodiversity.	Around 10% of the building's surface is vegetated, including walls, terraces and facades. The total amount of plants is 11 600 of 72 different species. Madibank also includes 1500 m^2 of green space with public access.
Data source	Vivian 2015	
Key challenges to address		
Urban setting		
Greening of Melbourne's famous laneways	In the central part of the city there are more than 200 laneways that lack of greenery. Out of them only 4 the most famous ones were chosen based on public nominations and expert assessment. Using mapping techniques lanes will be vegetated taking into account an amount of sunlight they receive; wind velocity in these areas as well as their physical characteristics.	Greening of the laneways will be held with the help of mixture of planter boxes, vertical gardens, climbing plants and trees. Such measures will ensure cooling of the city, stormwater cleaning and purification of the outdoor air.

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Data source	Green magazine 2017	
Key challenges to address		
Urban setting		
CERES Community Environment Park	The Park was once a wasteland, however in 1982 with the help of staff and volunteers it was reorganized in environmental education centre. CERES aims to protect the natural environment as well as to provide information and education on sustainable development through a variety of activities and community projects.	The area of the park was cleaned with further tree and shrubs planting, using this land to grow vegetables and to make compost. At the same time, CERES provides community gardens with more than 50 plots on-ground for people that lack household space.
Data source	Annual report 2018-19 (2018)	
Key challenges to address		
Urban setting		
Green roof at Victoria's Parliament House	Victoria's Parliament House was designed in the mid-19th century, but in fact it was never fully realised. Historic part of the building was improved with garden structure in order to preserve existing heritage trees. Thus, the project improved the exterior of one of the most important civic buildings.	The new structure of the building presupposes a rooftop garden. The depth of the substrate varies from 38 to 50 centimetres, and includes wildflowers, shrubs and grasses. Additionally, green rooftop provides thermal insulation to the building and preserves urban biodiversity.
Data source	Cheng 2018	
Key challenges to address		
Urban setting		
Fitzroy Gardens Stormwater Harvesting System	Fitzroy Gardens were created in 1848 as a public reserve. Around 117 million litres of water are needed annually to irrigate the area. In the last couple of decades water supply was challenged by drought. That is why, the system of irrigation for the garden's trees, plants and turf was introduced.	The system captures and stores stormwater for irrigation purposes in the park and can replace up to 59% of the drinking water. Additional benefit is educational and informative campaign about the stormwater harvesting system that is provided for the community.

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Table 2 continuation

Data source	City of Melbourne 2015	
Key challenges to address		
Urban setting		
Queenscliff centre	During the long period of time in the past this area was contaminated with oil, asbestos cement, etc. Environmentalists and locals tried to reverse the site to a pristine state. The modern project of the building anticipates responsive management of environmental resources and complex co-existence with the surrounding dunes, wetlands, and the bay.	The turf roof of the building carries 300 mm of topsoil and is supported on mushroom columns. It is expected that the rooftop will assimilate the local dune flora in the future. Another purpose is stormwater collection into on-ground water harvesting tank.
Data source	Archive 2005	
Key challenges to address		
Urban setting		

Based on **Table 2** results, among the prevalence types of NBS in Melbourne there are city parks and greening on buildings. They include vertical vegetation, walls, and facades; rooftop gardens; climbing plants and trees; planter boxes; indoor greening, etc. Newly created parks will encourage residents to spend more time outdoors with the benefit for their health. Additional advantage in many projects is educational and informative campaign.

'Greening of Melbourne's famous laneways' project has a particular interest as many laneways in the city are currently without vegetation. In order to address this problem, private owners of the buildings need to be involved in decision-making process. Adjacent walls and facades can be vegetated only with the permission of the building owners (Healthy and sustainable cities 2018).

Nature-based solutions such as green roofs and walls are widely used in dense urban areas of Melbourne in order to compensate for the loss of urban greenery and to improve the quality of environment providing social, economic and aesthetic benefits. A fair number of policy documents require introduction of green spaces into planning regulations in the city. It is estimated that policy impact will stimulates the development of green infrastructure in Melbourne (see **Fig. 9**).

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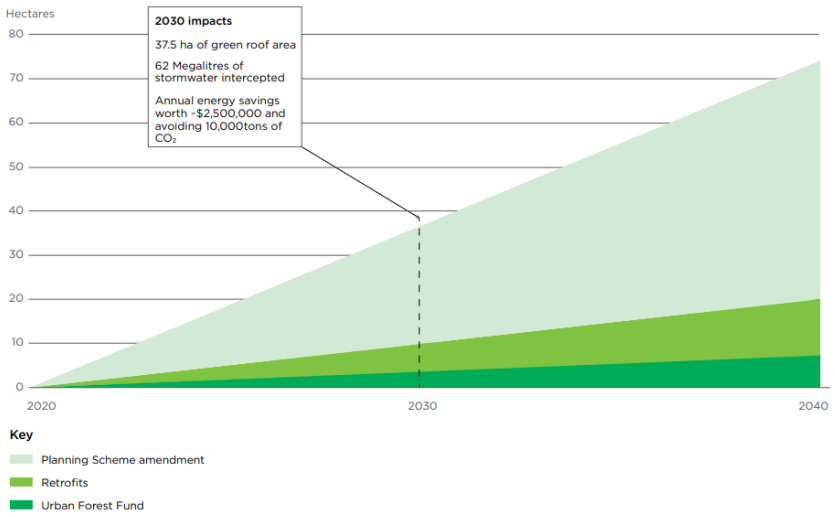

Fig. 9. Estimation of policy impact on the green roofs development from current levels, ha. Source: Green our city strategic action plan 2016

Today green roofs in Melbourne occupy approximately 880 ha of space, which is up to five times more than the area of Royal Park, the largest park in the city (Green our city strategic action plan 2016). It is reported that Melbourne has more than 100 green roofs, around 50 green walls and hundreds of green facades (Growing Green Guide 2014).

4.2.3. Types of NBS in Tianjin

Nature-based solutions that predominantly address the problem of climate change in Tianjin were identified and classified in accordance with Urban Nature Atlas (2017), following the same pattern as in Melbourne case (see **Table 3**). Each project includes short description, environmental components, challenges it meets and urban setting (description of the signs is provided in **Appendix III**).

Table 3. Nature-based solutions in Tianjin. Data source: Katona 2018

Name of NBS	Description	Environmental components
Eco-valley of the Sino-Singapore Tianjin Eco-City	The 'Eco-Valley' is one of the elements of Tianjin Eco-City that was built in cooperation with Singapore. The main aim of the project is to connect residential areas and commercial centres with the help of green and blue infrastructure network, providing recreation zones and community interconnection.	The project aims to achieve city's main requirements on green zones such as 45% green space and 12 m^2 green space per capita. About 70% of plants must be native species. The 'Eco-Valley' is a part of a national 'sponge city' program, seeking to capture and use minimum 75% of rainfall.

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Key challenges to address		
Urban setting		
Integrated green infrastructure at Jiefang South Road	The Jiefang South Road area seeks to transform industrial territory into environmentally-friendly space with green and blue infrastructure that will ensure healthy lifestyle and well-being of residents with preservation of its cultural significance.	Connection between residential zones is built on introduction of urban green infrastructure in these areas. Green spaces and lakes will be core centres of the area. The project is a part of China's Sponge Cities program.
Key challenges to address		
Urban setting		
Indoor garden, green walls and rooftop garden on an Eco-City building	Eco-City building is a part of the Sino-Singapore Tianjin Eco-City, which serves as an example of nature-based solutions for visitors. Children of school age can participate in gardening. Initially, this building was created as a research centre for scientists from China and beyond.	The building consists of rooftop garden with more than 30 types of crops; green wall and vertical green façade; indoor garden and storm water capturing system.
Key challenges to address		
Urban setting		
Sponge City Project in Tianjin	Tianjin is a part of China's national Sponge Cities Project and it aims to achieve 'sponge city' standard in 80% by 2030. Additionally, the city is planning to increase the figure of green space per capita from 9.72 m^2 to 12 m^2 by 2025.	In accordance with Sponge City Project requirements, Tianjin will reorganize landfills into public parks. Simultaneously, in order to absorb 75% of the rainfall, the city needs to utilize green and blue spaces, parks, residential and industrial areas for storm water capture.
Key challenges to address		
Urban setting		

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Table 3 continuation

Integrated green and blue infrastructure in Wuqing District	The district is characterized by rapid development as well as residence growth. It has a green coverage with more than 36% and meets national 'Garden City' requirements. In addition, Wuqing District was selected as role model in the sphere of green urban development in 2014.	Green spaces in Wuqing District have different forms, including parks, green rooftops, walls and facades; greenery along roads; vegetation near public buildings, healthcare facilities, educational and governmental institutions, etc.
Key challenges to address		
Urban setting		
'Twins City Parks' – Peri-urban reforestation program	This project includes reforestation program between the two core areas of the city – Central Tianjin and Binhai New Area.	The main aim of 'Twins City Parks' is to transform inappropriate agricultural lands and landfills to forested territories in 600 km^2. It has a significant importance for the city government as it helps to reduce air pollution and smog.
Key challenges to address		
Urban setting		

As shown in **Table 3**, Tianjin has a problem with air pollution and smog. The city tends to increase the number of green space at any cost. NBS in Tianjin have different forms such as green and blue infrastructure networks, greening along the roads, indoor gardens, green rooftops and walls, planter boxes, etc. Additionally, the city is the part of national 'sponge city' program, seeking to capture and use rainfall. For this purpose Tianjin needs to reorganize green and blue areas for storm water capturing systems.

4.2.4. Comparison of three cases

There is limited awareness of the benefits of nature-based solutions in Ukraine. In Kyiv there are no clearly identified requirements or propositions related to the implementation of NBS. There is also limited space in the central parts of Kyiv to create new green zones. Thus, from this prospective, examples of Melbourne's and Tianjin's NBS projects can be used.

In order to expand green spaces in a central urban area the 'Medibank Building' in Melbourne serves as an interesting example that includes green roofs, walls and facades. In addition, green

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areas inside the building promote the health of workers and reduce stress. The 'Queenscliff centre' in Melbourne also has a turf roof with local flora.

Tianjin has a similar project for an 'Eco-City building'. Vegetation is used not only externally as a green rooftop, façade and walls, but also in the form of an indoor community garden. Kyiv municipalities can apply this kind of NBS to existing business centers, educational and governmental institutions, healthcare centers, etc., especially in the districts with low vegetation, where allocation of additional areas for green space is impossible.

Another type of NBS that can be applicable in Kyiv is the green roof of Victoria's Parliament House. The Parliament House was built in the mid-19th century, but the historic part of the building was improved with a garden structure only in recent years. It includes a rooftop garden, where the substrate does not exceed 50 centimetres, with low-growing vegetation. Such project can be applicable to historical buildings in Kyiv. The structure of the building can incorporate green roofs, where the soil thickness is not significant and does not impose substantial load.

In both cities, Melbourne and Tianjin, roadside vegetation plays an important role. Greening of Melbourne's famous laneways is an NBS project that involves vertical gardens, climbing plants and planter boxes. The expectation is that such an initiative will attract city residents and improve the overall environmental state of the city.

Tianjin's green corridor along the Cuiheng Road in Wuqing District involves different types of vegetation along the roads that connect existing public spaces, residential areas and other green zones. In Kyiv, vegetation along the main roads of the city, so-called 'boulevards' is in sufficient amount and in a good condition. However, there is a lack of greenery along the roads that are far from the city center, especially in newly built-up areas as explained in the previous chapter. In the historical part of the city, laneways can also be improved with additional amount of vegetation, trees and green walls.

One of the NBS types that is raising interest is community gardens. CERES Community Environment Park in Melbourne is a particularly fitting example of community gardens. It has an organic urban farm, were everyone interested can participate. Moreover, CERES is an environmental education center which provides specific workshops and courses in order to increase an environmental awareness of residents. It is a considerable opportunity for Kyiv's residents without land for gardening. This option is particularly relevant for those who live in small apartments. Kyiv residents sometimes use balconies for gardening; however, these spaces are very often used for storing personal belongings.

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Finally, the project 'Integrated Green and Blue Infrastructure in the Wuqing District of Tianjin can be regarded as an example of NBS in new subdivisions of Kyiv. This project was constructed taking into account accessibility of green zones, the amount of green space per capita and green coverage of the area. In Kyiv there is insufficient compliance with green development related rules in new subdivisions of the city. Policies and regulations related to the creation of green zones and nature-based solutions in cities will be analyzed in the following section.

4.3. Policies and regulations of green space and nature-based solutions

This section provides information on governance instruments such as policies, strategies, regulations and guidelines related to the development of green areas and nature-based solutions in Kyiv, Melbourne, and Tianjin. The main aim was to determine the core policies and regulations that affect the presence of green space and NBS in the cities of interest. Policies applicable to Kyiv in the future are discussed in the last part of this section.

4.3.1. Laws and policies related to green space and NBS in Kyiv

There are many legislative documents that regulate urban greening in Ukraine as a whole and Kyiv specifically. The most important ones were identified and analyzed below in order to reflect on their adequacy to support the development of green zones in residential districts and thereby contribute to maintaining comfortable temperature regimes and microclimatic conditions that are changing due to climate change (see **Table 4**).

Table 4. Legislation and key policies relevant for green spaces in Kyiv

Document title	Regulations concerning green zones	Responsible authority
State building standards "DBN B.2.2-12:2018" State Committee for Urban Development (1992)	The key regulatory act that provides standards on green zones in urban and rural areas. It defines the quantity of vegetation that should be allocated for each structural elements of the settlement. The main drawback is a lack of responsibility for the violations.	Governmental authorities, local and regional institutions and companies
Law of Ukraine on Urban Development Verkhovna Rada of Ukraine (2006)	The term 'development' is applicable to all the types of green spaces in Kyiv. Protection and renovation should be provided for all types of green spaces with the exception of the category 'limited usage.' The Law is focused more on development rather than creation of new green areas.	Ministry of Justice of Ukraine

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Table 4 continuation

Rules for the maintenance of green spaces in the settlements of Ukraine Ministry of Construction, Architecture, Housing and Utilities of Ukraine (2006)	The Rules are the basis for legal and functional organization of green spaces in settlements. Special emphasis is done on protection and preservation of green areas in a healthy phytosanitary state. The main aim of the document is to ensure the well-being of resident with the help of vegetation. One should apply them during the construction stage, by taking into account tree species and planting material.	Local and regional authorities
Rules for the maintenance of residential houses and adjoining areas State Committee of Ukraine for Housing and Utilities (2005)	The Rules envisage protection, maintenance and restoration of green zones with limited usage, namely vegetated areas near households. Due to these regulations, all the greenery must be recorded within an inventory system including such data as vegetation cover area, age and condition, species composition.	Local authorities
Rules of Kyiv improvement Kyiv City Council (2008)	The Rules define economic factors, stakeholders and spheres of responsibility for green spaces in Kyiv. At the same time they declare the actions, prohibited on the territories of green objects.	Kyiv City Council
The Law of Ukraine about the Natural Preserve Fund of Ukraine Verkhovna Rada of Ukraine (1992)	Majority of parks in Kyiv belong to the objects of the nature reserve fund, so they have to be protected in accordance with legislation.	Ministry of Justice of Ukraine
The Procedure of tree, shrub, lawn and flower bed removing in settlements Cabinet of Ministers of Ukraine (2006)	This document provides concrete information on the procedure of removing trees, shrubs, lawns, etc. in settlements; types of permission needed as well as fines for incorrect observation of the Procedure.	Local and regional authorities

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As indicated in **Table 4**, legislation and key policies relevant for green spaces in Kyiv are responsible mainly for the protection, maintenance and development of green zones. They provide information on inventory system, including data about tree species and planting materials as well as define the procedure of removing trees, shrubs, lawns, etc. in settlements. The main shortfall of the policy documents is a lack of information on forms and types of NBS that can or should be implemented in Ukrainian cities.

4.3.2. Laws and policies related to green space and NBS in Melbourne

The development of green infrastructure in Melbourne involves the participation of governmental authorities as well as all the stakeholders, long-term investments, education

aspects and community engagement. Key documents that regulate green construction in the city are the following:

1. Building Urban Resilience with Nature (2008)

The document is focused on adoption of natural infrastructure as a part of the city in order to meet environmental goals such as heat island mitigation, storm water filtration, etc. through partnership and collaboration between cities. Natural infrastructure must be regarded on a par with grey infrastructure for societal benefits and resilience development.

The Strategy emphasizes the benefits provided by nature in the city such as maintenance of a healthy lifestyle, social cohesion and well-being due to stress reduction, ecosystem services, biodiversity conservation, etc. In this case, Melbourne's Urban Forest Initiative serves as a central document of the Resilient Melbourne strategy.

Building Urban Resilience with Nature proposes four main steps to the introduction of nature in cities:

1. formation of awareness and collaboration by tight connections with partners, stakeholders, governmental authorities as well as community involvement;
2. implementation of pilot project with further recognition of multiple benefits;
3. conduction of policy review, adoption of a Natural Infrastructure Policy and its inclusion in planning;
4. respond to pushbacks in proactive manner.

2. Nature in the City Thriving Biodiversity and Healthy Ecosystems (2017)

The policy aims to create an urban landscape that is more resilient to climate change. Moreover, it regards private realms as main contributors to ecosystem health and biodiversity conservation.

3. Climate Change Adaptation Strategy Refresh (2017)

One of the aims in this Strategy is to facilitate the development of natural environment and green space in Melbourne. City's parks, street trees, gardens, wetlands, etc. must contribute to reduction of Melbourne's temperature by four degrees by 2040 that will enhance resilience and adaptation capacity.

Additionally, the Strategy states that increase in green areas in the city should take into account greening of private areas. For this purpose, the best international practices from San Francisco,

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New York, Copenhagen and Paris on green roofs and vegetation for new developments will be considered.

The Strategy proposes a few steps in order to support the development of green spaces and natural environment in Melbourne:

- Partnership with the Victoria State Government on the implementation of nature-based solutions in the city, encouragement of green roof development;
- Newly created spaces will meet the requirements for adaptation to climate change;
- Additional greening of private areas should be supplemented with nature-based solutions;
- Further research on the benefits of green infrastructure in the city should be conducted.

4. Plan Melbourne 2017–2050 (2017)

This Plan has as one of the main directions an improvement in local parks and green areas with the help of community participation. In other words, citizens can be engaged in the creation of community gardens or revegetation of disused public land, street tree planting and so on.

Among the policies concerning green space in the city these are the following:

- To make Melbourne cooler through the increase in the number of green areas, roofs and walls, support urban forest development.

Greening must be a part of the planning frameworks along with the establishment of green roofs, facades and walls. It should be provided in open spaces as well as new subdivisions of the city.

- Network of green spaces must protect biodiversity and ensure connectedness with nature.

The Melbourne's network of green spaces should investigate potential spots for urban forest development together with government and local communities.

5. Future Melbourne 2026 (2017)

The Plan requires building a sustainable city based on natural environment that supports the development of the urban forest, community gardens, vertical greening, green roofs etc. in Melbourne in order to mitigate the impacts of climate change.

6. Living Melbourne "Our Metropolitan Urban Forest" (2019)

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The Strategy aims to encourage green development in Melbourne and recommends 6 main actions. Among them, it involves expanding greenery in private areas and funding for the protection of the urban forest.

Greening in new subdivisions and developments should be protected by specific regulations, planning policies and strong leadership that will benefit human health and wellbeing. Additionally, the regulations on the removal of trees in Melbourne should be strengthened and enforced as the problem of unpermitted removal still exists. Financial penalties can be an effective mechanism to protect tree removal on private land.

At the same time, there is a need to increase urban forest at the expense of private landowners. Sufficient funding should be provided to increase greening on private land in order to reach tree cover targets in the city.

7. Living Melbourne "Technical Report" (2019)

The Strategy points out benefits from urban forests and biodiversity in metropolitan Melbourne, including the ecosystem services they provide. It summarizes the key policies in the development and funding of urban forests and the associated risks. Additionally, it provides an analysis of distribution and quality of the vegetation, monitoring activities and public accessibility.

8. Urban Forest Strategy "Making a Great City Greener" 2012–2032 (2011)

The main goal of the Strategy is to create a sustainable city and to ensure resilient environment, health and well-being of the community, reduce exposure to natural hazards as a consequence of climate change. The urban forest includes the following types of vegetation: parks, gardens, green roofs, facades, walls, balconies, and others.

Main targets of the Strategy:

- Increase canopy cover by 40% by 2040;
- Increase tree diversity – no more than 5% of one tree species;
- Improvements in vegetation health by 90% by 2040;
- Improvements in soil moisture;
- Conservation of biodiversity;
- Community engagement.

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The management of urban forest is assigned to local government, however, local communities, businesses, schools, universities, volunteers, etc. can also contribute as stakeholders.

9. Urban Forest Diversity Guidelines "Tree Species Selection Strategy for the City of Melbourne" (2011)

This is supplementary document to the City of Melbourne Urban Forest Strategy. It provides technical information on street tree selection, the main criteria, types of tree species, conditions necessary for tree growing.

10. Growing Green Guide "A Guide to Green Roofs, Walls and Facades" (2014)

This policy provides information on the structure, qualities and potential benefits of green roofs, walls and facades in Melbourne. At the same time, best case studies as examples are identified. The Guide comprises technical information on the design and maintenance of green roofs, walls and facades.

11. Street Garden Guidelines (2015)

Gardening activities can promote sustainability in the city and provide educational benefits. Street gardening can be maintained by individuals for food purposes, aesthetic values or personal well-being. There are different options of gardening such as rooftops, community gardens, vertical gardens, balconies. All are regulated by Street Garden Guidelines, which include guidelines on maintenance of gardens within municipality and possibilities for community engagement.

12. Open Space Strategy "Planning for Future Growth" (2012)

This policy provides the main directions for the development of public open spaces in Melbourne with regard to population growth and consequences of climate change. Open spaces must be included into the city's planning documents. Among the main tasks there is also a target to improve and enlarge major parks in Melbourne.

13. The Victoria Planning Provisions

These are the main Rules in Victoria State on planting vegetation in residential zones and new developments. They may differ depending on municipality and specific local context. However, in general it gives explicit requirements on gardening and residential development standards in terms of greening. It is stated that non-built spaces must accommodate vegetation, while housing cannot cover more than 60% of a lot.

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To sum up all the information mentioned above on laws and policies related to green space and NBS in Melbourne, it can be concluded that the city is aiming to increase canopy cover and tree diversity, to make improvements in vegetation health and to engage community in different projects related to the creation of street gardens or revegetation of disused public land. Specific focus in policies is done on NBS as a tool to increase city's resilience. Melbourne aims to adopt a Natural Infrastructure Policy and to include it in planning regulations. Thus, additional greening of public and private areas should be supplemented with nature-based solutions.

4.3.3. Governing of green spaces and NBS development in Tianjin

As an example of nature-based solutions development in new subdivisions the 'Integrated Green and Blue Infrastructure in the Wuqing District of Tianjin' stands as the most relevant one. Overall, the governance of green infrastructure development in Wuqing involves a number of approaches. At the national level, the 13th Five-Year Plan plays a leading role in development of green and blue zones, following political goals of the country (Katona 2018). Corresponding Ministries and municipalities introduce main principles of Five-Year Plan into urban policy and programs. In order to be supported and funded by government, each project should meet the requirements of this plan. The implementation stage is strictly regulated by various indicators and standards under the control of district bureaus.

In 2017 local government prohibited the construction of high-density buildings in central part of the city as well as in suburbs with two strategies "Ecological Permanent Reserves" and "Ecological Permanent Red Line." The goal was to ensure residents have access to greenery within 50 m of their home area. Only developments with not less than 40% of green space in their residential area block were confirmed by the government (Katona 2018).

There are specific standards on green space, established by the Ministry of Housing and Urban-Rural Development of China such as the "Garden City" and the "Eco-Garden City" (Zou and Li 2014). The first one is focused on green space coverage, while the second defines higher environmental standards, including the quality of the greenery and levels of pollution control.

Standards for "Garden Cities" require green space ratio to be minimum 35% and 8 m^2 of green space per capita (Zou and Li 2014). Progress is monitored by remote sensing. Urbanized area of Tianjin responds to national "Garden City" standard with over 36% of vegetated spaces. As a long-term goal, it is expected that the green coverage of the area will increase to 45% (Katona 2018). It includes all types of greenery: parks, community gardens, forests, trees along roads, vegetated areas near residential buildings and other institutions, green roofs and walls.

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Funding for green infrastructure projects comes from district or municipal authorities. That is why all the standards, regulations and indicators must be strictly observed as well as these areas must be freely accessible by public. While there is no profit behind them, however, green infrastructure may increase the overall attractiveness of the district and engage new residents (Katona 2018).

4.3.4. Discussion of results

The State building standard "DBN B.2.2-12:2018" is the key document that regulates all types of green infrastructure in Ukrainian cities. It determines the quantity of vegetation in different structural elements of the city. The information on implementation of nature-based solutions is implicit; there are no details on forms, types or obligations to NBS that can be applied in cities. The main shortfall of these Standards is the absence of financial or administrative responsibility for violations. All the other types of legislative documents define the procedure of maintaining, protection, and restoration of green zones. However, they do not provide any information on green spaces or nature-based solutions in new sub-divisions of the city.

Among the analyzed documents on green zones and NBS in Melbourne, several include information on the adoption of natural infrastructure as a part of the city on par with grey infrastructure. Kyiv should gradually introduce a natural infrastructure policy and develop NBS that can start from implementation of single pilot projects.

Almost all strategies and guidelines in Melbourne highlight the need to increase greenery in the city due to climate change. It is emphasized that the city will suffer more from climate change implications in future; therefore, there is a need to make the urban landscape more resilient. Kyiv should also take the problem of climate change into account and reformulate or add specific regulations on its mitigation with the help of green space or NBS development.

Moreover, Melbourne guidelines involve the engagement of residents in activities connected with street gardening, greenery on balconies, street tree planting, community gardens, etc. Such initiatives can be applied in Kyiv, as most of the population live in apartments and do not have private land for gardens. Also, almost all Melbourne strategies point out the need for increasing the number of green walls, facades and rooftops. Melbourne has defined precise goals with quantitative indicators on NBS development. Kyiv policies, on the contrary, state only that green roofs and walls can be used as alternative source of greening, without any quantitative targets to achieve.

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As stated earlier, Kyiv has a problem with the lack of green zones in new sub-divisions of the city. An example of Tianjin's "Integrated Green and Blue Infrastructure in the Wuqing District" and Melbourne's "Victoria Planning Provisions" provide useful information on how to tackle this problem. The Victoria Planning Provisions as the main policy related to construction projects in Melbourne can be compared with the State building standards "DBN B.2.2-12:2018" in Kyiv. The Provisions provide precise information on greening and nature-based solutions in residential zones. This document must be followed during the planning and implementation stages as otherwise the project will be rejected by the municipality.

In the same way, national and local regulations and guidelines ought to be observed in Tianjin. The city has a multi-level governance structure within which all the new infrastructure projects must correspond to requirements of each level. If there are some violations, the project will be immediately rejected by governmental authorities. Moreover, in 2017 local government has adopted two strategies that prohibit high-density building in the central as well as rural areas of the city. The main goal of such strict policies is to ensure the access of residents to green zones within 50 m from their house and to provide not less than 40% of green space in residential blocks (Katona 2018). The other restriction is associated with funding. Only projects with sufficient green infrastructure receive funding from district or municipal authorities.

To sum up, Kyiv authorities have to consider revising the current legislations and policies related to the management of green zones. This must take into account the urgent environmental, human health and well-being related challenges such as climate change and to make the city more resilient to the projected more frequent and higher intensity heat waves. Thus, supportive laws should be implemented or the old ones transformed. More attention must be paid to nature-based solutions as alternative greening opportunities in the city. Existing State building standards should define them more precisely with concrete targets to be followed, especially in new sub-divisions of the city, but also in old districts, using technologies suitable for already developed areas. As Tianjin's example shows, the regulations on greenery must be monitored, followed and enforced strictly through project approvals and access to financing. The regulatory framework related to green infrastructure development in Kyiv must be improved.

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5. Conclusions

This Chapter includes the main findings of the work. The main aim of the research was to study nature-based solutions that are successfully implemented in urban areas *in part* as a response to negative implications from climate change. The starting point for my thesis was the interest in heat stress impacts on human health in cities. I have analyzed different possible response measures to climate change in cities and subsequently focused on NBS for building urban capacity and resilience. During my research I also realized that NBS and greening have multiple positive impacts for human as well as for the environment, which makes them even more precious in terms of urban sustainability. Hence, it is of high importance to understand how cities are dealing with NBS and how conscious they are of the potential impacts, heat stress reduction in my case. While primary focus was on Kyiv, the status and policy context of Melbourne and Tianjin were also studied for comparison. The results of content analysis and comparative analysis show that:

1) Nature-based solutions in Kyiv happen in ad hoc ways and are not obligatory to implement. Existing Ukrainian building standards allow the use of vertical greening as well as green rooftops in residential areas of the city. However, there are no specific requirements on their form and design. The center of Kyiv is a high-density area with many buildings, which seriously limits the expansion of green zones. Nevertheless, nature-based solutions can offer alternative options for green urban design e.g., through the use of vertical structures and rooftops.

The research found that nature-based solutions in Melbourne are represented in different forms. The most popular type is green roofs and greening of vertical walls and facades. Their introduction in the city is regulated by policy documents that stimulate the development of green infrastructure and provide qualitative indicators to asset targets, monitor progress and achieve specific implementation goals. Among the many diverse types of NBS in the city there are also community gardens and parks, external and internal greening of buildings, green laneways, etc.

It has been argued that Tianjin has successfully implemented the ‘Singapore Tianjin Eco-City’ project that stimulates the integral development of green space and nature-based solutions in the city. Additionally, the city is introducing a reforestation program on abandoned and low-productivity agricultural land. The ‘Twins City Parks’ initiative aims to connect two core areas of the city with greening and form a green corridor that besides its value for human health and well-being also has biodiversity benefits.

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2) The thesis has explored the main policy aspects and regulations related to green space and NBS in the cities of interest. In Kyiv the main focus of legislative documents is on management, protection and renovation of green zones, without any specific information on nature-based solutions. Additionally, some rules envisage the procedure of vegetation removal in settlements, requirements on the phytosanitary state of greening, and fines for their violation.

The content analysis of the Melbourne's strategies, plans and guidelines has shown that a large number of documents are focused on the adoption of nature-based solutions in the city as part of the responses to climate change, in order to make the urban landscape more resilient. Specific figures which include the development of green rooftops, walls and facades have been identified. Furthermore, guidelines on street gardening, community gardens, and greenery on balconies presume active engagement of resident that increase their ecological awareness inter alia.

The research has shown that Tianjin has a multi-level governance structure and must adhere to policy documents on greening and nature-based solutions at different levels, from national to local. In case the project does not correspond to requirements, it will be rejected or will not receive funding from district and municipal authorities. In addition, Tianjin has adopted two strategies in 2017 that involve the prohibition of high-density buildings in different parts of the city.

3) Cities are actively implementing nature-based solutions that can contribute to climate change impact mitigation and heat stress reduction. Melbourne has introduced 'the Elizabeth Street pop-up park' and 'CERES Community Environment Park' that increase the amount of green space in the city. Simultaneously, the Medibank Building and Queenscliff centre are two specific examples of using the building roofs, walls, facades and terraces for greening. The city's project 'Greening of Melbourne's famous laneways' is aiming to cool the city by introducing new green spaces such as vertical gardens, climbing plants and tree boxes in the laneways where the lack of greenery is tangible.

The content analysis of Tianjin's nature-based solutions for heat stress reduction has shown that the city has successfully implemented the 'Eco-valley of the Sino-Singapore Tianjin Eco-City' project and 'Twins City Parks' that facilitates the development of green spaces and corridors in the city and promotes reforestation program. Tianjin also stimulates the integration of green infrastructure at Jiefang South Road that seeks to increase vegetation along the roads. Additionally, Eco-City building became an example of buildings with indoor gardens as well as vertical green walls, facades and rooftops.

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4) The thesis argues that the green spaces in the central part of Kyiv city can be expanded through the introduction of indoor community gardens and external greening on walls, rooftops and facades as in the case of Medibank Building and Queenscliff centre in Melbourne or Eco-City building in Tianjin. For the historical buildings of the city, Victoria's Parliament House in Melbourne can be applicable, where an extensive green roof was installed. Additionally, greening Melbourne's famous laneways is a relevant example for central parts of Kyiv as well as new built-up areas, where the lack of areas for greening is tangible. In the same way, for people with small household space, 'CERES Community Environment Park' in Melbourne can stand as an example of a community garden. Finally, the project 'Integrated Green and Blue Infrastructure in the Wuqing District of Tianjin' is applicable to new built-up districts of Kyiv.

To sum up, nature-based solutions can be regarded as an additional element to green spaces development in the urban design. It is an effective tool in the mitigation of the impacts of climate change, including but not limited to heat stress as it reduces the vulnerability of the population, makes it more resilient and increases its adaptive capacity.

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Appendix I – Inventory of green zones in Kyiv as of 01.01.2017

КИЇВСЬКА МІСЬКА ДЕРЖАВНА АДМІНІСТРАЦІЯ

Київське комунальне об'єднання зеленого будівництва та експлуатації зелених насаджень міста «КИЇВЗЕЛЕНБУД»

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Call-центр (044) 272-40-18 E-mail:info@kievzelenbud.com Код ЄДРПОУ 03362123

15.03.2017 N 148-03/01-775

Забарній О.Г.

Шановна Олено Георгіївна!

Київське комунальне об'єднання зеленого будівництва та експлуатації зелених насаджень міста «Київзеленбуд», розглянуло Ваш інформаційний запит та повідомляє про наступне.

1. За даними Головного управління статистики у місті Києві на 1 січня 2017 року постійне населення міста Києва становить 2884454 чоловік. Площа зелених насаджень, закріплених за районними Комунальними підприємствами по утриманню зелених насаджень в межах міської забудови на 01.01.2017 року становить 7790,90 га. Враховуючи викладене на 1 мешканця міста Києва припадає 27 м^2 зелених насаджень, закріплених за районними КП УЗН.
2. 3. Дані інвентаризації з розподілом площ зелених насаджень між районними комунальними підприємствами по утриманню зелених насаджень додаються.

Додаток: на 1 арк. в 1 прим.

З повагою

Заступник генерального директора Ю.Курінний

Ткаченко 272-39-95

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Інвентаризація площ зелених насаджень по КП УЗН КО "Київзеленбуд" за 2016 рік станом на 01.01.2017

№ п/п	КП УЗН районів	Парки	Сквери	Бульвари	Проспекти	Площі	Схили	Урочища	Інші впорядковані зелені насадження	Всього зелених насаджень загального користування	Зелені насадження на вулицях	Зелені насадження на транспортних розв'язках	Зелені насадження на захисних зонах	Зелені насадження спеціального призначення	Всього зелених насаджень
1	Голосіївський	491,00	43,20	59,14	83,54	27,87	61,50	164,30		930,55	71,43			71,4	1002,0
2	Дарницький	122,11	32,49	1,50	25,14	5,00		696,00		1217,54	65,78	12,69	335,30	413,77	1299,33
3	Деснянський	504,83	11,41	3,19	27,28			496,84	12,02	1055,57	74,42	9,19		83,61	1139,19
4	Дніпровський	483,19	30,28	27,92	14,85	1,51			16,37	574,12	45,13	21,59	14,7	81,43	655,55
5	Оболонський	142,84	147,51	26,98	22,96				105,09	445,39	104,65	16,95		121,60	567,00
6	Печерський	211,22	7,19	14,40		1,54	34,43		12,22	281,00	59,02	7,13		66,15	347,15
7	Подільський	173,54	25,64	2,29	18,32		2,01		563,53	785,33	50,31	0,68		50,99	836,32
8	Святошинський	60,29	43,05	13,10	37,33				194,03	347,80	131,52	26,43	332,25	490,20	838,00
9	Солом'янсьий	180,60	50,77	17,31	14,35		31,69	100,13	59,60	454,45	86,81	3,80	4,63	95,24	549,69
10	Шевченківський	379,24	41,81	7,15	2,65		28,46			459,31	93,01	4,37		97,38	556,69
Разом:		2748,86	433,35	172,98	246,42	35,92	158,09	1457,27	962,86	6551,06	782,08	102,83	686,89	1571,80	7790,90

Appendix II – Inventory of green zones in Kyiv as of 01.01.2018

КИЇВСЬКА МІСЬКА ДЕРЖАВНА АДМІНІСТРАЦІЯ

Київське комунальне об'єднання зеленого будівництва та експлуатації зелених насаджень міста «КИЇВЗЕЛЕНБУД»

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12.07.18 N 148-03/а-2263162
*на № 226/2810 від 06.07.*2018

Забарна О.Г.

Шановна Олено Георгіївна!

Київським комунальним об'єднанням зеленого будівництва та експлуатації зелених насаджень міста «Київзеленбуд», розглянуто доручення Управління екології та природних ресурсів виконавчого органу Київської міської ради (Київської міської державної адміністрації) № 226/2810 від 06.07.2018 щодо запиту на отримання інформації гр. Забарної Олени Георгіївни. Повідомляємо наступне:

1. Фактична забезпеченність населення міста Києва зеленими насадженнями в межах міської забудови станом на 01.01.2018 становить: 1843008 штук дерев, 871502 штук кущів.

2. Розподіл територій зелених насаджень м. Києва за адміністративними районами:

Голосіївський р-н.	936,03 га
Дарницький р-н.	1257,67 га
Деснянський р-н.	1054,80 га
Дніпровський р-н.	573,29 га
Оболонський р-н.	412,03 га
Печерський р-н.	280,88 га
Подільський р-н.	785,62 га
Святошинський р-н.	245,56 га
Солом'янський р-н.	454,84 га
Шевченківський р-н.	459,27 га

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Appendix III – Legend

Key challenges		Urban setting	
Icon	*Description*	*Icon*	*Description*
	Climate action for adaptation, resilience and mitigation (SDG 13)		External building greens
	Cultural heritage and cultural diversity		Grey infrastructure with green features
	Economic development and decent employment (SDG 8)		Parks and (semi)natural urban green areas
	Environmental quality, including air quality and waste management		Allotments and community gardens
	Green space, habitats and biodiversity (SDG 15)		Blue areas
	Health and well-being (SDG 3)		Green indoor areas
	Inclusive and effective governance (SDG 16)		Green areas for water management
	Regeneration, land-use and urban development		Derelict areas
	Social justice, cohesion and equity (SDG 10)		
	Sustainable consumption and production (SDG 12)		
	Water management (SDG 6)		

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