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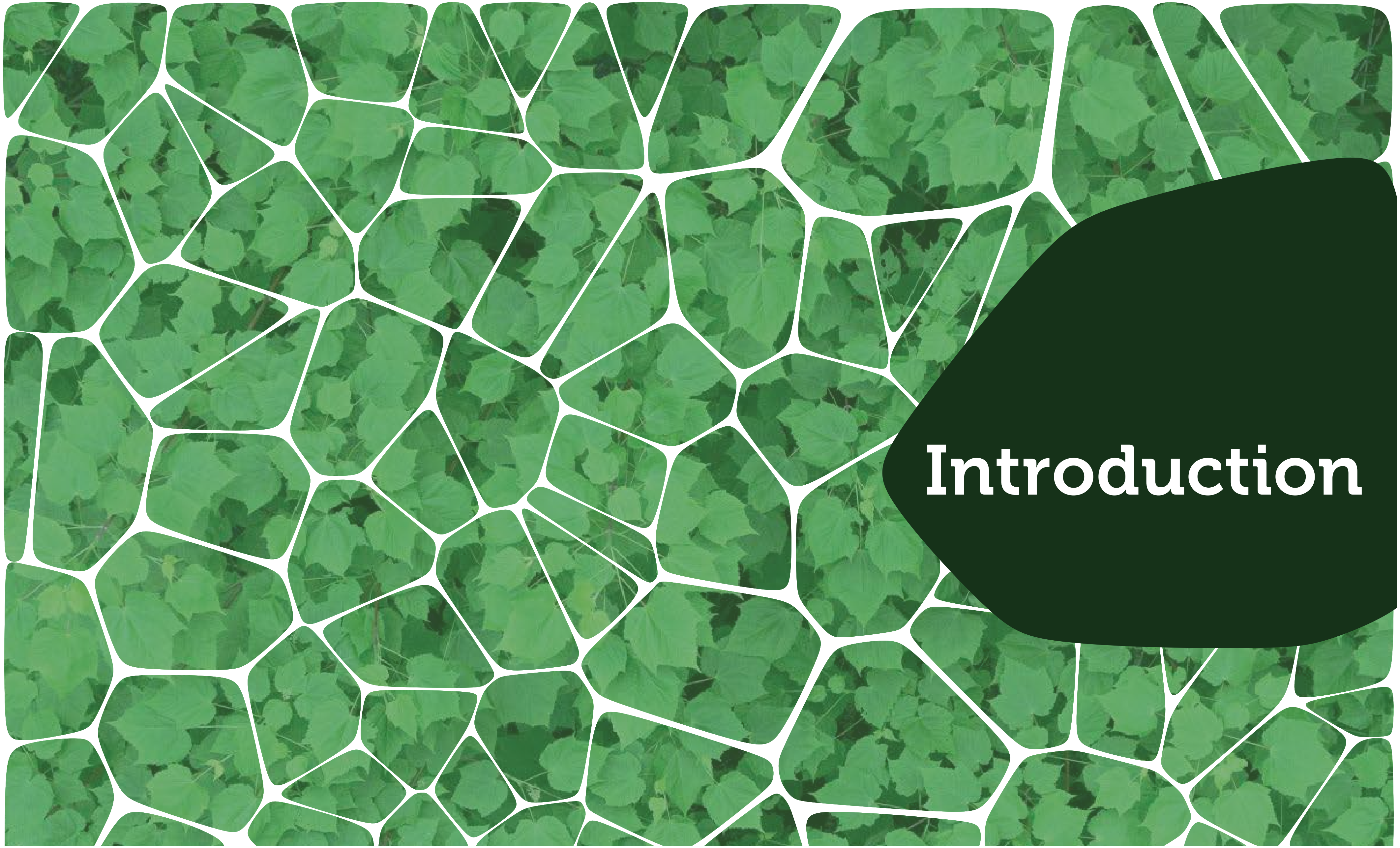
WEATHER AND CLIMATE CONSIDERATIONS FOR LOCAL GOVERNMENTS

2019



Introduction

1. INTRODUCTION

This report serves as a guide for the implementation of weather stations network in urban areas, following the World Meteorological Organization (WMO) standards. The main goal is to promote the adoption of weather and climate monitoring technology in order to collect observations on a more detailed scale and contribute to broaden the knowledge of climate change and the resulting atmospheric conditions at city level.

The characterization of meteorological and, consequently, climatic events plays an increasingly important role in the lives of citizens in terms of health, welfare and economy. The characterization of climate at the local scale, thus allows to outline strategies to adapt to the impact of climate change, such as temperature increase, droughts, floods, intense precipitation, among others.
There are several uses for monitoring this type of information, including real-time observation of weather conditions in each location, enabling forecasts, warnings, and long-term knowledge regarding adverse conditions that present a certain level of danger to citizens.

However, the scope of this report is to further knowledge about climate change management for local governments. It was written by and for "non experts" to facilitate the understanding for fellow cities willing to start their own weather monitoring networks and data collection.
Therefore, it should be read with a critic assessment about the proposed interpretations and must be understood as an exercise within the progress of Cascais' weather and climate monitoring process.

2. METEOROLOGICAL AND CLIMATE MEASUREMENT

Meteorology and Climatology are based on the study of atmospheric phenomena and their influence on the globe. It is the study of meteorological data obtained from measurements made at properly installed stations (weather stations), which have two types:

- Conventional - mechanical devices, requiring a properly trained operator to collect data on measurements made by the devices;
- Automatic - electronic devices that send information directly via wireless, providing the data in digital format and its continuous analysis.

Automatic stations provide greater benefits, in terms of data access, reduced labour and data representativeness, as it is possible to obtain data over short periods of time, which is not the case with conventional stations.

The main parameters which are measured at the weather stations and their devices are shown in Table 1.

Parameters	Devices
Temperature	Thermometer
Atmospheric pressure	Barometer
Humidity	Hygrometer
Precipitation	Pluviometer
Global Solar Radiation	Pyrometer
Wind Speed and Direction	Anemometer and weather wave

"Climate" is generally defined as the "average weather" [1] - in the narrow sense - which means the measure of the statistical data collected over long periods of time (at least 30 years). The changes in the various parameters mentioned before determine which variations usually occur in certain locations.
Climate measurement at the urban scale allows a more reliable definition of the type of climate that predominates in that area, providing a greater ability to react to changes occurring in the local climate, verifying the influence of anthropogenic effects on urban space.
Meteorological measurement is therefore the basis of climate measurement. Their main difference is the time scale to which they refer.

3.URBAN CLIMATE

The human development has been increasingly influencing on abnormal variations in atmospheric conditions, especially in the urban areas. The “urban climate” is essentially characterized on a scale whose range is between 3 km to 100 km (mesoscale) [2] and can be considered as mesoclimate.

There are several anthropogenic factors which have influence on the urban environment, such as height, density, structure and composition of the buildings and roofs.
These factors can determinate changes that occur at different atmospheric conditions.

Figure 1 - The urban climate

The urban agglomeration commonly has negative effect on the climatic characteristics of cities and municipalities due to different factors, including [3]:

- Replacing natural soil cover with materials such as cement, asphalt, stone and others has a great influence on the average temperature of the urban environment, contributing to its increase,
- As a result of this replacement, the new impermeable materials prevent water infiltration into soil, which is also contributing to thermal imbalance in the climate and often lead to flooding,
- Floods are not only related to soil sealing, but also to inadequate urban land management, as building construction is permitted in areas where the probability of flooding is significant,
- The increase of airborne solid particles (resulting from pollution), with the consequent decrease in the transparency of the atmosphere, can cause a decrease in direct radiation sent mostly into space and increases the absorption of ultraviolet radiation,
- The increase of mean temperature causes a decrease in evapotranspiration and as moisture concentration decreases in the urban area, the temperature rises again.

These events can be associated to the exponential increase of the population in the cities, which are leading to the occurrence of all the mentioned factors.
One of the most common phenomena in the large urban centres is the heat island, which is an area where high density of buildings and population interferes with the usual direction, reflection and absorption of radiation.
The buildings act as a barrier that does not allow the “loss” or dispersion of surface reflected radiation to the atmosphere, somewhat trapping the heat, and showing a discrepancy between temperatures within the city and the periphery.

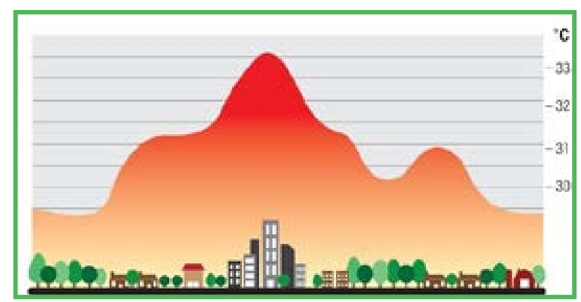


Figure 2 - Illustration of an Urban Heat Island [4]

The urban climate change layer is commonly referred to as the Urban Canopy Layer (UCL), which is delimited by the Urban Boundary Layer (UBL). The UBL separates the area influenced by the urban climate from the periphery where the influence of anthropogenic factors, which are characterizing the climate of urban area, is much less significant [6].

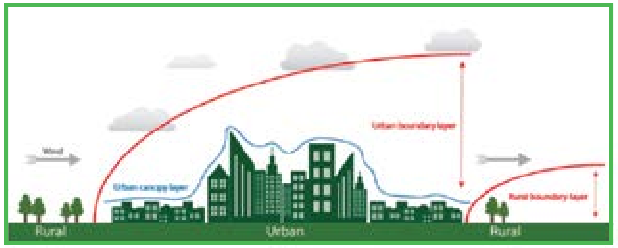


Figure 3 - Illustration of Urban boundaries [6]

The dispersion of buildings will have an impact not only on the absorption and reflection of radiation but also on how air circulates through urban mesh, having a significant influence on wind speed and direction.

The change in wind speed and direction in urban areas can be described by the Venturi Effect. It explains the increase in wind speed as it passes through a narrower section, creating a vacuum that will consequently push the mass of air, propelling it and causing its speed to increase [3].

Figure 4 - Venturi Effect in urban areas [7]

Summarized this effect, we can say that the buildings in the cities act as a barrier, which influence the direction taken by the air masses, redirecting the wind's path and increasing its velocity and as such, will contribute to a sensation of thermal discomfort (wind chill).
Occasionally, public spatial planning policies do not consider these environmental impacts, leading to negative consequences for public health and the local economy.
Increased pollution, abnormal temperature fluctuations, changes in rainfall intensity, the absorption of ultraviolet radiation and the occurrence of floods are just a few noteworthy factors that contribute to diminish the quality of life of citizens, especially in cities.

4. PARAMETERS

4.1 Temperature

Temperature is one of the most relevant parameters of an urban climate as most of the factors influencing the atmosphere lead to a (increase or decrease) change in temperature. It can be measured at various heights and locations, such as ground or sea level, and some temperature variables (maximum, minimum, and average) are important. Therefore, the temperature has an important role to monitor and define the urban climate.

How to measure?

As a rule, the device used to translate temperature into measurable units (ºC or K) is the thermometer. There are several types of thermometers, namely analog, mechanical and electronic thermometers.
For the characterization of an urban climate it is advisable to use an electronic thermometer as it can record the values of the various desired temperatures (maximum, minimum, average) digitally and send them via wireless (remotely), allowing continuous analysis of this parameter without the need to move an operator to the installation site.
According to WMO [1] the following parameters should be considered:

- Factors such as radiation, rain or wind may influence the thermometer values, so it must be protected from all these factors so that only the air temperature is measured;
- It is very important that thermometers are properly calibrated to appropriate standards;
- In non-urban locations, the recommended installation height is between 1.25m and 2m above the surface. However in areas with higher density of buildings (urban area) its placement at higher heights is acceptable.

4.2 Atmospheric pressure

Atmospheric pressure is the force per unit area on a given surface and determines the "weight" that the atmospheric layer exerts on the area.
It is highly important that the air pressure is properly set, as it's crucial for weather forecasts.

How to measure?

The device used for the measurement of atmospheric pressure is the barometer. The most advisable for meteorological purposes are electronic barometers, given the data communication facility they provide.
According to WMO [1] the following parameters should be considered:

- It is extremely important that the barometer is calibrated according to the appropriate standards;
- Readings of the barometer should not be affected by temperature variation;
- The device must be placed in a location where it is not affected by any external effects that may lead to measurement errors.

4.3 Humidity

Humidity corresponds to the water vapour mass per unit of air mass at a certain temperature and is a very important parameter in the climatic characterization of urban areas.

How to measure?

Any device whose function is to measure humidity is called a hygrometer (which translates humidity into percentage). It is preferable to choose an electronic device that records data in digital form which allows the remote reading and data management.

According to WMO [1] the following parameters should be considered:

- The hygrometer should be installed in an open area within a structure protecting from the effects of rain and wind;
- The heat radiated by the hygrometer may influence the measurements of other devices, so this should be taken into account with regard to the location where it will be installed;
- Atmospheric pollutants may have an influence on measurements made by the hygrometer because their concentration in the air may prevent a correct reading;
- It is extremely important that the hygrometer is calibrated according to appropriate standards;
- Device degradation in urban areas is foreseen, thus regular maintenance is recommended.

4.4 Surface Wind

The surface wind is characterized by circulating air masses in the atmosphere layer which is closer to the ground. It can be considered a two-dimensional vector, represented by direction and velocity.
The study of surface wind is very important to monitor weather conditions, make predictions and prevent possible damage caused by the wind.

How to measure?

The direction, speed and speed gusts (sudden movements of air masses over a short period of time) of the surface wind are monitored using a weathervane and anemometer, respectively. However, it is important to collect data at shorter intervals.
The choice of the equipment must be based on the preference of devices that transmit data remotely without the need for an operator to read the data at the place of installation.

According to WMO [1] the following parameters should be considered:

- The anemometer and weather vane should be installed about 10 meters from the ground surface;
- Wind speed and direction are very sensitive to obstacles;
- Avoid placing equipment near obstacles such as buildings or trees (the safety distance between the anemometer and the obstacle must be 10 times the height of the obstacle);
- The anemometer and weather vane have to be calibrated according to appropriate standards.

4.5 Precipitation

Precipitation is all liquid or solid products of condensation of the water vapor which forms clouds. It has a great influence on the characterization of the urban climate, and its monitoring is also important to predict phenomena such as floods, which pose a danger to public health.

How to measure?

Precipitation is measured based on the water height falling (mm) at a given location and, in the case of average precipitation, relates the water height to a certain time interval.
The instrument commonly used for measuring rainfall it's called a pluviometer (rain gauge, rain sensor) and it consists of a container, usually cylindrical, with a funnel on the top which allows the precipitation to be collected inside it. Once again, it is advisable to use a device capable of transmitting data remotely, so that it can be analyzed without the need for an operator to travel to the location of the station.

According to WMO [1] the following parameters should be considered:

- Wind effects in the surrounding areas to the rain gauge can lead to poor results, so it is important to choose the correct installation location and protect the equipment from the wind;
- No object should be less than twice the height to which it is the rain sensor hole;
- Hard and flat surfaces such as cement should be avoided in order to prevent splashes caused by surface precipitation from affecting the measurements (to avoid this, it is advisable to place the device at a height where splashes do not reach the hole ;
- The hole must be located (in the case of snow) above the maximum snow depth;
- The rain gauge has to be calibrated according to the appropriate standards.

4.6 Radiation

There are several types of radiation and the global solar radiation will be the most relevant measurement, since it includes direct and diffuse radiations which corresponds to the total radiation that hits the ground. However, it is also important to monitor ultraviolet radiation as it has a significant impact on public health.

How to measure?

Global solar radiation (Wm^{-2}) is measured by a pyranometer. Since the main aim of ultraviolet radiation monitoring is its impact on public health, a broadband sensor should be used as it is a device that measures the range of radiation (UV-A and UV-B) that affects human health. It is recommended that both devices have the capacity to transmit their measurements remotely to prevent the displacement of an operator to the station.

According to WMO [1] the following parameters should be considered:

- One of the challenges with using a pyranometer is the deposition of water on the protective surfaces due to condensation, reducing the amount of radiation reaching the sensor. This problem can be solved with ventilation or heating systems, although these can raise other problems;
- Avoid the proximity to obstacles that do not allow the incidence of radiation in the devices (shadow) as this will interfere with the validity of the results;
- The pyranometer and the broadband sensor have to be calibrated according to the appropriate standards.

4.7 Visibility

Visibility is associated with the amount of solid and liquid suspended particles in the atmosphere. The use of this parameter is often associated with other areas such as airports and roads.

How to measure?

Instruments used to measure optical range, such as transmitters or dispersion meters, usually work adequately in urban areas.

4.8 Evaporation

Evaporation is the amount of water vapor that evaporates from the soil and plants when the soil has a normal moisture of content.
Due to the reduction of the green spaces in urban areas, evaporation usually decreases.
It is considered an important parameter for the agricultural sector, however it is not very relevant for the characterization of the urban climate.

How to measure?

Evaporation measurement is rarely performed in urban areas due to the high difficulty in meeting the parameters defined by WMO [1]. Evaporation is measured using a lysimeter.

4.9 Soil moisture

Soil moisture is the amount of water present in the soil, being an important component in the characterization of the water cycle.
Due to the soils heterogeneity in urban areas and often its waterproofing, this parameter is very difficult to measure in this context.
It is considered an important parameter for the agricultural sector.

4.10 Atmosphere Composition

The study of atmosphere composition is based on the characterization of the atmosphere regarding its physical and chemical components.
It is considered for decisive parameter for determining the amount of pollutants in the urban atmosphere, which have a negative impact on public health. However, its utility for characterizing an urban climate is not so relevant.

5. INTEGRATED SOLUTION FOR WEATHER STATIONS INSTALLATION

Some of the most important characteristics for urban weather stations placement [16] are:

- Urban structure - Dimensions of buildings, the spaces between them, the width of the streets and their spatial distribution;
- Urban coverage - Buildings, pavements, vegetation, soil, water;
- Urban constitution - Type of construction and types of used materials;
- Urban metabolism - Heat, water and pollutants from human activity.

To choose for the most suitable location for the installation of weather stations, it should be the avoided:

- Buildings with the height as twice or more than the normal height of the buildings in the surroundings;
- Parking lots paved with waterproof materials near irrigated green spaces;
- Locations with high heat concentration due to anthropogenic factors;
- Unusual microclimate influences or other meteorological events that may influence the measurements.

It is not always possible to respect one of the most important parameters when installing meteorological stations (the distance to obstacles, due to the high density of buildings in urban space). However, it is important that the installation of the station is carried out in such a way that the measurements it performs are as representative as possible.

Places such as schools, universities or other public buildings are good options for installing weather stations as there is no need to pay rents to use the sites. They are easily accessible for installation and maintenance of structures, and also provide a safety factor, avoiding vandalism and providing access to electricity and mobile network, indispensable for the functioning of equipment and data transmission.

The installation of weather stations on buildings' roofs can lead to measurement errors due to high thermal amplitudes over short periods of time. These factors can be overcome by installing the stations on a roof-mounted pole, increasing the distance between the devices and the roof surface, thereby reducing the possibility of measurement anomalies.
It is important to remember that when installed on a mast it should be properly insulated (e.g. cork coating) so that its temperature does not interfere with the results obtained by the equipment.

6. DATA COMMUNICATION

Data communication refers to the exchange of data between a source and a receiver through a transmission medium (i.e. wireless, cable). Data communication is said to be local if communicating devices are in the same building or a similarly restricted geographical area. However, nowadays, wireless transfer of data is increasingly safe and, on the fly, giving the user automatic real time feed to process warning, occurrences or failures. It also facilitates data access by any given stakeholder (universities, weather websites, investigators and other cities as well) which help to develop the quality of data and possible analysis and management models.
The free, open source data favours scientific progress and data quality for all, as well as transparency in city management.
Requirements of the data communication networks according to WMO [17]:

- Based on an agreed technology available to the participating centres;
- Capable of handling the data volumes;
- Include satellite communication channels, terrestrial links and managed data network services, and use of Internet;
- Handle the agreed transmission protocols;
- Build on the Global Telecommunication System (GTS), including its satellite-based elements and the IMTN, for real-time data exchange.

Data communication networks that will be used according to WMO [17]:

- The GTS in its entirety will be part of WIS, especially for meeting real-time exchange requirements;
- Internet Virtual Private Network (VPN) - Will be an indispensable communication element for the WIS;
- Satellite communication channels such as those provided by the Integrated Global Data Dissemination Service (IGDDS) - for the exchange of data and products related to the WMO Space Programme, as well as terrestrial links or managed data network services.

7. Weather Indexes

As mentioned previously, meteorological parameters have several goals. They not only allow the characterization of the urban climate of a given area, but also enable the calculation of various meteorological indicators that help determine the direct impact of atmospheric conditions on humans.
Regarding the health and safety of citizens, it is extremely important to collect data to calculate these indexes in order to reduce risks and avoid any negative effects on the local population and ecosystems.

In the following subchapters some of these meteorological indexes, regarding safety, health and welfare are mentioned.
Some of them are characterized as "biometeorological indexes", since they express the effect caused by certain phenomena directly in the human being, affecting in some way, lives and safety of citizens.

7.1 Universal Thermal Index - Universal Thermal Climate Index (UTCI)

The Universal Thermal Index measure the feeling of thermal comfort felt by humans under the influence of certain conditions.
The heat exchanges that occur between the environment and the individual are considered, by assessing the temperature, radiation, humidity and wind in relation to the reference conditions set for these specific parameters. The reference conditions [18] are:

- Wind speed (v) from 0.5 m / s to 10 meters high (approximately 0.3 m / s at 1.1 meters);
- Average radiant temperature (RMR) equal to air temperature;
- Represents the activity (M) of a person moving at a speed of 4 km / h. This equates to a metabolism rate of 135 W.m-2.

It also considers the internal heat flow of a person (considering as a reference the activity of a person at a speed of 4 km/h) [18] and the factor "clothing".

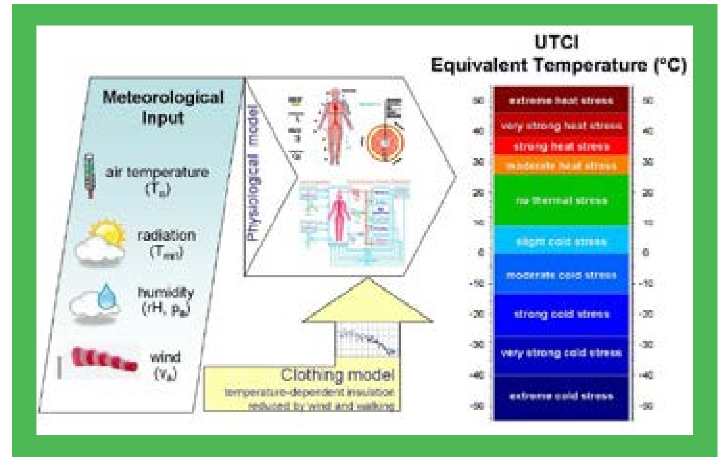


Figure 5 - Representative UTCI scheme at equivalent temperature [19]

7.2 Weather Stress Index (WSI)

The Weather Stress index (WSI) is often used as an indicator of comfort, representing, as a percentage, the amount of hot or cold days that occur over a given period of time. It is based on the "NET" (Net Effective Temperature), and it is applicable to both, hot and cold atmospheric conditions. The input parameters to the NET calculation are air temperature, humidity and wind, and it translates numerically the human thermal sensation through the following formula (Gregorczuk [20]):

$$NET = 37 - \frac{37 - T}{0.68 - 0.0014RH + \frac{1}{1.76 + 1.4v^{0.75}}} - 0.29T(1 - 0.01RH)$$

Where "T" is the dry thermometer temperature (in ° C), "v" is the wind intensity (in m/s) and "RH" is the relative humidity (in%).

NET is consistent with the common human perception:

a) In hot weather, NET increases with an increase in temperature and/or humidity and decreases with increasing wind speed,
b) In cold weather, NET decreases with decreasing temperature and with increasing humidity and/or wind speed.

As the WSI (Weather Stress Index) is an index (percentile) derived from the NET, for example, if WSI = 99%, it means that only 1% of days in the studied period exceeded that NET, but if WSI = 1% it means that only 1% of days had a NET below that threshold.
Extreme values of WSI are related to physiological values of great discomfort and therefore the WSI can be used as a risk index.

The WSI published daily online by IPMA [18] is calculated based on two observations per day, at 06 and 13 UTC.

7.3 Wind Chill Index (WCI)

The Wind Chill Index is the perceived decrease in air temperature felt by the body on exposed skin due to the flow of air.
Wind chill values are always lower than air temperature and when the apparent temperature is higher than the air temperature, the heat index is used instead.
Wind increases the rate at which body loses heat, so the air on a windy day feels cooler than the temperature indicated by a thermometer. This heat loss can be calculated for various combinations of wind speed and air temperature and then converted to a wind chill equivalent temperature (or wind chill factor).
The formula used to define the value of this index has remained unchanged for many years, but has recently undergone some corrections in order to merge the values obtained to the reality that is the human body, since the original formula was thought in relation to a plastic bag. The current formula is [21]:

WCI= 13.12 + 0.6215 T - 11.37 V0.16 + 0.3965 T V0.16 (2)

V - Wind Speed (Km / h)
T - Air temperature (° C)

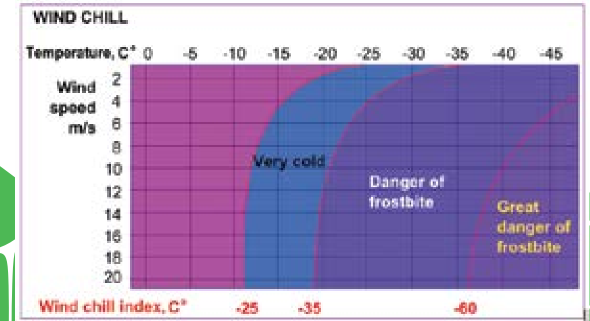


Figure 6 - Celsius wind chill index [22]

Ambient Air Temperature (°C)	"Chilled" Air Temperature (°C) Wind Speed (km/h)							
	5	10	15	20	30	40	50	60
10	10	9	8	7	7	6	5	5
5	4	3	2	1	0	-1	-1	-2
0	-2	-3	-4	-5	-6	-7	-8	-9
-5	-7	-9	-11	-12	-13	-14	-15	-16
-10	-13	-15	-17	-18	-20	-21	-22	-23
-15	-19	-21	-23	-24	-26	-27	-29	-30
-20	-24	-27	-29	-30	-33	-34	-35	-36
-25	-30	-33	-35	-37	-39	-41	-42	-43
-30	-36	-39	-41	-43	-46	-48	-49	-50
-35	-41	-45	-48	-49	-52	-54	-56	-57
-40	-47	-51	-54	-56	-59	-61	-63	-64

Table 2 - Child air temperature in °C [23]

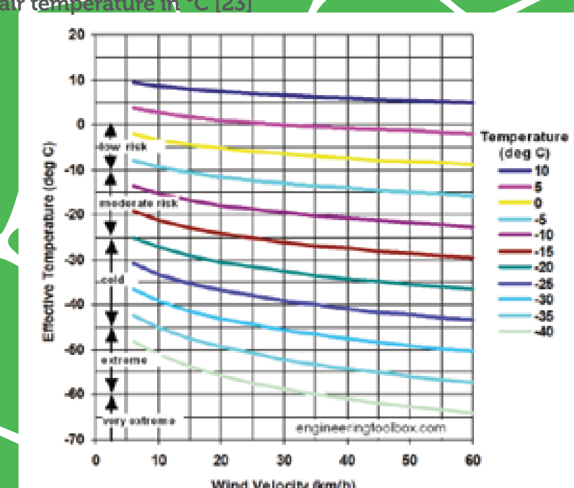


Figure7 - Risk of wind chill index[24]

7.4 Fire Hazard Index - Fire Weather Index (FWI)

The Fire Hazard Index evaluates the possibility of a fire occurring in a given location, taking into account the state of the combustible materials in the forest area.

This index [25], developed by Canadian Forest Service, consists of six components that account for the effects of fuel moisture and wind on fire behaviour.

The diagram below illustrates the components of the FWI System (source: http://cwfis.cfs.nrcan.gc.ca/background/summary/fwi) and the calculation of the components is based on consecutive daily observations of temperature, relative humidity, wind speed, and 24-hour rainfall. The six standard components provide numeric ratings of relative potential for wildland fire.

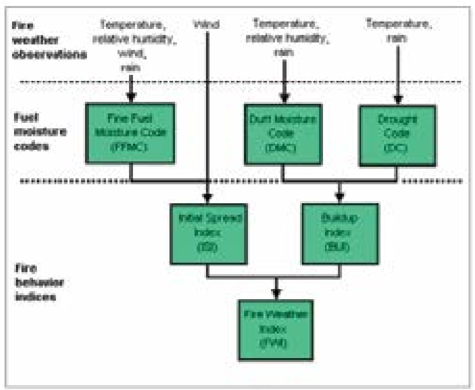


Figure8 - FWI system components [25]

- The Fine Fuel Moisture Code (FFMC) is a numeric rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and the flammability of fine fuel.
- The Duff Moisture Code (DMC) is a numeric rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material.
- The Drought Code (DC) is a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smoldering in deep duff layers and large logs.
- The Initial Spread Index (ISI) is a numeric rating of the expected rate of fire spread. It combines the effects of wind and the FFMC on rate of spread without the influence of variable quantities of fuel.
- The Buildup Index (BUI) is a numeric rating of the total amount of fuel available for combustion. It combines the DMC and the DC.
- The Fire Weather Index (FWI) is a combination of the Initial Spread Index and the Buildup Index representing intensity of the spreading fire as energy rate per unit length of fire front. It is often used as a single integration of fire weather.
- The Daily Severity Rating (DSR) is a numeric rating of the difficulty of controlling fires. It is based on the Fire Weather Index but more accurately reflects the expected efforts required for fire extinguishing.

7.5 Palmer Drought Severity Index (PDSI) - Palmer Drought Intensity Index

The most common index used to define and monitor drought is the Palmer Drought Severity Index (PDSI), which attempts to measure the duration and intensity of long-term, spatially extensive drought, based on precipitation, temperature, and available water content data.

This index is calculated using the following formula [26]:

$$X_i = 0.77X_{i-1} + \frac{z_i}{44.97}$$

Xi - PDSI Index for the Month Under Review
Xi-1- Previous month's PDSI Index
zi - Soil water anomaly index

Table 3. Drought classification by PDSI index [27]

PDSI Classification	
4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal

PDSI Classification	
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.0 or less	extreme drought

7.6 Hot Day

A hot day is characterized by the temperature values (minimum and maximum) higher than the value considered "normal" in a certain period of the year. Hot days are calculated as values of 90% of the maximum and minimum temperatures for that day, based on values collected for 30 years and defined as "normal" values.

7.7 Cold Day

The characterization of a cold day is similar to that of a hot day, however, it is characterized by having temperature values (minimum and maximum) below the value considered "normal" for a certain period of the year, as values of 10% of the maximum and minimum temperatures for that day, based on values collected over a period of 30 years, and defined as "normal" value.

7.8 Heat Wave

A heatwave is a period of prolonged abnormally high surface temperatures relative to those normally expected. Heat waves may span several days to several weeks and can have strong impacts on human activities and health, being significant causes of weather-related mortality. While definitions vary [2], the World Meteorological Organization defines it as five or more consecutive days during which the daily maximum temperature surpasses the average maximum temperature by 5 °C or more.
Heat waves can usually be detected using forecasting instruments so that a warning call can be issued.
In Portugal (in line with WMO), a heat wave occurs when temperatures increase 5 °C or more above the normal temperature over a period of 6 days [28].

7.9 Cold Wave

Cold wave is a strong cooling air (irradiation frost) or an invasion of very cold air (cold advection), frequently accompanied by abundant snowfall, which extends over a large territory. It is a rapid fall in temperature within a 24-hour period requiring substantially increased protection to agriculture, industry, commerce, and social activities. Cold effects concerning health are more severe than those caused by excess heat, but less immediate, so it is more complicated to establish cause-effect relationship.
A cold wave occurs when over a period of 6 days observed temperatures are lower by 5 ° C or more degrees compared to the average temperature of the observation site for that time of year [28].

8. CASE STUDIES

The previous considerations and interpretations can be found at many different cities throughout Europe. The following examples have different contexts, goals and investments. They should be carefully assessed before considering a replication.

8.1 Antwerp (Belgium)

Antwerp, the largest city in the Flanders region has a network of weather stations across its territory. All monitoring sites are equipped with air temperature and relative humidity monitoring, 2D sonic wind meters and pyranometers that measure global shortwave radiation. In order to reduce errors in air temperature measurements, radiation shields are used.
In addition to fixed monitoring stations, mobile temperature and humidity meters are also used, particularly for shorter periods such as seasons, to monitor the dynamics of the urban climate.

Figure 9 - Weather station in the city of Antwerp [29]

8.2 Szeged (Hungary)

Szeged, in the south-eastern region of Hungary. According to the climate classification system developed by Köppen, the city belongs to the Cfb climate category (temperate oceanic climate) with an annual mean temperature of 10.4°C and an amount of precipitation of 497 mm. The study area covers an 11.5 km x 8.5 km rectangle in and around Szeged. Within the framework of the project 23 stations were set up in Szeged and the whole network consists of 24 measurement sites.

In order to have a representative urban human comfort monitoring network seven "local climate zones" (LCZ) areas were delineated. Based on the LCZ map, the siting and configuration of 22 stations from the above mentioned 24 ones were based on:

- The site's distance from the border of the LCZ zone within which it was located;
- The ability of the selected network geometry to reproduce the spatial distribution of mean temperature surplus pattern estimated by an empirical model;
- The site's representativeness of its microenvironment;
- The site's suitability for instrument installation.

So, in summary, two stations represent the rural area, while the other 22 stations represent the different built-up areas of the city, respectively.

Figure 10 - Weather station in the city of Szeged (Hungary) [30]

8.3 Novi Sad (Serbia)

Novi Sad, located in the north Region of the Republic of Serbia and in south-eastern Region of Pannonian Plain. The area of the city is characterized by plain relief with elevation from 80 to 86 m and its climate is free from orographic effects. The Danube River flows by the southern and south-eastern edge of the city urban area. Southern parts of the city urban area are located on the northern slopes of Fruška Gora Mountain (539 m).
In Novi Sad the annual mean air temperature is 11.1°C with an annual range of 22.1°C and the annual precipitation is 615 mm (based on data from 1949 to 2008.
The city implemented 27 weather stations and their location was based on the above-mentioned parameters and rules. There are 25 urban monitoring stations and two rural stations (located north and northeast from the city outskirts). Seven LCZ types were defined on the territory of Novi Sad and the two rural stations are in LCZ's of low plants and dense trees.

Figure 11 - Weather station in the city of Nova Sad (Serbia) [30]

8.4 London (United Kingdom)

In the city of London there are a large number of weather stations, most of them private. The fact of being private implies that they may not be calibrated according to WMO parameters, and therefore the values measured by such stations may not be correct.
No effort has yet been made to aggregate data from all stations into one database and the above may be one of the reasons, however there is a database of 164 station values. The higher density of the network is of great use to further knowledge of the urban heat island effects.
The values obtained come from 4 types of stations:

- Stations calibrated according to WMO;
- Private stations;
- Private stations for educational purposes;
- Research stations;

Figure 12 - London [31]

8.5 Cascais (Portugal)

Cascais, is a coastal municipality located in the Lisbon Metropolitan Area. Within the scope of the municipality's Climate Adaptation Action plan, a small network of 5 weather stations were placed in different areas, representing different urban densities. This allows to compare the influence of the urban development at a micro and meso scale and their open access platform offers all registered data. It also contributes to monitor the impact of ther climate adaptation actions, namely those with regards to urban development and nature based solutions.

Figure 13 - Cascais weather station

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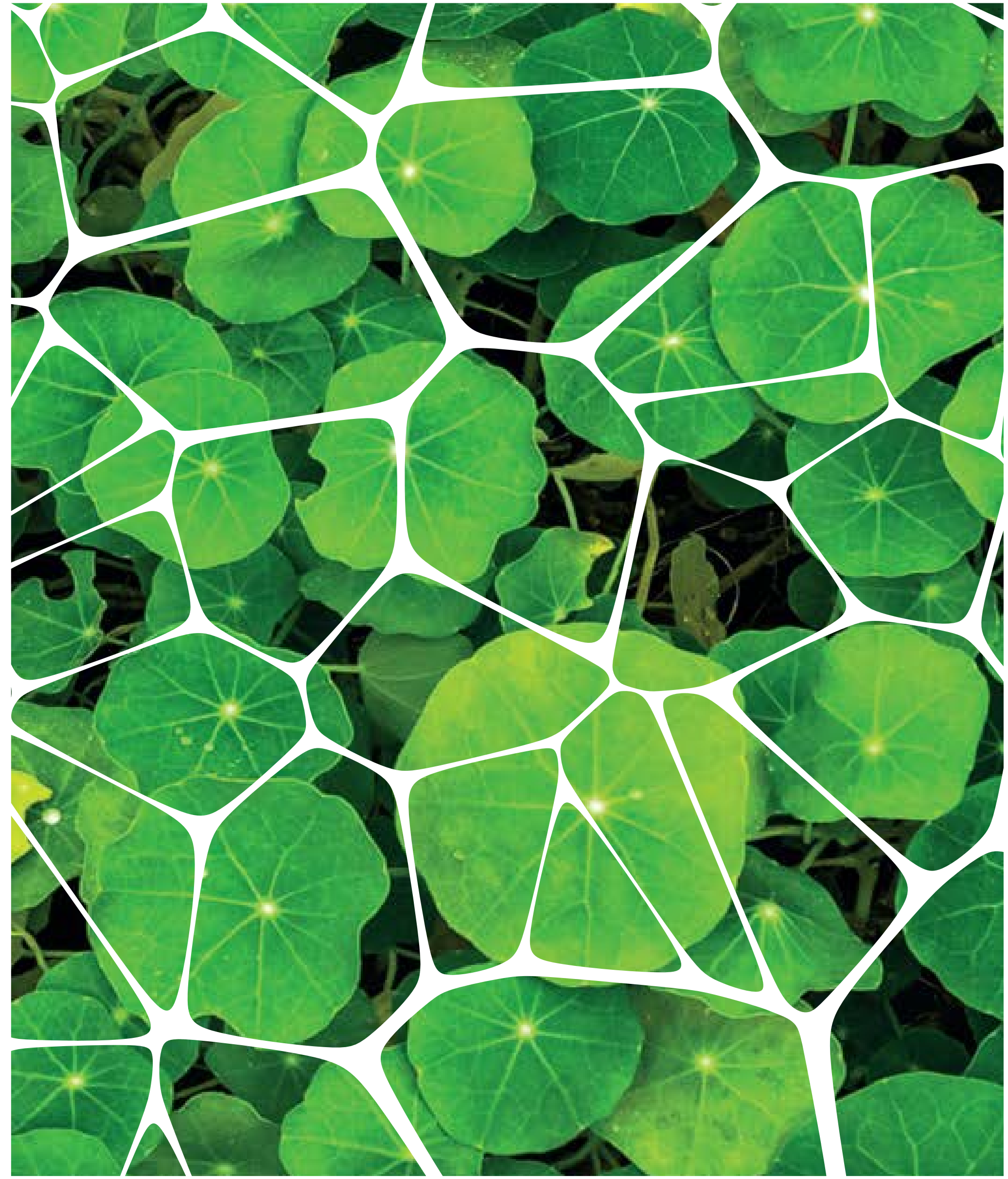

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