The impact of adaptation measures in Urban Heat Islands

CMCC Foundation - REMHI Division

Climate change, heat waves & the Urban Heat Island effect

The impacts of climate changes are expected to be highly different according to geographical areas, local features and socio-economic conditions, affecting, in a remarkable way, the poorest countries and needier sections of the population. It is now known how cities could experience deteriorating quality of life, posing tough challenges to the urban communities; briefly, increases in i) heat waves, worsened by increased warming characterizing anthropic built environments (UHI, urban heat island), ii) air pollution, and iii) extreme weather related risks are sharpened by urban geometries and high exposure.

Heatwave impacts

In recent years, the effects of heatwaves have interested different areas and large numbers of the population. Generally speaking, according to Oke et al. (2017), **there is not an absolute definition of a heat wave**: indeed, it refers to a sustained period of unusually high temperatures and then depends on the microclimatic background (e.g., geographical context, the climate at the local scale and the urban evolution of each city). However, this term is often adopted to refer to instances where relatively high temperatures (often accompanied by high relative humidity) cause thermal stress and discomfort in the population, leading in some cases to hyperthermia and death. During the summer of 2003, in Europe, such phenomena claimed about 70,000 lives with overall losses evaluated at 13,800 US$M (MunichRe data), and more than 55,00 victims were the taken by the 2010 heat waves in Eastern Europe and Russia; finally, in the summer of 2017, the Mediterranean Region and India/Pakistan areas were affected by events inducing more than 7,000 fatalities. Regarding the potential exacerbation induced by climate change in heatwaves, Guerreiro et al. (2018) have recently published a study accounting for 571 European cities in the Urban Audit database, considering climate projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5) under the more pessimistic but “business as usual” RCP8.5 scenario. They concluded that the number of heat waves days increase across all cities (especially in southern Europe) while the higher increases in temperature are expected in Central European cities.

Nevertheless, within the urban contexts, the effects could result very differently. In August 2018, The Guardian published an interesting article about heat waves and inequalities[1] highlighting that **in the biggest cities the poorest populations are those that mainly suffer the consequences of heat waves**. For instance, in the United States it is three times more likely that immigrants die during a heat event compared to American citizens, whilst in India, where it is expected that 24 cities will reach an average maximum summer temperature above 35 degrees by 2050, people most at risk are those living in shantytowns. On the same topic, The Lancet Countdown on health and climate change (Watts et al. 2017) highlights an increase of 125 million in adults suffering from intense heat waves between 2000 and 2016, and a reduction of 5% in the productivity of outdoor manual labor, with economic losses amounting to 129 billion dollars in 2016.

As said above, **cities are usually warmer than their rural surroundings resulting in a particular urban climate pattern known as the *Urban Heat Island***. Cities indeed absorb, produce and radiate heat: asphalt, bricks, cement and roofs become as sponges that absorb heat during the day and release it during the night (see Figure 1). In this sense, it is expected that **in the future the UHI, combined with the increasing urbanization, will make urban communities, especially the poorest ones, still more vulnerable to heat related health problems**.

[1] https://www.theguardian.com/cities/2018/aug/13/heat-next-big-inequality-issue-heatwaves-world

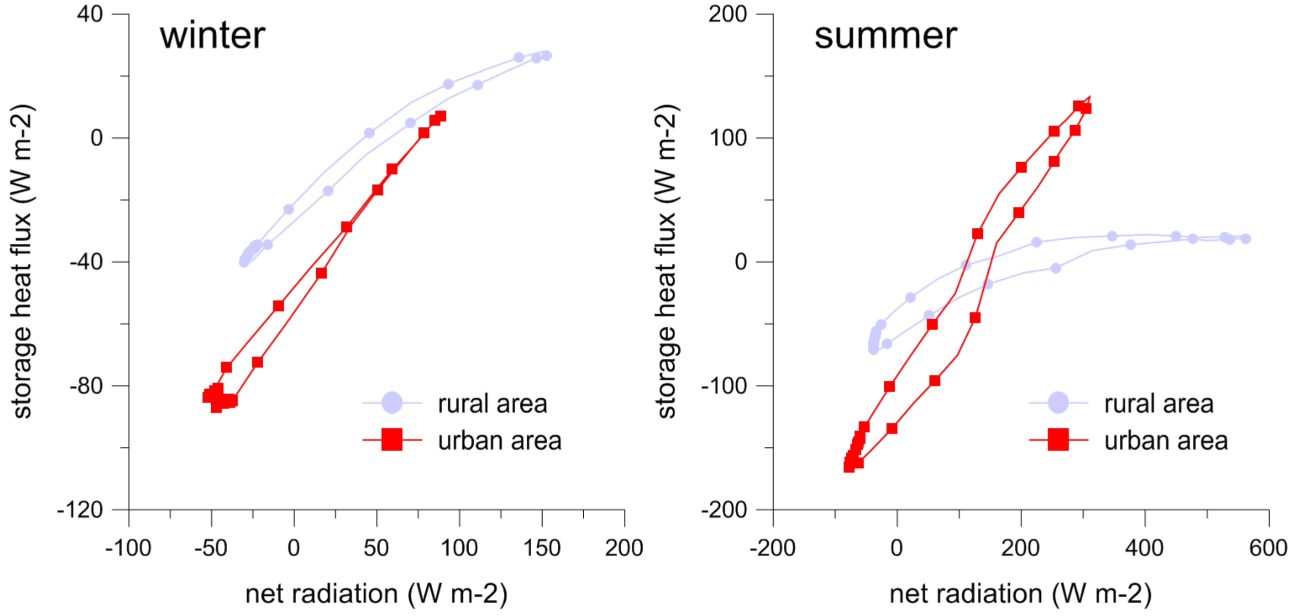

Figure 1: Comparison of energy cycles (net radiation against storage heat flux) for urban and rural areas during winter and summer (positive values of storage heat flux represent a flux warming the surfaces of the urban elements; negative values of storage heat flux tends to warm the canyon).

The urban area is able to store during the daylight hours a greater quantity of heat especially in the summer. During the daylight hours, characterized by positive values of net radiation, the urban area returns a sensible heat flux much greater than latent heat flux (practically negligible) due to the presence of impervious surfaces from which water is collected in sewage systems. For this reason, the urban area stores a high amount of heat capable of warming the town elements. On the other hand, the rural area returns great values of latent heat flux, that when added to the sensible heat flux, can almost completely balance the net radiation. During the night hours, characterized by negative values of net radiation, the storage heat flux is negative and so directed to the canyon. In absolute terms, it is greater for the urban area than for the rural area. Consequently, roads and walls release heat which remains trapped in the canyon, warming the air within the town (modified from Reder et al, 2018).

Measures to address heat waves & Urban Heat Islands

To cope with such challenges, city administrations and decision-makers are deploying significant resources with the aim to achieve sustainable and effective adaptation protection measurements.

Following again Oke et al. (2017), the Climate Urban Sensitive Design (CSUD) can be viewed as an effective vision able to reduce climate risks in urban areas through the conscientious adoption of a series of evidence-based tools relying on a proper understanding of current and future conditions. In contexts as complex as cities characterized by relevant space constraints, **the identification of best solutions should be always inclined to prioritise those permitting the achievement of concurrent, multiple goals**. In this regard, Nature Based Solutions (NBSs) have attracted great interest in recent years; they can be defined as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (IUCN, 2016); in specific, in the city, they could address, at the same time, different needs: lowering local air temperatures through several mechanisms (shadowing, evapotranspiration), reducing runoff after heavy rainfall events and then flood risks, and last but not least, permitting recreational activities. Nevertheless, the long-term maintenance of these ones and their effectiveness compared to other tailored grey (structural) solutions actually represent challenging open questions.

In this perspective, the REMHI Division has recently published the peer-reviewed research paper *Parametric investigation of Urban Heat Island dynamics through TEB 1D model for a case study: Assessment of adaptation measures*. The paper proposes expeditious tools for quantifying the alterations in temperature and energy patterns induced by urban anthropised environments and the effectiveness of different local adaptation measures, based on NBSs or not, specifically dealing with urban heat discomfort issues (Reder et al. 2018, https://doi.org/10.1016/j.scs.2018.03.023). These issues have been addressed through a parametric study carried out adopting the TEB (Town Energy Balance) model and assuming the city of Toulouse as a reference case, for which the following are available:

- 1-year dataset of monitoring measures of surface energy fluxes and temperatures (on the "town elements", that are road, roof and wall and in general in the so-called "urban canyon") as a part of the CAPITOUL (Canopy and Aerosol Particles Interactions in TOulouse Urban Layer) project (Masson et al., 2008);
- model parameters relating to urban geometry (e.g., average buildings height, average road width, cover fractions of buildings, green areas and road) and architectural features of the town elements (e.g. albedo, emissivity, thickness, conductivity and thermal capacity).

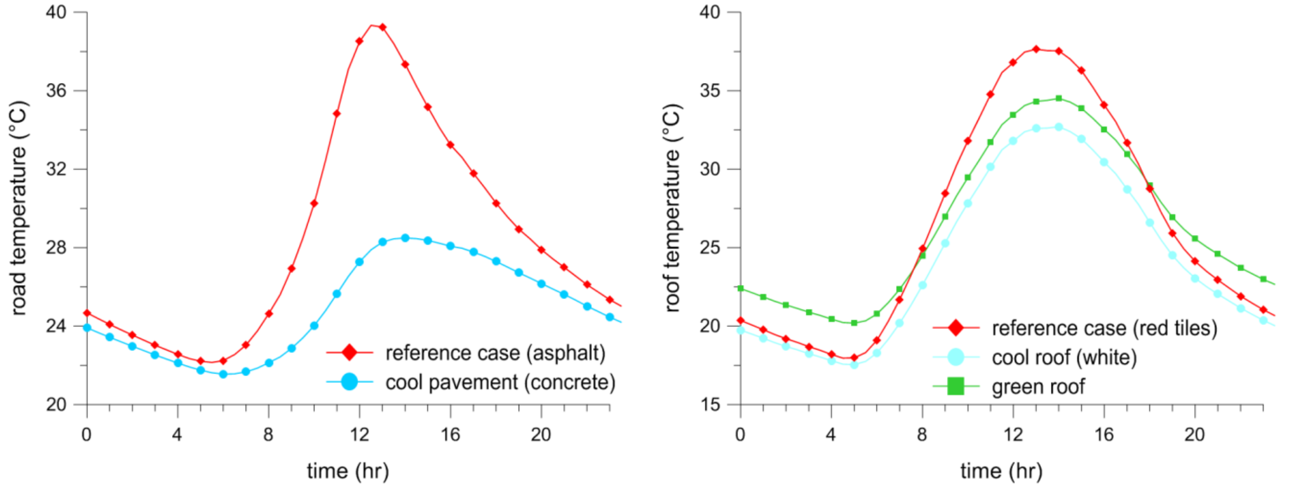

Figure 2: Summer average diurnal cycle of road temperature (left) and roof temperature (right) for different adaptation strategies.

(left) The presence of a cool pavement returns temperature values on the road lower than those projected for the reference case. The differences are quite small at night (about 1 °C) whereas they are accentuated in the daytime with a maximum bias of about 12 °C. (right) Adopting a cool roof returns temperature values on the roof lower than those projected for the reference case. The effect is highest during the daylight hours while practically negligible at night. In the daytime, the bias reaches about 5 °C. On the other hand, the presence of an urban vegetation on the roof has the advantage of shielding the underlying surfaces from incident solar radiation during the day, reducing the heating. This phenomenon results during the daylight hours in a reduction of the roof temperature compared to the reference case; this reduction is more noticeable in the summer. However, in the night hours, the temperature pattern of the two cases is reversed and we observe an increase in temperature of about 1 °C in winter and even about 2 °C in summer: the presence of a green roof then could prevent the radiative cooling of the surface, contributing to the urban night heat island (modified from Reder et al, 2018).

The impacts of adaptation measures

Modifying on a case-by-case basis either urban geometry or architectural characteristics of the reference case, keeping the other features constant, different urban configurations were hypothesized, and some adaptation measures implemented and their effects on the urban microclimate were assessed. Specifically, for urban configurations, the relationship between areas used for civil buildings and not, and green spaces has been modified, whereas for adaptation measures, the adoption of “white” roofs and green roofs (in place of the classic dark and/or tiles roofs), green areas and “clear” pavements (in place of, for example, the classic asphalt) has been assumed.

The main outcomes of this research activity are:

- reducing the ratio between areas for civil buildings and not, and areas used as green spaces is an excellent strategy to minimize the intensity of the UHI; it represents a good practice to consider for the development of new urban centers or for the recovery of brownfield sites;
- implementing "white" roofs reduces the temperature on the roofs, especially during the daylight hours (see Figure 2);
- implementing "clear" pavements (for example concrete) instead of "dark" pavements (for example asphalt) reduces the temperature on the road surface mainly during the daylight hours (see Figure 2);
- replacing road fractions with green areas leads to a reduction of the energy stored in the urban environment, as well as the introduction of pervious surfaces;
- introducing a vegetation on the rooftop presents the advantage of shielding the underlying surfaces from solar radiation during the day, reducing the heating and consequently the roof temperature; however, at night, it could prevent the radiative cooling of the surface, thus partly avoiding the nighttime temperature lowering (see Figure 2).

The research suggests a plain engineering approach for the identification of best strategies for reducing heat related impacts on urban communities. Thus, it accounts for the adoption of planning decisions: varying urban geometry, modifying land use, and then land cover introducing green spaces or construction methods: building materials in terms of colors or thermal properties. Nevertheless, it should be clearly recalled that the identified optimal choices for facing UHI and heatwaves may not represent the best options in a systemic framework for which all potentially provided services are considered.

References

Guerreiro, S.B., Dawson, R.J., Kilsby, C., Lewis, E., Ford, A. (2018). Future heat-waves, droughts and floods in 571 European cities. Environmental Research Letters, 13(3): 034009, doi: 10.1088/1748-9326/aaaad3.

Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). Urban climates. Cambridge Press University.

Reder, A., Rianna, G., Mercogliano, P., Castellari, S. (2018) Parametric investigation of Urban Heat Island dynamics through TEB 1D model for a case study: assessment of adaptation measures. Sustainable Cities and Society, 39: 662-673, doi: 10.1016/j.scs.2018.03.023.

Watts, N., Amann, M., et al. (2017). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. The Lancet, 391(10120): 581-630, doi: 10.1016/S0140-6736(17)32464-9.