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Be Ready

Urban Heat Islands Vulnerability and Risk Assessment

Methodology with guide for application and tools

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List of Abbreviations

AC	Adaptive Capacity
ADB	Adult Disabled Benefit
AI	Artificial Intelligence
BCR	Building Coverage Ratio
BTUs	British Thermal Units
CCM	Climate Change Management
CLC	Copernicus Land Cover
CORINE	Coordination of Information on The Environment
EEA	European Environment Agency
EER	Energy Efficiency Ratio
ESA	European Space Agency
ESMERALDA	Enhancing Ecosystem Services Mapping for Policy and Decision Making
EU	European Union
FAR	Floor Area Ratio
FSI	Floor Space Index
FSR	Floor Space Ratio
FUAs	Functional Urban Areas
GDPR	General Data Protection Regulation
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LIFE ASTI	Life Adaptation to Climate Change in Urban Areas
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGOs	Non-Governmental Organizations
NSO	National Spatial Order of Slovenia
SPN	Spatial Planning Decree of Slovenia
SRI	Solar Reflectance Index
UHI	Urban Heat Island
UHIVRA	Urban Heat Islands Vulnerability and Risk Assessment
VI	Vulnerability Index
WCRP	World Climate Research Programme

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Introduction

GENERAL CONTEXT

The urban heat island (UHI) effect presents a growing threat to the livability of urban environments. As the climate crisis intensifies, the issue of UHIs is increasingly affecting not just city centers but also a wide range of built-up areas beyond urban boundaries. These include industrial zones, suburban shopping complexes, and villages, highlighting the widespread impact of this phenomenon. Addressing the UHI effect is crucial for ensuring the sustainability and comfort of all inhabited areas in the face of ongoing climate change. So, when speaking about UHI in this document, the whole scale of built-up areas affected by emergence of UHI is considered.

UHIs occur when urban environments trap and retain more heat than surrounding suburban or natural areas. The dense concentration of buildings, roads, and other structures absorb and re-emit solar and heat energy more efficiently than natural landscapes, leading to higher temperatures in urban areas compared to their surroundings. These localized pockets of heat are most prevalent in parts of cities with high building density and lack of blue or green infrastructure, particularly during summertime and heat waves. Several factors contribute to the formation of UHI, including the extension of built-up areas that replace natural surfaces with heat-absorbing structures, variations in the geometry of settlement patterns that affect wind flow and solar heat absorption, properties of construction materials and surfaces (color, albedo, etc.) influencing heat retention, and the geographical features of the surrounding landscape influencing local weather patterns, particularly in cities located in basin-like areas where airflow is restricted (Zhao et al., 2014; Nuruzzaman 2015).

To counteract this negative effect risk and vulnerability assessment have become key approaches as they refer to the process of evaluating the potential impacts and vulnerabilities of urban areas. UHI risk assessment involves identifying and studying the various factors that cause urban areas to become hotter than their surroundings. It also looks at how heat affects people's health, infrastructure like buildings and roads, natural ecosystems, and the overall urban environment. The assessment of vulnerability determines the vulnerable populations at risk (e.g. elderly persons, children, low-income households), the vulnerability of the infrastructure to heat stress and extreme temperature, as well as the adaptive capacity of communities and institutions to adapt to and cope with UHI (Sidiqui et al., 2022; Cheng et al., 2021).

THE UHI ASSESSMENT METHODOLOGY IN THE BE READY FRAMEWORK

This document presents Deliverable D1.1.1, Urban Heat Islands Vulnerability and Risk Assessment Methodology. The deliverable provides the overall framework for UHI risk assessment at city level; it is the first step in a line of activities planned in the project to prepare the partner cities to carry out their local pilots and to test a selected green acupuncture measure to mitigate the UHI effects.

The UHI assessment methodology lays the ground for local workshops with stakeholders and UHI experts in each partner city, which will facilitate shared learning on UHI drivers and effects, on building predictive scenarios and simulations to address UHI. Each partner city will carry out UHI risk assessment, testing the joint methodology and the tools developed for the 4 vulnerability elements: exposure, sensitivity, preparedness and adaptive capacity and risk groups. The methodology for and the actual UHI assessments at city level will lead to one of the key outputs from the BeReady project, namely, the online UHI vulnerability assessment toolkit for cities, an open access instrument that will allow other cities to do guided UHI risk assessment as well as to request methodological assistance and mentorship from the project partners. Core elements of the methodology will be integrated into the BeReady virtual training program, which is aimed to provide knowledge and skills to city-level experts on UHI.

The methodology and the tools will serve as a basis also for developing and adopting a joint strategic framework for increasing the resilience of cities in the Danube region to UHI effects. The joint framework will have components focused on risk assessment, prevention, adaptation mechanisms (including the proposed acupuncture strategies), and harm reduction (which contributes to saving lives and reducing damage to the environment, economy, and built infrastructure). This framework will serve as a blueprint for the partner cities to draft their action plans to mitigate the effects of climate change at the level.

DESCRIPTION OF THE UHI RISK ASSESSMENT METHODOLOGY

The deliverable aims to address the lack of standardized data collection, data availability and methodologies for assessing and mapping UHI risks. This shall close gaps including the lack of awareness about the content and needed capacities for the risk and vulnerability assessment and its practical importance for UHI mitigation measures. Effective assessment and mapping are crucial for developing strategies for UHI risk reduction and informed decisions making.

Given the urgency and novelty of the issue, the project **BeReady** focuses on providing practical solutions for municipalities of different sizes including holistic information based on scientific findings and pathways for risk assessment based on data availability. Cities require a better understanding of the factors driving heat waves and UHI effects, as well as the extent of their risk exposure, including vulnerable population groups and critical infrastructure

The work is based on recent literature (e.g. Leconte et al., 2015; Cheng et al., 2021; Ellena et al., 2023; Lauwaet et al., 2024) and includes findings from finalized or running projects with valuable insights into UHI risks and vulnerabilities assessment. The "Urban Heat Islands – Strategy Plan Vienna" identified effective urban planning measures to reduce UHI effects by integrating urban ecology. The project "CLIMABOROUGH" provided information for climate neutrality and including UHI mitigation. The World Bank Initiative "City Resilience Program" supported resilience planning and UHI strategies. "LIFE ASTI" developed an urban adaptation strategy and forecasting system for UHI effects. "Cool Towns" highlighted the impact of heat stress and developed localized solutions for UHI mitigation. The CCM Climactions project improved the knowledge base for the implementation of micro-scale UHI risk assessment by looking at the heat-health nexus within cities. A GIS-based methodology was developed within the ESMERALDA project which presents the map calculation with very high resolution (10m) for the average urban heat island situation in large regions, taking the cooling effect of green/blue infrastructure into account.

Prior to developing the document, a needs analysis was conducted among the partner cities through an online questionnaire. The results indicated a general lack of strategic planning to address UHI (for example, only 38 percent of the cities currently have plans directly focused on the issue). Cities also respond that they do not collect or have no access to relevant data; that there are no dedicated budgets to tackle UHI-related effects, etc. When it comes to motivation to strengthen the cities' capacity to tackle UHI, close to 70% cite the need to climate adaptation and mitigation, public health concerns, disaster preparedness and energy savings. The cities also state that they would need expert assistance to gather, analyze and use data for policy formulation. The input from the city partners served as a baseline for the scientific and methodological partners in developing the methodology and the self-assessment tools.

This document provides an overview of shared methodologies and tools for assessing vulnerability and mapping city zones with the highest urban heat island effect intensity. This overview does not have any ambition to be a handbook for the execution of risk and vulnerability assessment as the complexity of the problem and specifics in each city/municipality/region do not allow simple implementation of the overall methodology. They require the professional capacities of interdisciplinary teams to adapt the methodology, choose the proper combination of approaches and tools reflecting specifics of the place, availability of data, affordability of means and time for assessment as a solid and efficient base for evidence and place-based strategies in dealing with UHI in each locality.

Deliverable D1.1.1 provides four tools to carry out the UHI vulnerability assessment for a municipality or city. The tools include:

- **Exposure of buildings and surroundings**
- **Sensitivity of equipment and material**
- **Risk groups among city residents**
- **Preparedness and adaptive capacity of cities/municipalities**

Each tool is described as part of the methodological framework for the evaluation to be carried out in the partner cities and provides a step-by-step guideline for its application. The focus thereby lies on the practicality of application for municipalities of different sizes. Each individual tool can be applied in a standalone manner. A step-by-step guide is included providing guidance along the assessment procedure per tool.

Methodology and tools

GENERAL DATA FOR UHI ASSESSMENT

The four following methodologies and tools give specific information on the assessment of (i) the exposure of buildings and surroundings, (ii) the sensitivity of equipment and material, (iii) the share of risk groups among the residents and (iv) the preparedness and adaptive capacity of cities/municipalities. Importantly, general data on urban climate is needed in more than one assessment and is presented below.

Urban climate

Urban climate refers to climatic conditions in urbanized areas. Different human activities, impervious surfaces, and geographical locations with natural environments impact urban climate conditions.

The location and geography of the city's surrounding natural landscape greatly impact the weather conditions in cities. Mountains prevent the wind from reaching towns and influence urban climate conditions, especially in valleys or basins, while the wind can easily reach cities located in flat areas, reducing the heat in cities and preventing the UHI effects. Sunny, warm and windless weather conditions are raising the urban temperature of built-up areas in cities and minimizing the reduction of excess heat in inner cities, while on the other side, windy and cloudy weather suppresses the UHI effects.

The risk and vulnerability assessment methods provided by the four tools in the following chapters gives detailed information on specific indicators and the data sets needed. To describe and assess areas experiencing UHI a general dataset and monitoring is needed. Each of these play a critical role in the formation, intensity, and mitigation of UHI. This dataset shall include the following parameters (1) Air Temperature, (2) Surface Temperature, (3) Solar Radiation (4) Humidity, (5) Windspeed and Direction, (6) Precipitation.

Local climate data from weather stations and remote sensors (e.g. Landsat data, Copernicus Climate Change Service, EOS-Aqua-MODIS V5) are the main data sources for measuring temperature in different parts of the city. Citizen science, as the other sources of data, can also be used to identify the hottest spots in cities. A full example for the UHI identification can be found by Peng et al. (2011).

(1) Air Temperature

Air temperature is a crucial parameter for the UHI effect. In cities, air temperature can be much higher because of the concentration of buildings, roads, and other heat-retaining structures. Comparing air temperature data from urban and rural areas helps determine the temperature difference and assess the UHI effect.

Air temperature data is generally measured using weather stations in different parts of the city, using mobile temperature sensors to measure at specific points to close data gaps or carry out measurements during specific times and can be determined using citizen science including the personal datasets from inhabitants. Based on the definition of UHI it is key to also establish a dataset in the rural area around the city and in multiple parts of the city. As the negative effects on humans come also during the nighttime, it is not just important, but urgent to not only have daytime but also nighttime data, underlining the critical nature of our research.

(2) Surface Temperature

The surface temperature helps us understand how much heat is absorbed by different materials. Infrared camera measurements can be done using satellites, drones, and handheld devices. Urban surfaces like asphalt and concrete tend to absorb more heat during the day and release it slowly at night. This data helps identify hot spots within a city and evaluate solutions like green roofs and reflective pavements.

(3) Solar Radiation

Solar radiation is the main source of heat in urban areas. It is measured using pyranometers, providing the amount of solar energy reaching the surface. Urban materials absorb and reflect this radiation, affecting surface and air temperatures. Understanding solar radiation patterns helps identify areas with high heat accumulation and develop shading strategies to reduce heat absorption.

(4) Humidity

Humidity refers to the amount of water vapor present in the air. It impacts thermal comfort and the overall heat balance in an environment. High humidity levels make the air feel hotter and increase the perceived temperature. Humidity is typically measured using a hygrometer, which can be part of a weather station or a standalone portable device. Hygrometers measure the relative humidity, indicating the percentage of moisture in the air relative to the maximum amount it can hold at a given temperature.

(5) Wind Speed and Direction

Wind speed and direction are key parameters for heat and pollutant transport. Wind speed measures how fast the air is moving, while wind direction indicates the wind vector. Together, they influence the cooling effect and ventilation of an area. These parameters are typically measured using anemometers often integrated in weather stations.

(6) Precipitation

Precipitation affects the cooling of surfaces and the overall heat balance. Rain can temporarily cool both surfaces and the air, mitigating the UHI effect. Data on rainfall intensity, duration, and frequency is collected using rain gauges and weather radars. Knowledge on past precipitation events supports planning for rainwater harvesting and reuse in irrigation of green infrastructure for UHI mitigation.

The sections below describe in more detail each of the four tools proposed to facilitate the city UHI vulnerability and risk assessment. Each section provides a general introduction to the respective tool, the associated data sets needed for the risk assessment, as well as sample checklists to guide city planners and experts to conduct the assessment.

TOOL 1 – ASSESSMENT OF EXPOSURE OF BUILDINGS AND SURROUNDINGS

AIM OF THE ASSESSMENT TOOL

The extension of built-up areas and urbanization processes have a great impact on the negative effects of UHI in cities municipalities and even regions (especially metropolitan regions). The UHI is a microclimatic phenomenon by which built-up area (urban areas: cities) retain more heat compared to its natural surroundings (rural areas). UHI occurs when urban built-up areas experience higher temperatures compared to its natural surroundings. That means that cities with the highest concentration of built-up areas are the most exposed environments to UHI effects due to the combination of physical and functional factors (Figure 1).

Figure 23: Impact of the city characteristics on UHI

The physical aspect is related to the urban form and shape of the city, the design and organization of building structures, the relationship between built-up areas and open spaces in cities, the density and heigh of buildings, the level of vegetation, while the functional aspect is related to the organization of human activities in cities.

Each city is unique. There is no uniform solution to tackle UHIs in all cities. Cities differ by geographic characteristics, topography, climate conditions, urbanization processes, urban form and density, organization of activities, etc. causing different conditions for the UHI effects. Since urbanization processes and expansion of cities are changing the land surface into the urban environment, increasing the level or built-up areas, density, impervious surfaces, etc. there is a need to identify the most critical factors of the urban areas exposed to the UHI negative effects.

To mitigate UHI negative effects, cities first need to identify areas that are the most exposed to the UHI negative effects. Mapping zones will support cities to focus their actions, develop solutions, strategies and measures tailored to physical and functional specifics of the location to successfully tackle the UHI challenges.

The main aim of the tool is to conduct vulnerability assessment and mapping critical zones as “hot spots” with the highest intensity of UHI on the entire city level. Buildings with surroundings are the major elements of the exposure aspect vulnerable to the UHI negative effects. Aside from the assessment of urban physical characteristics with buildings and other built-up areas, it is important to identify also functional characteristics of cities. A side effect of human activities is heat, as an additional source contributing to the UHI effects, which can be trapped between buildings raising the temperature of urban surfaces and urban climate inner cities especially in summer season.

CRITERIA AND INDICATORS FOR IDENTIFYING UHI AREAS

Assessment of the urban environment will be based on the following major urban criteria:

urban morphology/urban form,
vegetation,
permeability of surfaces,
human activities,
urban climate.

Each criterion is thoroughly described below, considering its potential impact on the UHI. The rationale for selecting the criterion is provided, along with defined assessment indicators. Each indicator is described, and guidelines for data collection, including data sources, are proposed for measuring these indicators (Figure 2).

Figure 24: Description of criteria for identifying UHI areas

While assessing different criteria it is important to acknowledge that all criteria are interconnected and have different impacts on each other, which in turn affects the UHI effect (Figure 25). For example, higher building densities reduce green areas while reducing the availability of permeable surfaces, or densification of building structures in cities increases human activities, which causes heat-related side-effects and ultimately contributes to increased temperatures in the urban climate, causing the UHI effect.

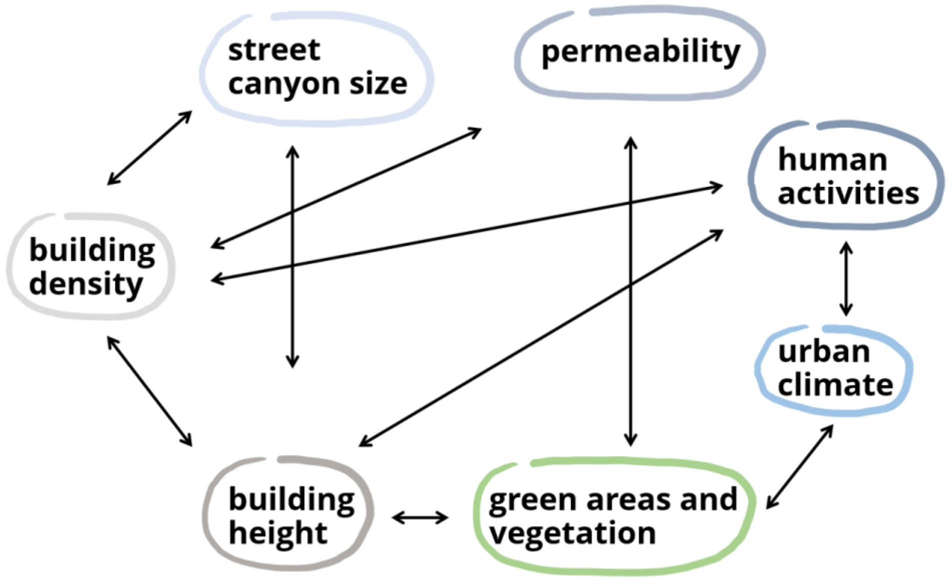


Figure 25: Interrelationship of UHI urban criteria

Urban morphology/urban form

Urban morphology and urban form refer to spatial patterns of urban landscapes composed by different urban elements. Building form, arrangement of buildings and their interrelation, street and plot patterns are the main elements of urban morphology and form defining the physical characteristics of the city.

Different morphological structures with different shapes and sizes of built-up areas have a great impact on the UHI effects from several aspects. Built-up structures (buildings, roads, squares and other) absorb and re-emit the solar and other heat more than natural landscape. Different geometry arrangements of streets and buildings affect wind ventilation and radiation level which can have a great impact on heat trapped within the street canyon.

The expansion of cities and densification is displacing natural surfaces (soil, vegetation) with buildings, roads, squares, parking areas, and other hard artificial surfaces that absorb heat and, in the summertime, contribute to higher temperatures in inner cities.

The density of built-up areas strongly influences UHI intensity. In cities, where the density of built-up areas is very high and the level of the natural landscape and greenery (forest, water bodies, green areas, vegetation, etc.) is very low, the temperature is higher than in its surroundings. High-density built-up structures reduce airflow and ventilation, trap heat, especially during the day, and increase the heat island effect.

Different dimensions and street distances (street canyon) influence the ability of construction materials to absorb and release the solar heat, etc. Street canyons imply on the movement, direction and the speed of wind which affects the quality of air and the surrounding temperature which can increase by 2-4 degrees depending on the geometry of the street (https://www.worldatlas.com/articles/what-is-a-street-canyon.html). The wind speed is also affected by the street orientation. North-south orientation can store up to 30 % energy of the midday radiant which is released at night when the temperature cools.

By changing urban form with built-up structures, cities can create cooler and more comfortable urban spaces, especially inner cities. A proper urban planning that accounts for building spacing, orientation, and clustering can enhance air circulation and reduce UHI negative effects.

Indicators related to urban form

Building coverage ratio (BCR)
Floor area ratio (FAR)
Street canyon aspect ratio

Green urban spaces and vegetation

Green urban spaces are open spaces in cities and towns defined by a certain degree of vegetation and other natural features, regardless of ownership, function and position in space (Spatial Planning Decree of Slovenia, 2004, National Spatial Order of Slovenia, 2023). Green urban spaces are ecosystems and vital elements in enhancing the quality of life in an urban environment and supplying ecosystem services like climate regulation (Vargas-Hernandez, 2020).

Urban green spaces have different sizes and shapes with different functions like natural green space in urban areas like parks, squares and plazas with green areas, private/semi-private gardens, including shared (communal) spaces around apartment buildings, backyards, balconies, roof gardens and community (productive) gardens, green roofs and walls, including roof gardens and living walls, river banks, residential and other streets, comprising street verges and associated open space pockets, sports and recreational facilities, including tracks, golf courses, school and other institutional playing fields, and other significant parks.

Cities usually have limited green spaces especially inner city, in city centres, with a high density of buildings and high concentration of activities. Green spaces together with vegetation and water bodies are cooling the urban climate by providing shade and evaporating the moisture in the air compared to build up structures and surfaces. Trees in cities provide shade, evaporate the moisture in the air compared to build up structures, cooling and regulate temperatures of urban climate. Insufficient level of trees implies on cities to become “islands” of higher temperatures compared to surrounding rural areas.

Vegetation refers to all plant species in the city.

The focus of the assessment in the Be Ready project will be on the grassland or other low vegetation coverage and coverage of tree canopy on the city level.

Indicators related to green urban spaces

Green coverage ratio
Tree canopy coverage

Permeability of surfaces

Permeability of surfaces refers to the ability of urban surfaces to pass water through into the soil. Green spaces are the main permeable surfaces in cities. They can be also partly permeable depending on the level of the soil used on impermeable surfaces. Green roofs and green walls can be categorized as semipermeable surfaces in cities. Paved impermeable surfaces are mostly roads, pavements, parking lots and other paved-over surfaces with the ability to redirect water runoff to stormwater systems instead of allowing it to be absorbed by plants or bodies of water. They also absorb solar radiation and heat, especially during the day and radiate the heat during the night.

Green spaces are natural surfaces with the soil and vegetation with a function of water absorption lowering the temperature inner cities. Natural processes like evapotranspiration and evaporation help to cool the city areas while on the other side, impermeable surfaces hinder this cooling effect.

Indicators related to permeability of surfaces

Share of permeable surfaces related to impermeable surfaces

Human activities

Humans use different ways to meet their individual and public needs and carry out activities like transportation, industry, air-conditioning, buildings, waste heat, etc. Human activities have an impact on the land use, affecting ecosystems, water quality and microclimate. They are related to the utilization of land for different economic, cultural and other purposed. In cities human activities are related transportation, industrial processes, and energy consumption.

Human activities release anthropogenic heat, contributing to the overall warmth of cities and consequently to the UHI effects. The organization of activities and transportation system are important since they affect the heating level in different parts of the city.

Indicators related to human activities

Population density
Land use
Energy consumption of buildings
Energy consumption of transportation

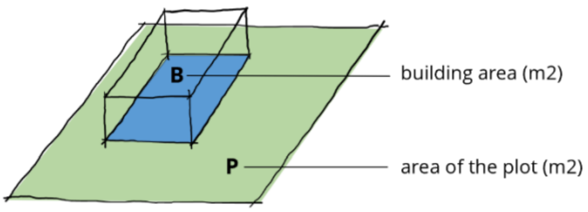
DATA COLLECTION GUIDANCE FOR TOOL 1

To evaluate the physical and functional characteristics of the built environment exposed to the UHI negative effects, a combination of different data collection from different data sources for evaluating indicators are needed. For evaluation of the indicators, several tools and instruments are proposed in this methodology.

Building coverage ratio (BCR) and Floor area ratio (FAR)

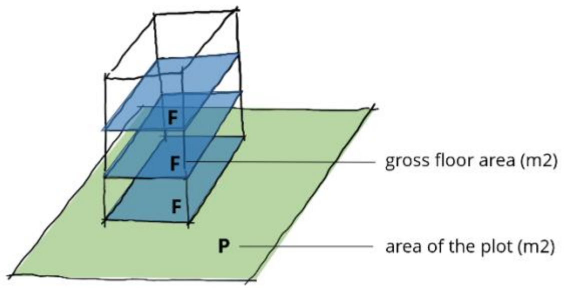
Building coverage ratio (BCR) (Figure 26) reflects the relationship between the ratio of the site occupied by the building and the site area (plot/parcel or larger area).

Floor area ratio (FAR) (also floor space ratio (FSR), floor space index (FSI), site ratio or plot ratio) (Figure 27), is a measure describing how much land is covered by a building. It is a relationship between the total floor area of land covered by buildings and the whole area where the building stands. A higher FAR allows for more intensive development (Figure 7 and Figure 8).



$$\textbf{Building Coverage Ratio (BCR)} = \frac{\textbf{building area (B)}}{\textbf{area of the plot (P)}}$$

Figure 26: Building Coverage Ratio (source: Urban Planning Institute of Slovenia)



$$\textbf{Floor Area Ratio (FAR)} = \frac{\textbf{gross floor area (sum of all F)}}{\textbf{area of the plot (P)}}$$

Figure 27: Floor Area Ratio (source: Urban Planning Institute of Slovenia)

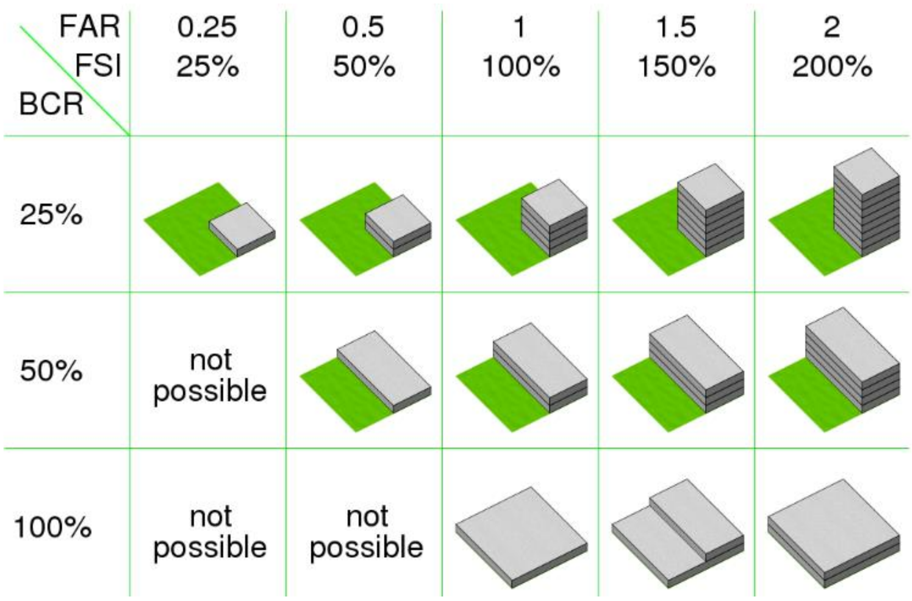


Figure 28: Relationship between FAR and BCR (source: Wikipedia (2024, April 29 https://en.wikipedia.org/wiki/Floor_area_ratio)

Data collection sources

BCR and FAR (Figure 28) are urban planning codes which are usually defined in the Implementation part of the City/ Municipal Spatial Development Plan. The cadaster of buildings can be also a vital data source for measuring building density.

Measuring guidelines

The assessment of different combinations of the BCR and the FAR can support the identification of the densest built-up areas and their distribution in different parts of the city. For assessing UHI areas, cities can design their own assessment classification scale. It is proposed that cities develop their 5-point rating scale separately for BCR and FAR, depending on their values of the BCR and FAR. Higher values can be demonstrated in darker color and the lowest with the lighter color. Each city will also present the distribution of different BCR and FAR values on the entire city level for each spatial planning unit or in the grid cells adapted to the city size.

As an alternative to the FAR indicator, the elevation of buildings can also be used as an indicator for assessing the building structure.

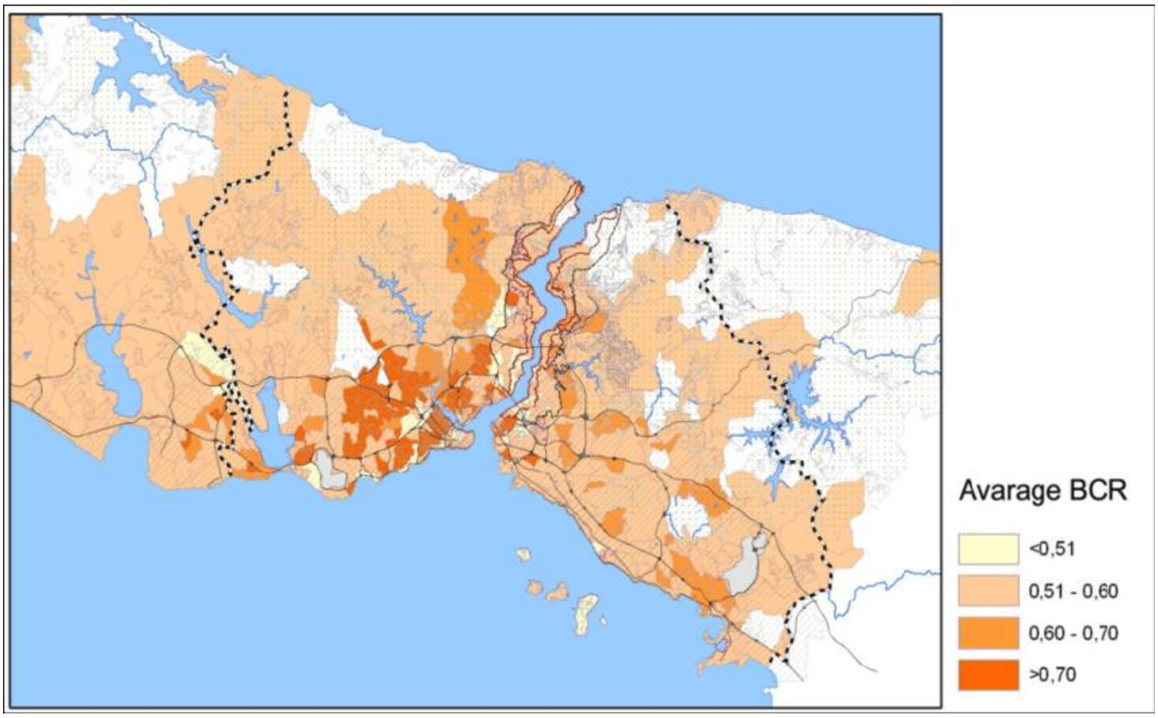


Figure 29: Example of an average building coverage ratio mapping (source: Bölen et al., 2007

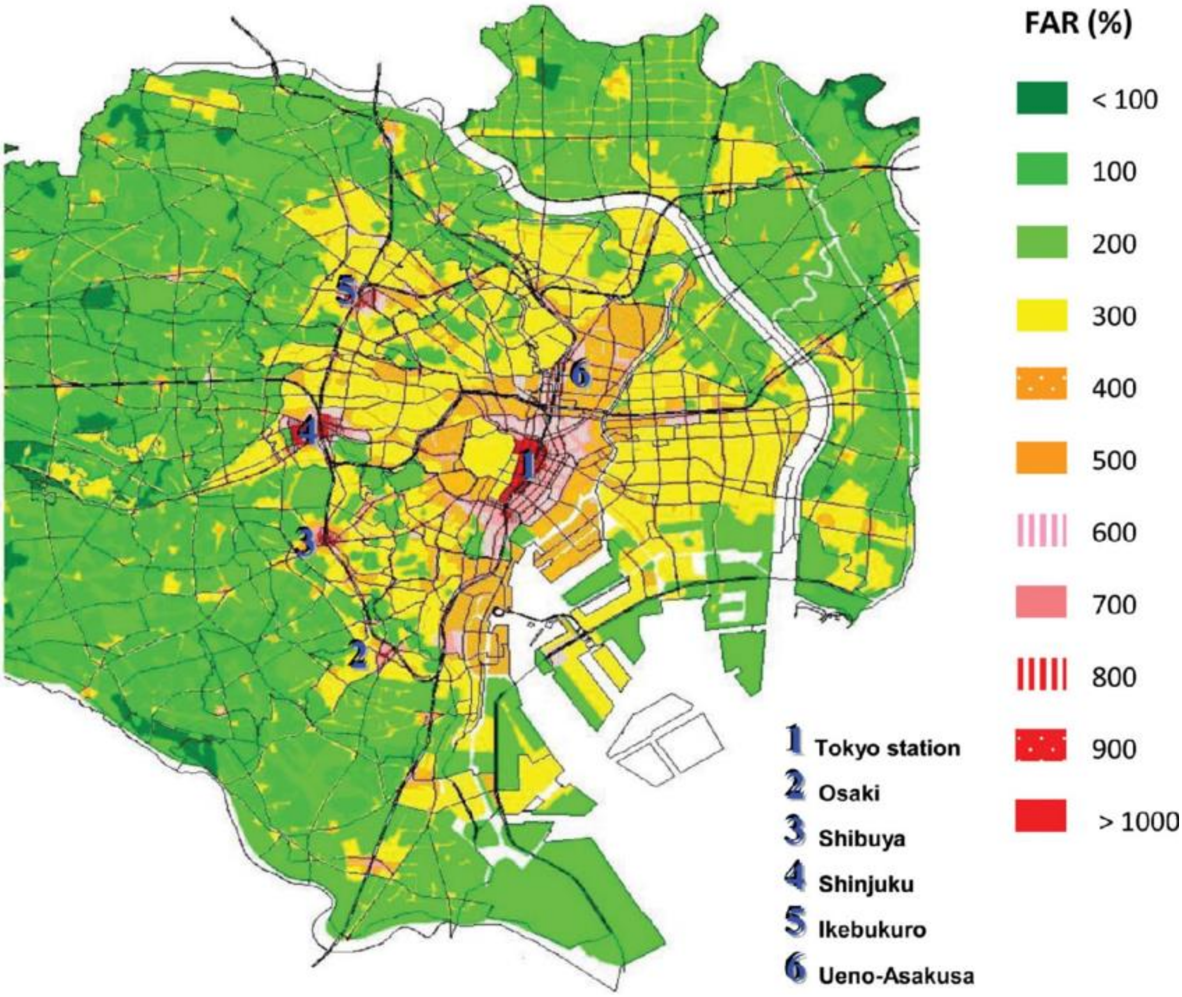


Figure 30: Example of a Floor area ration (FAR) mapping (central Tokio, Chorus et al., 2014)

Overlapping the layer with BCR and FAR values or average building elevation of the spatial planning unit / cell or average building height of the spatial planning unit / cell will demonstrate the most vulnerable areas in cities from the building density aspect.

Street canyon ratio

Street canyon is a narrow street with tall buildings along the street on both sides of it. It can be measured as an aspect ratio of average building height along the street and street width.

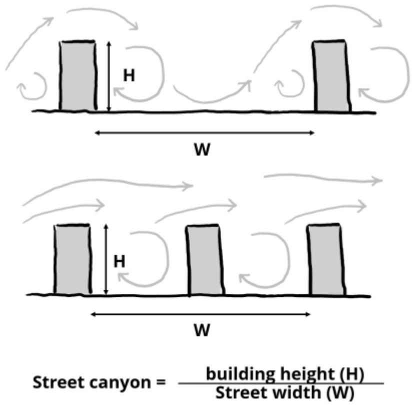


Figure 31: Differences in the wind flow patterns of urban canyons

The indicator can be measured as a ratio of the average building height of the street and the street width, or the average building height divided by the most frequent width of the street canyons in the grid cell with a size for example 250 m x 250 m (Schoetter, 2013).

The size of the grid cells needs to be adapted to the size of the city territory.

Data collection source

Street width and building height are main data needed for measuring the street canyon. The Implementation Municipal Spatial Development Plan, the cadaster of buildings, the 3D city model, open-source platforms like OpenStreetMap (www.openstreetmap.org) or Google Maps (www.google.com/maps) can support the measuring of different types of street canyons.

Measuring guidelines

Higher aspect ratio (taller buildings compared to street width) intensifies the UHI effect by trapping heat and reducing ventilation. Areas with the higher aspect ratio are the most exposed areas to the UHI effect.

The assessment of different aspect ratios on the city level needs to be graphically presented on the map. Different values of the aspect ratio need to be classified based on at least 5-point rating classification scale where higher values can be demonstrated in darker color and the lowest with the lighter color. The size of the grid cells needs to be adapted to the size of the city (Figure 33 and Figure 11).

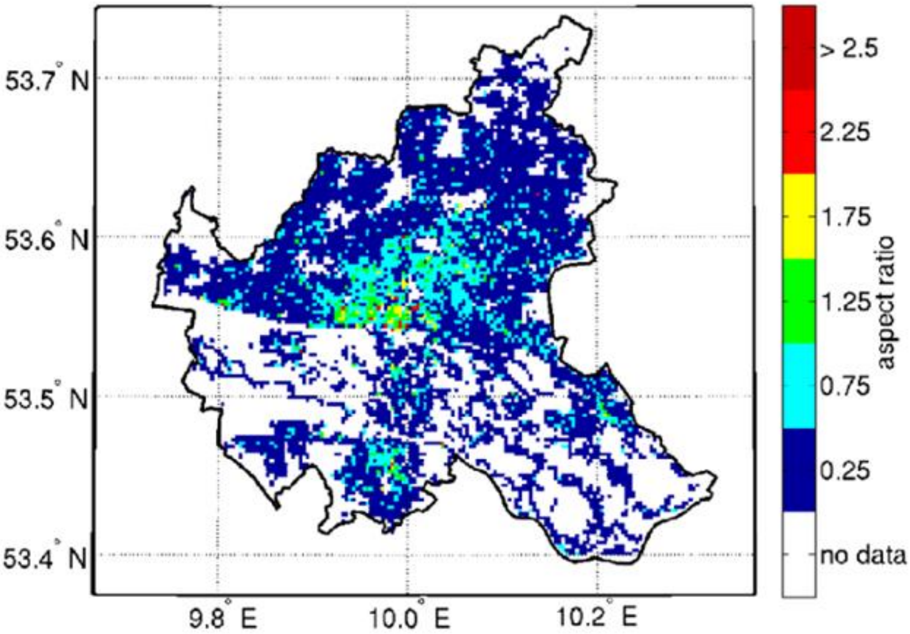


Figure 33: Mapping aspect ratio on the city level (source: Schoetter, 2013)

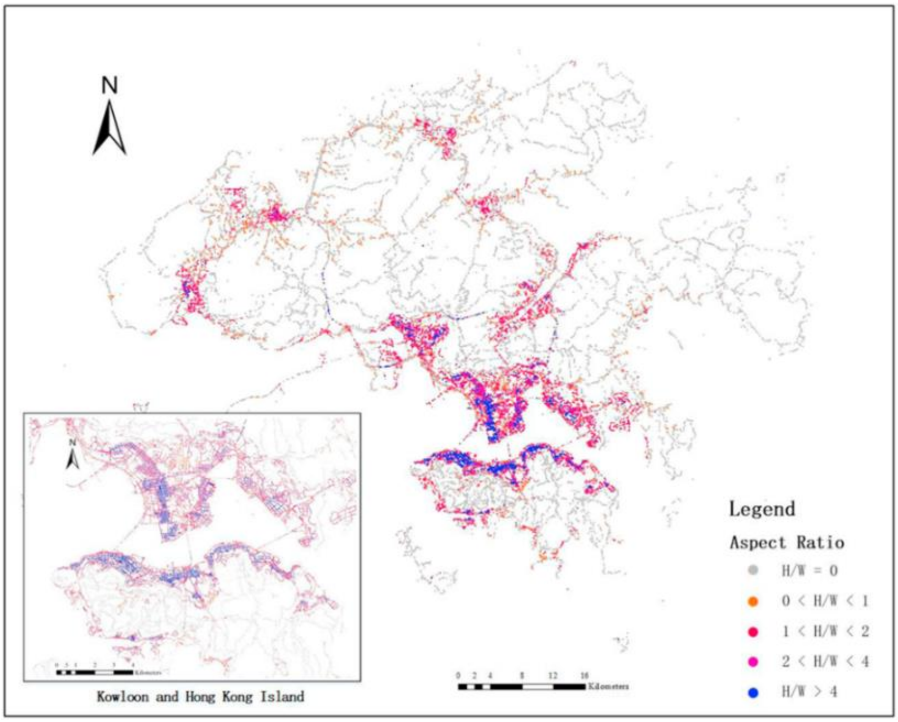


Figure 32: Mapping aspect ratio (source: Hu et al., 2019)

Tree canopy coverage

Tree canopy coverage is a ratio of tree canopy coverage on the entire city level and a city unit (neighborhood, district, city level).

Data collection source

Satellite images are the major data source for measuring tree canopy coverage Figure 12. Tree canopy coverage can be measured by the GIS software programs or online portals like OpenStreetMap (www.openstreetmap.org), Google Maps (www.google.com/maps).

On the EU level data about the tree canopy coverage is available using the Copernicus system (https://land.copernicus.eu/en/products/corine-land-cover/clc2018) which can support mapping tree canopy coverage areas in cities.

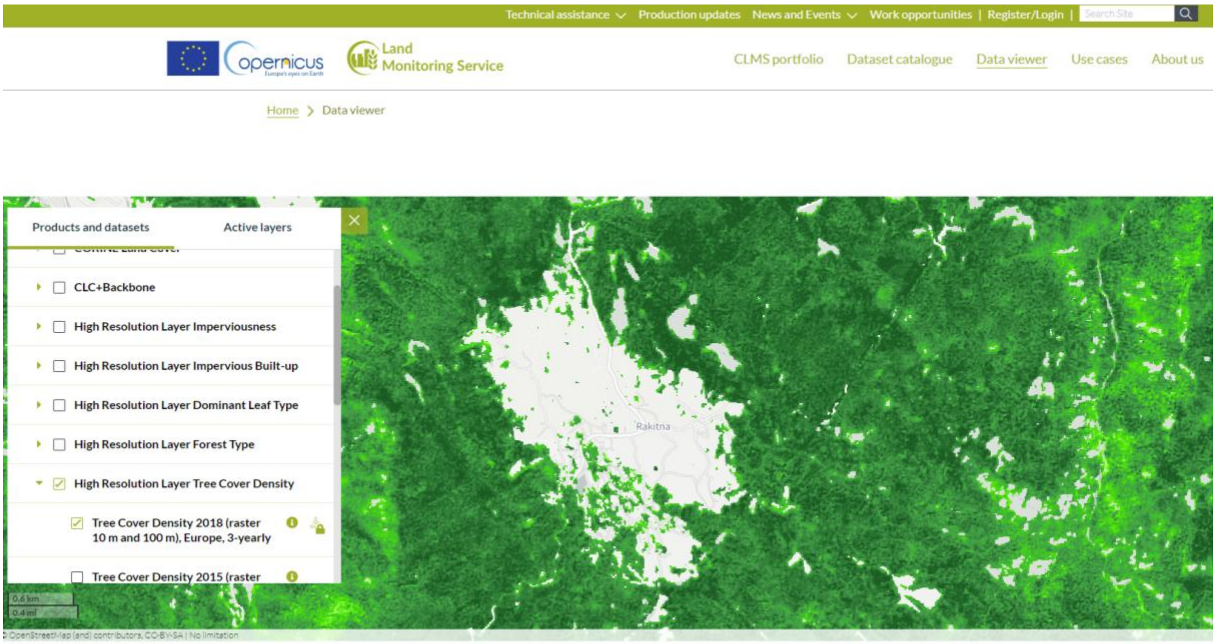


Figure 34: Tree cover density (source: Data viewer — Copernicus Land Monitoring Service)

Measuring guidelines

The assessment of different aspect ratios on the city level needs to be graphically presented on a map. Different values of the tree cover density need to be classified based on at least 5-point rating classification scale where higher values can be demonstrated in lighter color and the lowest with the darker color. They can be demonstrated per spatial planning units or per grid cells. The size of grid cells needs to be adapted to the size of the city territory (Figure 13).

<u>Proposed classification scale:</u>

- **0 % - 20%**
- **21 % - 35 %**
- **36 % - 52 %**
- **53 % - 75 %**
- **76 % - 100**

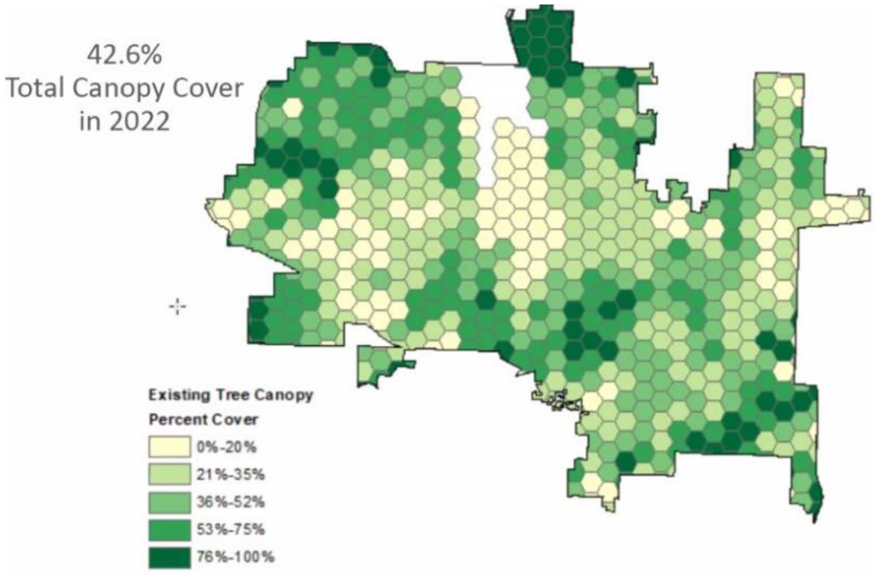


Figure 35: Map with different tree canopy cover ratios on the level of a selected territory (source: https://www.thejoltnews.com/stories/tree-canopy-assessment-olympia-has-426-coverage-with-less-than-3-loss-over-the-past-decade,13080)

Ratio of impermeable surfaces

A ratio of impermeable surfaces is the relation between permeable and impermeable surfaces.

Three categories for permeability are defined:

- permeable surfaces (green spaces)
- semi-permeable surfaces (green roofs and green walls)
- impermeable surfaces (e.g. roads, pavements, parking spaces; covered by hard construction materials like asphalt).

Data collection source

The actual land use layer, the cadaster of buildings, the cadaster of roads and other paved surfaces, the CORINE Land Cover 2018 and other portals are the main sources of data for assessing the level of the permeability of urban surfaces.

Measuring guidelines

The relationship of the permeable and impermeable surfaces can be assessed in different parts of the city and presented on a map at city level. Each city will assess a ratio between permeable and impermeable surfaces as a sum of all permeable and permeable surfaces (e.g. roads, paved parking areas, squares, etc.) and present distribution on a city map as shown below.

The relation of permeable surfaces and impermeable surfaces is a basis for measuring the share of both types of surfaces (Yang et al., 2021). An example of mapping different type of surfaces is shown in Figure 14.

Figure 36: Relation of permeable and impermeable surfaces (source: https://www.ecopiatech.com/resources/blog/impervious-surface-mapping)

Population density

Population density is a measurement of the number of people in an area (inhabitants per hectare or inhabitants per m^2).

Data collection source

Statistical data collections on the national and local level are the main source of information for measuring the population density in cities. Population density can be measured on city level or on the level of parts of the city. Some countries have developed data for population density on different scales with different precision. For example, in Slovenia, data is prepared on the level of a city/municipality, settlement or on the grid with a precision of 1.000 m x 1.000 m (Figure 15).

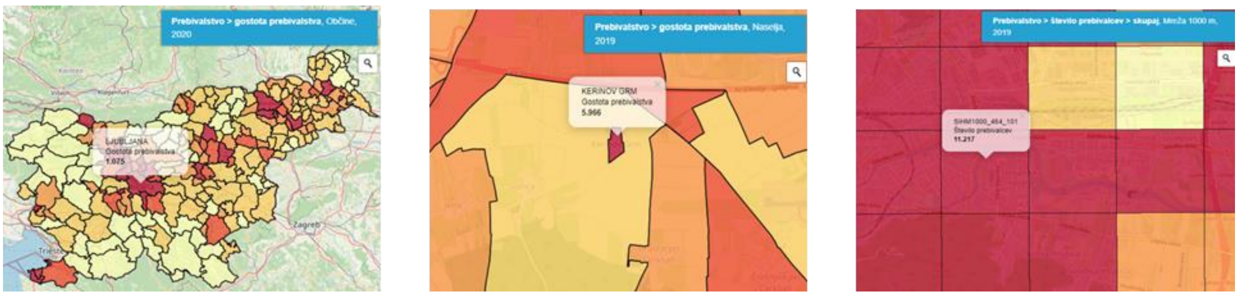


Figure 37: Population of density on different scales (city/municipality, settlement, grid; source: https://www.stat.si/statweb/Field/Index/17)

Measuring guidelines

A distribution of the areas with different densities based on a classification scale at the city level is an important information for addressing solution for UHI. Different population densities need to be classified based on at least a 5-point classification scale where darker colors indicate higher values lighter color indicate lower values. They can be demonstrated per spatial planning unit or per grid cells. The size of grid cells needs to be adapted to the size of the city territory (Figure 16).

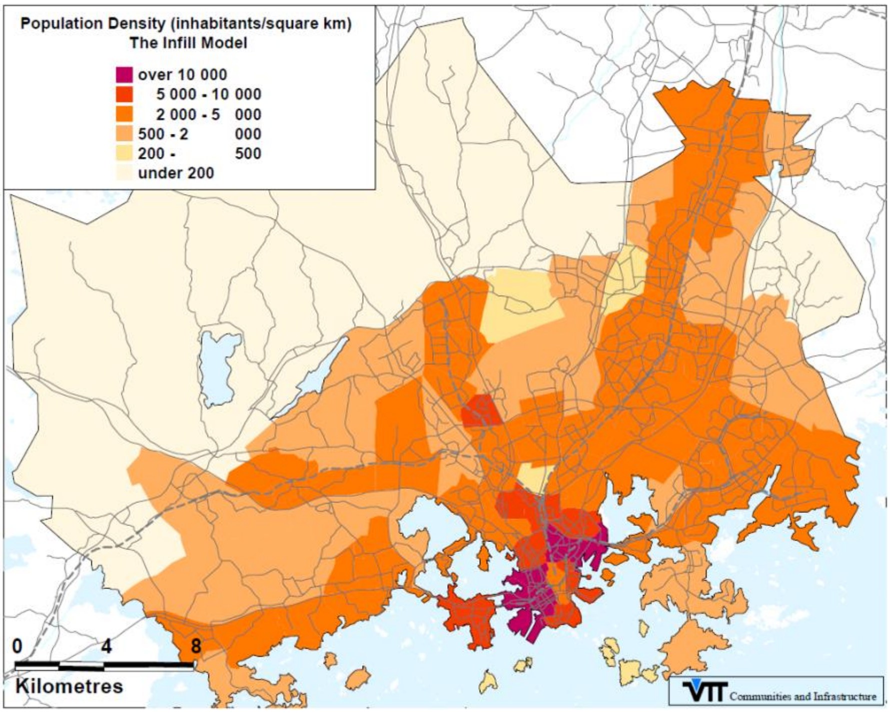


Figure 38: Population density (inhabitants per square kilometre) in the Helsinki Metropolitan Area in the year 2020 in the Infill Model (source: Perrels, 2000).

Land use

Land use is related to the use of land for the needs of human activities like agricultural, residential, industrial, mixed use, recreational and other.

Data collection source

Municipal Spatial Development Plans, especially the implementation part, and actual land use are the main source of data for different types of use of the land. The data of the land use can be available on the national or local portals or another digital version of the city spatial plan.

Some data about the land use is also available from open-source portals like https://data.europa.eu/en (Figure 39 and Figure 40).

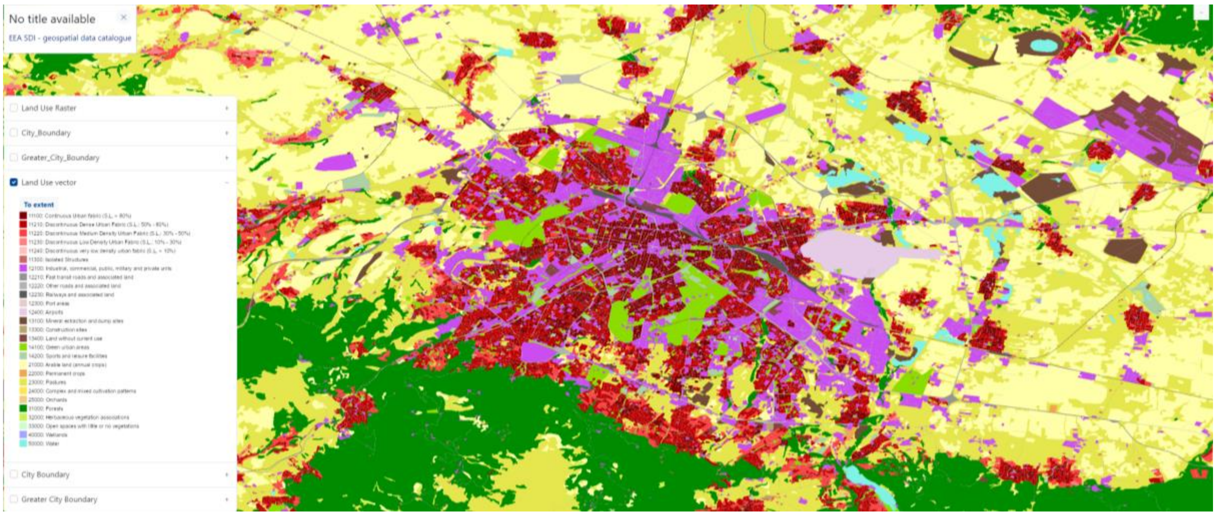


Figure 39: Land use map (source: The official portal for European data | data.europa.eu).

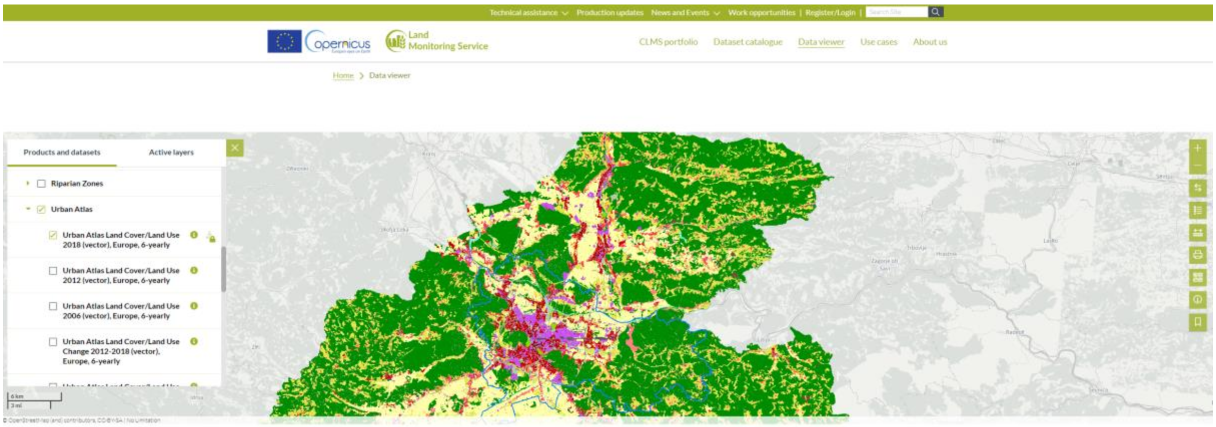


Figure 40: Land use (source: Data viewer — Copernicus Land Monitoring Service).

Measuring guidelines

The distribution of different activities in the city affects energy consumption. Different activities consume different amounts of energy. In case data on energy consumption of buildings is missing, the data about distribution of activities can support the identification of major areas vulnerable to the UHI. In residential areas they can be combined with the building density and population density. For example: industrial areas are the most energy intensive areas in the city, followed by the mixed used areas, high residential areas, etc.

Energy consumption of buildings

Energy consumption of building is the amount of energy consumed by buildings for residential, commercial, industrial and other purposes.

Data collection source

There are different sources of data for energy consumption of buildings. The main source of data are energy certificates of buildings. The other sources can also be energy providers who are responsible for energy supply, energy managers, local energy agencies, etc. which can support the identification of energy intensive consumers on the city level.

Measuring guidelines

For mapping UHI vulnerable areas, distribution of major energy consumers in cities are needed. The results of the assessment of urban areas will be textual and graphical presentations on a map. If possible, cities will define the classification scale for different levels of energy consumptions.

Energy consumption of transportation

Energy consumption of transportation is the amount of energy consumed by transport vehicles.

Data collection source

The Municipal Spatial Plan, Google Maps, Open Streetview are the main source of data for defining main transport corridors with the highest traffic congestion. Additionally, the experts from the transportation sector can also be a vital source of data.

Measuring guidelines

Each partner city will identify areas on the city level with the highest level of traffic congestion and present them on the map of the city UHI assessment.

TOOL APPLICATION GUIDE

Municipal spatial development plans, especially the implementation part, will be the main policy document for mapping UHI vulnerable areas. Assessment of the urban environment can be also supported by other documents like detailed spatial development plans developed for parts of the city, studies and other documents related to the UHI.

- GIS software like QGIS, ESRI Arc Map, etc. enable the evaluation of different indicators of different areas in cities based on the proposed data.
- OpenStreetMap and Google Street view are other alternatives for assessment and evaluation of urban areas based on the guidelines for measuring different indicators.

GUIDELINES FOR MAPPING POTENTIAL UHI AREAS

Each city involved in the Be Ready project will assess their urban environment and define the most sensitive areas in the city (related to the component Exposure of buildings and surroundings vulnerable to the negative effects of UHI. The results of the assessment will be presented in a textual and graphical version once the assessment per risk area/vulnerability area is completed. The results of the evaluation of each indicator will be described and graphically presented with charts and maps of the city.

The results of the assessment of each indicator will be presented based on at least a 5-level scale, where the darkest color will present the areas with the most critical factors with the highest impact on the UHI negative effects, while the lighter color will represent the lowest risk factor to the UHI negative effects.

The assessment of each indicator will be organized along the following steps:

Step 1: Identify which source of data for measuring indicator will be the most useful for the risk assessment process.

Step 2: Identify the data for measuring the indicator.

Step 3: Each indicator needs to be measured in line with the proposed measuring guidelines.

Step 4: Develop a 5-level classification scale where the highest impact on the UHI is the darkest color while the lowest is the lighter color. Usually, higher values have a greater impact on the UHI than the lowest values, except green areas.

Step 5: Present classification of different areas on the map of the entire city territory.

Based on the results of the evaluation process of all selected indicators (Figure 19), the city area that is most vulnerable to UHI effects will be identified. The identified area will be addressed in the following activities of the **Be Ready** project.

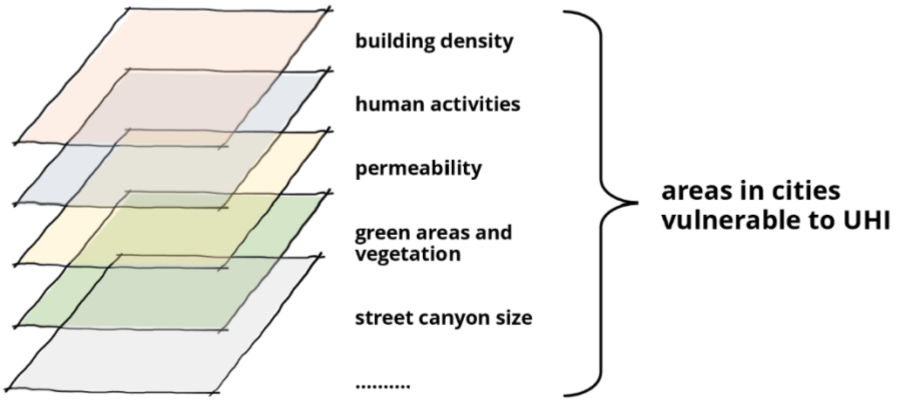


Figure 41: Example of layers of building density, human activities, permeability, green areas and vegetation and street canyon size for the assessment of areas influenced by UHI

TOOL 2 – SENSITIVITY OF EQUIPMENT AND MATERIALS

Aim of the assessment tool

Understanding the properties and conditions of surface materials is essential for assessing their impact on local heat dynamics. Different materials have varying levels of heat absorption and reflectivity, which influence the overall temperature and comfort in urban areas. This data helps identify materials that exacerbate or mitigate the UHI effect. Also, this information is important to document the types of roofing materials used in buildings, their condition, their reflective properties, and their surface temperatures. It is very important for understanding how different roofing materials influence the heat dynamics of urban areas. Regarding heat emitting equipment the idea is to catalog the types of heat-emitting equipment present, their density, typical operational hours, and whether any heat mitigation measures are in place.

This section aims to quantify the contribution of equipment like air conditioning units, industrial machinery, and vehicles to the local heat load. To record current temperature readings, the assessment includes summarizing historical temperature trends if available, and noting the presence of reflective surfaces. Quantifying the contribution of heat-emitting equipment to the local heat load helps identify significant sources of anthropogenic heat. This information can guide efforts to manage and reduce these heat sources, thus mitigating the UHI effect. This helps in understanding the thermal environment and the effectiveness of reflective materials in reducing heat absorption.

Regarding community feedback the aim is to record current temperature readings, summarize historical temperature trends if available, and note the presence of reflective surfaces. This helps in understanding the thermal environment and the effectiveness of reflective materials in reducing heat absorption. The overall purpose is to provide a structured framework for collecting detailed and relevant data on surface materials, heat-emitting equipment, temperature conditions, and community perceptions.

This data can be used to: identify the main contributors to the UHI effect in specific areas, analyze the effectiveness of different materials and technologies in mitigating UHI, develop targeted strategies and policies to reduce the UHI effect, engage the community in the process of identifying problems and solutions and support urban planners and policymakers with empirical data for informed decision-making. The implementation of this serves as a comprehensive approach to systematically collect and analyze field data related to the Urban Heat Island (UHI) effect in urban areas. By standardizing the data collection process, it ensures that the information gathered is consistent, accurate, and thorough, thereby facilitating a more reliable analysis of the factors contributing to local temperature increases. The detailed data obtained through checklists can significantly enhance our understanding of the UHI effect and support the development of effective mitigation strategies and informed urban planning decisions.

The main contributors to UHI regarding equipment and materials are presented below.

Surface Materials - Asphalt and Concrete

Commonly used for roads, pavements, and buildings, these materials have low albedo (reflectivity) and high thermal mass. They absorb and retain heat during the day, releasing it slowly at night, contributing to higher ambient temperatures.

Roofing Materials: Traditional roofing materials like asphalt shingles and metal sheets can significantly absorb heat. Light-colored or reflective materials, such as cool roofs, have higher albedo and can mitigate some of these effects.

Pavements: Materials like conventional concrete and asphalt contribute to the UHI effect, whereas permeable or reflective pavements can help reduce it.

Heat-Emitting Equipment - Air Conditioning Units

Widely used to cool indoor spaces, these units expel hot air into the environment, increasing outdoor temperatures.

Industrial Machinery: Factories and industrial sites often use machinery that generates substantial heat, contributing to local temperature rises.

Vehicles

High traffic density results in significant heat emissions from engines and exhaust systems, especially in congested urban areas.

The UHI effect exacerbates the energy demand for cooling, increases air pollution levels, and intensifies heat-related health issues. Understanding the specific contributors within urban settings is crucial for developing effective mitigation strategies.

Criteria and indicators for identifying equipment and materials as potential contributors to UHI

To effectively identify and assess the impact of materials and equipment contributing to the UHI effect, specific criteria and indicators must be established. These criteria will help in systematically evaluating the potential contribution of various elements to the UHI effect.

Criteria for surface materials

To determine the impact of various equipment and materials on the UHI effect, it is important to understand several key metrics. These metrics provide insight into how different surfaces and objects absorb, retain, and emit heat. Below is an explanation of each metric and its relevance to UHI evaluation (summarized in

Table 18).

Albedo (Reflectivity) Coefficient

Albedo is a measure of how much sunlight a surface reflects. It is expressed on a scale from 0 to 1, where 0 indicates no reflection (all light is absorbed) and 1 indicates total reflection (no light is absorbed). Surfaces with high albedo, such as white roofs or reflective coatings, reflect more sunlight and thus stay cooler. Conversely, low-albedo surfaces, like asphalt, absorb more heat, contributing to higher surface temperatures and the UHI effect.

Thermal Conductivity

Thermal conductivity is the rate at which a material conducts heat. It is measured in watts per meter per Kelvin (W/m·K). Materials with high thermal conductivity transfer heat quickly and can contribute to rapid temperature changes in urban environments. Understanding thermal conductivity helps in selecting materials that minimize heat retention and transfer.

Heat Capacity

Heat capacity is the amount of heat required to raise the temperature of a material by one degree Celsius (or Kelvin). It is measured in joules per kilogram per Kelvin (J/kg·K). Materials with high heat capacity can store large amounts of heat, contributing to prolonged elevated temperatures in urban areas. Evaluating heat capacity is important for understanding how different materials influence overall heat retention.

Surface Temperature

Surface temperature is the temperature of a material's surface, typically measured in degrees Celsius (°C) or Fahrenheit (°F). High surface temperatures are a direct indicator of the heat retention and emission characteristics of materials. Monitoring surface temperatures helps identify hot spots and areas contributing significantly to the UHI effect.

Emissivity

Emissivity is a measure of a material's ability to emit infrared radiation. It is expressed on a scale from 0 to 1, where 0 indicates no emission and 1 indicates perfect emission. Materials with high emissivity efficiently release absorbed heat, while those with low emissivity retain it. Understanding emissivity helps in selecting materials that can effectively dissipate heat.

Material Condition

Material condition is a qualitative assessment of the state of a material, typically categorized as good, fair, or poor. The condition of materials affects their thermal properties. For example, deteriorated surfaces may absorb more heat and have reduced reflectivity. Assessing material condition is essential for accurate evaluation of their impact on UHI.

Coverage Area

Coverage area refers to the extent of a surface or material, measured in square meters (m^2). The larger the coverage area of a heat-contributing material, the greater its impact on the UHI effect. Quantifying coverage area helps in understanding the spatial distribution of heat sources.

Vegetative Cover

Vegetative cover is the percentage of an area covered by vegetation. Vegetation plays a crucial role in cooling urban environments through shading and evapotranspiration. Higher percentages of vegetative cover can mitigate the UHI effect. Assessing vegetative cover is vital for identifying areas where increasing green spaces could reduce urban temperatures.

The following tables provide information on criteria for surface material evaluation for the assessment of their impact on the development of UHI.

Table 19 categorizes surface materials by their impact on UHI development. Asphalt has high heat absorption and low reflectivity, significantly contributing to UHI. Concrete has moderate absorption and reflectivity. Cobblestone's absorption varies by material type. Green roofs and pervious pavers have low absorption and high reflectivity, making them effective implementations for UHI mitigation.

Table 18: Indicators for the assessment of the influence on materials and UHI

Indicators - materials	Measurement unit
Albedo (reflectivity) coefficient	Scale from 0 to 1
Thermal conductivity	Watts per Kelvin
Heat capacity	Joules per KG Kelvin
Surface temperature	Degrees Celsius (Fahrenheit)
Emissivity	Scale 0 to 1
Material condition	Qualitative assessment (good, fair, poor)
Coverage area	Square meters
Vegetative cover	% of area covered by vegetation

Table 19: Description of the type of surface material

Type of material	Notes
Asphalt	High heat absorption and low reflectivity.
Concrete	Moderate heat absorption and moderate reflectivity.
Cobblestone	Variable heat absorption depending on material type.
Green Roofs/Pervious Pavers	Low heat absorption, high reflectivity.

Table 20 outlines the condition of surface materials, which affects their heat absorption properties. Materials in good condition are new or well-maintained and typically perform better in terms of reflecting heat. Fair condition materials are moderately worn, while poor condition materials are deteriorated and may increase heat absorption due to their degraded state.

Table 20: Description of the condition of different materials

Condition of material	Notes
Good	New or well-maintained surfaces
Fair	Moderately worn surfaces
Poor	Deteriorated surfaces that may increase heat absorption

Table 21 explains the albedo coefficient, which measures the reflectivity of surface materials. High albedo materials, such as light-colored concrete, reflect a large portion of sunlight, reducing heat absorption. Conversely, low albedo materials, like dark asphalt, absorb most sunlight, contributing to higher surface temperatures and UHI effects.

Table 21: Categorization of the albedo coefficient of surfaces

Albedo Coefficient	Notes
High Albedo	Reflects a large portion of sunlight (e.g., light-colored concrete)
Low Albedo	Absorbs most sunlight (e.g., dark asphalt)

Table 22 describes the thermal properties of surface materials, focusing on thermal conductivity and heat capacity. Thermal conductivity indicates how quickly a material absorbs and transfer's heat. Heat capacity measures the amount of heat a material can store. Both properties are crucial in understanding how different materials contribute to UHI by retaining and transferring heat.

Table 22: Thermal properties of materials

Thermal Properties	Notes
Thermal Conductivity	How quickly the material absorbs and transfers heat
Heat Capacity	The amount of heat the material can store

Table 25 provides information on surface temperatures measured during different times of the day. Daytime temperature is measured with thermal imaging during peak sunlight hours to assess the material's heat absorption. Night-time temperature measurements help determine how well the material retains heat, which is important for evaluating its impact on night-time cooling and overall UHI effects.

Table 23: Surface temperatures

Surface Temperature	Notes
Daytime Temperature	Measured with thermal imaging during peak sunlight hours
Nighttime Temperature	Measured to assess heat retention

Criteria and indicators for heat-emitting equipment

Heat emitting equipment can have an impact on amplifying the negative effect of UHI. By assessing the type of equipment, operational hours, heat output, location density, and proximity to sensitive areas, we can develop strategies to manage and reduce heat emissions effectively.

To effectively assess the impact of various equipment on the Urban Heat Island effect, it is crucial to understand several key indicators. These indicators provide insight into how different types of equipment contribute to heat generation and retention in urban areas. Below is an explanation of each indicator and its relevance to UHI evaluation (summarized in Table 24).

Operational Hours - Average hours per day

This indicator measures the average amount of time per day that equipment is operational. Equipment that operates for longer periods tends to generate more heat, contributing to the UHI effect. Understanding operational hours helps in identifying which equipment has the highest impact on urban temperatures.

Heat Output - British thermal units (BTUs) or kilowatts (kW)

Heat output is the amount of heat energy emitted by equipment, measured in BTUs or kilowatts. High heat output from equipment such as air conditioning units or industrial machinery can significantly raise local temperatures. Quantifying heat output helps in assessing the contribution of different equipment to the UHI effect.

Density of Equipment - Number of units per square meter (m²).

Density of equipment refers to the number of units present in each area. High density of heat-emitting equipment in a specific area can lead to localized hotspots. Measuring equipment density helps in understanding the concentration of heat sources and their potential impact on urban temperatures.

Proximity to Sensitive Areas – Distance in meter

Distance in meters. This indicator measures the distance of heat-emitting equipment from sensitive areas such as schools, hospitals, and residential zones. Equipment located close to sensitive areas can pose higher risks to vulnerable populations. Assessing proximity helps in identifying and mitigating potential health risks associated with the UHI effect.

Cooling Load and Efficiency - Energy efficiency ratio (EER)

Energy efficiency ratio (EER). Cooling load is the amount of cooling required to maintain a desired temperature, while energy efficiency ratio (EER) measures the efficiency of cooling equipment. Efficient cooling systems with high EER values produce less waste heat, reducing their contribution to the UHI effect. Evaluating cooling load and efficiency helps in promoting the use of energy-efficient equipment.

Maintenance Status

Maintenance records, visual inspections. Maintenance status indicates the condition and upkeep of equipment, assessed through maintenance records and visual inspections. Well-maintained equipment operates more efficiently and emits less heat compared to poorly maintained units. Assessing maintenance status helps in ensuring optimal performance and minimizing heat emissions.

Surface Area of Equipment - Square meters (m²) or cubic meters (m³)

Surface area refers to the physical dimensions of equipment, measured in square meters for surface area and cubic meters for volume. Larger equipment tends to have a greater surface area for heat exchange, potentially increasing heat emissions. Measuring surface area helps in understanding the scale of heat contributions from different equipment types.

Table 24: Indicators for the assessment of equipment

Indicators - equipment	Measurement unit
Operational hours	Average hours per day
Heat output	British thermal units kilowatts
Density of equipment	Number of units per m2
Proximity to sensitive areas	Distance in meters
Cooling load and efficiency	Energy efficiency ratio
Maintenance status	Maintenance records, visual inspections
Surface area of equipment	Square meters, cubic meters

Table 25 categorizes equipment based on their heat emission characteristics. Air conditioning units have high operational heat output, industrial machinery emits constant and high levels of heat, and vehicles serve as mobile sources with variable output.

Table 25: Type of equipment

Type of Equipment	Notes
Air Conditioning Units	High operational heat output
Industrial Machinery	Constant and high levels of heat emission
Vehicles	Mobile heat sources with variable output

Table 26 This table describes equipment based on their operational hours. It differentiates between equipment running during peak temperature hours (daily operation) and machinery that operates continuously, 24/7.

Table 26: Description of operational hours of equipment

Operational Hours	Notes
Daily Operation	Equipment running during peak temperature hours
Continuous Operation	Machinery that runs 24/7 versus intermittently

Table 27 classifies equipment by their heat emission levels. Low output includes small residential AC units, medium output covers commercial AC units, and high output pertains to industrial machinery.

Table 27: Output of heat - equipment

Heat Output	Notes
Low	Minimal heat emission (e.g., small residential AC units)
Medium	Moderate heat emission (e.g., commercial AC units)
High	Significant heat emission (e.g., industrial machinery)

Table 28 examines the density of heat-emitting equipment in an area. Low density has fewer than 1 unit per 100 m², medium density has 1-10 units, and high density includes more than 100 units per 100 m².

Table 28: Description of location density

Location Density	**Notes**
Low Density	Fewer than 1 unit on 100 m2
Medium Density	1-10 units Moderate number of units
High Density	More than 100 units per 100 m2 in certain area

Table 29 assesses the proximity of equipment to sensitive areas. Equipment close to residential zones has a higher impact on human comfort, while proximity to green spaces, categorized as close (1-50 m), moderately near (50-200 m), and far (more than 200 m), can offset heat effects.

Table 29: Determination of the proximity of equipment to sensitive areas

Proximity to Sensitive Areas	**Notes**
Close to Residential Zones	Higher impact on human comfort
Near Green Spaces	Potential to offset heat effects (Near 1-50 m, moderately near 50-200 m, Far more than 200 m)

Data collection for identifying materials and equipment as contributors to UHI

To effectively identify and map the data on materials and equipment contributing to the UHI effect in local municipalities, a structured data collection approach is essential. Although all the methods are equally important to get relevant data, it is recommended to use remote sensing and thermal imaging because they provide comprehensive coverage, precise temperature measurements and detailed analysis. Table 13 provides the detailed steps and methods for gathering relevant data.

To collect data, the current methodology proposes guidelines for field data collection on factors contributing to the Urban Heat Island effect. They ensure comprehensive and consistent documentation of surface materials and heat-emitting equipment in urban areas.

Location information

This section captures the basic details about the location and the individual conducting the assessment. This information is essential for data validation, replication, and contextual analysis.

- **District/Neighborhood**: Specifies the area where the data is being collected, helping to identify and categorize different urban zones.
- **Coordinates**: Provides the exact geographical location using latitude and longitude, ensuring precise mapping and analysis.
- **Date**: Indicates the date of data collection, which is important for tracking temporal changes and seasonal variations.
- **Assessor Name**: Records the name of the person conducting the assessment, which helps in tracking data sources and accountability.

Surface materials

This section focuses on documenting the types of surface materials present in the area, their condition, and thermal properties. This information is crucial for understanding how different materials contribute to the UHI effect.

- **Material Type**: Identifies the type of surface material (e.g., Asphalt, Concrete, Cobblestone, Green Roof), which affects heat absorption and retention.
- **Condition**: Assesses the current state of the material (Good, Fair, Poor), which can influence its thermal properties and longevity.
- **Albedo Coefficient**: Measures the reflectivity of the surface on a scale from 0 to 1. Higher albedo indicates more reflectivity and less heat absorption.
- **Surface Temperature**: Records the surface temperature in degrees Celsius (°C), providing direct data on heat retention by different materials.
- **Coverage Area**: Measures the area covered by the surface material in square meters (m^2), helping to quantify its extent and impact.

Heat-emitting equipment

This section catalogs various types of equipment that emit heat, their operational characteristics, and their impact on the surrounding environment.

- **Equipment Type**: Identifies the type of equipment present (e.g., Air Conditioning Units, Industrial Machinery, Vehicles), each with different heat emission profiles.
- **Density**: Assesses the concentration of equipment in the area (Low, Medium, High), indicating the potential intensity of heat emission.

- **Operational Hours**: Measures the average number of hours per day the equipment is operational, influencing the overall heat output.
- **Heat Output**: Quantifies the amount of heat emitted by the equipment, measured in British Thermal Units (BTUs) or equivalent units, providing a direct measure of its contribution to the UHI effect.
- **Proximity to Sensitive Areas**: Measures the distance from the equipment to sensitive areas such as schools, hospitals, and residential zones in meters. This helps assess the potential health impacts on vulnerable populations.

The collected data can be analyzed to identify key contributors to the UHI effect, inform mitigation strategies, and support urban planning efforts to create more sustainable and comfortable environments. By ensuring consistency and comprehensiveness of the data in the assessment process, city authorities can make informed decisions to reduce the UHI effect and protect vulnerable populations from heat-related risks.

Table 30 Data collection methods related to materials and equipment

	Data to collect	Methods
Surface materials		
Roads and Pavements	Type of materials (asphalt, concrete, cobblestone, permeable pavers)	-Remote Sensing: Use satellite imagery (e.g., Google Earth, Sentinel-2) to identify material types and condition -On-Site Surveys: Physically inspect and document material types and conditions -Municipal Records: Access construction records and permits for detailed material information
	Surface condition (good, fair, poor)	
	Albedo coefficient	
	Surface temperature	Thermal Imaging: Deploy thermal cameras or infrared thermometers for on-ground surface temperature measurements
Roofs	Types of roofing materials (asphalt shingles, metal sheets, ceramic tiles, green roofs)	-Aerial Imagery: Use aerial photographs or drone surveys to identify and document roofing materials -Building Permits: Review historical data on roofing materials from building permits -On-Site Inspections: Conduct physical inspections to validate remote data
	Surface condition (good, fair, poor)	
	Albedo coefficient	
	Surface temperature	Thermal Imaging: Measure surface temperatures using thermal cameras or infrared thermometers
Heat-emitting equipment		
	Location and density of units per building	Field Surveys: Conduct physical counting and documentation of air conditioning units

Air conditioning units	Average operational hours	Utility Data: Analyze energy consumption records to estimate operational hours
	Heat output	-Utility Data: Analyze energy consumption records to estimate heat output -Thermal Imaging: Use thermal cameras to measure heat emissions from units
Industrial machinery	Type of machinery Average operational hours	-Industry Records: Obtain information from local industries about machinery types and operational schedules -Surveys: Conduct interviews with industry representatives to gather detailed data - Utility Data: Analyze energy consumption records to estimate operational hours
	Heat output	-Field Inspections: Document and measure heat emissions using thermal cameras - Utility Data: Analyze energy consumption records to estimate heat output
Vehicles	Traffic density Types of vehicles (cars, trucks, buses) Average idling times	-Traffic Cameras: Use existing traffic cameras to monitor and record vehicle density and types -Thermal Imaging: Measure heat emissions from vehicles during peak traffic hours -Surveys: Collect data from traffic management authorities and conduct roadside surveys
Community engagement		
Citizen science	Perceived heat levels Presence and type of equipment and materials Suggestions for mitigation	- Mobile Apps: Utilize apps like Survey123 for community-driven data collection -Workshops and Focus Groups: Conduct sessions to gather qualitative data and validate findings
Remote Sensing and GIS mapping		
	Land surface temperature Vegetation cover (NDVI)	-Satellite Imagery: Use Landsat and Sentinel-2 for temperature and vegetation data -GIS Software: Employ GIS tools (e.g., ArcGIS, QGIS) to integrate and analyze spatial data.

Tool application guide

To effectively evaluate and map equipment and materials contributing to the UHI effect, a combination of remote sensing technologies, field survey tools, data analysis software, and community engagement methods should be used. Below is a detailed list of the exact tools required for this evaluation.

Step 1: Planning and Preparation

- Define Objectives and Scope

Identifying the specific goals (e.g., pinpointing hot spots, assessing material impacts, evaluating mitigation strategies).

Defining the geographic area of interest (e.g., specific neighborhoods, districts, or cities).

- Assemble the Team

Including experts in remote sensing, GIS, urban planning, data analysis, and community engagement.

- Gather Required Tools and Resources

Ensuring availability of remote sensing tools, thermal imaging tools, field survey tools, data analysis software, and community engagement tools as outlined in the checklist.

To help the assessment of heat emissions from buildings, look at these Standards and Reference Materials:

- Construction standards ISO 13790: for energy performance of buildings
- ASTM Standards: For measuring albedo and thermal properties of materials
- Building codes: Local building regulations that provide information on commonly used construction materials.

Step 2: Remote Sensing and Preliminary Analysis

- Collect Satellite and Aerial Imagery
    - Obtain thermal infrared data from open-source observation satellite (Landsat 8) for land surface temperature mapping.
    - Use another satellite (Sentinel-2) for high-resolution imagery to identify material types and vegetation cover.
    - Leverage satellite-based sensor (MODIS) for broader scale surface temperature mapping.
    - Use Google Earth Pro and drones equipped with thermal cameras for high-resolution, localized temperature data and material identification.
    - Analyze Imagery for Initial Insights
    - Use QGIS software to overlay satellite and aerial imagery with existing maps.
    - Identify areas with high surface temperatures and potential heat-emitting equipment. This can be completed with urban planning documents like Spatial Development Plan, that provide information on land use and zoning, which helps in identifying areas with different types of materials and equipment.

Step 3: Field Surveys and Data Collection

- Prepare for Field Surveys
    - Equip field teams with GPS devices for accurate location tracking during field surveys (e.g., GPSMAP Series), thermal cameras (e.g., FLIR Systems, Seek Thermal

(which is more affordable), and infrared thermometers (e.g., Fluke Infrared Thermometers (for quick and spotted measurements).

  - Install and configure data collection apps:
    - Epicollect5: Mobile app for systematic data collection in the field
    - Survey123 for ArcGIS: for creating and distributing surveys and collecting spatial data.

- Conduct Field Surveys
  - Visit identified hot spots and areas of interest to collect detailed data on surface materials and heat-emitting equipment.
  - Use GPS devices for accurate location tracking.
  - Measure surface temperatures using thermal cameras and infrared thermometers.
  - Record material types, conditions, and coverage areas using the checklist.
  - For measuring distances on the ground, use measuring wheels or tape measures for precise measurements.
- Collect Community Feedback
  - Distribute surveys via Google Forms or Microsoft Forms to gather community perceptions of heat levels and suggestions for mitigation.
  - Encourage community participation using mobile apps such as:
    - Survey123 for ArcGIS: Enables community members to report observations and participate in data collection.
    - Next-door: a community networking app that can be used to engage residents and collect localized data.

Step 4: Data Integration and Analysis

- Integrate Collected Data
  - Import field survey data, remote sensing data, and community feedback into QGIS, for example, an open-source GIS software for mapping and spatial analysis.
  - Ensure all data is georeferenced and properly aligned for spatial analysis.
- Perform Spatial and Statistical Analysis
  - Use GIS tools to map heat distribution and correlate with material types and heat-emitting equipment density.
  - Perform statistical analysis using R or Python (with libraries like GeoPandas and Matplotlib) to identify significant contributors to the UHI effect.

Step 5: Reporting and Visualization

- Generate Maps and Reports
  - Create detailed maps showing temperature variations, material distributions, and equipment locations using GIS software.
  - Compile a comprehensive report summarizing findings, including statistical analysis and community feedback.
- Develop Recommendations

- Based on the analysis, develop targeted strategies for UHI mitigation, such as increasing green roofing, enhancing reflective materials, or improving heat emission controls.

- Share Results with Stakeholders
    - Present findings to urban planners, policymakers, and the community through meetings, workshops, and digital platforms.
    - Use visualizations and maps to clearly communicate key insights and recommendations.

TOOL 3 – VULNERABLE GROUPS

Aim of the assessment tool

Heat waves in combination with UHI pose severe health risks to vulnerable populations including children, elderly persons, individuals with pre-existing health conditions and inhabitants in socioeconomically disadvantaged areas. The elderly population is especially susceptible due to their reduced ability to regulate body temperature and the presence of chronic health issues. Children, with their developing bodies and higher surface-area-to-mass ratio, are also at greater risk of heat-related illnesses. Individuals with cardiovascular, respiratory, and other chronic conditions may experience exacerbated symptoms during heat waves, leading to increased morbidity and mortality rates. The risk of mortality is increased by 1% to 3% for each rise of 1°C (Alonso and Renard, 2020). Vulnerable populations living in urban areas face compounded risks due to the UHI effect, which can lead to higher incidences of heat stroke, dehydration, and other heat-related illnesses. Additionally, socioeconomic factors often limit access to cooling resources like air conditioning, further increasing the vulnerability of these groups during extreme heat events.

To address this specific issue this tool provides a guide for cities/municipalities to identify the needed data to map the vulnerable groups, better understand the dynamics of heat-related risks and to identify priority areas for intervention. This information allows for targeted implementation of measures such as increasing green spaces, enhancing urban design to improve airflow, and providing resources like cooling centers in the most affected areas. Effective mapping and analysis help prioritize efforts, ensuring that resources are allocated efficiently and that the most vulnerable populations receive the necessary protection during heat waves.

For a quantitative assessment this tool will provide a Vulnerability Index (VI) which measures the overall vulnerability regarding risk groups. The VI is calculated using multiple indicators based on the population of a defined area. The methodological framework for the assessment is presented in Figure 42. The provided method includes the determination of the needed data sources, indicator selection, data collection and VI calculation. In addition, the application of story maps shall further support the knowledge by using a narrative collection method of inhabitants.

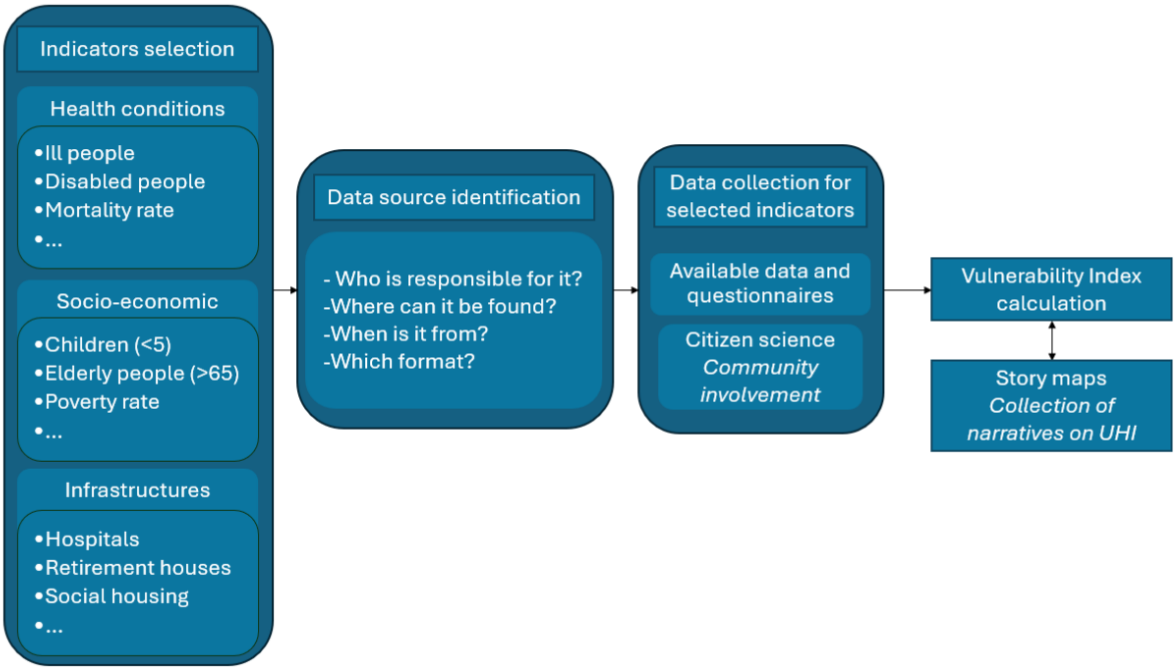


Figure 42: Methodological framework for the assessment of the vulnerability index (source: BOKU)

CRITERIA AND INDICATORS FOR VULNERABLE GROUPS

A vulnerable group is defined as a population more likely to experience harm caused by the effects of UHI (Kuran et al., 2020). These groups are either less resistant to heat or more exposed to it. The human body must maintain a temperature around 37°C year-round, employing various thermoregulatory mechanisms, such as sweat production, increased cardiac output, and redirection of blood flow to the skin, especially in high temperatures (Hajat et al., 2010). There are multiple vulnerable groups to consider, each with unique susceptibilities to the adverse effects of heat. A full list of indicators is provided in Table 31. The indicators are divided into three categories: *socio-economic*, which contains information on the people's age and their social and financial situation; *health conditions*, providing information on the health state of the population and *infrastructure*, informing on the number of infrastructures containing vulnerable people.

The elderly population, defined as individuals over the age of 65, faces unique challenges during periods of high temperatures. Older adults often have a diminished ability to perceive heat and may not feel the need to drink adequate fluids, making them more susceptible to dehydration and heat-related illnesses. Physiological changes associated with aging, such as reduced sweat glands function and lower cardiovascular efficiency, further increase their vulnerability to extreme heat. Additionally, elderly individuals are more likely to live alone or in social isolation, which exacerbates the risks associated with high temperatures. Without regular social interactions or a support network, they may not receive timely assistance or reminders to stay hydrated and cool. This isolation also means they are less likely to have access to air-conditioned environments, further increasing their risk during heatwaves (Hajat et al., 2010).

Children under five years old and infants, like elderly individuals, have difficulty regulating their body temperature. Their underdeveloped metabolic systems make it harder for them to dissipate body heat, rendering them more susceptible to overheating. This reduced ability to thermoregulate makes them less resistant to high temperatures and at a higher risk for heat-related illnesses.

People with chronic illnesses, such as respiratory and cardiovascular conditions, are at a higher risk of heat-related death compared to healthy individuals. Medications for asthma, heart disease, and diabetes can impair thermoregulation by reducing the ability to sweat, thereby increasing their vulnerability to high temperatures. Additionally, disabled individuals, including those with reduced mobility, often rely on caregivers for assistance, limiting their ability to seek cooling measures independently and making them more susceptible to heat-related health issues.

The homeless population is also affected by UHI as they often remain within these heat-prone areas with limited access to water. This exposure is exacerbated by a lack of access to healthcare and social services that could provide support during heatwaves. Low-income individuals are also of concern because they are more likely to live in poorly insulated buildings, face unaffordable hospital expenses, and have less access to information resources, further increasing their vulnerability to extreme heat conditions.

As most urban construction work occurs during the summer, outdoor workers are directly exposed to high temperatures for extended periods, making them particularly vulnerable to the negative effects of UHI. Prolonged exposure to high temperatures can lead to heat-related illnesses such as heat exhaustion, heat stroke, and dehydration, significantly impacting their health and productivity. Additionally, the physical nature of their work increases their internal body temperature, compounding the risks associated with extreme heat.

Residents in densely populated urban areas are particularly susceptible to UHIs. The height and density of buildings in these areas can obstruct wind flow, reducing natural ventilation and trapping heat. This phenomenon increases the ambient temperature, making these neighborhoods significantly warmer than their rural counterparts. The lack of green spaces and high concentration of heat-absorbing surfaces, such as concrete and asphalt, further exacerbate the UHI effect. Consequently, residents in these areas face increased risks of heat-related health issues, decreased air quality, and heightened energy consumption for cooling purposes. Urban planning initiatives that incorporate more green spaces, reflective materials, and improved building designs are essential to mitigating these effects.

Certain ethnic and racial groups often reside in poorly insulated buildings, making them more vulnerable to extreme temperatures exacerbated by the UHI effect. Language barriers can impede access to crucial information about heat warnings and available resources, further compounding their risk. Additionally, these groups are frequently marginalized socially, economically, and politically, limiting their access to healthcare, financial support, and political advocacy. This marginalization can lead to poorer health outcomes and reduced resilience to environmental stressors. Addressing these disparities requires targeted interventions, including community outreach programs, translation services for public health information, and policies aimed at improving housing quality and accessibility for marginalized communities. Ensuring equitable access to resources and support is critical for enhancing the resilience of these vulnerable populations.

Table 31 : Indicators for the evaluation of the Vulnerability Index. All indicators, except for hospitals capacity and health centres* are increasing the value of the vulnerability index when increasing themselves. Grey highlighted indicators are essential.*

Indicator	Definition	Relation to UHI
	Socio-economic	
Young people (%)	The proportion of children under the age of 5 over the total population	Children under 5 years of age are more rapidly dehydrated because of their difficulty in regulating their metabolism
Elderly people (%)	The proportion of people over the age of 65 over the total population.	Like children, elderly people are more rapidly dehydrated because of their difficulty in regulating their metabolism
Poverty rate (%)	The proportion of people living below the risk-of-poverty threshold over the total population	People living below the risk-of-poverty threshold don't have the financial resources to deal with overheating
Unemployment rate (%)	The proportion of unemployed people over the total population	People with low income don't have the financial resources to deal with overheating
Gender (%)	The proportion of females over the total population	Women are disadvantaged compared to male in heat stress situations because of physiological differences, even more for pregnant women
Immigrated people (%)	The proportion of immigrated people over the total population	Immigrated people can be linguistically isolated and live in poor insulated buildings
Low-skilled jobs (%)	The proportion of people with low-skilled jobs over the employed population	Low-skilled jobs offer less financial opportunity to face the heatwave events and they are often in extreme conditions like for outdoor workers
Social housing (%)	The proportion of people living in social housings over the total population	Social housing indicates more about the poverty rate and low-income proportion
Density of population	The number of inhabitants per km²	People living in high density places are more vulnerable because they generally have lower income and no air-conditioning
Retired people (%)	The proportion of retired people over the total population	The number of retired people indicates more about the number of elderly people
	Health conditions	
Ill people (%)	The proportion of people with illnesses like diabetes, asthma, hypertension, obesity over the total population	People with chronic illnesses take medication that can affect thermoregulation by reducing their ability to sweat

Disabled people (%)	The proportion of people receiving Adult Disabled Benefit (ADB) over the total population	People receiving ADB are dependent on other people and services
Mentally ill people (%)	The proportion of people receiving mental health services over the total population	People with mental illness may be prone to cognitive impairment and medication side effects that can interfere respectively with awareness and thermoregulation
Mortality rate (%)	The proportion of deaths in a year over the total population	The mortality rate can indicate deteriorated health and thus vulnerability to high temperatures
Infrastructure		
Hospitals capacity*	The number of beds in hospitals per 1000 inhabitants	Hospital's capacity indicates especially the preparedness of the city to manage heat-related diseases
Health centres*	The number of health institutions of all types (private or public) per 1000 inhabitants	The number of health institution indicates how much the citizens have support and care in the event of a heat-related disease
Retirement houses	The number of retirement houses	The number of retirement houses in the area indicates the presence of elderly people
Social housing	The number of social housings	The number of social housings indicates the presence of financially disadvantaged people

Vulnerability Index

For the evaluation of the vulnerability in different areas of the municipality. The vulnerability index is calculated by a weighted sum of all indicators: it is the sum of the products of the normalized value of each indicator with their respective weight (Equation (1)). The scale of the VI is from 0 to 1.

$$VI_0 = \sum_i w_i * nv_i \quad (1)$$

With VI_0 the vulnerability index on the scale from 0 to 1, w_i the weight of the indicator i, and nv_i the normalized value of the indicator i.

The normalization of the values is for a better comparison and to ensure the final scale of the VI. The values are normalized by subtracting the minimum value for the specific indicator to the value and then dividing it by the difference between the maximum and the minimum (Equation (2)).

$$nv_i = \frac{(v_i - v_{min})}{(v_{max} - v_{min})} \quad (2)$$

With v_i the value of the indicator i, v_{min} the minimum value of this indicator and v_{max} the maximum value of this indicator.

A higher value of this index means that the studied area is more vulnerable to the UHIs regarding risk groups. That can mean that during heatwaves, potentially a lot of people will suffer from heat-related disease. For the scale to go from 1 to 5 with 5 being the highest value, you must change the scale of the index (Equation (3)).

$$VI_1 = 1 + 4 * VI_0 \quad (3)$$

For example, if the VI calculated is of 0,5 out of 1, its value on the scale from 1 to 5 would be of 3 (Equation (4)).

$$VI_2 = 1 + 4 * 0{,}5 = 3 \quad (4)$$

With VI_2 the value of the Vulnerability Index of the example on the scale from 1 to 5.

Determination of index weights

For each indicator a weight needs to be assigned (values between 0 and 1). This weight expresses the importance of the indicator and therefore its contribution to the vulnerability index. For example, the proportion of elderly people can be more important to consider for assessing the vulnerability of an area regarding risk groups than the population density.

For the identification of weights, hence, to determine the importance of specific indicators over others, a workshop including the involved persons from the municipality needs to be carried out during the city UHI assessment process. First, identify the involved persons, stakeholders and experts to include in the workshop. During the workshop, present the indicators that will be used in the vulnerability index and facilitate discussions to gather input on their relative importance and systematically assign weights to each indicator. Ensure a structured process for collecting and analyzing the data and provide opportunities for feedback and revisions. Finally, document the findings and consensus reached during the workshop, and communicate the results to all stakeholders, ensuring transparency of the vulnerability index.

This method has its limits especially because of the weighting of the indicators and the choice of indicators. It is, therefore, important to combine this result with the input of the citizens. Cities can, for example, organize meetings with some designated citizens to get feedback. Local authorities can use social media to engage even more the community and inform them of the results. Through this media, they can also raise awareness before and during heatwaves by communicating appropriate behavior.

Data collection

Most important for the calculation of the vulnerability index for vulnerable groups is the availability of data for the indicators listed in **Error! Reference source not found.**. The municipality needs to identify the departments or organizational units for each indicator and identify the data availability.

The data, categorized into socio-economic, health conditions, and infrastructure sections, can be sourced from various places, including existing datasets and open-source platforms (e.g., European Union's data portal http://data.europa.eu/euodp or governmental databases). Data related to socio-economic status can usually be found on national census statistics or official household surveys. For the statistics on health, it is possible to get them via health ministries and departments, open data from national disease control bureaus or health surveillance systems. The information on the hospitals' capacity is generally found via local health authorities and hospital networks.

The data may be available in various formats, such as tables, GIS (Geographic Information System) – compatible maps, or text documents. Ensuring that the data is accurate and up to date is crucial for the reliability of the vulnerability index. Additionally preprocessing of the data may be needed. Utilizing tools like data validation and cleaning software can help maintain the quality and consistency of the data, ultimately leading to a more accurate and comprehensive vulnerability assessment.

Data gaps and community engagement

Besides surveys or investigations to fill data gaps, citizen science can also be applied to complete the vulnerability assessment of social groups. This is a helpful approach to not only gain specific data but also to engage with communities. The following tools exist:

- **Mobile Apps:** Mobile applications are easy to use to submit data such as heat observations from residents. To make sure that everyone feels free to share, this tool is anonymous.

  Example: SpeakUp, Your Priorities

- **Community surveys:** Community surveys collect data, both quantitatively and qualitatively, on the vulnerability indicators but also on people's risk perception, their behavior during heat waves and their needs. You can also do a census. Respondents need to provide their socioeconomic status, their potential health issues, the residential area in which they live and if they suffer from UHI effects.

  Examples (free): Google forms, SurveyMonkey, LimeSurvey.

- **Collaborative data analysis platforms:** To implicate even more the community, once the data has been collected, citizens can be engaged in the data analysis. That would be an asset because the interpretation of these results would be made collectively and so with most of the underlying issues.

  Examples: Datawrapper (free version), GitHub, Jupyter Notebook.

Essential data

The basic data to assess the vulnerability index consists of the essential indicators for the categories listed in **Error! Reference source not found.**. Per defined area one value for each essential indicator needs to be determined or collected. For methods closing data gaps on vulnerability please refer to the end of this chapter.

Additional data

The additional data both for socioeconomic and health conditions categories helps completing the essential ones by being more precise and accurate. The additional indicators in **Error! Reference source not found.** are arranged according to importance and it is not necessary to have them all.

Story mapping

Besides the vulnerability index calculation, story mapping can provide valuable qualitative information on the perception of the inhabitants on UHI effects in residential areas and on different social groups. A story map contains multiple media tools to illustrate a story based on a map, with a narrative structure and a possibility of interactivity and sharing with others. City representatives can also directly go to the citizens, especially elderly people that don't necessarily have access to a computer and ask them about their story and their experience with UHIs. It is a great way to enhance communication and implication of the community into the UHI problem. It also gives a more precise and comprehensive idea of the risk groups because of the localization of the stories.

TOOL APPLICATION GUIDE

Step-by-step guide for vulnerability assessment

Step 1: Inventory of the available data

Cities need to understand the indicators and what is at stake in UHI assessment. It is also important to identify the people or the departments of the local authority to get the relevant information and to discuss indicators. For instance, cities will probably have to turn to the health department for the data concerning health. Consider these questions for each indicator:

- Do you know what it is about?

  → For example: for unemployed people, it is the number of adults of the population within the area that do not have a current job but are looking for one or are not able to work because of a disability or illness. It implies that they don't receive any sufficient income.

- Who has/collects the data?

  → For example: for unemployed people, it is most likely the employment agency. Identify the local institutions or departments who are in charge and ask the right people for the information.

- Do you already have that information?

  → For example: for unemployed people, you could have the numbers from previous years.

- For which area is this information available?

  → For example: statistics about the number or the proportion of unemployed people may be available for the entire city and not per residential area. In this case, it would not be sufficient.

- How is the data presented?

  → Many formats exist: table (excel document), text (pdf) like reports or publications, geographical data (shapefiles) for instance for the location of infrastructures.

- When is it from?

  → For example: data about unemployed people in a specific area could go back to the last century, but it would be outdated for the purposes of this UHI risk assessment. Instead, it would be better to use data from approximately 10 years ago maximum, especially if there have been significant changes in the city population.

Step 2: Selection of the indicators

The indicators presented in Table 14 are not all required to do the UHI assessment. Cities can select them from their perspective and knowledge of the population. As they are listed from most important to additional from top to bottom for each category, it is recommended to choose the first ones in each section (socioeconomic, health conditions, infrastructures).

Step 3: Dividing the city into areas

This is crucial to be able to distinguish between areas with different vulnerabilities. The areas may already be existing (corresponding to district or census tract) or not. Their size must not be too large to provide sufficient precision of the analysis and not too small to ensure data are available.

Step 4: Story map

Start the story map by referring to the tool below. This is a task that can be done independently of the other steps.

Step 5: Collection of the remaining data

For each area, collect the remaining data that you do not have on the selected indicators. They can be put in an excel or simply and directly on a paper map (if there aren't that many areas).

- <u>Demographic data</u>

- Young and elderly people
- Poor people
- Unemployed people
- Gender
- Immigrated people
  - → Census data
  - → If not available: questionnaire
- People with low-skilled jobs
  - → Census data
  - → If not available: Get a sense of it from story maps
- Population density
  - → Census data
  - → If not accessible directly: take the number of citizens of the area and divide it by the surface of the area (in km²)
- Retired people

→ Census data or records of social security agency

→ If not available: questionnaires

- People without high school diploma

→ Census data

→ If not available: replace it with the proportion of people without high education

- <u>Health data</u>

- Ill people

→ Census data, data from health institutions or Red Cross, open data from national disease control bureaus

→ If not available: get a sense of it with story maps

- Disabled people

→ Data from health institutions, open data from national disease control bureaus or records of ADB (adult disabled benefit)

→ If not available: get a sense of it with story maps

- Mentally ill people

→ Data from health institutions, open data from national disease control bureaus or through the number of psychological institutes

→ If not available: get a sense of it with story maps

- Mortality rate

→ Data from health institutions, municipal health department

→ If not available: you can proceed without it

- <u>Geographical data</u>

- Hospitals capacity

→ Data from local health authorities, health department

- Where are the hospitals, retirement houses and social housing located?
- How many facilities are in the city?

A questionnaire may be a less efficient way to get the information and could avert citizens from the project as questions may be perceived as intrusive. Therefore, questionnaires should be the last resort. Cities should prioritize more inclusive tools like story maps and mobile applications.

Step 6: Validation of the data

Validate the data to ensure the quality of the assessment.

- With other sources if available
- With the citizens through meetings or collaborative data analysis platforms

Step 7: Calculation of the Vulnerability Index

Calculate the VI for each area.

- Equal weights between indicators
- Normalize the values
    - Make a weighted sum

Step 8: Visualize
Using QGIS or a paper map, visualize the different indexes to see which areas are the most vulnerable. Refer to the story map to have more insights on what people have experienced and felt during heatwaves.

Story map

The goal is to have a map with the citizens' story regarding UHIs. Story maps are usually done on an online website that allows collaboration and sharing as well as the integration of photos or videos. Free software examples include Esri (StoryMaps, free version), MapStory (free), StoryMapJS.

1. Share the map with the citizens and ask them to share their story regarding the UHI on the right spot on the map. In
2. Table 32, there is a list of questions to help them.
3. Pinpoint health care facilities (hospitals or doctor offices), social housing and retirement houses.
4. Create a new division of the city areas which have produced similar stories.

Table 32: Sample questions for the story map

Sample questions
• In which area do you live in? • Do you consider yourself to be particularly sensitive to heat? • Are you familiar with the concept of UHIs? • Have you ever experienced its effects? • If yes, did it lead to heat-related diseases such as heat exhaustion or heat cramps? • If yes, were you able to access healthcare services if so? • How do you manage these high temperatures? • Is your home equipped with air conditioning? • Do you have friends or family you can rely on during extreme heat events? • What are the biggest challenges you face during heatwaves? • How do your living conditions (e.g., type of housing, availability of air conditioning) affect your ability to deal with heatwaves? • How does your neighborhood environment (e.g., presence of green spaces, tree cover) influence your experience of heatwaves? • If you could send a message to local leaders or policymakers about the impact of heatwaves, what would you say?

TOOL 4 – PREPAREDNESS AND ADAPTIVE CAPACITY OF CITIES AND MUNICIPALITIES

Aim of the assessment tool

The escalating impacts of climate change on built-up urban areas including increasing number of UHIs have a direct connection with the adaptation capacity of the given territories. Climate change impacts are manifest in direct costs to human lives and wellbeing, destruction of assets, and other economic damages, as well as indirectly through impacts on different sectors which can trigger effects on economies, human health, education, and human mobility (IPCC 2022).

Municipal and regional management are often reactive to disasters, with little consideration given to reducing or managing risk in a comprehensive, preventive manner. Territorial self-governments are often constrained by a lack of up-to-date, comprehensive, and sufficiently detailed information about hazard and exposure in settled areas. This concerns cities, their functional areas (FUAs) as well as microregions and regions considered social ecosystems. Despite the potential impacts that disasters have on the financial resources of local and regional governments/self-governments and the functionality of the municipalities and regions, the management of disaster risk remains ex-post, with little attention to preventing or mitigating measures.

This methodology for UHI risk assessment offers a possibility to develop adequate competences to cope with the challenge of climate change at the local and regional level with a focus on built-up areas.

The methodology focuses on natural climatological hazards in built-up areas and their FUAs. As indicated in a World Ban report, “[t]he distinction between natural and manmade hazards is often very small. Land use and technological interventions in the built-up areas can sometimes trigger natural hazards and vice versa. While many hazards are of a natural origin, manmade changes can exacerbate the frequency or intensity of the hazard.” (Dicksonp E. et al., 2012). The current methodology for Urban Heat Islands Vulnerability and Risk Assessment is applicable in various types of inhabited zones in urban areas.

The Urban Risk Assessment methodology developed by the World Bank suggests that similar assessments focus “on three pillars that collectively contribute to understanding urban risk, including UHI risk: a) a hazard impact assessment, b) an institutional assessment, and c) socioeconomic assessment” (Dicksonp E. et al., 2012). This approach “allows flexibility in how it is applied, depending on available financial and other resources, available data relating to hazards and population living in the assessed area, and institutional capacity of a given city.”

Adaptive capacity describes an arrangement's capability to overcome the consequences and risks of a change that happens, both in determining actions, resource use, and technology utilization. To determine the adaptive capacity of an area, it is necessary to identify the risks and hazards associated with it.

How to assess adaptive capacity

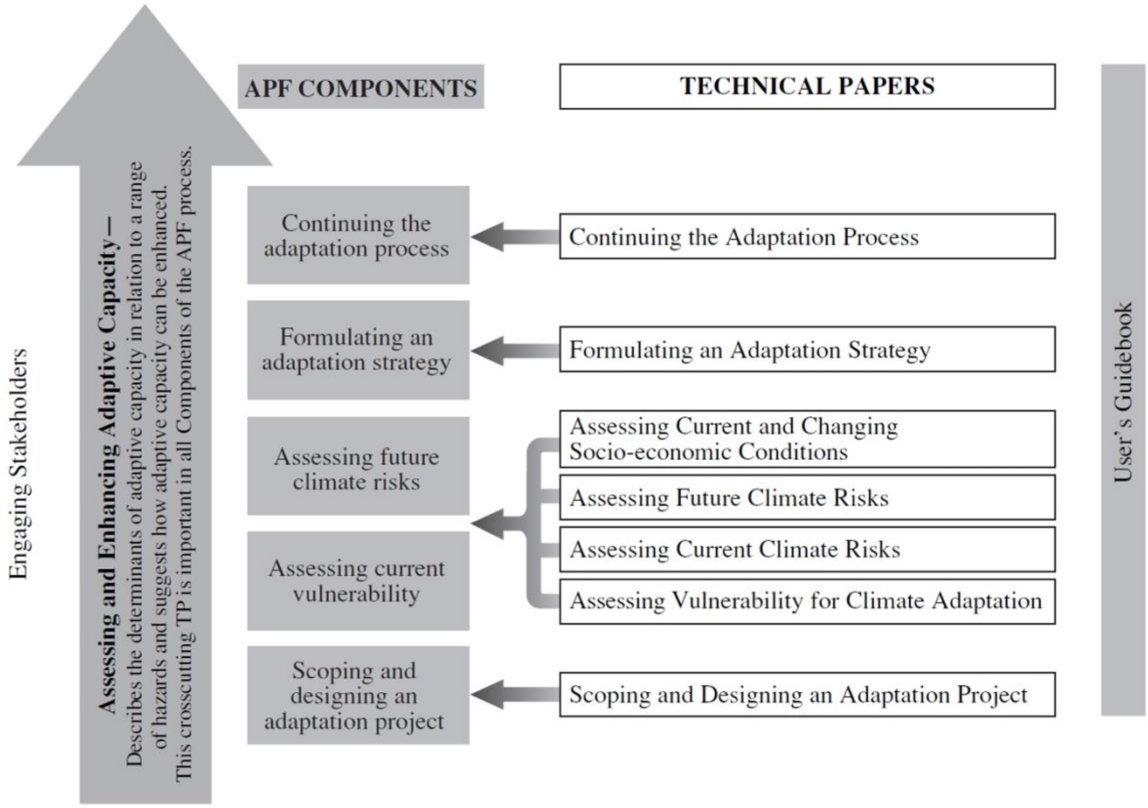


Figure 43: Relationship of adaptive capacity to the Adaptation Policy Framework (APF) (Brooks and Adger, 2005)

Adaptive capacity refers to "the ability" of a human system (also settlements or regions) to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Agard and Schipper et al., 2014).

One possible definition of adaptive capacity, as proposed by current research, is as follows: “Adaptive capacity is the property of a system to adjust its characteristics or behavior to expand its coping range under existing climate variability, or future climate conditions. In practical terms, adaptive capacity is the ability to design and implement effective adaptation strategies, or to react to evolving hazards and stresses to reduce the likelihood of the occurrence and/or the magnitude of harmful outcomes resulting from climate-related hazards.” (Brooks and Adger, 2005). Since adaptive capacity represents the framework of adaptation policy, it is covered by five basic components (Figure 21).

Adaptive capacity will differ depending on the territorial level; local or regional (microregional) level responses to climate change may differ significantly from those at national level.

The adaptive capacity "represents the set of resources available for adaptation, as well as the ability or capacity of that system to use these resources effectively in the pursuit of adaptation. Such **resources** may be **natural, financial, institutional** or **human**, and might include access to ecosystems, information, expertise, and social networks" (Brooks and Adger, 2005; emphasis added). As the authors clarify, "the realization of this capacity may be frustrated by outside factors; these external barriers, therefore, must also be addressed. At the local level, such barriers may take the form of national regulations or economic policies that hinder the freedom of individuals and communities to act or make certain adaptation strategies unviable." Adaptive capacity, therefore, depends on a society's ability to act collectively and resolve conflicts between its members – factors heavily influenced by governance. The most common indicators for adaptive capacity are (Eugenio et al., 2016): experience, knowledge, social learning, individual competence, access to resources and adaptation action.

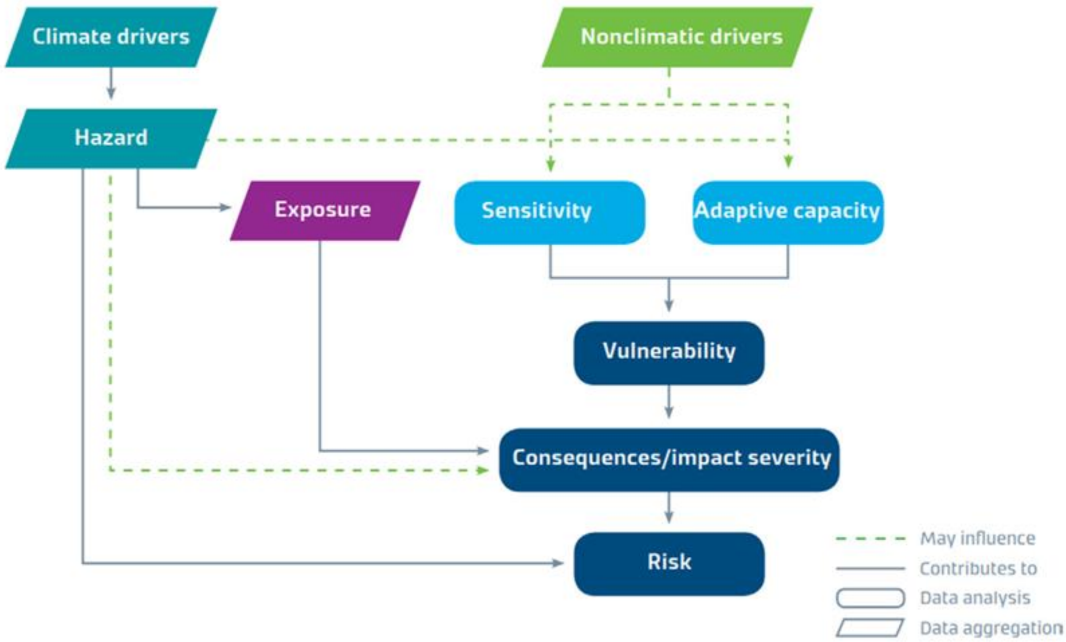


Figure 44: Scheme of climate risk (within UHI) assessment framework (Rome et. al, 2019)

Development of adaptive capacity to various climate hazards is the most effective when it is targeted to the systems (e.g., to the built-up areas and especially to UHI) and populations which are the most risk from climate hazards (elderly people, children), where risk is a function of vulnerability and exposure to hazard (**Error! Reference source not found.**). Hazard, vulnerability and sensitivity determining processes are very useful, as these identify zones (as well as UHI), areas, regions and groups with high vulnerability, i.e., items elevated socially determined vulnerability and climate hazard). Vulnerability to climate change is difficult to measure objectively. Typically, vulnerability to climate change is taken to be a function of physical impact and adaptive (or social) capacity, that is, the severity of change (which is a function of exposure and sensitivity) and our ability and willingness to respond to this change (**Error! Reference source not found.**).

Adaptive capacity determination

The aim of adaptive capacity determination is the ability to design and to implement effective adaptation strategies, or to react to evolving hazards and stresses to reduce the likelihood of the occurrence and/or the magnitude of harmful outcomes resulting from climate-related hazards. The adaptation process requires the capacity to learn from previous experiences to cope with current climate, and to apply these lessons to cope with future climate, including unexpected events. Other factors include the quality of institutions and decision-making processes, the availability of data, resources and technologies and the stock of human and social capital (Tol and Yohe, 2007).

Adaptive capacity is a function of available financial and human resources and adaptation options and may differ among risks and different sectors. UHI risk assessment enables the formulation of public policy and actions to mitigate UHI-related impacts in an effective manner and enhances individual-level UHI adaptive capacity (Xu et al., 2019; Filho et al., 2018). According to the intergovernmental panel on climate change a higher adaptive capacity to climate change induced UHIs reduces socioeconomic losses and improves resilience to excessive heats events (IPCC, 2014).

It can be expected that adaptive capacity will be negatively affected by the intensity of climate change itself. Different regions display different levels of adaptive capacity to date and face different types of adaptation constraints and limits. As the regions are also differently exposed to climate hazards (heat waves, UHI, drought, storms, heavy rains, floods, landslides, etc.), their levels of future adaptive capacity are also different.

Criteria and indicators for the assessment of adaptive capacity at local and regional level

Adaptive capacity is not directly measurable. Indicators of adaptive capacity are more difficult to identify than indicators of risk. Physical risks associated with the impacts from climate change may be triggered by specific events (extreme weather events, e.g. heat or cold waves, floods etc.) driven or associated with longer-term shifts predicated by the climate patterns (e.g., higher mean air temperatures, changing precipitation patterns etc.). Risk in IPCC terminology use applies only to "human or ecological systems". The definition of 'risk' related to climate change impacts has retained the notion of 'hazard' to describe the climatic driver of a risk. This is consistent with the definition of the concept of risk in the IPCC Sixth Assessment Report (2023). UHIs represent risks caused by extreme climatic events (heat waves, tropical days and nights) in built-up areas.

Indicators for determining adaptive capacity will result from answers to key questions (the questions below are drawn from the World Bank report on urban risk assessments, referred to above):

- What are the indicated principal hazards faced by respective socio-ecosystem (e.g. municipality)?
- What are the major impacts of these hazards and which system elements are most vulnerable?
- Why are these elements particularly vulnerable?
- What measures would reduce the vulnerability of these elements?
- What are the factors that determine whether the measures are taken?

- Can we assess these factors to measure the capacity of the system's population to implement these measures?
- What are the external and internal barriers for implementation of these measures?
- What social system capabilities are available now and will be available/lacking in the future to reduce the relevant risk?

Financial resources, institutional capacities, human and natural resources and infrastructure are key determining factors of adaptive capacity.

Examples of adaptive capacity indicators:

- **Institutional factors: governance structures, legislative and regulatory regimes, policies, plans, institutions.**
- **Social factors: social connections, community cohesion, self-learning/self-organizing capacities of communities, available skills and knowledge.**
- **Economic factors: public financial resources, household income, access to financial resources, insurance contracts.**
- **Technological factors and scientific knowledge: availability of technological, social, institutional, environmental and other innovations; ability to use the innovations, or availability of information on adaptation to climate change.**

When identifying indicators of adaptive capacity, it is important to consider all relevant aspects of the system (region, municipality, zone, UHI, community etc.). For example, when assessing a city's capacity to manage floods, factors such as existing flood protection plans and the availability of financial resources for flood protection investments need to be considered.

Factors of indicators of adaptive capacity often influence each other. For example, quality legislation and policies can improve society's ability to cope with the adverse consequences of hazards and adapt to future changes. High social capital may increase a community's ability to cope with the adverse consequences of a threat and help it adapt to future changes.

By increasing the value of adaptive capacity indicators, the system's vulnerability to threats is reduced and its resilience is increased.

In general, the selected indicators should be relevant, measurable, achievable, relevant and time-bound:

- Specificity/relevance: Indicators should be relevant to the assessed risk and provide information on the impact of climate change on the assessed system. The indicator should be specific enough to be understandable and usable. It should clearly define what it measures and how it is measured.
- Measurability: Indicators should be measurable using available data.
- Time-limited: Indicators should be sensitive to changes in time.
- Achievability/affordability: Collecting and updating data on indicators should be financially accessible. The indicator should be achievable within the set time and resource constraints.

Data collection and data sources for adaptive capacity assessment

Before collecting data, it is advisable to create a list of preliminary indicators for each factor. It is important to note that there is no one-size-fits-all list of indicators for assessing adaptive capacity. The choice of indicators depends on specific socio-ecosystem (e.g. city, village) and the available data. Examples of procedures on how to select adequate data can be found at https://joint-research-centre.ec.europa.eu/peseta-projects/jrc-peseta-iv_en; relevant data can be mined from multiple sources, collected or derived via modelling, simulation, etc.

Sources of data:

- Information from the local/regional office/ city district office, self-governmental office (department of spatial planning, department of environmental policies, spatial plan, GIS department)
- Freely available relevant data including satellite imagery, for example CORINE, LandCover, Copernicus Land Monitoring Service – Urban Atlas (land.copernicus.eu), the Landsat Program (landsat.gsfc.nasa.gov), ESRI basemaps (https://arcgis.com), Google maps (maps.google.com), OpenStreetMap
- Information from state administration and subordinate bodies, e.g. availability of water pipes, water resources, degree of protection of the territory, etc.
- Climatological institutions in the country (climate threat indicators)
- Statistical office (demographic and other census data)
- Available thematic maps – flood risk, landslides etc.

Examples of data collection methods

Expert assessment

- Methods: participatory workshops, interviews
- Indicators: knowledge of local conditions, community cohesion, social connections etc.
- Advantages: can be used quickly and cheaply, can provide unique insights
- Disadvantages: subjective, relies on the expertise of individual respondents

Modelling/simulation

- Methods: adaptive capacity models based on data from thermal and hydrological models, groundwater models; drought modelling, data synthesis using Artificial Intelligence (AI)
- Indicators: runoff volume, groundwater flow systems
- Advantages: can simulate complex systems, provides insights into future scenarios etc.
- Disadvantages: time-consuming, require expert knowledge, data-intensive

Measurements and satellite imaging

- Methods: analysis of satellite data, thermometers, hygrometers and other measuring devices
- Indicators: surface temperature, air humidity, water runoff, land coverage
- Advantages: highly accurate data
- Disadvantages: requires a certain level of professional knowledge and skills, possibly statistical analysis

Census data, surveys

- Methods: questionnaires, surveys
- Indicators: age structure, education, condition of buildings, cooling in buildings
- Advantages: provides detailed data on socioeconomic factors
- Disadvantages: data acquisition is time-consuming, requires expert knowledge, statistical analysis; GDPR risk.

Tool application guide

Before proceeding with the UHI assessment, it is necessary to create a framework of indicators for determining adaptive capacity. General considerations for addressing climate change, disaster risk, and adaptive capacity in each region are:

- Climate change adaptation should not be considered an additional challenge to existing local policies and planning routines, but an opportunity for cities to set relevant future priorities.
- Given limited resources, the initial focus should be on addressing existing shortfalls in infrastructure investment and basic services (e.g. in urban greening, drainage, piped water etc.)
- Policies and investments in municipalities should be based on improved information and data (local measurements), including quantitative data and an understanding of community actions and adaptive capacities.
- Enhanced collaboration with the administrations of neighboring municipalities/regions, as well as with the local communities — this is crucial to the success of long-term planning.
- Capacity building should be emphasized at every level. The capacity-building and community-led actions must be even.

Step 1: Political support, awareness and communication

- Get permanent political and professional support (mayor, local/regional council members, local/regional representatives in the parliament)
- Public involvement is important including entrepreneurs, interest organizations and ngos

Step 2: Creating a working group/team

Determining the area's adaptive capacity and bridging inequalities in adaptive capacity across sectors through capacity building programs for stakeholders, practitioners, municipality/regional managers, and decision makers is very important. Structured learning resources and the exchange of experiences with other cities can increase the understanding of the linkages between climate change and disaster risk management. Therefore, it is necessary to create a cross-sectional interdisciplinary working group:

- Executive representatives of the local/regional government
- Experts from other institutions and areas (environment, spatial planning, water, forests, energy, security, construction, transport, healthcare, social services, civil protection, in the case of smaller municipalities, for example, agriculture, local economy, tourism, etc.
- Organizations, e. g., water and sewage companies, watershed administration, public health office, etc.)
- Business representatives
- Community representatives / citizens.

It is recommended:

- To cooperate with the academic community
- To determine working group coordinator.

For smaller cities/municipalities:

- The coordinator will hold joint meetings/interviews about the perception of problems and possible solutions in individual systems
- Interviews and meetings should be held with key actors, e.g. mayor, deputy mayor, municipal councilors, industry, non-profit organizations.

Step 3: Consideration of socioeconomic contexts

- In the preparatory phase consider the city socioeconomic and geographic conditions and current trends (e.g., demographic changes, urbanization tendencies), based on assessment of existing strategic and planning documents.

Outputs:

  - Brief description of the territory (location, area, altitude, relief, types of landscape etc.)
  - Analysis of strategic documents in the given area.

Step 4: Identification of the most significant climate threats

- Heat waves
- Strong storm activity (including snow, dust/sandstorms)
- Drought
- Torrential precipitation – rain/hail/snow/ice
- Floods (fluvial, pluvial)
- Landslides and land subsidence
- Fires.

The following climate indicators are suitable for smaller areas (towns/neighborhoods):

- Change in average annual temperature
- Change in the average annual number of summer (tropical) days – in the context of heatwaves
- Change in the average number of days with precipitation over 20mm per year (or annual maximums of one-day precipitation totals with a probability of recurrence once in 100 years) in the context of flash floods in certain areas, with an emphasis on landslides
- Relative change in annual potential evapotranspiration (or change in the climatic indicator of irrigation) in the context of drought.

In mountainous territories, consider also the following:

- Change in the average number of days with snow cover per year
- Change in the average annual number of frosty days.

Step 5: Selection of key sub-systems

The following systems are examples of identified sub-systems:

- Agriculture and food supply
- Forests
- Industry

- Services
- Other sectors of the local economy, e.g. tourism
- Water and water resources
- Nature protection, biodiversity, and ecosystems
- Health, built-up area (construction)
- Transportation.

After identifying the key systems, an initial evaluation (screening) is recommended – the most "threatened" systems in the city for a given climate threat are determined. The initial evaluation can be done using an assessment matrix. The evaluation can be carried out in the form of a working group session, using a 5-point evaluation scale.

Assessment matrix for adaptive capacity

For the evaluation of the adaptive capacity an assessment matrix can be used. Two aspects are included in the rating, (i) the categorization of the consequences (

Table 33) and (ii) the probability of threat occurrence assessment (Table 34.)

Assessment matrix for adaptive capacity

Assessment matrix for adaptive capacity		**Sensitivity value**				
		very high	**high**	**average**	**low**	**very low**
Adaptive capacity value	**very high**	very high	very high	high	high	average
	high	very high	high	average	average	low
	average	high	average	average	average	low
	low	high	average	average	low	very low
	very low	average	low	low	very low	very low

Table 33: Categorization of the consequences (source: Třebický, Novák, 2015)

Category	**Degree**	**Example**
very high	5	Extensive damage to the environment
		Serious injuries, loss of life and property
High	4	Extensive deterioration of services and quality of life
		Exceptional loss of life and serious injuries
average	3	Damage to the environment that can be repaired
		A small number of injuries
low	2	Locally significant, isolated cases of damage to roads, economic damage
		Smaller injuries
very low	1	Threat but not damage to the environment

Table 34: Probability of threat occurrence assessment

Probability of occurrence	Repeated consequence	One time event
very high	It may occur several times a year	Probability over 50%
high	It can occur about once a year	Probability 50%
average	It can occur approximately once every 10 years	Probability 50%, still high low
low	It can occur approximately once every 10 to 25 years	Unlikely but not impossible, Probability significantly higher than 0
very low	Unlikely in the next 25 years	Probability approaching 0

Checklist to identify factors that influence a city's adaptive capacity

Assessing a city's adaptive capacity requires a detailed examination of various influencing factors. The following checklist can help evaluate how prepared and effective local and regional governments are in handling disaster risk and climate change. It offers a simple way to assess their readiness and response capabilities.

Rating scale

1= not set at all, non-existence of the system
2 = setup/equipment/preparedness at a very low level
3 = average level of setup/equipment/preparedness
4 = good level of setup/equipment/preparedness
5 = high (precise) level of setup/equipment/preparedness

A. Local/regional government office structure (the questions below are based on the World Bank report) (Dicson at al., 2012):

- At what level is the disaster risk management department? (scale 1–5)
- At what level is the environment, sustainability, or climate change department? (scale 1–5)

B. Responsibilities for disaster risk management and climate change management

- Are responsibilities clearly specified in municipality? (scale 1–5)
- Is responsibility for climate change management established? (scale 1–5)
- At what level is the responsibility for disaster risk management established? (scale 1–5)
- At what level is the existence, capacity, and effectiveness of a city's emergency and disaster response plan? (scale 1–5)
- How is the response system set up in terms of comprehensive and equipment for all specified natural hazards? (scale 1–5)
- At what level is the update of the disaster response system set in municipality? (scale 1–5)

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Annex 1

UHI RISK ASSESSMENT GLOSSARY

Adaptive capacity: The ability of individuals to adjust to climate variability and extremes in order to mitigate potential impacts and cope with the consequences.[1]

Albedo coefficient: Albedo (sometimes referred to as 'reflection coefficient') is a measure of how reflective a surface is. The term is derived from the Latin *albus* meaning 'white' and is either determined by a value between 0 and 1 or a percentage value.[2] The more reflective a surface is the higher the albedo value.

Anthropogenic heat. In cities, people drive cars, run air conditioning units, and operate buildings and industrial facilities in close contact with each other—activities that generate waste heat that increases local temperatures.[3]

Atmospheric heat islands. These heat islands form as a result of warmer air in urban areas compared to cooler air in outlying areas. Atmospheric heat islands vary much less in intensity than surface heat islands.[4]

Building coverage ratio: The ratio between ratio of the site occupied by the building and the site area (plot/parcel or larger area

Buildings volume ratio: The area occupied with the volume of all buildings in a site area

Evaporation: Evaporation is the process that changes liquid water to gaseous water (water vapor).

Evapotranspiration: the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Floor area ratio (FAR): A measure describing how much land is covered by a building.

Fragility refers to the susceptibility of individuals with certain health conditions that make them more prone to suffering from extreme climate events.

Non-residential suburban area: Area with shopping centers, malls and industrial activity, wide streets and very little vegetation.

Permeability of surfaces: Ability of urban surfaces to pass water through into the soil.

Residential suburban area: Sparse area intended almost exclusively for households.

Social vulnerability refers to the difficulty of having access to facilities that can protect from the extreme temperatures, such as air conditioning or proper ventilation, or to support networks that can provide assistance or care.

Street canyon: A narrow street with tall buildings along the street on both sides of the road.

Surface heat islands: These heat islands form because urban surfaces such as roadways and rooftops absorb and emit heat to a greater extent than most natural surfaces.[5]

Temperature thresholds*:* Temperature thresholds at which materials and equipment pose a risk of exacerbating UHI effects.

Transpiration: The process of water movement through a plant and its evaporation from aerial parts, such as leaves, stems and flowers.

Tree canopy coverage: Ratio of tree canopy coverage on the entire city level and the city unit (neighbourhood, district, city level).

UHI risk assessment provides information about the existing weaknesses of a natural or a socioeconomic system and the plausible causes of the weaknesses.[6]

Urban built-up area: "Built-up area" is defined as the presence of buildings (roofed structures). This definition largely excludes other parts of urban environments or human footprint such as paved surfaces (roads, parking lots), commercial and industrial sites (ports, landfills, quarries, runways) and urban green spaces (parks, gardens).[7]

Urban climate: Climatic conditions in urbanised areas

Urban geometry: The dimensions and spacing of buildings within a city

Urban morphology: Spatial patterns of urban landscapes composed by different urban elements.

Urban surfaces: Human-made building materials such as pavement and concrete reflect less sunlight and absorb more heat than natural surfaces.