Impetus

Co-funded by the Erasmus+ Programme of the European Union

Innovative Measurement Tool towards Urban Environmental Awareness

Heat Stress

Author
Isabel Pedroso de Lima

E-mail
iplima@uc.pt

Affiliation
University of Coimbra, Portugal

This project has been funded with support from the European Commission.

This publication reflects the views only for the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Project Partners

POLITECHNIKA GDAŃSKA | Rotterdam University of Applied Sciences | Hanzehogeschool Groningen University of Applied Sciences | Universität Klagenfurt | Universidade de Coimbra | Fachhochschule Graubünden University of Applied Sciences

Table of contents

1 Heat Stress 3
1.1 Introduction 3
1.2 Urban heat island effect 3
1.3 Assessing heat stress 6
1.4 Location and characterization of the study area 8
1.5 Exploratory field survey description 11
1.6 Example of a check list for field data collection and analysis 14
1.7 Final results description 19
1.8 External materials 19
1.9 Bibliography 19

1 Heat Stress

1.1 Introduction

The weather is not the only factor that contributes to many cities feeling uncomfortably hot. The built environment itself exacerbates high seasonal temperatures in urban environments. This is caused by the increasing urbanisation, characterized by increased construction density and paving of ground surfaces, among other factors. This effect is furthermore amplified by climate change and the results in increasing temperatures. At many locations in the world, climate change threatens city development and human safety.

There is thus the need to increase awareness about different urban environmental issues and climate change related vulnerabilities and challenges at local level, and to deal with local adaptation planning.

However, there is often limited availability of up-to-date data about local conditions and the impact of climate change on wellbeing and urban environment, in particular at the local street and neighbourhood level. In addition, there is lack of interdisciplinary approaches and public actions to solve local problems and inability to select the best solutions from a set of alternatives.

The material in this document is aimed at giving support to the exploratory assessments of urban heat stress vulnerabilities and risk.

1.2 Urban heat island effect

In fact, different factors contribute towards a typical climate phenomenon called the **urban heat island (UHI)** effect, which results in an increased air temperature in cities when compared to their rural surroundings. For example:

I. vehicles stuck in traffic emit heat,
II. air conditioners pump waste heat into the air,
III. concrete and asphalt surfaces absorb and radiate the sun's rays
IV. urban canyons formed between tall buildings, trap heat at the street level.

Regarding urban building materials, such as concrete and bituminous materials (asphalt), they can absorb heat during the day and radiate it back at night, much more than areas covered with vegetation do. The effect can add as much as 6–7°C to night-time temperatures in large cities and densely urbanized areas in relation to the surrounding countryside temperatures. There could also be different temperature conditions within the urban area.

Thus, within cities, air temperature strongly depends on building geometry, the thermal properties of the building's construction materials, radiative properties of the urban surfaces (e.g., building, roads and pavements) and anthropogenic thermal release, e.g., domestic heating, traffic and industry (Figure 1.1).

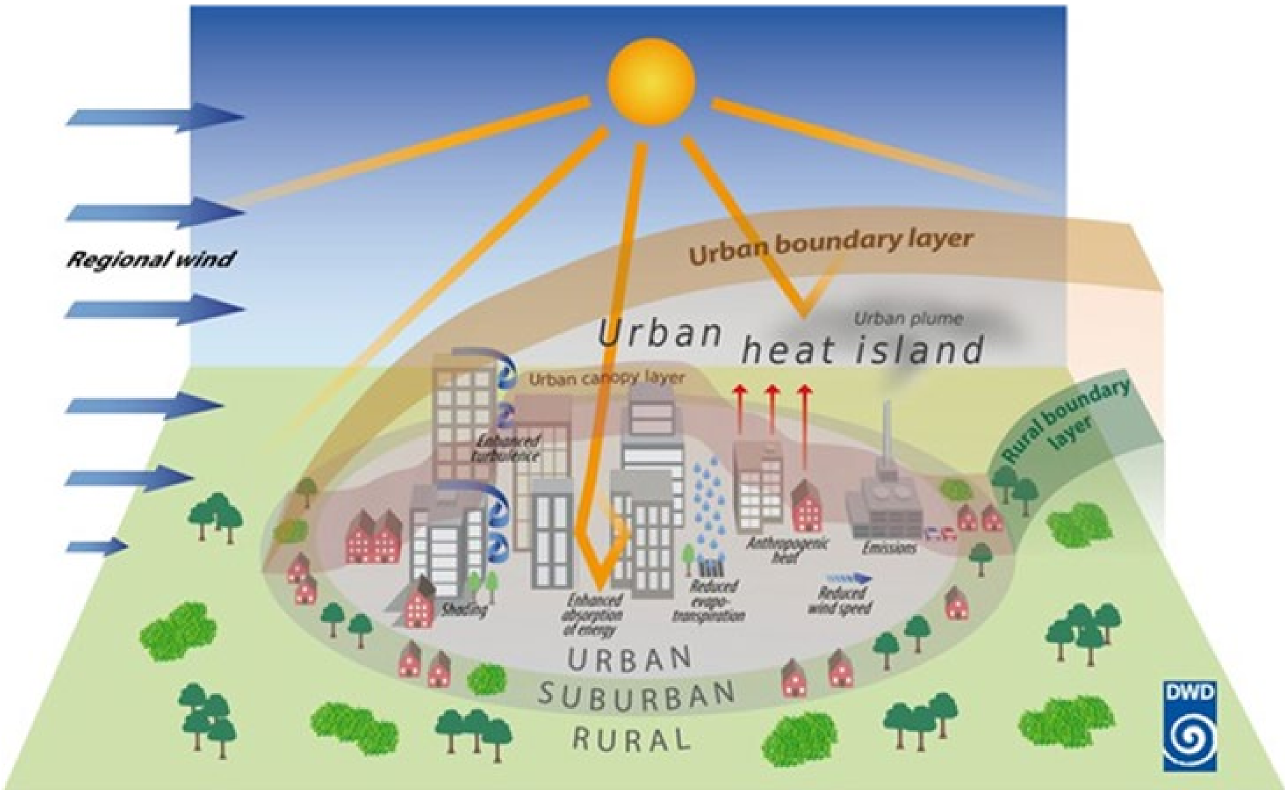


Figure 1.1. The urban climate and its influencing factors (DWD, 2021).

Several studies show also the dependency of UHI on a city's layout, i.e., the spatial organisation/pattern of a city's streets and buildings, including their orientation, plays a crucial role in the local UHI effect. The differences in the heating effect seem to result, for example, from the way buildings re-radiate heat that can then be reabsorbed by other buildings that face them directly.

However, each city is made up of a mosaic of individual buildings and other land-use units; their form and disposition are highly complex and, in detail, unique. Also, each urban unit, wall, roof, pavement, courtyard, street or park creates above it a climatological sheath with which it interacts. The way in which groups of buildings and whole cities affect the overlying air vary between different cities.

Among other main factors contributing to UHIs are the attributes of the surrounding area, the topography upon which the city is built, time of the year (i.e., season) and the regional climate, determined by synoptic factors. The UHI effect intensity might also differ, or not, between seasons (i.e. warmer or colder season), depending on geographical location and attributes of the urban area. Furthermore, this effect does not necessarily apply to cities in desert climates. In the desert, the evapotranspiration of the irrigated vegetation of the city may actually keep the city cooler than the surrounding barren region.

Especially during heatwaves, the higher temperatures in cities lead to a greater use of cooling and air conditioning systems and, thus, to a greater consumption of energy and higher costs. They also contribute to increased emissions of greenhouse gases (e.g., CO_2) and air pollutants (e.g., if fossil fuels are used), and to deteriorate water quality. The increased temperatures can lead to smog formation, which is unhealthy and damaging to materials. This is boosted by a warming climate and rapid population growth.

The temperature of surfaces, e.g. pavements and facades, is related with air temperature. Overall, the urban air temperature is influenced, for example, by the percentage of sealed soils, or by the presence of water and vegetation in a neighbourhood. The heating of the air in urban areas is mainly determined by the geometry of the built environment (e.g., sky view factor) and the albedo (Figure 1.2) and emissivity of the surface materials.

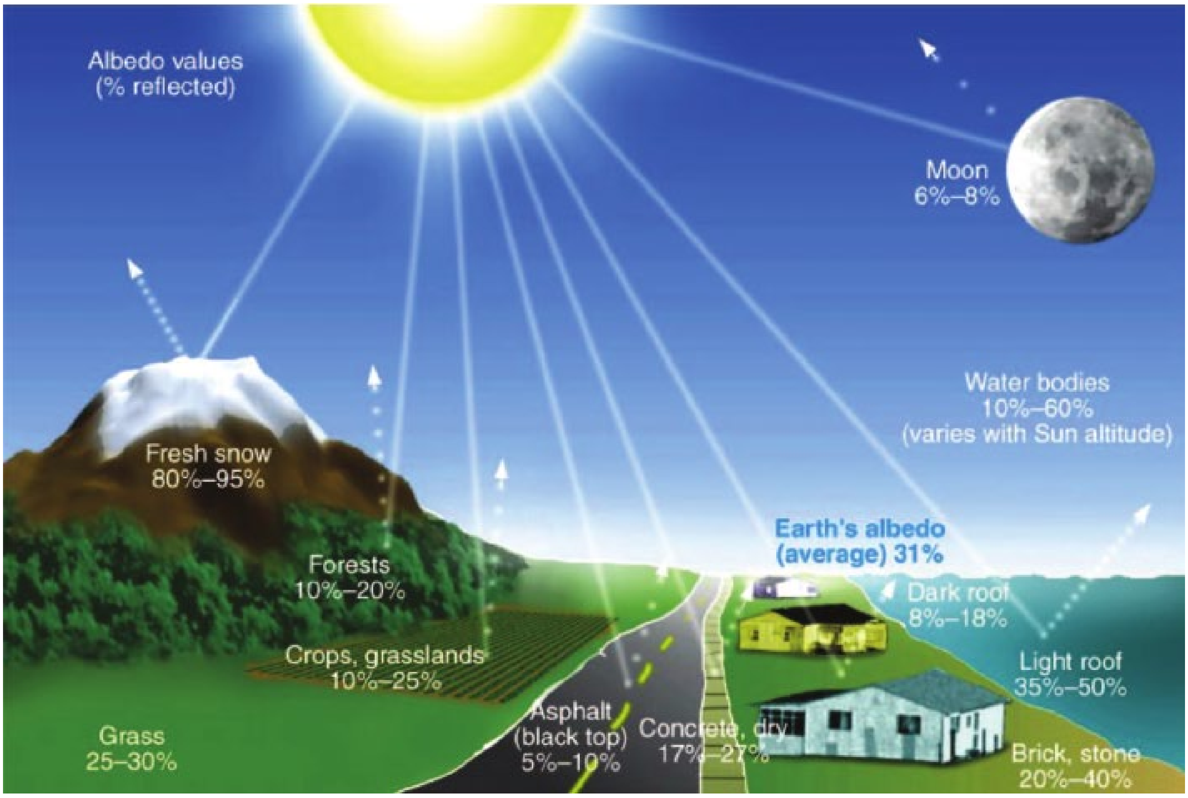


Figure 1.2. Albedo values for various surface materials.

Thus, overall, **why is it important to analyse urban heat islands?** The urban heat island effect and the evolution of the urban thermal environment has a close relationship with human society and important health, environmental and economic consequences.

With the frequency and intensity of heat waves increasing (whether the change has already been experienced or predicted by climate scenarios) it is urgent to tackle the excess heat faced both inside the buildings, and in the cities' outside spaces. There are many ways in which the UHI effect can be mitigated, while also creating more attractive places to live, work and play.

For example, to reduce UHI effects, many cities are planting more vegetation (including intensive tree-planting, creation of new parks, vertical planting and green roofs), recognising its value for urban cooling and the psychological wellbeing of residents; greenery provides shade and it stimulates evapotranspiration, the process by which water evaporating from plants' leaves reduces the adjacent air temperature. Besides cooling, abundant vegetation contributes also to other benefits: absorbing pollutants from the air, producing oxygen, increasing biodiversity and creating a calming, natural setting within the dense city and built environment.

Attaining cooler cities also demands changing the materials they are built from. As urban areas are dominated by dark and hard materials – concrete, asphalt, paving – most of which absorb, rather than reflect, solar radiation, cities are nowadays also using more reflective surfaces. For this purpose, bright roofing materials and cool coatings (typically, lighter pigments in asphalt or white-coloured coatings applied to roads, roofs and facades), which reflect more solar energy away from the city, back to space, are being used.

Water has also been used as a tool to cool cities, for centuries: house courtyards with pools and fountains, stimulate the evaporation of water and cool hot air. However, with respect to water, contemporary heat-proof cities accommodate ponds, pools, fountains, sprinklers and misting systems to cool outdoor spaces. Combining water with other urban cooling strategies can yield significant temperature reductions.

In fact, there is a suite of green-blue infrastructures that use nature-based solutions, which can increase the quality of urban ecosystem services.

There are also solutions that involve adaptable buildings and infrastructure that can morph to respond to different seasons and weather events, and thus keep the inside of buildings cool and comfortable in a warming climate.

The UHI phenomenon has several impacts on the living environment and on the population, namely the increase in **heat stress** risk. High temperatures can have, among others, significant health impacts.

Reducing the effect of UHI is thus vital to ensure that urban growth does not increase heat stress risks that urban citizens will face in the future, which are already being worsened by global warming and climate change.

1.3 Assessing heat stress

Heat stress occurs when our body is unable to cool itself enough to maintain a healthy temperature. Normally, the body cools itself by sweating, but sometimes sweating is not enough and the body temperature keeps rising. In the summer months, urban dwellers face increased risk of heat stress, with negative impacts on human health and comfort. The consequences of heat stress are usually more severe on older people, or people with previous illnesses, e.g., of the cardiovascular system, and small children who are often unable to adapt to higher temperatures.

To appraise the risk of heat stress in a given area, measurements at small scales are needed to provide information on surface and air temperature distribution and to better characterize thermal comfort/stress, at the local/micro urban scale. Ground observations and surveys are crucial to better understand the local conditions and the type of measures that could actually be more adequate to respond to and reduce high heat stress risk. Google Street view can be used as a complementary exploratory tool to conduct virtual appraisals of a city without the need to physically visit the area.

In addition to air temperature, other data such as fine-scale topographic maps, air humidity and urban attributes also provide important information that help to further assess the spatial variability of risk of heat stress.

Several approaches, of varying degree of complexity, have been developed for assessing the risk of heat stress. One example of a comprehensive approach is the Physiological Equivalent Temperature (PET) index (Höppe, 1999), that calculation is based on a diversity of specific variables and models, including physiological ones; however, the use of this indicator is often hampered by data unavailability.

A much simpler indicator of the thermal conditions is offered by the **Heat Index** (HI), which is based on only two atmospheric parameters: air temperature and relative humidity. This index describes how humidity affects the perception of high/warm temperatures in shaded areas, giving a measure of apparent temperature. Since the human body cools itself by evaporating sweat from the skin, higher humidity attenuates the effect of this mechanism. According to the HI, for temperatures below 27°C the HI equals air temperature. This index can be used in expedite assessments of the danger of heat exhaustion and strokes when performing outdoor activities. The HI is the result of extensive biometeorological studies over a period of decades by various researchers, most notably Steadman (1979).

To find the HI temperature, check the Heat Index Calculator or use the Heat Index Chart (Figure 1.3). This chart associates HI classes with different levels of alert in relation to the risk of heat stress: caution, extreme caution, danger and extreme danger (in Figure 1.3, the area without numbers indicates extreme danger). Usually, special alert is issued when the HI is expected to exceed ≈41°C for at least 2 consecutive days, but this limit might depend on the local climate.

A Heat Index Chart for areas with high heat but low relative humidity has also been developed by the U.S. National Weather Service (NOAA). Since HI values were devised for shady, light wind conditions, exposure to full sunshine can increase HI values by several degrees. Also, strong winds, particularly with very hot, dry air, can be extremely hazardous in terms of heat stress.

HEAT INDEX (HI), °C													
Temp. (°C)	Relative Humidity (%)												
	40	45	50	55	60	65	70	75	80	85	90	95	100
47	58												
43	54	58											
41	51	54	58										
40	48	51	55	58									
39	46	48	51	54	58								
38	43	46	48	51	54	58							
37	41	43	45	47	51	53	57						
36	38	40	42	44	47	49	52	56					
34	36	38	39	41	43	46	48	51	54	57			
33	34	36	37	38	41	42	44	47	49	52	55		
32	33	34	35	36	38	39	41	43	45	47	50	53	56
31	31	32	33	34	35	37	38	40	41	43	45	47	49
30	29	31	31	32	33	34	35	36	38	39	41	42	44
29	28	29	29	30	31	32	32	33	34	36	37	38	39
28	27	28	28	29	29	29	30	31	32	32	33	34	35
27	27	27	27	27	28	28	28	29	29	29	30	30	31

Category	Heat index	Possible heat disorders for people in high risk groups
Extreme Danger	≥ 52°C	Heat stroke or sunstroke likely.
Danger	40–51°C	Sunstroke, muscle cramps, and/or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity.
Extreme Caution	33–39°C	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity.
Caution	27–32°C	Fatigue possible with prolonged exposure and/or physical activity.

Figure 1.3. Heat Index chart and classes, associated with different levels of risk of heat stress (adapted from NWS, NOAA, U.S.).

1.4 Location and characterization of the study area

When investigating the risk of heat stress in a given urban area and actions to prevent or minimize it, it is important to understand the area's geographical context, including its relief and altitude, characteristics of the surrounding area (e.g., forest, agricultural areas), distance to the sea, climate, and demography. For characterizing the local climate, parameters such as air temperature, humidity, precipitation, wind and solar radiation are important.

For example, annual mean air temperature as well as the temperature in the warmest season, its range (what is the maximum and the minimum temperature), and the number of days a year that register air temperature above given thresholds (e.g., maximum temperature above 25°C or 30°C), which is case/location dependent, should be identified. These data are usually available from historic records of weather stations from national monitoring networks, but only representative weather stations will allow you to understand the local climate, and the vulnerability of the area to face critical warm weather conditions (e.g. intensity of the heat, frequency of very warm days, air humidity during hot weather). This type of data will allow you to picture potential heat stress vulnerabilities in a given city or urban area, and the pertinence of studying and fighting heat stress at the local scale, towards a better city liveability.

However, quite often, despite the fact that in many countries the number of urban automatic weather stations has been increasing, data will be available for stations/locations that might not represent well the conditions in the urban area of interest. So, field monitoring at the local scale is important.

Information on precipitation, including mean annual precipitation, identification of wet and dry seasons, and if they superimpose with the warmest season should also be gathered. The conditions regarding air humidity should also be assessed because it relates closely with thermal comfort/discomfort.

It is also important to understand how a given street is embedded in a more or less dense urban grid, and the main features of the urban environment and of the neighbouring/surrounding areas. Google Maps can be used to obtain a quick overview of the study area, and insight on the surroundings, such as the presence of green areas, rivers, lakes, etc. Figure 1.4 shows an example of such an image.

Figure 1.4. Example of an overview of urban residential areas (on the right hand side) and its surroundings, obtained from Google Map. The type of urban layout(s), the proximity between the residential areas and the river (at the bottom of the image) and the extension of the surrounding green areas can be easily appraised.

For an overall insight into the spatial distribution of temperature in the area of interest, different remote sensing technology-based monitoring tools are now able to provide detailed/high spatial resolution information on temperature. The applications promise well for urban climatology where the problems of physical size, and spatial integration of countless individual elements are most difficult.

Remote sensing data, obtained by sensors (e.g. infrared radiometers) deployed in satellites has been shown capable of identifying UHI, due to the extent of the data spatial coverage; these data allow one to appraise (and compare) the temperature in the cities and in their surrounding areas. The satellite-based data are also providing valuable tools to improve our insight into the air temperature distribution across cities and, therefore, assist in identifying problem areas, due to their current high spatial resolution.

Satellite (e.g., Landsat, the NOAA-AVHHR system) systems can provide, for example, Land Surface Temperature (LST) data. LST is the radiative skin temperature of the Earth's surface derived from infrared radiation; it refers to the effective radiating temperature of the soil plus canopy surface. Thus, LST measures the emission of thermal radiance from the land surface where the incoming solar energy interacts with and heats the ground, or the surface of the canopy in vegetated areas. Various methodologies have been developed to retrieve LST from space-based, remotely sensed thermal-infrared data that provides spatially continuous LST measurements with global coverage to examine the thermal heterogeneity of the Earth's surface, and the impact on surface temperatures resulting from natural and human-induced changes.

Figure 1.5 shows an example of such a LST map, which is based on data downloaded from Landsat-8 satellite (https://www.usgs.gov/landsat-missions/landsat-8); the LST map was obtained using QGIS software. This map shows that the surface temperature varies across the urban area and that the city registers higher temperatures than the surrounding area.

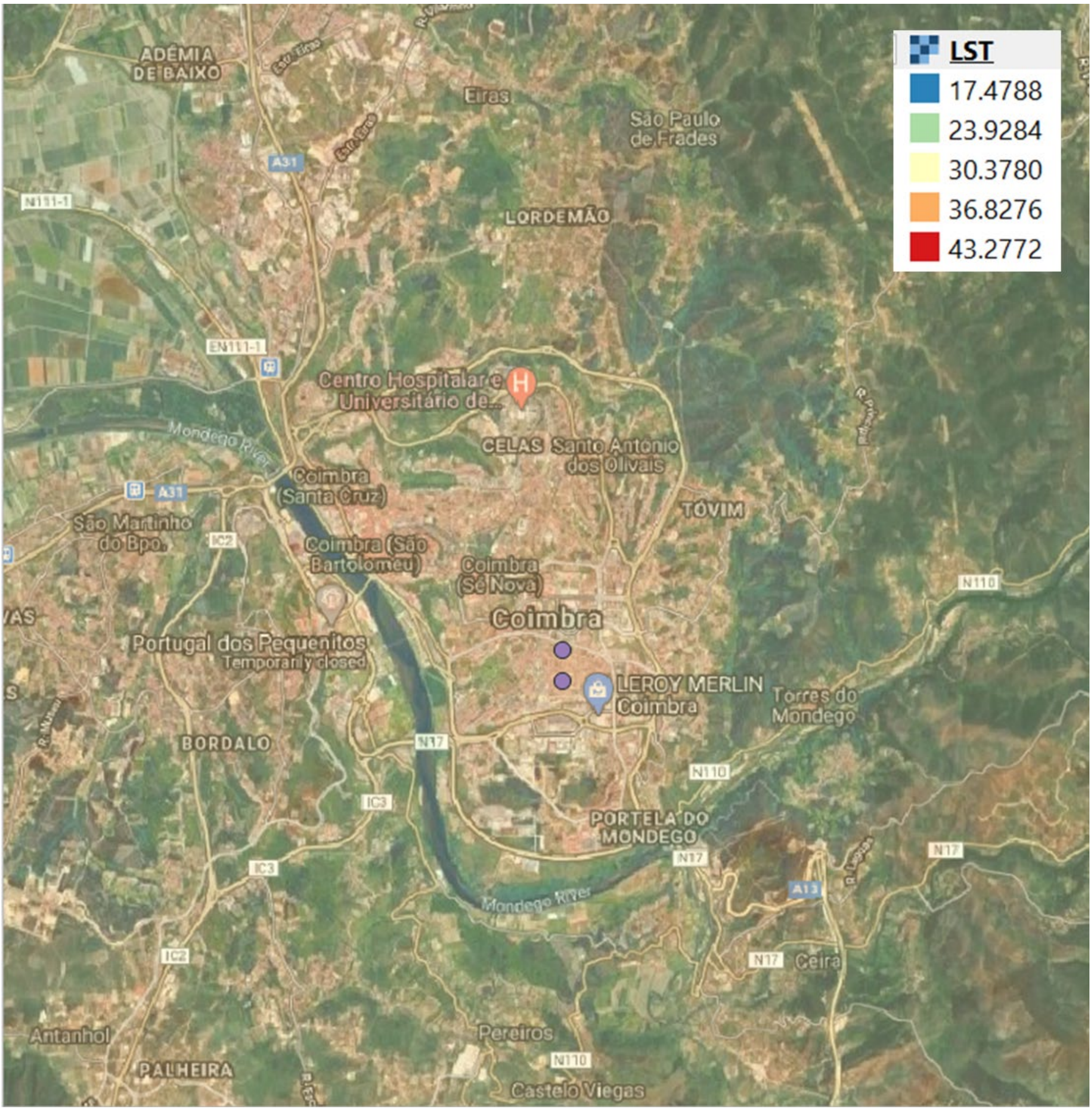


Figure 1.5. Example of a Land Surface Temperature (LST) map view. The image is for the city of Coimbra (Portugal), from August 5, 2018 (reference local time is 11:13am).

There is a strong relationship between LST and near surface air temperature, although the two temperatures have different physical meaning and responses to atmospheric conditions. In complex terrain, these differences are amplified. Because LST influences the partition of energy between ground and vegetation, it determines the surface air temperature. In general, air temperatures above a surface reflect the same trends as ground surface temperatures, but ground temperatures are likely to be more extreme.

Nevertheless, LST is an easy to access indicator and is one of the most important parameters to quantify urban microclimate; microclimate refers to the climate of a very small or restricted area, which assessment is especially important when it differs from the climate of the surrounding area.

1.5 Exploratory field survey description

An exploratory field survey focusing on an urban area, or street(s), could provide important knowledge on the local urban environment and increased understanding of the role played by different urban attributes. Overall, usual aims of such a survey are:

- to appraise ambient conditions, namely with respect to air temperature and relative humidity;
- to assess the risk of heat stress through, e.g., the calculation of the Heat Stress Index;
- to try to identify relations between air temperature, relative humidity and surface temperatures, and features of the urban area and streets, with special emphasis on the urban layout (e.g., street width, type of buildings, buildings' height, density of construction, orientation), surface materials (e.g., stone facades, green facades, lawns, streets and tracks' pavements, vegetation type), shades, water bodies, among others.

It is useful and recommended to follow a checklist to assist you in exploring the study site and collecting information on urban features that might have an impact on the urban thermal comfort/stress, and that might also determine the type of adaptive measures to adopt locally. An example of such a list is given in section 1.6. The list of features identified in that example is not exhaustive, so you can always identify other attributes that would likely have a potential important impact on the overall assessment of the local conditions and heat stress vulnerabilities, at the street and neighbourhood level.

For each one particular street of interest, the investigation should focus on the conditions along the street and the area in which the street is embedded. For each street, for reference, consider a start point coordinate (0,0,0) for the experiment. Consider the coordinates x, y and z (x,y,z), with x being the distance to the origin (along the street that is being studied, see Figure 1.6), y the distance in the perpendicular direction, and z representing the elevation. The start point can be used to identify the position of the different elements that are identified as being pertinent for the case study. Use a GPS to identify the spatial coordinates of the relevant points.

Google maps and tools can be used, namely, to roughly estimate elevation, lengths (e.g., street length, street width, distance to a water body or green space), building's heights and areas (e.g., green areas, parking lots, yards).

In order to assess the vulnerability of the urban areas to heat stress, you should explore **weather data** (air temperature and relative humidity) obtained, for example, using simple portable weather stations, which are easily accessible, at low cost. These observational data on a warm day will allow you to roughly estimate the Heat Index for the local conditions, and better understand how this and other indicators can be used to classify the thermal comfort/stress at different locations and conditions. Annotate, always, the time of the records. Be aware that if the performance of the sensors is not known, there could be some unquantifiable bias in the measurements, which should only be accepted for exploratory studies.

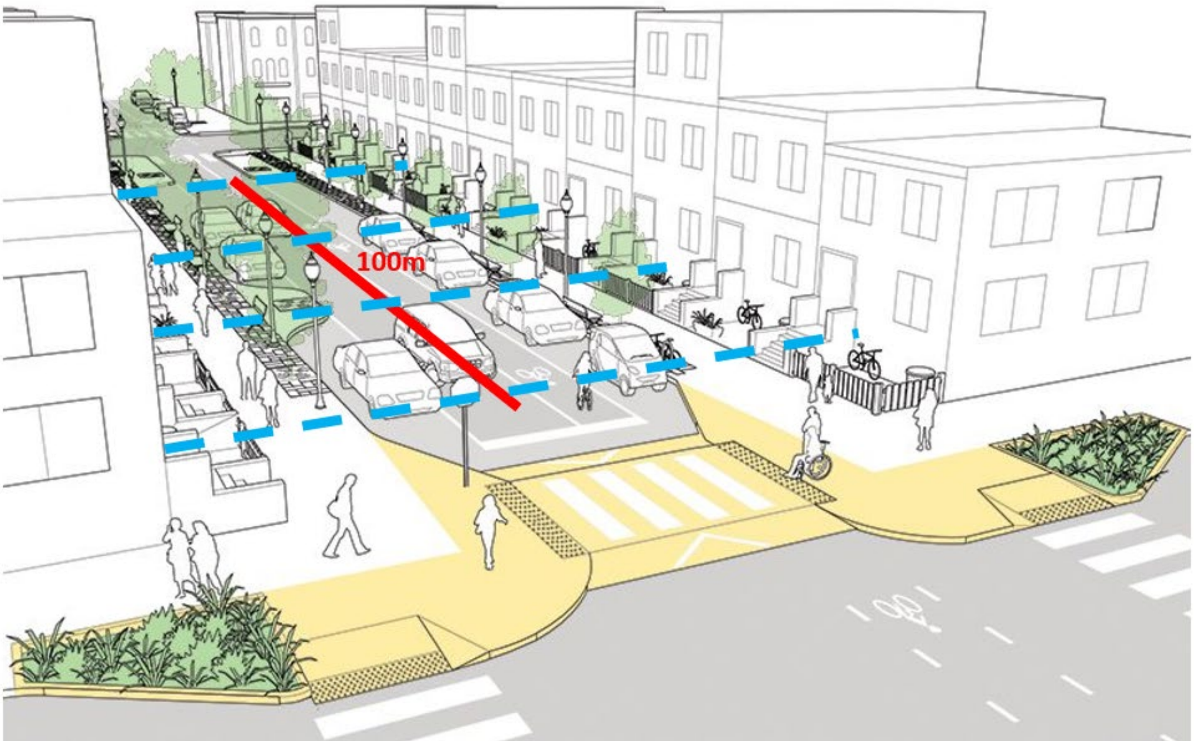


Figure 1.6. Sketch of an example of a survey, at the street level, illustrating the longitudinal direction and cross sections (sketch not to scale).

During the survey, an infrared thermometer can also be used to measure the **temperature of different urban surfaces** such as pavements and walls. Pay attention to the **urban environment and construction details** that surround you, even if you are unable to register the temperature of those surfaces.

Bear in mind that the weather data that are collected on a given day might not represent well the typical conditions of a local "warm day", which might bias conclusions if you rely only on circumstantial observations.

For example, you might like to additionally assess the weather data obtained at a nearby (ground) weather station (air temperature, relative humidity, wind speed, and global radiation) for a broader insight and characterization of critical weather conditions, regarding the risk of heat stress. Identify the existence of such a weather station(s), at a short distance from the study area; annotate the coordinates (including the altitude) and name of the weather station(s). The sample graphs in Figure 1.7 illustrate the type of data that you could access via the web interface with many automatic stations; the data are usually access free. These types of records will illustrate what type of daily variation you could expect for temperature and air humidity, and for other atmospheric data.

Bear in mind that the proposed exploratory appraisal of the study area is expected to assist you in identifying problem areas in the urban environment with respect to heat stress, and the effect of urban features on air temperature and humidity, which are determinant parameters of the risk of heat stress. This is key to gain insight into the potential usefulness of different heat adaptive measures, namely green-blue solutions.

Daily Mode | August | 5 | 2018 | View

Previous | Next

Summary
August 5, 2018

	High	Low	Average
Temperature	40.2 °C	21.4 °C	29.4 °C
Dew Point	22.7 °C	17.3 °C	19.7 °C
Humidity	85 %	27 %	60 %
Precipitation	0.00 mm	--	--

	High	Low	Average
Wind Speed	29.0 km/h	0.0 km/h	4.1 km/h
Wind Gust	29.0 km/h	--	7.5 km/h
Wind Direction	--	--	East
Pressure	1,016.26 hPa	1,013.85 hPa	--

Graph | Table

August 5, 2018

Figure 1.7. Example of an interface with weather data measured at a weather station. The data were measured on August 5, 2018, at the weather station ICOIMBRA14, Portugal, coordinates 40o 11' 6''N, 8o 24' 46,8''W. (https://www.wunderground.com/dashboard/pws/ICOIMBRA14/graph/2018-08-5/2018-08-5/daily).

So, **summing-up,** the proposed survey approach to gathering field data on the urban environment includes the following actions:

- Inspect longitudinal (and cross sectional…) temperature (and air relative humidity) variations for each street of interest based on data mapping, if available (e.g., LST maps), for an exploratory appraisal;
- According to the different local conditions found at the street/neighbourhood level, take on site measurements of air temperature and air relative humidity with a portable weather station/sensor. Be aware that you will need to wait a few minutes before taking the reading given by the sensor(s), which depends on the response time of the sensor(s). If the data are collected manually, take also note of each point measurement coordinates. If possible, check the temperature of different surfaces (e.g., wall, pavements) using an infrared thermometer, or the air temperature in the proximity of those surfaces.
- During the visit to the sites, take note of observed attributes of the urban environment that could potentially explain the assessed temperature and humidity variations in the urban area;
- Take pictures of important features of the urban environment, including the built environment, to better understand the result of your survey, and conditioning factors of the observed air temperature and humidity fields.
- Use the portable weather station data on air temperature and relative humidity to estimate the Heat Index range [min, max], for the relevant locations in the studied area/street (add the date and time during the day, for this result), and its variation across the area, and classify the corresponding local thermal perception conditions based on this index;
- Using available data from local weather stations (the data is only relevant if the station is in the proximity of the study area): *i)* assess the difference between the portable sensor records

and the station's records, for simultaneous records; ii) appraise the diurnal variation in weather parameters and, thus, how heat stress risk may typically vary during the day.

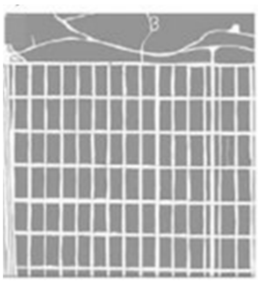
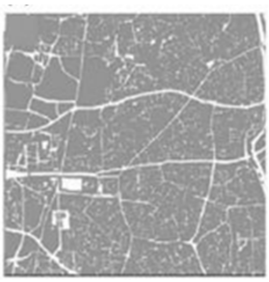
- Summarize the results obtained in your survey and observations, in particular, regarding the association between observed local features of the urban areas of interest and the temperature records. Give location for the corresponding key measurement points, and describe briefly the surrounding area, highlighting the features that are likely contributing to less favourable thermal conditions or heat stress. This could be the basis for discussing suitable measures to deal with the conditions found, which could contribute potentially to lessen heat stress risk.
- Remember that web platforms such as the existing database ClimateScan (https://www.climatescan.nl/) can be used to map heat stress vulnerabilities of a defined urban area, as well as solutions implemented (namely blue-green approaches). ClimateScan provides an interactive web-based map application for international knowledge exchange that works as an open educational resource and community awareness tool.

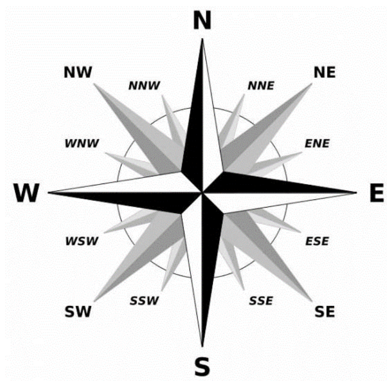
1.6 Example of a checklist for field data collection and analysis

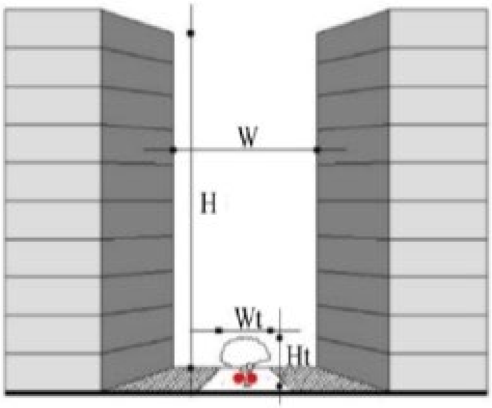
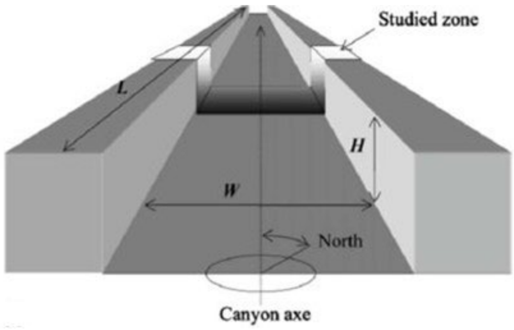
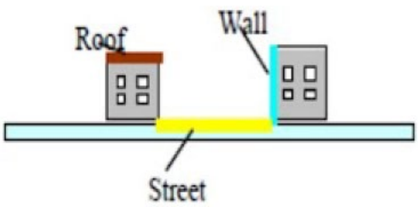
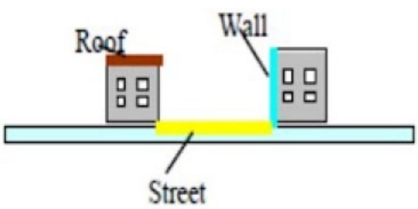
For gathering field data, it is important to be systematic. The use of a registration form, or similar dedicated product, can be helpful in this task.

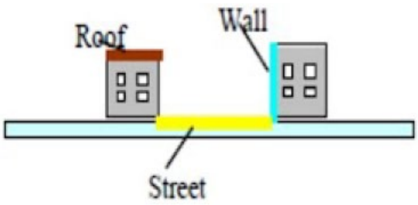
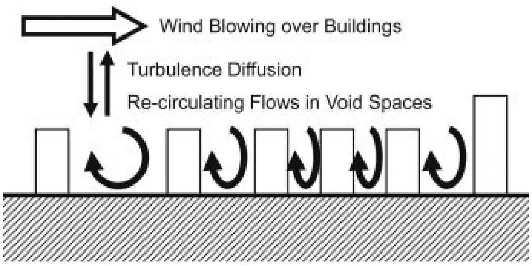
Using the same measurement procedures in different surveys is important, since it allows to unify the measures and make datasets comparable.

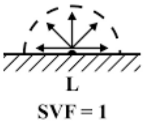
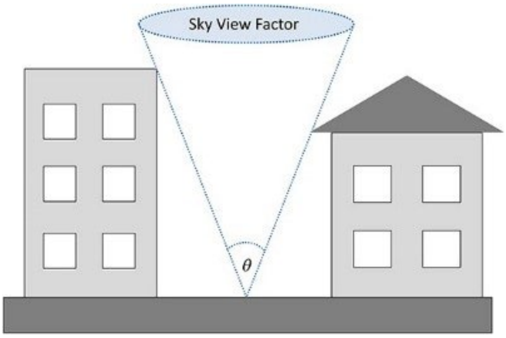
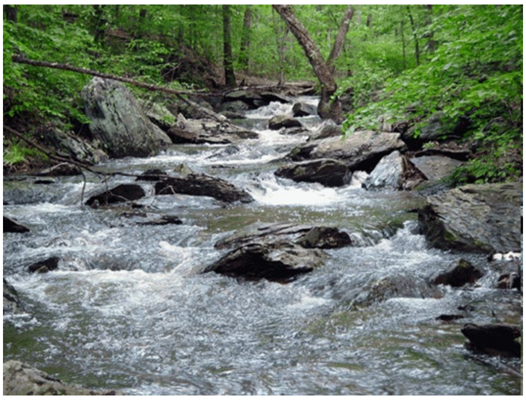
See the example that follows:

FIELD SURVEY FOR HEAT STRESS ASSESSMENT IN URBAN AREAS				
#	**Feature description**	**illustration**	**Answer/observation**	**X**
Identification of the observer				
1	Name of the observer(s)			
Identification of the urban area and observations				
2	City name			
3	Name of selected street or neighbourhood			
4	Date of observation (DD/MM/YY)			
Based on your observations, register representative attributes of the selected street and neighbouring area				
5	Type of urban area grid	 	regular grid	
			irregular grid	

6	Type of construction composition		compact low-rise	
			open low-rise	
			compact mid-rise	
			open mid-rise	
			compact high-rise	
			open high-rise	
7	Type of occupation		residential	
			commerce	
			business Centre	
			services	
			parking	
			green area (leisure)	
			schools	
			sport fields	
			other	
8	Length of the studied street (m)			
9	Maximum elevation difference (m)			
10	Orientation of the main street and buildings		N-S	
			E-W	
			NE-SW	
			NW-SE	
			NNE-SSW	
			NNW-SSE	
			WNW-SES	
			WSW-ENE	

<table>
<tr><td>11</td><td>Mean buildings' height (H, in m)</td><td rowspan="3">
</td><td colspan="2"></td></tr>
<tr><td>12</td><td>Mean street's width (W, in m)</td><td colspan="2"></td></tr>
<tr><td>13</td><td>Street canyon aspect ratio (=H/W)</td><td colspan="2"></td></tr>
<tr><td rowspan="3">14</td><td rowspan="3">Consider the distance between two major intersections along the street, defined as the length (L, in m) of the street canyon. The street canyon is a</td><td rowspan="3">
</td><td>short canyon (L/H ≈ 3)</td><td></td></tr>
<tr><td>short canyon (L/H ≈ 3)</td><td></td></tr>
<tr><td>long canyon (L/H ≥ 7)</td><td></td></tr>
<tr><td rowspan="2">15</td><td colspan="2" rowspan="2">Symmetry of the street canyon, with respect to the height of the buildings that make the canyon (i.e., on both sides of the canyon)</td><td>symmetric canyon</td><td></td></tr>
<tr><td>asymmetric canyon</td><td></td></tr>
<tr><td rowspan="5">16</td><td rowspan="5">Building's <u>roof</u> material</td><td rowspan="8">
</td><td>terracotta</td><td></td></tr>
<tr><td>metal</td><td></td></tr>
<tr><td>concrete</td><td></td></tr>
<tr><td>green roof</td><td></td></tr>
<tr><td>other</td><td></td></tr>
<tr><td rowspan="3">17</td><td rowspan="3">Building's roof colour:</td><td>light</td><td></td></tr>
<tr><td>medium</td><td></td></tr>
<tr><td>dark</td><td></td></tr>
<tr><td rowspan="9">18</td><td rowspan="9">Buildings' <u>facade/wall</u> material:</td><td rowspan="12">
</td><td>glass</td><td></td></tr>
<tr><td>concrete</td><td></td></tr>
<tr><td>plastering</td><td></td></tr>
<tr><td>bricks</td><td></td></tr>
<tr><td>stone</td><td></td></tr>
<tr><td>metal</td><td></td></tr>
<tr><td>wood</td><td></td></tr>
<tr><td>green wall</td><td></td></tr>
<tr><td>other</td><td></td></tr>
<tr><td rowspan="3">19</td><td rowspan="3">Buildings' facade colour:</td><td>light</td><td></td></tr>
<tr><td>medium</td><td></td></tr>
<tr><td>dark</td><td></td></tr>
</table>

<table>
<tr><td rowspan="5">20</td><td rowspan="5">Type of <u>street</u> paving material:</td><td rowspan="8">
</td><td>bituminous (asphalt)</td><td></td></tr>
<tr><td>cement</td><td></td></tr>
<tr><td>stone</td><td></td></tr>
<tr><td>bricks</td><td></td></tr>
<tr><td>other</td><td></td></tr>
<tr><td rowspan="3">21</td><td rowspan="3">Type of street paving colour</td><td>light</td><td></td></tr>
<tr><td>medium</td><td></td></tr>
<tr><td>dark</td><td></td></tr>
<tr><td rowspan="5">22</td><td rowspan="5">Type of <u>side-walk</u> paving material</td><td rowspan="11"></td><td>bituminous (asphalt)</td><td></td></tr>
<tr><td>cement</td><td></td></tr>
<tr><td>stone</td><td></td></tr>
<tr><td>tiles</td><td></td></tr>
<tr><td>bricks</td><td></td></tr>
<tr><td rowspan="6">23</td><td rowspan="6">Type of side-walk paving colour</td><td>other material</td><td></td></tr>
<tr><td>no side-walk</td><td></td></tr>
<tr><td>light</td><td></td></tr>
<tr><td>medium</td><td></td></tr>
<tr><td>dark</td><td></td></tr>
<tr><td>no side-walk</td><td></td></tr>
<tr><td>24</td><td>Squares/void spaces along the street (approx. % of total street length)</td><td>
</td><td colspan="2"></td></tr>
<tr><td>25</td><td>Front yard of houses along the street (approx. % of total street area)</td><td></td><td colspan="2"></td></tr>
<tr><td>26</td><td>Public greenery areas along the street (approx. % of total street area)</td><td></td><td colspan="2"></td></tr>
</table>

27	Type of vegetation in green areas		lawns	
			shrubs/bushes	
			small canopy tress	
			big canopy trees	
			there are no green areas	
28	Shade on the street		shade from canopy of trees, sparsely distributed	
			shade from canopy of trees, close together	
			there is shade, but from other sources	
			there is no shading	
29	Visibility of the sky (Sky View Factor - SVF, ranges from 0 to 1); when a location has buildings and trees, SVF decreases. 		unrestricted	
			reduced	
			very limited	
30	Type of nearby water body		River	
			Canal	
			pond	
			Lake	
			None	
31	Proximity to water body (minimum distance, in m)			
32	Air temperature range [min, max] along the street, in degree Celsius (on the observation date)			
33	Air relative humidity (%) range [min, max] (on the observation date)			
34	Give your estimate of the Heat Index range [min, max], for the observation date, in the studied area/street. Add the time of the observations, for this result.			

35	Based on the Heat index, comment on the overall local thermal perception condition. Give location for the corresponding measuring points, and identify striking features in the proximal area.	
36	Based on the observation of the urban area, identify the local attributes that likely have stronger impact on heat stress in the area.	
37	In your view, what could be the nature of measures that could be implemented to benefit the area with respect to heat stress risk?	
38	Collect material (e.g. photo, map) that illustrates your assessment. Upload pertinent material in a dedicated platform.	

1.7 Final results description

To analyse heat stress in urban areas, use the Heat Stress Field Survey Report to print.doc or the app and put the results at the ClimateScan database. Having surveys from different urban areas done on the same day or several surveys from the same urban area but from different days you select the material ready to be discussed with your students. If possible, find for your analysed location the heat stress maps and compare the results. For the students' knowledge income verification use the Heat stress pre-post test to print.doc and Heat Stress pre-post test key.doc.

1.8 External materials

See: https://impetus.aau.at/outputs/

Folder: Heat Stress

- Heat Stress instruction.pdf
- Heat Stress Field Survey Report to print.doc
- Heat Stress pre-post test to print.doc
- Heat Stress pre-post test key.doc

1.9 Bibliography

Chandler, T.J., 1970. Urban climatology - Inventory and prospect. In: Urban climates, Proceedings of the Symposium on Urban Climates and Building Climatology, jointly organized by the World Health Organization and WMO, Brussels, October 1968. WMO TECHNICAL NOTE No. 108, WMO - No. 254. TP. 141, Geneva, Switzerland, 1-14.

Chandler, T.J., 1976. Urban climatology and its relevance to urban design. World Meteorological Organization (WMO), TECHNICAL NOTE No. 149, WMO - No. 438, Geneva, Switzerland.

Chandler D.L., 2018. Urban heat island effects depend on a city's layout (published 2018, February 22). Accessed March 2021 from https://phys.org/news/2018-02-urban-island-effects-city-layout.html.

DWD - Deutscher Wetterdienst, 2021. Urban climate - urban heat islands. Accessed March 2021, https://www.dwd.de/EN/research/climateenvironment/climate_impact/urbanism/urban_heat_island/urbanheatisland_node.html.

EPA - U.S. Environmental Protection Agency, 2021. Heat Island Impacts. Accessed March 2021 from https://www.epa.gov/heatislands/heat-island-impacts.

Höppe, P., 1999. The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology, 43(2), 71–75.

Jin, M.; Dickinson, R.E., 2010. Land surface skin temperature climatology: benefitting from the strengths of satellite observations. Environmental Research Letters, 5, 041002.

Lee, K.; Kim, Y., Sung, H.C.; Ryu, J.; Seong Woo Jeon, S.W., 2020. Trend Analysis of Urban Heat Island Intensity According to Urban Area Change in Asian Mega Cities. Sustainability, 12, 112; doi:10.3390/su12010112.

Li, Y.; Zhao, M.; Motesharrei, S.; Mu, Q.; Kalnay, E.; Li, S., 2015. Local cooling and warming effects of forests based on satellite observations. Nature Communications, 6, 6603.

NWS – U.S. National Weather Service, National Oceanic and Atmospheric Administration, 2022. Heat Index Chart. Retrieved November 2022 from https://www.weather.gov/safety/heat-index.

Sobstyl, J.M.; Emig, T.; Abdolhosseini Qomi, M.J.; Ulm, F.-J.; Pellenq, R.J.-M., 2018. Role of City Texture in Urban Heat Islands at Nighttime. Physical Review Letters, 120, 108701. DOI: https://doi.org/10.1103/PhysRevLett.120.108701.

Steadman, R. G., 1979. The assessment of sultriness. Part I: A temperature–humidity index based on human physiology and clothing science. Journal of Applied Meteorology, 18, 861–873.