Urban climate multiscale modelling in Bilbao (Spain)

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Abstract

Despite development of cities are including more sustainable aspects (e.g. reduction of energy consumption), urban climate still needs to be consolidated as an important variable in urban planning. In this sense, the analysis of urban climate requires a multi-scale approach. Results for Bilbao (Spain) are presented. In the mesoscale, an Urban Climate Map (UC-Map) is developed using a method based on GIS calculations, specific climatic measurements and urban climate expert knowledge. All the information is grouped in 5 information layers (building volume, building surface fraction, urban green areas, ventilation paths and slopes). The final UC-Map presents areas with relative homogeneous climate variables (i.e. climatopes) that are classified in terms of thermal comfort. Urban planning recommendations are defined. In the microscale, thermal comfort results extracted from ENVI-met model in four urban spaces show the influence of regional climate conditions and the urban development type of each area and its location inside the whole city. In both spatial scales, climate modelling should include specific measurement campaigns to validate results

Keywords: urban climate, thermal comfort, urban planning, modelling, measurements

1. Context and information

During the 20th century urban development extended significantly producing a tremendous alteration of the natural environment. Thus, urban areas have lost the necessary ecological balance with the surroundings.

Two are the more significant effects of urban areas in the climate: a) an alteration of local winds and turbulence, and b) an increase in temperature compared to rural surroundings (known as Urban Heat Island).

Additionally, nowadays one of the major environmental problems is climate change and the urban areas are known to be very vulnerable to this phenomenon. Thus, thermal comfort inside urban areas can be seriously affected in the future. However, until the last three decades urban climate knowledge was rarely applied in urban planning.

The work presents the results of a multi-scale analysis of the urban climate and thermal comfort in Bilbao urban area. This approach is necessary to provide climate information to urban planners and decision-makers in a suitable way so that they can use it for planning purposes. In each spatial scale, different information is presented, and the approach and tools to undertake the urban climate analysis are different.

2. Methodology

Two different spatial scales at which urban climate is considered have been defined. These are the urban and local scale, i.e. mesoscale and microscale (Fig 1).

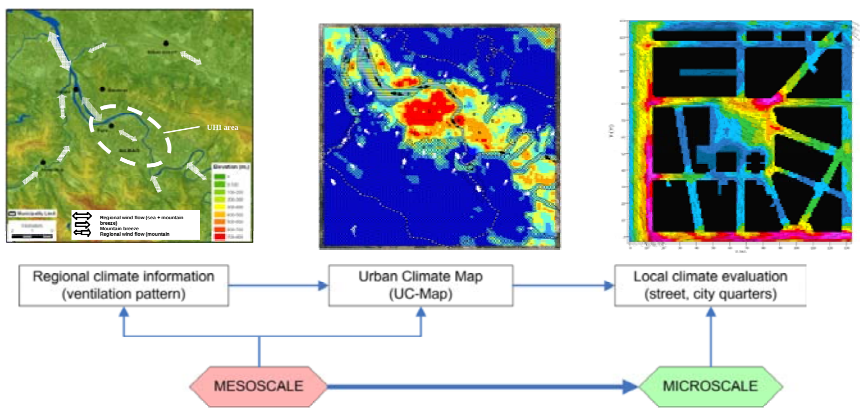

Fig 1. Multi-scale approach of urban climate. Steps to evaluate climate in an urban planning context

Mesoscale

An Urban Climate Map (UC-Map) was developed to include climate information from the regional to the urban scale. At this scale, the analysis of regional climate affecting the urban area was essential to define the ventilation pattern in the urban area. The UC-Map mainly consisted of two maps. One is the Urban Climate Analysis Map (UC-AnMap) and the other is the Urban Climate Recommendation Map (UC-ReMap). The UC-AnMap included climate information describing UHI effects and ventilation patterns. It defined and evaluated areas with specific climate characteristics that have similar impact on thermal comfort. These are known as climatopes. The UC-ReMap included urban planning instructions to improve or protect climate in different areas of the city.

In the case of Bilbao an 8.7 x 8.4 km. domain was defined with a 100 m. resolution.

The method used to develop the UC-AnMap was based on calculations made with different GIS layers, climate measurements and urban climate expert knowledge. The layers included information of the physical variables affecting the urban climate. The combination of GIS layers with adequate weighting factors allowed analyzing the effects of thermal load and dynamic potential in Bilbao urban climate. All the necessary data and information was included in five GIS layers (Fig. 2):

- Building volume: affecting heat storage capacity
- Building surface fraction: describing the effect on heat storage and ventilation due to urban permeability to wind
- Green areas: affecting surface heat balance and vegetation cooling potential
- Ventilation paths: describing local to regional ventilation properties influenced by surface roughness and topographical structures
- Slopes: describing the effect of increasing ventilation due to urban permeability to background winds, and development of thermal induced circulations

Additionally to regional climate evaluation to consider ventilation properties of the urban area, climate measurements were carried out to validate the GIS calculations and thus the UC-AnMap (Fig. 1). Consequently, at this stage, urban climate expert knowledge turned out to be important.

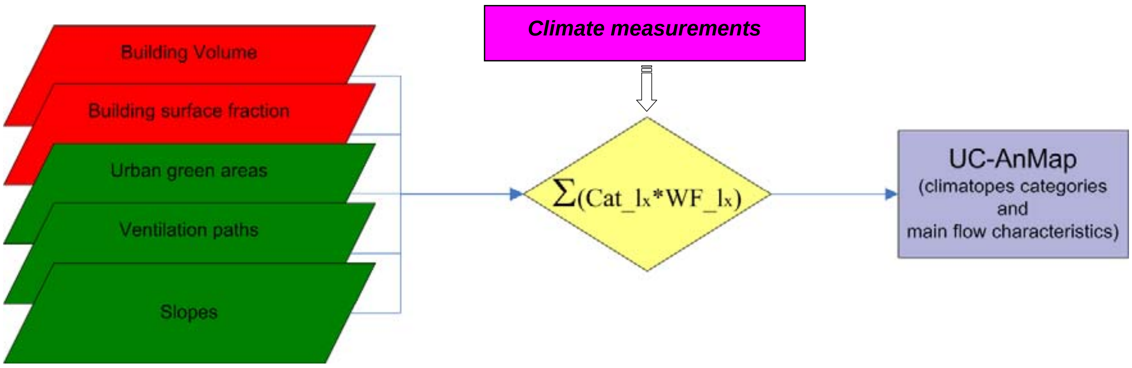

Fig 2.. Combination of GIS layers with weighting factors based on measurements3.2 Description of regional climate

Microscale

To evaluate climate at scales from street to city quarter, microscale analysis were performed in different district of Bilbao. These spaces are basically squares and parks but were quite different regarding the urban development type and the exposure to influence of regional climate.

Detailed microscale climate mapping was performed to analyse climate variables and thermal comfort spatial distribution. In this case, ENVI-met model (version 4) was used. Daytime thermal comfort evolution and differences between the areas were evaluated. Also different urban design scenarios were analysed.

The results were compared with local climate measurements carried out during three days (6th to 8th August 2010) in typical summertime weather (i.e. influence of sea breeze) using mobile devices from sunrise to sunset. Measured data were: air temperature, relative humidity, pressure, wind speed, wind direction and mean radiant temperature.

3. Results

To derive the UC-AnMap, the number of categories and the weighting factors applied to each GIS layer to are summarized in Table 1. The weighting factors were reasonable from the point of view of urban climate in Bilbao.

Table 1. Categories and weighting factors applied to each GIS layer

Layer	Nº categories	Weighting factor
Building volume	4	6
Building surf. fraction	6	6
Green areas	4	-4
Ventilation paths	4	-5
Slopes	3	-3

Fig. 3 shows Bilbao UC-AnMap including all the relevant climate aspects for urban planning. It shows up to seven categories of climatopes based on thermal comfort impact (from cold air production areas to high heated areas). Ventilation paths turn to be an important factor in Bilbao urban climate (i.e. air flow along the river crossing the urban area and thermal induced downslope winds during night-time). These air systems need to be preserve with the aim of mitigating the UHI. Additionally, strategic actions could be taken in the nearby areas to allow a wider influence of ventilation paths.

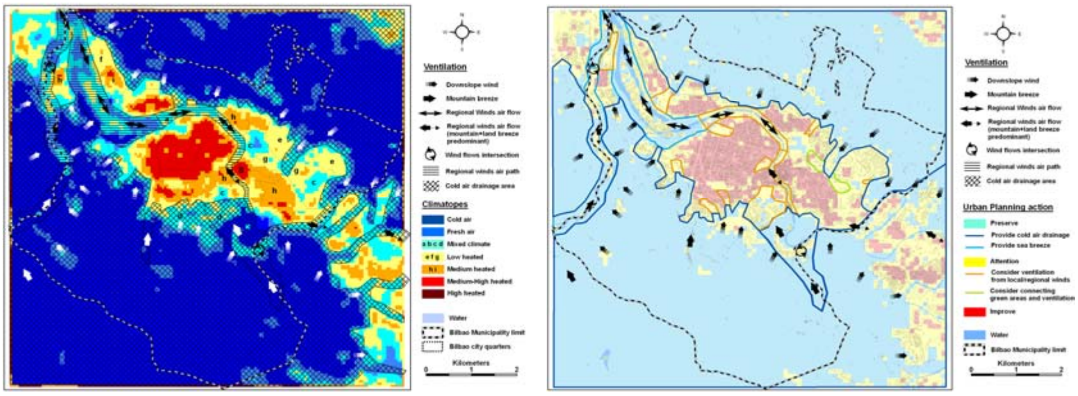

Fig 3. Bilbao UC-AnMap and UC-ReMap

Three urban climate sensitivity zones were defined in the UC-ReMap (Fig.3):

1. Areas to preserve: cold and fresh areas with good ventilation,
2. Areas to attend climate: low thermal load areas where the effects of new developments should be evaluated,
3. Areas to improve: areas where relief of urban heat load is needed. Specific cooling actions should be considered together with an improvement in ventilation.

On the microscale, results for thermal comfort show the influence of building distribution and orientation, location of vegetation and characteristics of surface materials of the four urban spaces, together with the regional climate conditions. Each urban space presents different urban development characteristics that affect thermal comfort temporal evolution. However, modelling results have shown differences with respect to measurements due to model limitations.

5. Conclusions

The UC-Map includes climate information from the regional to the urban scale. However, when downscaling to local scales, the UC-Map is useless. To evaluate climate at scales from street to city quarter, microscale analysis is mandatory. In this sense, it is important to remark that for complete and adequate urban climate considerations in urban planning a combination of analysis at different spatial scales (i.e. mesoscale and microscale) is mandatory.

The method proposed on this work for the UC-Map is simple (5 GIS layers) and has proven to be suitable and adequate for urban planning purposes. Due to its simplicity, it can be exportable to many other urban areas and results are expected to be optimal.

Both UC-Maps and microscale climate modeling should include specific measurement campaigns to validate results.