THE URBAN HEAT VULNERABILITY MAP OF VIENNA, AUSTRIA

Presented by:

ECOTEN s.r.o
Lublaňská 1002/9 120 00 Praha 2
Czech Republic

For:

Magistratsabteilung 20 - Energieplanung
Rathausstraße 14-16
1010 Wien
Austria

Prepared by:

Sagnik Bhattacharjee
Urban Environmental Engineer
ECOTEN Urban Comfort Division
bhattacharjee@urban-comfort.eu

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SUMMARY

This report contains the work done by ECOTEN for producing the urban heat vulnerability map of Vienna, Austria. This report starts with a brief introduction to extreme heat events and their impacts on urban areas followed by the concept of vulnerability to climate change impacts and its components: exposure, sensitivity and adaptive capacity. The framework for quantifying vulnerability to climate change based on its constituting components is based on what has been proposed by the Intergovernmental Panel on Climate Change (IPCC). Vulnerability and its components were indexed through normalization between 0 and 1 (lowest to highest respectively).

Exposure refers to the direct danger of urban heat that affects the considered area. It manifests as the prevalence of very high temperatures across the whole city area hereby referred to as “hot-spots”. It can vary based on various factors of the given area and its built environment. It was calculated by taking the weighted average of the annual maximum at-satellite brightness temperatures from 2015 to 2019 which were obtained from Landsat 8 satellite.

Sensitivity refers to the strength of human’s reaction to high temperatures and depends on individual characteristics as age, existing health problems, etc. Sensitivity is assessed by identifying the people within a given area who are most affected by extreme heat. It was calculated by the density of vulnerable population in the age-groups below 14 and above 60 (as per recommendation by IPCC). The data was obtained from Opendata of the city of Vienna, Austria.

Adaptive capacity refers to the ability to cope with, recover and adjust to the impacts of heat events. In simple words, adaptive capacity is the capacity for the systems that constitute the urban environmental ecosystem to adapt and respond to this change, which in this case is extreme heat. For urban areas, it is well known that greenery and water-bodies help in cooling the urban environment. Therefore, the adaptive capacity was calculated through the sum of the enhanced vegetation index (for measuring the density of vegetation) and the normalized difference vegetation index (for measuring water-bodies).

Urban heat vulnerability index of Vienna, Austria was calculated by the difference between the adaptive capacity and the product of exposure and sensitivity. urban heat vulnerability along with its components were all mapped accordingly.
1. INTRODUCTION

1.1 About ECOTEN s.r.o. (Prague, Czechia)

ECOTEN is a consultancy company founded by Dr. Jiri Tencar in 2012 with its main office located in Prague, Czechia. The company started as a startup of 2 people and grew rapidly since. Today, it has more than twenty qualified thermal, civil and urban engineers in the Prague office and eight in Košice (Slovakia).

ECOTEN's technical services are diverse and focused on energy savings, optimization and design for the built environment. The main services that it provides to its clients are as follows:

- Producing strategic maps for urban planning, providing information on urban heat islands, to assess the vulnerability and resiliency of urban areas to extreme heat events. Its goal relies on the protection of vulnerable population (<16 and >65) to major heat stress.

- Assessing the urban climate of a city district modeled in 3D by simulating microclimate conditions and physical phenomena involved. It provides valuable information with the aim to optimize urban development strategies and their environmental impacts, to create sustainable and eco-friendly neighborhoods.

The branch ECOTEN Urban Comfort provides consultancy services to architects, developers, engineers, urban design and planning consultants by easing their work in making effective decisions to develop sustainable and energy-effective cities.

It consists of a team of building and urban environmental specialists, which notably propose environmental consulting services like the following:

- Producing strategic maps for urban planning, providing information on urban heat islands, to assess the vulnerability and resiliency of urban areas to extreme heat events. Its goal relies on the protection of vulnerable population (<16 and >65) to major heat stress.

- Assessing the urban climate of a city district modeled in 3D by simulating microclimate conditions and physical phenomena involved. It provides valuable information with the aim to optimize urban development strategies and their environmental impacts, to create sustainable and eco-friendly neighborhoods.

We accompany public and private actors with our expertise at every stage of their projects, to find the most ergonomic solutions for urban planning, which will contribute to improve people’s quality of life within urban areas by designing sustainable cities.
1.2 Our scope of Work

1.2.1 Urban Heat Islands

The United Nations Framework Convention on Climate Change (UNFCCC) has defined climate change as “a change of climate which is attributed directly or indirectly to human activity which alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. One of the most significant impacts of climate change is the increasing number of heat waves across the world.

The impacts of heat waves upon human beings are first experienced in cities because more than half of the world's population is currently living in cities\(^1\).

One phenomenon that exacerbates cities vulnerability to heat waves is the formation of urban heat islands which can be defined as the relative warmth of a city compared with surrounding rural areas. In general, the urban heat island effect can be characterized by the fact that urban areas are generally warmer than its surrounding rural areas.

![Image of Urban Heat Islands in Paris (France).](image)

**Figure 1**: Urban Heat Islands in Paris (France).

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**SOURCES:**

\(^1\) World Urbanization Prospects: The 2018 Revision, Population Division of the UN Department of Economic and Social Affairs.
1.2.2 Urbanization and Extreme Heat Vulnerability (Europe)

Europe has experienced several extreme heat waves since the year 2000 and sees the number of warm days almost doubled since 1960. The extreme heat wave of 2003 has witnessed up to 70,000 deaths\(^1\). Such events are projected to occur repetitively and with more strength, as often as every two years under a high emissions scenario in the second half of the 21\(^{st}\) century. The increasing urbanization, with 73 percent\(^2\) of people in Europe living within urban areas, has increased the vulnerability of European cities.

Vienna is no exception to this trend. Between 1961 and 1990, the city experienced on average 9.6 heat days per year and from 1981 to 2010, the number of heat days rose to 15.2 per year\(^3\). The population forecast envisages an increase over the coming decades from 1.8 million currently, to 2 million by 2030. The impacts of this are ever-increasing urban development, inner-city densification, and the loss of permeable open green space, in turn leading to an increase in temperature differences between the city and its surrounding areas. Due to all these factors, during the heatwave of 2003, Vienna experienced an overall 44 heat wave days and lead to 180 heat related deaths\(^4\).

The extent of smart efficient urban design and management can buffer these negative effects. Despite the fact that European cities are known to have high response capacity; further actions are still essential to maintain this high degree of preparedness to Climate Change.

Future initiatives to improve the readiness of cities will require a systematic assessment of the vulnerability of the city to these impacts. The heat vulnerability map produced by ECOTEN s.r.o. (Czech Republic) is aimed at providing a strategic document for the city as well as urban stakeholders, to assess the threats of extreme heat and to assess the level of heat resiliency in their city. This is of paramount importance to maximize the efforts of urban stakeholders to protect the citizens.

**Figure 1**

**SOURCES:**

2. CONCEPT OF HEAT VULNERABILITY AND ITS COMPONENTS

Vulnerability is a complex concept; therefore, many factors impact on its definition and evaluation. The IPCC (Intergovernmental Panel on Climate Change) has given a general definition as “the propensity or predisposition to be adversely affected”. According to the reports published by the IPCC, as well as existing studies, the majority of researchers define vulnerability as a function of exposure, sensitivity and adaptive capacity (Figure 2).

2.1 Exposure

It refers to the direct danger of urban heat that affects the considered area. It manifests as the prevalence of very high temperatures across the whole city area hereby referred to as “hot-spots”. It can vary based on various factors of the given area and its built environment.

2.2 Sensitivity

It refers to the strength of human’s reaction to high temperatures and depends on individual characteristics as age, existing health problems, etc. Sensitivity is assessed by identifying the people within a given area who are most affected by extreme heat.

2.3 Adaptive Capacity

It refers to the ability to cope with, recover and adjust to the impacts of heat events. In simple words, adaptive capacity is the capacity for the systems that constitute the urban environmental ecosystem to adapt and respond to this change, which in this case is extreme heat.

Figure 2: Vulnerability as a function of exposure, sensitivity and adaptive capacity
3. METHODOLOGY

ECOTEN’s objective is to produce an urban heat vulnerability map of Vienna, using the IPCC’s assessment technique where vulnerability depends on exposure, sensitivity and adaptive capacity. This is done by quantitatively evaluating heat vulnerability with the help of its three components as follows:

Weighting of Indices: The indices for exposure, sensitivity and adaptive capacity had equal weight with respect to each other for the calculation of the urban heat vulnerability index.

Exposure: The exposure for the city was obtained by mapping the various hotspots within its urban areas.

Sensitivity: The sensitivity to extreme heat of a city is obtained by identifying the most vulnerable population to these effects of climate change. Whereas extreme heat affects independently the entire urban area, some age groups will be more impacted by it and will suffer from it in terms of health and well-being.

Adaptive Capacity: The adaptive capacity consists of the level of heat resilient infrastructure which is available within the city to protect its citizens against the adverse impacts of extreme heat events. The level of greenery and water-bodies present in the city are well known for reducing these impacts.
Figure 3.1 presents the framework for the calculation of the urban heat vulnerability of Vienna. In this framework of urban heat vulnerability, exposure and sensitivity constitute the impact of extreme heat in cities and the adaptive capacity works to negate this impact. Table 3.1 lists the various steps for the calculation of the urban heat vulnerability index and its maps.

<table>
<thead>
<tr>
<th>STEP</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Collection of Data</td>
</tr>
<tr>
<td>2</td>
<td>Calculation and Mapping of Sub-Indices</td>
</tr>
<tr>
<td>3</td>
<td>Calculation and Mapping of Component Indices</td>
</tr>
<tr>
<td>4</td>
<td>Calculation and Mapping of Urban Heat Vulnerability Index and Map</td>
</tr>
</tbody>
</table>

### Table 3.1: Steps for Calculation of Heat Vulnerability

#### 3.1 Data Collection

Table 3.2 lists the data that was initially collected.

<table>
<thead>
<tr>
<th>DATA SOURCE</th>
<th>DATA TAKEN</th>
<th>PURPOSE</th>
<th>DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 8 TIR EO Satellite</td>
<td>Band 10 - Thermal Infrared Radiation</td>
<td>Calculation of At-Satellite Brightness (ASB) Temperatures</td>
<td>Annex 1</td>
</tr>
<tr>
<td></td>
<td>Band 2 - Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Band 3 - Green</td>
<td>Calculation of Enhanced Vegetation Index and Normalized Difference Water Index</td>
<td>Annex 2</td>
</tr>
<tr>
<td></td>
<td>Band 4 - Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Band 8 – Near-Infrared Radiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opendata Vienna</td>
<td>Wohn- und Pflegehäuser, Standorte, Wien</td>
<td>Identification of Retirement Houses in Vienna, Austria</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Sub-Index Creation

3.2.1 At-Satellite Brightness (ASB) Temperature

The ASB temperature is a measurement of the radiance of microwave radiation traveling upward from the top of the atmosphere to the satellite. It is expressed in units of the temperature of an equivalent black body.

The ASB temperature dataset is obtained with the help of remote-sensing technique from NASA’s Earth observation satellite series called Landsat. It provides repetitive acquisition of high-resolution multispectral data of the Earth’s surface on a global basis. Among these satellites, Landsat 8 contains the Thermal Infrared Sensor (TIRS) payload which measures the land surface temperature which can be represented by ASB temperatures. This satellite orbits around the Earth and passes over each point of the globe every seven days. TIRS contains two bands: Band 10 and Band 11.

The ASB temperatures were calculated from Band 10 data taken from Landsat 8 for all available days in June, July and August for all years between 2015 and 2019. For 2019, only data for June was taken due to the availability of satellite data. Appropriate atmospheric corrections were applied for each Band 10 data to obtain the ASB temperatures.

3.2.2 Annual Maximum ASB Temperatures from 2015 to 2019

The maximum ASB temperatures were taken for each pixel area in the city from 2015 to 2019 (Figure 3.2).

3.2.3 Weighted Average of Annual Maximum ASB Temperatures

The weighted average of the 5 years was calculated by taking the number of hot days as the weighting factor using the equation given below:

$$ T_{avg} = \frac{(T_{max} \times D_{heat})_{2015} + (T_{max} \times D_{heat})_{2016} + (T_{max} \times D_{heat})_{2017} + (T_{max} \times D_{heat})_{2018} + (T_{max} \times D_{heat})_{2019}}{(D_{heat})_{2015} + (D_{heat})_{2016} + (D_{heat})_{2017} + (D_{heat})_{2018} + (D_{heat})_{2019}} $$

(3.1)

Where,
- $T_{max}$: Maximum temperature dataset from Landsat 8 for each year obtained in Step 3
- $D_{heat}$: Number of heat days for each year obtained in Step 2
- $T_{avg}$: Average weighted temperature dataset for all 5 years (2015-2019)

The weighted factor is based on the number of days within each respective year when Vienna experienced a temperature above 30 °C. They are presented in Table 3.3. After obtaining the weighting factors for each year, the weighted average Surface Temperatures of Vienna Austria were obtained using Equation 3.1 as illustrated by Figure 3.3.
Table 3.3: Number of Hot Days per Year \textsuperscript{1,2}

<table>
<thead>
<tr>
<th>YEAR</th>
<th>HEAT DAYS (&gt;30°C) - WEIGHTING FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>42</td>
</tr>
<tr>
<td>2016</td>
<td>20</td>
</tr>
<tr>
<td>2017</td>
<td>38</td>
</tr>
<tr>
<td>2018</td>
<td>18</td>
</tr>
<tr>
<td>2019 (until June)</td>
<td>18</td>
</tr>
</tbody>
</table>

Annual Maximum ASB Temperatures

\[\text{Weighted Average}\]

\textbf{SOURCES:}

\textsuperscript{1}ZAMG: \url{https://www.wien.gv.at/statistik/lebensraum/tabellen/eis-hitze-tage-zr.html}

\textsuperscript{2}Weather Data Archives: \url{rp5.ru}
3.2.4 Vulnerable Population Density Index (VPDI)

The VPDI was calculated using the data "VIE-Bevölkerungsprognose 2014 bis 2024 - Wiener Zählbezirke" obtained from Opendata Vienna. The following age-groups were taken as the most vulnerable age-groups to extreme heat based on the recommendation of the IPCC.

- **Age-Group 1**: Age 0 to 14
- **Age-Group 2**: Age 60 and above

![Vulnerable Population Density Index (VPDI)](image1)

The population density was found for each sub-district for Age-Group 1 and Age-Group 2 as shown in Figure 3.4 by using Equation 3.2:

\[
\text{Population Density} = \frac{\text{Total Population}}{\text{Total Area}}
\] (3.2)

3.2.5 Enhanced Vegetation Index (EVI)

The EVI is an 'optimized' vegetation index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring. The European Space Agency has been developing a new family of missions called Sentinels which consists of a set of two earth observation satellites for each mission in order to fulfil revisit and coverage requirements. The EVI was calculated using the Band 2, 4 and 8 from Sentinel 2A. Only values between 0 and 1 were taken as they represent vegetation as shown in Figure 3.5.
3.2.6 Normalized Difference Water Index (NDWI)

The NDWI is a remote sensing-derived index related to liquid water. It was calculated using the Band 3 and 8 from Sentinel 2A. It is most appropriate for water body mapping because water body has strong absorption and low radiation in the range from visible to infrared wavelengths. The index uses the green and Near Infra-red bands of remote sensing images based on this phenomenon.

Only values between 0 and 1 were taken as they represent water-bodies.

The NDWI map of Vienna is shown in Figure 3.6.

![Normalized Difference Water Index (NDWI)](image)
3.3 Calculation of Component Indices

3.3.1 Exposure Index (EI)

To measure the EI, annual weight average temperatures obtained in Section 2.3 were normalized between 19 to 40 degrees Celsius to obtain a value between 0 and 1. Figure 3.7 illustrates this step.
3.3.2 Sensitivity Index (SI)

The SI was calculated by adding the vulnerable population densities for Age Groups 1 and 2 and then normalizing it to obtain a value between 0 and 1. This step is illustrated in Figure 3.8 where SI is represented by the Vulnerable Population Density Index.

Vulnerable Population Density Index

**Figure 3.8: Calculation of SI (represented here as Vulnerable Population Density Index)**
3.3.3 Adaptive Capacity Index (ACI)

To obtain the ACI, the EVI and the NDWI were added. Normalization was not needed here as both were already normalized and had values remained between 0 and 1. This step is illustrated in Figure 3.9.

Adaptive Capacity Sub-Indices

![EVI and NDWI](image)

Figure 3.9: Calculation of ACI
3.4 Calculation of Urban Heat Vulnerability Index (UHVI)

UHVI was calculated by obtaining the difference between the ACI and the product of EI and SI as shown in Equation 3.3.

\[ UHVI = EI \times SI - ACI \]  

Equation 3.3

This step has been illustrated in Figure 3.10.

Figure 3.10: Calculation of UHVI
4. TOTAL HEAT VULNERABLE POPULATION

In this section, the total number of people who are vulnerable to extreme heat events in Vienna is assessed. The data used for this calculation is presented in Table 5.1.

Table 5.1: Data for the Calculation of Total Heat Vulnerable Population

<table>
<thead>
<tr>
<th>DATA</th>
<th>DATA SOURCE</th>
<th>REFERENCE</th>
<th>PIXELS(m)</th>
<th>VALUE RANGE: MIN – MAX (UNIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMST*</td>
<td>Landsat 8 Satellite</td>
<td>Section 3.2.3</td>
<td>30</td>
<td>19 – 40 (°C)</td>
</tr>
<tr>
<td>ACI*</td>
<td>Sentinel 2A Satellite</td>
<td>Section 3.3.3</td>
<td>10</td>
<td>0 – 1 (No Units)</td>
</tr>
<tr>
<td>Population</td>
<td>Open-Data Vienna</td>
<td>Bevölkerungsprognose 2014 bis 2024 - Zählbezirke (2) Wien</td>
<td>n/a</td>
<td>1 – 25072 (People)</td>
</tr>
</tbody>
</table>

- **ACI* refers to** Adaptive Capacity Index/Indices.

5. RANKING OF SUB-DISTRICTS AGE GROUP: 0 – 14 AND 60 - ABOVE

<table>
<thead>
<tr>
<th>RANK</th>
<th>SUB-DISTRICT</th>
<th>AVERAGE URBAN HEAT VULNERABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1610</td>
<td>0.896174</td>
</tr>
<tr>
<td>2</td>
<td>0304</td>
<td>0.889238</td>
</tr>
<tr>
<td>3</td>
<td>1007</td>
<td>0.884200</td>
</tr>
<tr>
<td>4</td>
<td>0202</td>
<td>0.877351</td>
</tr>
<tr>
<td>5</td>
<td>1022</td>
<td>0.855616</td>
</tr>
<tr>
<td>6</td>
<td>0503</td>
<td>0.851640</td>
</tr>
<tr>
<td>7</td>
<td>2003</td>
<td>0.850973</td>
</tr>
<tr>
<td>8</td>
<td>0207</td>
<td>0.847720</td>
</tr>
<tr>
<td>9</td>
<td>0204</td>
<td>0.837980</td>
</tr>
<tr>
<td>10</td>
<td>1005</td>
<td>0.836119</td>
</tr>
</tbody>
</table>
Annex 1: Details of Sentinel 2A

A1.1 Details of Band Data

<table>
<thead>
<tr>
<th>BAND NUMBER</th>
<th>CENTRAL WAVELENGTH (nm)</th>
<th>BANDWIDTH (nm)</th>
<th>SPATIAL RESOLUTION (m)</th>
<th>PIXEL SIZE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>496.6</td>
<td>98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>560.0</td>
<td>45</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>664.5</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>835.1</td>
<td>145</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A1.2 Data Acquisition Details

<table>
<thead>
<tr>
<th>Location</th>
<th>Vienna, Austria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dates of Data Acquisition</td>
<td>2019-04-21</td>
</tr>
<tr>
<td>Scene Central Time</td>
<td>16:30 GMT (18:30 CEST) - For DS1*</td>
</tr>
<tr>
<td></td>
<td>10:00 GMT (12:00 CEST) - For DS2*</td>
</tr>
</tbody>
</table>

*For Sentinel 2A data over Vienna no single data-set could be collected. There were two data-sets that covered Vienna, namely:
- S2A_MSIL1C_20190421T100031_N0207_R122_T33UWP_20190421T121337 (Referred as DS1)
- S2A_MSIL1C_20190421T100031_N0207_R122_T33UXP_20190421T121337 (Referred as DS2)
Annex 2: Details of Landsat 8 TIRS

A2.1 Details of Band Data

<table>
<thead>
<tr>
<th>SPECTRAL BAND</th>
<th>WAVELENGTH (µm)</th>
<th>RESOLUTION</th>
<th>PIXEL SIZE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 10 - Long Wavelength Infrared</td>
<td>10:300 - 11:30</td>
<td>100</td>
<td>30*</td>
</tr>
</tbody>
</table>

* TIRS bands 10-11: collected at 100 meters but resampled to 30 meters to match OLI multispectral bands.

A2.2 Data Acquisition Details

<table>
<thead>
<tr>
<th>Location</th>
<th>Vienna, Austria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dates of Data Acquisition</td>
<td>All available days in June, July and August from 2015 to 2018. June 2019</td>
</tr>
<tr>
<td>Scene Central Time</td>
<td>09:45 GMT (11:45 CEST) - Approximate</td>
</tr>
</tbody>
</table>

Annex 3: Details of OpenData

A3.1 Details of OpenData Vienna

<table>
<thead>
<tr>
<th>DATA</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIE-Bevölkerungsprognose 2014 bis 2024 - Wiener Zählbezirke</td>
<td>Population projection for 250 sub-districts in Vienna by Age Group and sex 2014 to 2024.¹</td>
</tr>
</tbody>
</table>

Sources:

¹ [https://www.data.gv.at/katalog/dataset/32b03b8c-e860-4416-a433-fab84cb935a6](https://www.data.gv.at/katalog/dataset/32b03b8c-e860-4416-a433-fab84cb935a6)