Nature-based climate adaptation for compact cities: green courtyards as urban cool islands

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Abstract

Urban heat island (UHI) and heat waves are two important phenomena that affect city livability and citizen's health. Most of experts agree that it is necessary an adaptation strategy to climate changes for the whole urban context. Urban Green Infrastructure (UGI) planning can represent the proper tool to pursue this strategy concretely, also in the compact city, but new approaches, based on the environmental process assessment, are necessary. They are based on closed cycles, efficient local resources optimization and emulation of ecological processes. Modeling approach is fundamental to evaluate the benefits of green strategy scenarios and to define urban regenerations adapted to local conditions. This paper proposes a first climatic assessment based on Envi-met management model to analyze summer air temperatures and thermal comfort related to a green (Nature-based) scenario of a typical urban courtyard of Bari city. The climatic differences between actual and post scenario is analyzed in terms of air T decrease and thermal comfort index (PMV). These indicators are then proposed as proxy for local climatic regulation services. It emerges the relevant role of courtyards as Urban Cool Island (UCI) for

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UHI mitigation and this result gives new strategic importance to these urban structures. Courtyards, often considered marginal spaces, characterize many Italian cities and towns, and they can be redesigned adding an ecological value to compact cities where very few non-urbanized and open spaces still remain.

Keywords

Open spaces, urban regeneration, resilience.

Introduction

Urbanization defines significant changes in land uses and climate. The natural surfaces and the land morphology are altered and thermal, moisture and aerodynamic properties of built-up areas lead to new, human-induced climates often characterized by Urban Heat Islands (UHI) (Martins et al., 2016). UHI is a phenomenon characterized by urban air temperatures higher than the rural surroundings. This altered urban climate is mainly a result of modified albedo surfaces and air circulation, due to the natural vegetation replacement with artificial surfaces, buildings and roads (Hashem Akbari, Menon, & Rosenfeld, 2009).

UHI has a series of negative, synergic, consequences. As the air temperature rises, so does the demand for indoor air-conditioning, which means higher energy consume, outdoor heat emissions as well as increased Green House Gasses from power plants. On the other hand, there is an increment of plant evapotranspiration and vegetative stress, ozone formation, concentrations of fine particulate matter, air pollutants and temperature-dependent biogenic hydrocarbon emissions (Watts et al., 2015). Nevertheless, UHI as well as the consequences on human health and ecosystems can be exacerbated in a global climate change context.

UHI mitigation and reduction define therefore direct and indirect benefits for urban environments. As an example, looking at meteorological impact of UHI mitigation Georgescu, Steyaert, & Weaver, (2009) have reported correlations between urbanization and precipitation in Arizona. Moreover, UHI mitigation and the decrease of the near-surface temperatures result also as an effective strategy for the reduction of the air pollution also if in some local conditions higher ozone concentrations can be pointed out (Taha, Douglas, & Haney, 1997).

To mitigate the impact of UHI on urban dwellers and environments, three main strategies exist: implementation of heat warning systems, individual adaptation of citizens by clothing and behavior and urban planning strategies (Oertel, Emmanuel, & Drach, 2015). Traditional economy and, above all, recent circular economy approaches push to reduce UHI impacts and the planning option seems to be the most lasting and sustainable adaptation strategy to climate change for complex social-ecological systems like cities (Leone, Gobattoni, & Pelorosso, 2016; Leone, 2013).

Planners and designers can contribute to create better and healthy urban places looking at both urban geometry and "cooling" material and land uses. Various national and international studies have been carried out to evaluate the multidimensional effects of UHI and outdoor thermal comfort control and the different variables influencing them (Krüger, Drach, Emmanuel, & Corbella, 2013; Taha, 2015).

The main factors affecting urban climate are albedo surfaces of roads and buildings, greenery, water features (Martins et al., 2016), canyon orientation and aspect ratio, sky view factor (SVF) (Hien, Kardinal Jusuf, Samsudin, Eliza, & Ignatius, 2011).

Simple ways to cool the cities are reflective cool surfaces (rooftops and pavements) and the so-called Nature Based Solutions (NBS). NBS, as green roofs or tree plantations are actions inspired by, supported by or copied from nature. NBS can be designed to enhance the Urban Green Infrastructure (UGI) functionalities in urban environments, e.g. sustainable urban storm water management (Pelorosso, Gobattoni, Lopez, & Leone, 2013) improved recreation and tourism opportunitiesor aesthetic externalities. Definitely, NBS aim to mimic Nature furnishing similar provisioning, regulating, supporting and cultural ecosystem services (EU, 2015).

In particular, urban vegetation plays an important role in urban climate regulation and UHI mitigation. UGI can reduce air and surface temperature by providing shading and enhancing evapotranspiration, which leads to a reduced energy use and an improved thermal comfort at building and neighborhood scale (Demuzere et al., 2014). Moreover, there is an increasing evidence that NBS can provide flexible, cost- effective and broadly applicable alternatives to cope with the magnitude, speed and uncertainty of climate change (EU, 2015; Munang et al., 2013).

As an example, Akbari, Pomerantz, & Taha (2001) through computer simulations for Los Angeles (CA) showed that retrofitting about two-third of the pavements and rooftops with reflective surfaces and planting three trees per house can cool down summer air temperature by an average of 2–3°C, which, in terms of smog production, is equivalent to clear the entire basin from road vehicle exhausts. Besides localized cool shaded areas, transpiring plants release water vapor to the surroundings, this process induces the humidity increase (which increases air reflection of solar radiation) and temperature decrease. Typical rates of heat loss by evaporation in arid environments with good irrigation range from 24,5 to 29,5 MJm^{-2} per day, whereas, in temperate climates, rates range from <0,7 (winter) to 7,4 MJm^{-2} per day (summer) (Barradas, 1991). Vegetation can furthermore cool surrounding area with a variable radius in function of green size and typology, wind and urban morphology (Shashua-bar & Hoffman, 2000). Therefore, green areas and parks can become small islands which are cooler and more humid ("Park Cool Island", PCI), and produce, also into the hotter and drier cities, an urban mosaic of microclimates. This effect also changes thermal comfort indexes, making city parks more comfortable compared to the surrounding urban environment, mitigating UHI effects. PCI intensity largely depends on the characteristics of urban parks. Generally, there is a significant positive correlation between PCI intensity and urban park size (Ren et al., 2013). However, the cooling effect of urban parks may be also related to other characteristics of parks, such as the urban forest structures and the tree canopy. The relationship between PCI intensity and urban forest structures in parks has rarely been studied and is not yet fully understood (Ren et al., 2013). UGI also contributes, both positively and negatively, to the indoor environment in terms of climate, energy use, air quality, sonic environment and aesthetic quality (Wang, Bakker, de Groot, & Wörtche, 2014). Energy savings are extremely time- and context dependent but as an indication of the potential economic effects of UGI, Wang et al. (2014) report up to almost \$250/tree/year, while the air quality regulation was valued between \$0,12 and \$0,6/m^2 tree cover/year. Maximum monetary values attributed to noise regulation and aesthetic appreciation of urban green were, respectively, \$20 e \$25/person/year.

The economic implications of the nature in the city seem obvious: several human activities depend on natural capital and on the full range of ecosystems services provided by UGI (TEEB, 2009). As a consequence, many studies have proposed the introduction of Nature-based solutions in cities as sustainable planning strategies aimed to reduce impacts of UHI and extreme heat events (Demuzere et al., 2014; EU, 2015; Norton et al., 2015; Pelorosso, Gobattoni, La Rosa, & Leone, 2015; Pelorosso, Gobattoni, & Leone, 2014; Santiago Fink, 2016). Adaptation plans to climate change of cities are becoming the mainstream in many countries. However, Italian cities are still in delay in this planning process. The Bologna climate adaptation plan is one of the first examples where NBS are used to mitigate UHI (Bologna Municiplaity, 2015) but research and practical applications on different climates and urban study cases are needed to support effective planning strategies. Indeed, the socio-ecological complexity of urban structure and the geographic variability of cities require strategies adapted to the local conditions to maximize the NBS effectiveness (Leone, Pelorosso, Gobattoni, 2018). The translation of these notions in urban planning practice seems still inadequate.

This work starts from the observation of a great amount of unused spaces in the compact cities that often are source of environmental and social degradation. In particular, the paper analyses the potential climatic benefits of including urban courtyards in the UGI of Bari by the modeling simulation of a NBS scenario. The city of Bari presents an abundance of courtyards generated by the particular urban planning of the nineteenth century (Reale, 2012). These open spaces are usually not included in the UGI and often represent a rejected and under-used space for the population. The conducted research provides a contribution to UGI planning and urban regeneration programs, searching for a new identity for courtyards. The potential role of courtyard as Urban Cool Islands (UCI) (Martins et al., 2016) with thermally comfortable microclimates counteracting UHI and heat summer waves is then proposed as planning strategy for climate adaptation plans.

Study area and potential UGI for UHI mitigation: urban empties and courtyards

The conurbation of Bari has dimensions and dynamics of use and exploitation of the territory that go far beyond administrative boundaries; it is characterized by a strongly inhabited territory, result of the juxtaposition of local urban policies with infrastructural policies, which have led, in the decades of growth, to the realization of large urban equipment, productive poles and the infrastructural system (Calace & Angelastro, 2015).

The town planning history of Bari, starting from the nineteenth century, first saw a planned orthogonal mesh development and then an expansion for meshes oriented along the lines of territorial connection inside a territory without surface hydrography and characterized by the presence of erosive furrows – “lame”– expressions of karstic activity, many of which converge, due to slopes and geomorphological course, in the area of Bari.

The current shape of the city is characterized by a very compact inner core (the study area of this research), consisting of the city built from the early nineteenth century adjacent to the historical nucleus located on a small promontory on the sea, and its developments until the mid twentieth century. The compact block, built in curtain and with the inner courtyard, has been the basic component of such expansions.

Since the post-war period, Bari has mainly developed along preferential directions and nuclei: the southern direction, which involved the welding of the city with its areas immersed in the olive grove countryside, the directions along the coast, almost entirely settled by low-density buildings during the 1960s and 1970s; the residential and productive planned nuclei of public initiative, with particular relevance in the western sector of the territory, where there

is a large public building district and one of the largest "ASI" zone in the south. In this period, the closed block was flanked by the settlement model of the free building in the lot, gradually leaving more and more large open spaces, also these differently used and treated.
Between these major directions and the nuclei, often cut off by infrastructures, there are still large open spaces, characterized by the presence of erosive grooves already mentioned and agricultural areas. The presence of numerous roads (above all railway infrastructures) and the urban design defined by the current planning have led to the formation of many interstitial spaces, mostly abandoned.
Therefore, the most critical environmental issues interest the most central areas, compactly constructed and with few open spaces and permeable surfaces. In these areas, the only potential resources for improving both climatic conditions and the overall quality of the living environment are the courtyards inside the blocks. However, the original function of hygiene and decoration in the courtyards, established in the nineteenth century by the Murat Statutes, has been progressively distorted, due to the increasing clogging with waterproofing, building structures for depots, parking lots and activities.
The study area (850 ha) corresponds to the most compact and populated district of Bari city considering also the historical center (Fig. 1). In general, Bari city suffers a strong scarcity of urban green spaces. Among the biggest European cities, Bari presents one of the lowest level of accessibility to green spaces within a walking distance from home: only around 20% of population has urban green space (≥2 ha) available within 500m in its administrative boundary (Kabisch, Strohbach, Haase, & Kronenberg, 2016). This green space scarcity has several consequences on people health and functionality of the urban system, in particular on storm water control (Pelorosso et al., 2013), climatic

regulation and UHI phenomenon. Summer extreme heat events have potential high impact on people, above all for young and old citizens that cannot move for cooling places (e.g. sea or green space with shade trees) or which do not have cooling systems in their homes. Since the historical structure of the city and the lack of public and shaded green spaces, planners should look for new spaces and strategic actions.

Several unused or underused spaces could be subject of green regeneration projects with the aim to mitigate the UHI impact and provide further UES to the citizens. These spaces (Fig. 2) are however outside the compact city and the possibilities of action appear very limited. The compact city presents, however, many courtyards inside buildings due to the particular urban configuration of Bari (Pelorosso et al., 2013). Approximately, these courtyards amount to 300.000 m^2 and they represent about the 6% of the study area.

A courtyard is an enclosed outdoor or semi-outdoor space surrounded by buildings and open to the sky. Courtyards were adopted in building practice in Asia, the Middle East, South America, and the Mediterranean countries (Ghaffarianhoseini, Berardi, & Ghaffarianhoseini, 2015). Their main function was to improve comfort conditions by modifying the microclimate around the building and by enhancing ventilation. Different courtyards have been realized for different countries and times. For example Romans and Arabs often included colonnades, and courtyards were often present in convents and important palaces. In the post-industrial cities, courtyards have lost the traditional functions. The socio-ecological role of XIX century courtyards in many Italian cities was often changed. Many courtyards are became unused spaces (often turning into dump sites) or they are reconverted to other uses (e.g. car park). In several cases, courtyards present artificial covertures in order to allow increasing volumes to be realized. In all these cases the climatic functionality of courtyard is consequently reduced and a regeneration of these spaces, aimed to reconnect their historical role with the actual needs, is then welcomed and desirable.

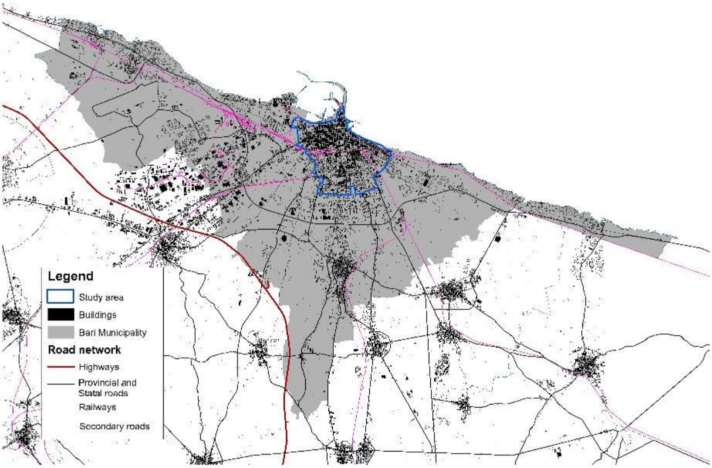

Figure 1 - The Bari Municipality and the study area.

The impact of courtyards in some climates has been assessed qualitatively and quantitatively by using field measurements and computer modeling (see Ghaffarianhoseini et al., 2015). Green courtyards show generally an improved thermal comfort with respect to paved and concrete surfaces or even bare soils. Tree shading adds an important contribution to improve the climatic condition of courtyards. Shashua-Bar et al. (2009) concluded that the best cooling efficiency for courtyards

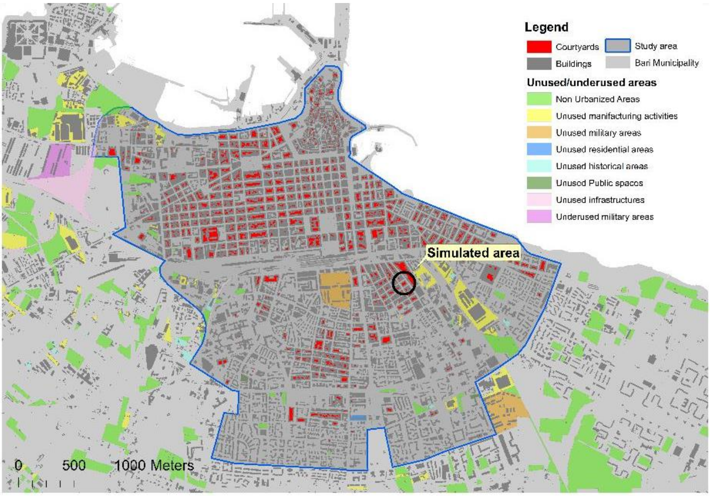

Figure 2 - The study area. Source: Authors' elaboration.

was with shade trees and that grass yielded a daytime temperature reduction of up to 2.5 °C in hot and dry condition of Israel. However, many geographic (e.g. latitude, altitude), climatic (e.g. wind, aridity, season) and structural factors (e.g. building height, orientation, albedo surfaces, dimension, openings) can affect the courtyard climate and the relative thermal comfort (Ghaffarianhoseini et al., 2015). The following paragraph presents an assessment of the potential benefits of Nature-based solutions designed in a typical courtyard of Bari (fig. 2).

Model simulation

The ecological and functional regeneration of unused spaces needs the assessment of environmental processes and, consequently, the simulation of the interactions among natural phenomena (climatic factors as radiation, wind, transpiration etc.) and anthropogenic features (artificial surfaces and buildings). These simulations can be realized through the so-called environmental modeling. Usually, several managerial models are used to analyze environmental dynamics. These models are based on mathematical functions and physical and natural processes and they focus on the use of land. Managerial models allow evaluating the contribution of each different land use to the environmental degradation or amelioration of a defined geographic space and, therefore, they are also named Spatial Decision Support Systems (SDSS) (Sugumaran & Degroote, 2010). These models allow planners to understand the general behavior of the system and, consequently, to decide the best strategic proposals in terms of land use with respect to the considered environmental and territorial processes. In other words, managerial models allow land use decision making (i.e. NBS planning and design) to be supported on the basis of the optimization of environmental processes (i.e. ecosystems services).

In order to evaluate how the green strategies affect the microclimate and outdoor thermal comfort of a courtyard, ENVI-met version 4.0 Beta II was used (Bruse, 2016). ENVI-met is a free 3D microclimate model designed to simulate the interactions among buildings, surfaces, vegetation and air in urban environment. It relies on the fundamental laws of fluid dynamics and thermodynamics and it can be used for neighbored urban scale evaluations. Several scientific studies have adopted this model even in the simulations of courtyards (e.g. Berkovic, Yezioro, & Bitan, 2012; Ghaffarianhoseini et al., 2015; Salata et al., 2015). The software is able to calculate several meteorological and microclimatic variables and thermal comfort indexes. Moreover, several land use scenarios and NBS can be simulated and therefore the model was used as SDSS in many climatic urban studies.

Thermal indexes are usually used to estimate the thermal comfort of indoor and outdoor environments. These indexes are based on the human body energy balance and are supposed to be universally applicable. Several different thermal indexes are used in outdoor urban spaces (Oertel et al., 2015; Ruiz & Correa, 2014). The present work focuses on Fanger's Predicted Mean Vote (PMV), one of the most widely used indexes to evaluate outdoor thermal comfort. PMV is a thermal comfort index developed for indoor environments based on 1,565 surveyed people. Afterwards, it was modified and adapted to outdoor environments also taking into account the solar radiation. PMV considers some environment variables as air temperature, mean radiant temperature, relative humidity, wind speed and some operative variables as clothing insulation and the metabolic rate (Salata et al., 2015). PMV scale ranges between −4 (very cold) and +4 (very hot) where 0 is the thermal neutral (comfort) value. However, the PMV depends on the local climate and its values can exceed the interval [−4; +4]. The use of this index is suggested by the German engineering guidelines VDI 3787 for outdoor environments. Moreover, a recent study has demonstrated a satisfactory similarity between PMV values and actual thermal sensation votes of an outdoor survey realized at Glasgow (UK) (Oertel et al., 2015).

The model simulations have investigated the thermal characteristics of a typical building in the study area with courtyard inside. The building is 23 m high and the courtyard has an area of around 1000 m^2. The model geometry is constituted by a grid of cells 50x40x30 with a cell resolution of 2 m. High of the 3D model top is around 87 m. Streets and buildings around the area were also simulated in the model to evaluate the interaction of the planned NBS with the microclimate of the area.

The simulated green scenario (Fig. 3) is constituted by two main interventions (NBS): an extensive green roof (20 cm of grass) on the top of the building and the greening of the courtyard with trees and grass soil coverage. Green roof installation is here simulated to test their effectiveness in microclimate regulation in high density district with high buildings. Indeed, Peng & Jim (2013) reports that green roofs have a potential impact on local climate and thermal comfort. Extensive green roof typology (20 cm of grass) was selected in order to assess a realistic green regeneration with lightweight of NBS (old building could not bear excessive loads), low maintenance costs and added benefits in storm water regulation (Pelorosso, Gobattoni, & Leone, 2015).

In this work, the coupled effect of greening on courtyard and roof is then evaluated in a typical dense district of a Mediterranean city. Inside the courtyard, four trees were planned on a natural soil covered by grass. The selected tree (*Cercis siliquastrum*) is with a medium high (10 m) and canopy. Three specific locations for the climate analysis have been chosen. The first location is situated directly on the green roof where a receptor is identified to acquire and register all the local climate data, in order to evaluate the effects of green roofs on the microclimate.

The second point of measure is located at the street level outside the courtyard. The second station point was selected to investigate the cooling effect extension of the planned NBS in the simulated area with respect to vertical and horizontal gradient. The third location for data gathering is inside the courtyard. The microclimates inside the courtyard and on the streets (second and third points of measures described above) were evaluated by mean values of the ENVI-met outputs on the whole dataset at 1 m high instead of fixed station points. These mean climatic values were chosen in order to consider the different sun exposition, radiation fluxes and shades provoked by walls and trees during the day.

Table 1: Input parameters for the ENVI-met simulations

Main data settings	
Start Simulation at Day (DD.MM.YYYY)	23-07-2003
Start Simulation at Time (HH:MM:SS)	06:00:00
Total Simulation Time in Hours	24
Wind Speed in 10 m ab. Ground [m/s]	1,6
Wind Direction	East
Initial Temperature Atmosphere [K]	305,50
Specific Humidity in 2500 m [g Water/kg air]	7,0
Relative Humidity in 2m [%]	50
Max temperature 2 p.m. [K]	311,00
Max humidity 5.00 a.m. [%]	70
Min temperature 5.00 a.m. [K]	300
Min humidity 2 p.m. [%]	35
Settings for PMV-calculation	
Walking speed [m/s]	0,0
Metabolic rate [W/m2]	70
Mechanical factor	0,0
Thermal resistance of clothing [clo]	0,35

Cooling effect of NBS was then estimated comparing base scenario with the NBS scenario in terms of atmospheric T and PMV index at street and roof level. Table 1 reports the main ENVI-met input parameters. The simulated day was the 23 July 2003, one of the hottest days of the last years. Only a light wind from east (from sea) was considered to describe the climate of a heat wave day. Settings for PMV calculation were referred to the thermal resistance of a typical summer clothing (Salata et al., 2015).

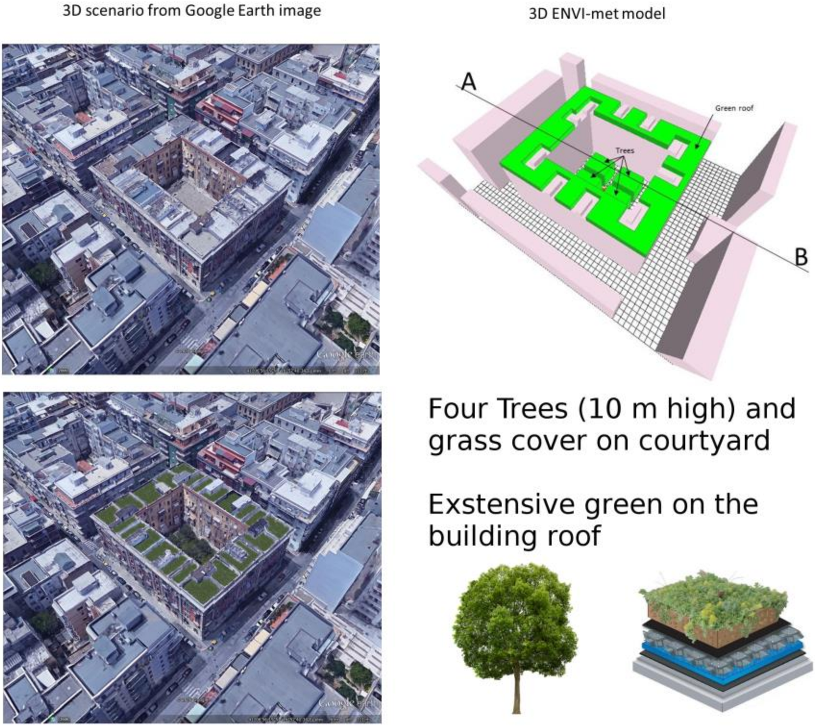

Figure 3 - 3D-model of the courtyard and identification of the NBS. Source: Authors' elaboration

Results

Fig. 4 shows the climatic trend in terms of Air temperature and PMV at roof level in the two scenarios. Considering the green scenario (NBS scenario), a mean reduction of air temperature of 0,1 °C was registered during the simulated day with respect to the base scenario. PMV decrease was around 0,3 with a higher thermal benefit of the green roof pointed out during the night (mean PMV reduction of 0,5). The climate data registered for the two scenarios by the receptor on the roof, highlight that green roofs have only a limited cooling capacity in the first layer of air (see also thermal profile of Fig. 5). Namely, temperatures and PMV corresponding to the receptor on the roof are not impacted by the greening of the courtyard.

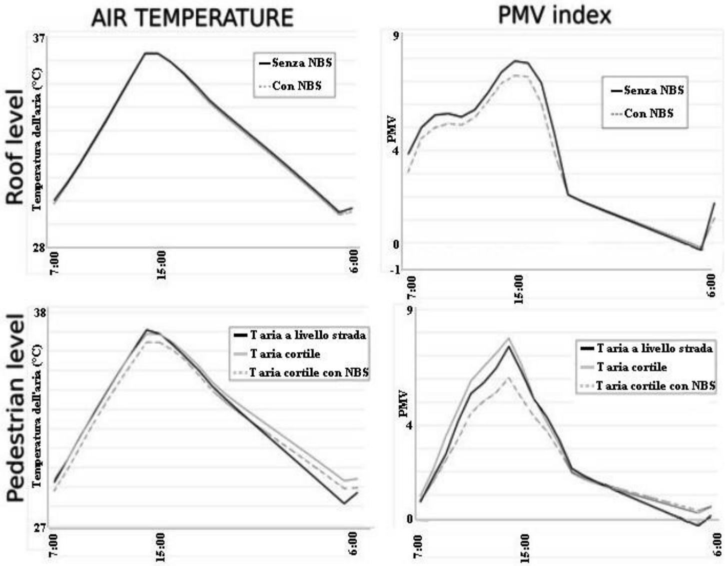

Figure 4 - Air temperature and PMV trends at roof and pedestrian level in the two scenarios. Source: Authors' elaboration.

T and PMV comparisons at street level between NBS scenario and base scenario are showed in Fig. 4. Courtyard with the planned NBS shows an improved microclimate with a mean reduction of 0,45 C° during all the simulated hours with respect to the base scenario. Moreover, NBS scenario defines a less warm environment than the neighborhood streets above all during the hottest hours of the day (-0,63 C° at 14.00) as shown in the Fig. 4 where the Street Air Temperature is compared with Courtyard Air Temperature (NBS scenario). The Street Air Temperature represents the air temperature at street level at 1 m height and it's not affected by the greening interventions on courtyard and roof (NBS scenario).

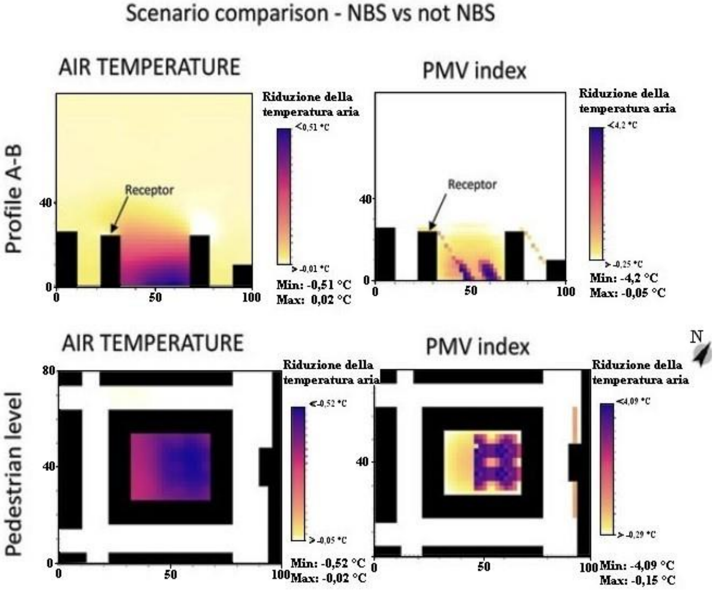

Figure 5 - Scenario map comparison. The arrow indicates the measurement point (receptor) on the roof. Source: Authors' elaboration.

A similar trend is reported also in terms of PMV reduction. During the hottest day hours, within the green courtyard, the mean PMV reduction is 0,8 with respect to the base scenario without NBS with a peak of -1,7 points at 14:00.

Comparing the green courtyard with the neighbored streets the mean PMV difference (between PMV at street level and PMV in the courtyard with NBS) is around 0,5 points less with a reduction peak of -1,35 at 14:00 thus underlining the increased comfort inside the courtyard due to the greening. From the Fig. 4, it is also evident that PMV in the courtyard in the base scenario is less than PMV evaluated at the street level: the obtained results suggest a cooling effect of NBS interventions not only with respect to the previous condition inside the courtyard (base scenario) but also with respect to the street level thus showing the potential benefit for citizens which could be induced to access the courtyard to have much more thermal comfort.
Fig. 5 shows the maps (section and plan view) of the air temperature and PMV index distribution at 14:00 at pedestrian level and along the middle profile A-B (see Fig. 3) in the two simulated scenarios. The effect of the NBS on microclimate is well demonstrated. It is worth to note that in shaded areas, the reduction of PMV index has reached also -4 point defining small area of thermal comfort inside the courtyard during the hottest hours of the day. Along the profile A-B, the air temperature decrease reaches -0,51°C at pedestrian level. The Fig. 5 underlines that the greening effect diminishes while moving away from the soil.

Discussion

Model assessment has defined a critical situation of the simulated area under the climatic point of view. PMV values define high human discomfort both inside and outside the courtyard. However, the courtyard presents highest values of T and PMV in the simulated environment resulting as the warmest and unhealthiest open space during the hottest hours of the day.

The simulated green roof didn't show significant benefits to the courtyard and at street level. Reduced wind and strong sun exposition have surely limited the cooling effect of this NBS in the local environment. These results are in line with other findings reported in literature for highbuilding-height-to-street-width (H/W) ratio where thermal green roof benefits at pedestrian level were not pointed out (Ng, Chen, Wang, & Yuan, 2012). However, benefits of thermal insulation of the building and large-scale green roof installation are here not considered.

The simulated NBS inside the courtyard have demonstrated their capacity to mitigate the microclimatic condition of the courtyard. Further studies and evaluations are necessary to setup the best NBS configuration (e.g. increasing the tree canopy and the shaded area inside the courtyard).

However, the ENVI-met model has shown its capacity to provide useful and objective information regarding climatic functionality (microclimatic regulation service) of NBS. In particular, the impact of the vegetation on the thermal index PMV is resulted significant even with small air temperature reductions. Both indexes (Air temperature and PMV index) can therefore be employed as proxy indicators of urban ecosystem services related to climate regulation of urban systems. The impact of the simulated study case on UHI cannot be determined directly by the model output. However, the model results appear encouraging since a clear climatic improvement of courtyard was pointed out, above all with respect to the neighborhood streets where traffic congestion can further worse the climatic situation. Courtyards, above all if no green areas are present in the proximity of the home or office, can therefore represent cool islands, the only possibility for the citizens to counteract adverse climatic conditions in the hottest hours of the day. Further studies on a wider area and temporal scale (e.g. considering different days of the year and climatic conditions) could help to quantify the extended thermal benefits for people during the year and even the reduction of UHI phenomenon due to courtyard greening. A census of the courtyard typology and distribution in relation with the density of population and real green area availability is then welcomed. We argue that a coupled urban assessment of courtyard and model simulations could point out useful information to the planners and designers in order to choice the best location for urban regenerations based on nature strictly related with local conditions.

In the compact city, the introduction of precise limitations to soil sealing, the roofing ratio and, more generally, the introduction of parameters that would allow the reuse of the courtyards as "new environmental equipment" (to be applied for example in cases of intervention on existing buildings), it should be accompanied by other urban planning measures (i.e. volumetric incentives for relocation, finding of pertinent parking areas also through agreements with private individuals), tax exemption for virtuous interventions for which the collective value is recognized, as well as use of new technologies and materials. However, it should be considered that these norms and measures can have significant effects only if the theme derives from a planning approach, i.e. considering all the courtyards as a system, rather than as a sum of individual cases to which the same design solution must always be applied.

Conclusions

Courtyards are often the only open spaces in densely built-up areas. They can be re-thought as green and accessible areas to face the climate change issues, to mitigate the UHI and heat waves phenomena and, in general, to improve the citizen life quality even under social point of view. We think that the courtyard integration into the green infrastructure and into the planning of cities is indispensable in order to set-up effective climate change adaptation strategies.

Two main problems hamper courtyard planning integration and regeneration. First, the fact that many courtyards are not considered in land use planning and governance instruments increases the difficulties of including them into effective spatial plans and wide urban regeneration actions. Second, environmental and social benefits of courtyards are often not fully evaluated and recognized by population and policy. Indeed, citizen acceptation and maintenance of courtyards can be realized only if the NBS are designed to fulfill several functions simultaneously (e.g. habitat conservation, stormwater control and recreational services) and access to residents is allowed as more as possible. Ensuring the usability of courtyards as green spaces represents a tool to make dwellers aware of the potential ecosystem services provided by the green in the cities and, at the same time, aware of the key role that courtyards can play in increasing green spaces in cities.

Urban courtyards often represent a real refusal of land since many of them are left to the uselessness which, consequently, becomes degradation. Territorial Engineering (Leone et al., 2016), based on the principles of the circular economy and of the laws of thermodynamics, cannot then refrain from proposing solutions for these particular and complicated situations. Namely, courtyards are often private spaces, with scarce "traditional" economic value, whose valorization will find skepticism least. For these reasons, applied research and experimentation are needed to give new prospective to these areas. The way of ecosystem services (the enhancement of summer climate with green areas, in particular) is providing positive results which represent an incentive factor to open to new urban policies, to a virtuous re-use of these spaces. The encouraging model simulations and the results obtained assume the role of powerful communicator of the importance of these spaces for increasing city resilience and sustainability in climate change contexts.

Recognized the value of these spaces in the ecological regeneration of the city, a goal for urban planning and regeneration should be the introduction of tools to promote and encourage operations of "liberation" of the courtyards, through the elimination of existing structures and the restoration of the open permeable space. However, it should be considered that in such congested urban environments, a plurality of services now find space in the courtyards, first of all the parking spaces, but also the functions related to commercial services and public and private services that contribute to the life of the neighborhoods. It means that these spaces are precious and therefore potentially useful to solve many problems of the compact city; being contended between different functions and opportunities, only by operating integrated policies on different sides and so combining the needs and priorities of the interventions, it is possible to build a reuse strategy of these spaces aimed at selecting places and choices of operations, in order to maximize the benefits in terms of environmental and urban regeneration, also aimed at adapting to climate change.

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