Mitigation of rising urban temperatures starting from historic and modern street canyons towards zero energy settlement

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Abstract. The necessity of restraining global warming to 1.5°C (IPCC Special Report 2018) implies many actions at global and local level in order to reduce CO2 emissions to net zero by 2050. Moreover, in urban area, the intensity of more and more frequent heatwaves is magnified by Urban Heat Island (UHI) effects and it increases the production of CO2 due to the intensification in cooling demand. Over the years, the historic settlement (medieval town) has showed to be more resilient to temperature changes than modern district. This paper compares the historic district with the modern one in Bari (southern Italy) in terms of morphology, type and construction technology through Envi-met simulations. It highlights how the fabric of the old town may have positive impact on summer regime for thermal comfort and its analysis can be useful for the definition of some guidelines for contemporary settlement. Natural solutions (e.g. vegetation, green roofs and water jects) and cool materials are proposed to reduce energy demand according to EU directive 2018/844 and complying with the constraints for consolidated urban area. The aim is also to evaluate the solutions for microclimate mitigation of urban canyons towards zero energy settlement starting from the old town features.

1. Introduction

Cities have a key role in increasing the capacity to cope with climate change. In fact, world urban population is estimated to grow to 66% in 2050 [1]. The exacerbation of high temperatures is projected to increase morbidity and mortality especially in cities. Therefore, it is necessary to contain global warming to 1.5°C, according to recent IPCC Special Report [2]. This is to avoid an increase of 2°C that may be very harmful for nature and human beings. On regional scale, in the Mediterranean countries, many hot peak temperatures have been recorded. In particular, specific studies on Italian climate of the last years demonstrate that the increasingly occurrence of heat extreme events makes difficult to predict the frequency of hot temperatures records because the average temperature is not yet stationary [3]. In fact, heat waves and extreme heat events are more and more intense and recurrent and the built-up urban areas become more and more vulnerable also because of UHI phenomenon. Hence, in existing urban area, where it is often impossible to change the building configuration, the interventions on urban canopy layer are fundamental in order to cope with rising temperatures. The surface cover of urban section, from pavement to building skyline, should be considered for the actions of mitigation and adaptation to climate change, since it affects, at the same time, indoor and outdoor comfort in buildings and in urban space, respectively. Indeed, urban canyon influences building behaviour in summer regime. Urban geometry, morphology and materials can affect the pedestrians’ thermal comfort. These features of cities have changed over the years losing connection to microclimate. The medieval old towns were built in relation to hotter climate as it is demonstrated by studies on historical data. In fact, in the last 2000 years the temperature of the Earth has changed profoundly due to the variability of the natural climate and
only in recent years also for anthropogenic changes in atmosphere composition. After a hot period in Roman times, there was a period when a small glaciation occurred but in the Middle Ages between 10th and 14th century there was a temperature increase similar to that of Roman times [4]. Thus, the medieval street design was also influenced by climate considerations: the street canopy was made of light-coloured materials and the streets were built narrow in order to reduce solar penetration but simultaneously with funnel shape to make up for the reduction in wind speed, typical of compact fabric, and so to accelerate the wind due to the Venturi effect. Therefore, the complexity of the medieval urban fabric, similar to a maze shape inherited from Athens and Arabic period, gives to old town the characteristics linked to energy performance, as in Toledo that presents a particular use of narrow and high winding streets [5]. Instead, the impact of UHI on energy performance was studied for Barcelona correlating the Sky View Factors (SVF) and aspect ratio of different streets in the old town to the increase of energy demand [6]. Regarding the historical city of Naples, some urban design elements are proposed in order to mitigate temperature increase in current and future scenarios [7].

This paper aims at highlighting how the fabric of the old town may have positive impact on the summer regime for thermal comfort and its analysis can be useful for the definition of some guidelines for contemporary settlement. In addition to passive systems, typical of old town, the use of renewable energy source is recommended to go towards zero energy settlement.

2. Methodology
The defined methodology consists of three main phases:
- Phase 1: Study of the urban and climatic context of two representative areas of the medieval old town and the modern town;
- Phase 2: Definition of scenarios and comparative analysis through discretized 3D models and energy and environmental simulations;
- Phase 3: Identification of guidelines to implement mitigation strategies from the medieval town to the modern town, tending to near zero Energy Settlement.

The first phase includes the identification of the two studied areas, based on the analysis of the historical evolution of the urban fabric and of the technical-constructive characteristics that influence the microclimate. In the selected urban canyons, geometric surveys, materials and climatic parameters investigations are carried out as well as thermographic analyses on the hottest days in summer. The data of the reference weather station for the subsequent comparisons with those detected in the studied area are also analysed. To identify the behaviour of the urban fabrics with reference to extreme conditions, the temperatures of the last 20 years are compared to select a day with the most critical weather conditions. In the second phase, the discretized 3D models of both medieval town and modern one are created through the software Envi-met, a holistic modelling software, based on Navier-Stokes equations and fluid-dynamic analysis [8] to simulate urban microclimate and surface-plant-air interactions. The simulations are set with the most critical climatic conditions in the summer regime with reference to the surveyed year and the hottest day identified in the previous phase. In relation to the strengths and weaknesses of the medieval and modern cities, scenarios are defined for the mitigation of heat waves. The comparison between the solutions proposed with respect to the two reference cases is carried out through thematic maps (SVF, air temperature, wind speed) with a colour palette that highlights the differences in thermal behaviour. The analysis is further investigated in significant points of the urban fabric (receptors) in relation to the main environmental parameters (temperature, wind speed, relative humidity, and mean radiant temperature). Finally, the results of the previous phases are used to define guidelines for interventions on urban canyons. They integrate natural solutions (i.e. shading, water jets, variations in the technical characteristics of the surface) with elements for energy production from renewable sources (e.g. Grätzel cells, etc.) to tend towards almost zero energy settlements.

3. Case study
The city of Bari is characterized by a complex historical evolution. The old city is the witness of the urban development within the ancient walls near the sea and it faces the modern city, started in the 1813 with G. Murat, marshal of Napoleon. A typical medieval urban fabric, characterizes the old town (OT), with narrow and twisted streets surrounded by ancient buildings of irregular shape. They have generally
thick and high thermal inertia limestone walls. Instead, the modern town (MT) is characterized by streets in orthogonal grid, typical of the checkerboard growth pattern of many cities in Nineteenth century. A pedestrian and shopping street (via Argiro) is chosen for the analysis and interventions. These areas are located in a Mediterranean city (C Climate Zone -910<GG<1400) with mild winter and hot summer. Two simulation models were defined in ENVI-met, assigning the thermal properties to the materials and surfaces and the climatic conditions of the selected hottest days in summer. The facades of buildings in OT present degradation phenomenon (rising damp, biological patina, detachment of the plaster, chromatic alteration, surface dust stratification). Thus, an albedo of 40% was considered for walls, which may become 65% after maintenance interventions. The paving is made of the so-called “chianche”, a kind of stone, whose albedo was defined as 35% due to the presence of black and white surfaces. As regard the main Envi-met models setting, the size of grid cell is 1m (in OT) and 2m (in MT) for dx, dy, dz, the extension of grid is 99 x 99 x 34, the simulation hours are 24 (from 4:00 a.m.), the initial wind speed is 3.0 m/s and its direction is 245°. To evaluate the best practice for the contemporary design of urban areas facing summer hot days, the models were simulated in different climate conditions. They were chosen by analysing the temperature of the last 20 years provided by historical weather data (Weather Underground Stations). The data revealed that the hottest day was 24 July 2009 and so the simulations were carried out on that day (Extreme Temperatures day) and on 19 July 2018, when parameters measurements and thermographic analysis were conducted. The comparison allowed us to obtain the actual behaviour of the area and in extreme conditions. Moreover, the data provided by Bari Karol Wojtyla airport weather station on 19 July 2018 were used only in OT_WS and MT_WS. They are lower than measured data used for all the other models on the same day (e.g. ∆Ta is - 1.1 °C at 11:00 a.m., -1.7 °C at 12:00, -1.5 °C at 1:00 p.m., -3.7 °C at 2:00 p.m., -2.9°C at 3:00 p.m. and ∆RH is -17% at 1:00 p.m.). To obtain the design guidelines, it was decided to adopt some solutions suitable to the context. It was evaluated the influence of walls albedo, changing it from 40% to 65% to analyse the effect of lighter coloured finishing layer on external microclimate and of green roof, greenery and water jets. The last ones are placed to create an alternation of wider paths with narrower ones that recall the old city. For greenery, it was chosen climbing plants and deciduous trees (Acer Campestre) with deep roots that allow evapotranspiration even in hot weather [9, 10]. In ENVI-met simulation, water content at root zone is taken into account in terms of water extraction from the soil. Then, different models (Table 1) were analysed through ENVI-met with four receptors for OT and with five for MT (Figure 1).

**Table 1.** Old Town (OT) and Modern Town (MT) models for ENVI-met simulation run on 19 July 2018 and 24 July 2009 (extreme temperature)

| Case study | Street paving albedo (%) & Building Walls type, albedo (%) | Case study | Street paving albedo (%) & Building Walls type and albedo (%) |
|------------|---------------------------------------------------------------|------------|---------------------------------------------------------------|
| OT_Base    | 35% & Limestone Walls (40%)                                   | MT_Water (Water Jets) | 65% & Double Walls (40%)                                      |
| OT_WS     | 35% & Limestone Walls (40%)                                   | MT_GR (Green roof) | 12% & Double Walls (40%)                                      |
| OT_65%    | 65% & Limestone Walls (65%)                                   | MT_Green (Greenery) | 65% & Double Walls (40%)                                      |
| MT_Base   | 12% & Double Walls (40%)                                     | MT_MixWG (Water jets & Greenery) | 65% & Double Walls (40%)                                    |
| MT_65%    | 65% & Double Walls (65%)                                     | MT_WS | 12% & Double Walls (40%)                                      |

**Figure 1.** ENVI_meth simulation models, receptors location and thermographic survey of OT and MT.

4. Results and discussion
The difference between the results in measured conditions (OT_Base and MT_Base) and those with the data detected by weather station (OT_WS and MT_WS), is evident especially for the hottest hours
(Figure 3 a, b, c, f) and in correspondence to the receptors (e.g. for R_{OT1} and R_{MT2} at 2:00 p.m., Ta rises of 2.17°C in OT_Base versus OT_WS and of 2.34°C in MT_Base versus MT_WS - Figure 4a). It demonstrates that considering the climate file of the weather station implies a considerable underestimation of the energy behaviour of the built settlement. After the peak of solar radiation at 12:00 a.m., the canyon canopy layer begins to return the accumulated heat that overlaps with the new solar inputs as revealed by the thermographic analyses (Figure 1). Figure 2 shows that the SVF in OT_Base streets is lower than in MT_Base one and involves a reduction of incident solar radiation penetration.

Figure 2. Sky view factor of OT, MT_Base, MT_Green

Figure 3. Air Temperature maps with wind speed vectors at the hottest hour on 19 July 2018 (h=1.4m)

The MT_MixWG solution has an intermediate but still advantageous behaviour. The wind, having a reduced speed, does not entail particular benefits even if you notice at the entrance of the road an acceleration of the airspeed, which is reduced due to the presence of obstacles especially in OT (Figure 3 a, f, g). The same results are confirmed by the receptors analysis. For brevity, only the comparison of Ta e Tmrt between different scenarios in the receptors R_{OT1} of OT and R_{MT2} of MT is reported (Figure 4). The old city (OT_Base and OT_65) has in the hottest hour a Ta less than MT_Base of 1.03 and 2.8 °C, respectively. Among the mitigating strategies, it is obtained a lowering of temperatures of only 0.24°C for MT_65%, of 0.6 °C for MT_Green and MT_MixWG and up to 1.61 °C for MT_Water. Also for Tmrt, the old city for the different receptors has a lower value than MT_Base: at 1:00 p.m. the peak difference is reached (∆Tmrt for MT_Base versus OT_Base is equal to 25.31 °C and ∆Tmrt for MT_Base versus OT_65 is equal to 35.37 °C) (Figure 4). Due to the albedo rise in MT as a result of direct sunlight, the short waves are reflected in the canyon towards other objects and people, reducing their comfort during the central daylight hours. The presence of the greenery, due to its shading, determines a reduction of Tmrt in the morning and makes the MT behaviour similar to the OT one. Only after 9:00 p.m. the behaviour of OT_Base is reversed in favour of MT_Base, while for the case with 65% albedo, the situation is always in favour of the ancient city. For MT_Green there is a decrease of Tmrt (up to 20 °C at 11:00 a.m.) compared to MT_Base. Regarding to Relative Humidity, it follows the rise of air Temperature in an inversely proportional way and increases with the presence of water jets and greenery (e.g. at 12:00 a.m. ∆RH is of 1.37% in MT_Water and of 0.08% in MT_Green versus MT_Base). Regarding wind speed, in R_{OT1} it is reduced of about 1 m/s with respect to R_{MT2} but at the entrance to the road there is an increase in wind speed. The presence of green reduces the wind speed of 0.2 m/s, while the jets reduce it of 0.6 m/s, but anyway the water jets determines cooling effect.
Figure 4. Air Temperature and Mean Radiant Temperature in Receptors R_{OT1} e R_{MT2} (h=1.4 m)

Figure 5. Air Temperature maps with wind speed vectors at the hottest hour on extreme day (h=1.4m)

Analysing the same cases in extreme conditions (Figure 5), OT performs better of MT that reaches Ta between 40.50 and 41.50 °C, while for most of the analysed roads the range of Ta is 39.25-39.80 °C in OT_Base and 37.05-37.60 °C in OT_65%. The advantages of the highest albedo are reduced in extreme temperature conditions. The water jets introduction represents the best mitigating action for MT_Base, since Ta is lower than 38.70 °C for most of the studied street and RH is of 21.12% (ΔRH=1.12%) at 1:00 p.m., followed by the greenery introduction. This last scenario results less advantageous, since plants at high temperatures reduce their mitigating action because the soil is more dry and according further research because they close the stomata [11]. In Figure 5, MT_Base versus OT_Base and versus OT_65 has ΔTa equal to 1.5°C and 3.91°C respectively, while MT_Water has a mitigating effect similar to OT. In MT_MixWG, presenting the advantages of MT_Water and MT_Green also for Tmrt, the cells of Grätzel were inserted as a covering of the path between climbing plants offering a splendid play of light and shadows along the pedestrian path (Figure 6). The Grätzel cells have a 12% efficiency and the characteristic of working even in low light conditions (cloudy skies, indirect light). They are recyclable. By Solarius-Pv software, they result to produce 1 910 kWh, deriving from 12 modules with a total area of 18.90 m², allowing to cover the consumption for street artificial lighting and for the water jets pumps. Anyway, the study has some limitations: the main ones are that it does not analyse the effects of the selected solutions on indoor comfort and on a larger urban area.
5. Conclusions
The work analysed many configurations of mitigation strategies in old and modern town to understand which are the best solutions to be applied in urban design to improve the microclimate behaviour. The results give the possibility to obtain some guidelines, useful for achieving this goal:

- When the SVF is higher than about 0.25, it is important to reduce it by inserting trees and green systems. Indeed, the study of the old town demonstrates that low SVF means low penetration of incident solar radiation in urban canyon that can be provided by greenery cover in modern town.
- Plants have to be selected to withstand high temperatures (e.g. with deep roots) and supplied by watering systems to prevent them from reducing the evapotranspiration process.
- The use of high albedo materials has to be accurately evaluated. They decrease air temperature but increase mean radiant temperatures. Thus, if shading systems are not provided, problems of excessive short-wave reflections towards pedestrians happen with consequent glare and sense of overheating.
- Too dark surfaces (albedo < 40%) have to be avoided because they induce an increase in air temperatures due to the intensification of long waves radiations and minor effects on night cooling.
- Water is a fundamental strategy to mitigate rising temperature and to promote passive cooling. Finally, it is important to fix a new aim that is the “urban zero energy settlement”, tracing the footsteps of Nzeb energy building. At urban level, this goal can be achieved by the insertion of active elements that exploit solar energy and at the same time create shading areas, i.e. the aesthetically valuable Grätzel cells, capable of producing energy from both sides and also from indirect light.

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