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SMALL GREEN AREAS FOR ENERGY SAVING: EFFECTS ON DIFFERENT URBAN SETTLEMENTS

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Abstract

The aspects of sustainability, to date, emerge as a central theme within the plethora of definitions of the Smart City. In the current debate, the awareness that ICT is only one of the tools and not the key to the new design of the urban organism is growing, especially according to the new requirements *to meet the needs of the present without compromising the ability of future generations to meet their own needs*, placed on top of the increasingly pressing global challenges (climate change, energy, land use, etc.). One goal of urban sustainability seems to be in contradiction with one of the main points of the Smart City model: the need to densify the city, caused by the rapid population growth. If cities are designed to be more compact to optimize land use, how do we prevent the risk of *town cramming*?

A possible answer may come from the study of the relationship between full and empty urban spaces: the buildings on the one side, and the open spaces on the other. The equilibrium between these spaces needs to be studied in order to direct policies and interventions to correctly locate, size and design the green spaces systems, in relation to energy consumption, environmental comfort and CO_2 reduction positive effects. This contribution presents the first results of a study aimed at determining the green space dimensions threshold values, which influence urban microclimate lowering temperatures, and their cooling distances, in relation to different settlement density values of the urban fabric.

1. Introduction

Since the very first definition of sustainable development was adopted (WCED, 1987) several approaches to the resulting issues have been elaborated (Kjellén, 2014), (Berardi, 2013). According to the Brundtland Report definition (WCED, 1987) most scholars highlighted the need

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to balance economic development, social wellbeing and environmental protection, the elements of the triple bottom line sustainability. These three dimensions can be also considered as trade-offs to achieve, especially when the concept of sustainability is applied to cities (Kemp et. al, 2005; Brits et al, 2009; Weaver and Rothmans, 2007). In fact, the complexity and the dynamicity of urban systems, together with the ever more pressing global challenges that cities have to face (climate change, urban growth, etc.) may make *urban sustainability*, if it isn't yet, an *oxymoron* (Ahern, 2013; Donovan and Butry, 2009).

So one of the key themes for the future is urban efficiency, and, new instruments brought about by the smart revolution, thanks to the potential of ICT in the management of complex systems, appear to be critical to manage sustainable growth (Papa, 2013; Papa et al., 2015). On a regional basis, the issue has many facets, economic, social and environmental, but one of the main aspects is certainly the loss of non built land within the city limits.

The urbanization of the last two centuries, with the rise of the automobile as a favorite means of transport, brought urban sprawl with a low population density and a consequent high consumption of land. This irreversible conversion of land to urban uses in continuous growth has caused, in addition to significant alterations of the hydrogeological and environmental layout, also high-energy consumption and an increase of pollutants. This has led, since the early 90's to a debate centered on the relationship between population density and environmental sustainability (EU, 1990).

The desired higher densities in the compact city model, however, can generate a phenomenon common to many contemporary city centers: town cramming. A poorly managed building density may indeed have some negative effects on the urban environment and user comfort. One of the main consequences of this phenomenon is the accumulation of thermal energy and the consequent increase in temperatures in the summer period, known as the Urban Heat Island. Research in multiple fields investigates the relationship between urban morphology and socio-environmental instances. The tendency is to no longer see the building separate from the surrounding environment, but as a single body, in which the balance between open and closed, confined and wide, spaces determines relation systems between physical entities that trigger mechanisms able to change the environment in which they are located.

The aspect we have chosen to study is the relationship between built volumes and empty urban spaces, such as those used as parks and gardens. Proper localization and dimensioning of the green spaces system, in fact, can help boost the number of positive effects related to the presence of vegetation within the urban built environment. It can improve, for example, air quality filtering out dust and other particles in the air; reduce energy consumption related to summer cooling through the shading and evapotranspiration processes, maintaining thermal comfort.

During the past decades, several studies investigated the effects of tree shade on energy cooling consumption of houses and buildings (Donovan and Butry, 2009; Rudy and Dewers, 1984; Pandit and Laband, 2010), paying particular attention to the correct location of trees relative to the orientation of the houses. However, the rise of global temperature with the related growth of extreme heat events and the awareness that cities will be more densely built, drove

the scientific debate to analyze the cooling effects of urban green areas and parks. These studies can be articulated into three main categories, according to (Yu and Hien, 2006):
- Studies based on meteorological data and satellite images at macro-level (Asrar et al, 1984; Saito et al, 1991; Nichol, 1996).
- Studies based on specific measurements at micro-level (Ca et al, 1998; Barradas et al, 1999; Sonne and Vieira, 2000).
- Studies based on numerical calculation to forecast the thermal benefits of urban green areas (Honjo and Takakura, 1991; Avissar, 1996; Shashua-Bar and Hoffman, 2000).

For this paper the third kind of research was taken into account, in order to determine the incidence of the cooling effect produced by small green areas on the temperature variations in urban areas, and define the cooling distances (R_i) of green areas, according to their extension and the values of building density considered. In addition, although different studies have tried to determine the extent to which the presence of green influences its surrounding environment (Honjo and Takakura, 1991; Givoni, 1998), few are focused on cities of the Mediterranean countries, particularly those in Italy.

The results usually show that the bigger the green area, the lower the air temperature in the surroundings. This reduction may vary from 0,5°C to 4°C, depending on local climate, the vegetation species and the size of green space. In addition, the maximum cooling distance may vary from 20 m. to 2.000 m.

However, the built environment-green areas interactions influencing the green cooling effects depend also on other elements related to urban form and geometry, such as building density, buildings height, width of streets, building orientation (Zhou et al, 2011; Li et al, 2012; Zoulia et al, 2009; David Suzuki Foundation, 2015). For instance, by considering different spatial resolutions (Li et al, 2012; Li et al, 2013), found that the percentage of cover of green space is correlated negatively with land surface temperature and that, the more closely linked and continuous the green spaces are, the stronger the cooling effect is.

Even though the density and the green area size are important, the spatial configuration may be more important, in terms of cooling effects. In fact, (Honjo and Takakura, 1991) showed that the cooling influence area is a function of the size of green areas, and especially, of their distance: the optimal range of the cooling effect can be achieved when the distance among urban green areas is about 300 m.

In practice, achieving the numerous benefits provided by urban green spaces is challenging due to space constraints. If cities are in fact to be more compact, how do we prevent them from becoming crammed and guarantee the right amount of green spaces? The present paper intends to answer this question illustrating the results of a study aimed at establishing the green space dimensions threshold values, which influence urban microclimate lowering temperatures, and their cooling distances, in relation to different settlement density values of the urban fabric. The work is part of the broader research project *Smart Energy Master for the energy governance of the territory* (SEM), aimed at the development of a governance model of the territory for energy saving and efficiency (Papa et al, 2014a; Papa et al, 2014b; Papa et al, 2014c; Papa et al., 2016). Among the different urban components considered within the project

SEM, there is the urban/environmental subsystem focusing on green areas and building density as significant elements for energy saving in the urban built environment.

2. Data and Methodology

In order to determine the maximum cooling distance of urban green areas and to tie these values to building density, the simulation tool ENVI-met (developed by professor Michael Bruse of the University of Johannes Gutenberg Mainz) was used. "ENVI-met is a three-dimensional microclimate model designed to simulate the surface–plant–air interactions in urban environment with a typical resolution of 0,5–10 m in space and 10 s in time" (ENVI-met website: www.envi-met.com) "ENVI-met seems to be the most suitable for simulating real-world cases as it can simulate environmental aspects such as irradiation, humidity and especially evapotranspiration processes" (Roset and Vidmar, 2013: 16), which are crucial for reaching our aim.

For our simulations, it was necessary to determine three elements: climatic conditions, settlement density values and green area size. The input data were defined to describe the study area of the SEM project that consists of the three districts Chiaia, Vomero and Arenella.

The source of the climate information was for:
- Temperatures, retrieved from the National System for the collection, processing and dissemination of data Climate of environmental interest (SCIA) ISPRA, that represent the average value of t in July and August registered at the station of Capodichino (airport of Naples) in the decade 2004 - 2014.
- Humidity and wind speed, provided by the ENEA institute, relative to the entire municipal area and registered in the same weather station.
- The software input parameters were:
- Date of the solar simulation: the hottest day (26/07) found in the last decade, in order to simulate the worst summer weather conditions.
- Duration of the simulation (hours subject to simulation): 24 hours.
- Start time of the simulation (on the day indicated in the first point): 00:00.
- Wind direction and speed: 0,1 m / s from the south.
- Air temperature: 26,8 °C.
- Relative Humidity: 70%.

Table 1. **Average settlement density values chosen for the simulation**

Class	Density (mc/sqm)	Average value
1	0,0025 – 4,101	2,084
2	4,102 – 7,033	
3	7,034 – 9,898	8,482
4	9,899 – 12,415	
5	12,452 – 19,486	13,280

Source: Self-elaboration.

Table 2. **Average green areas values chosen for the simulation**

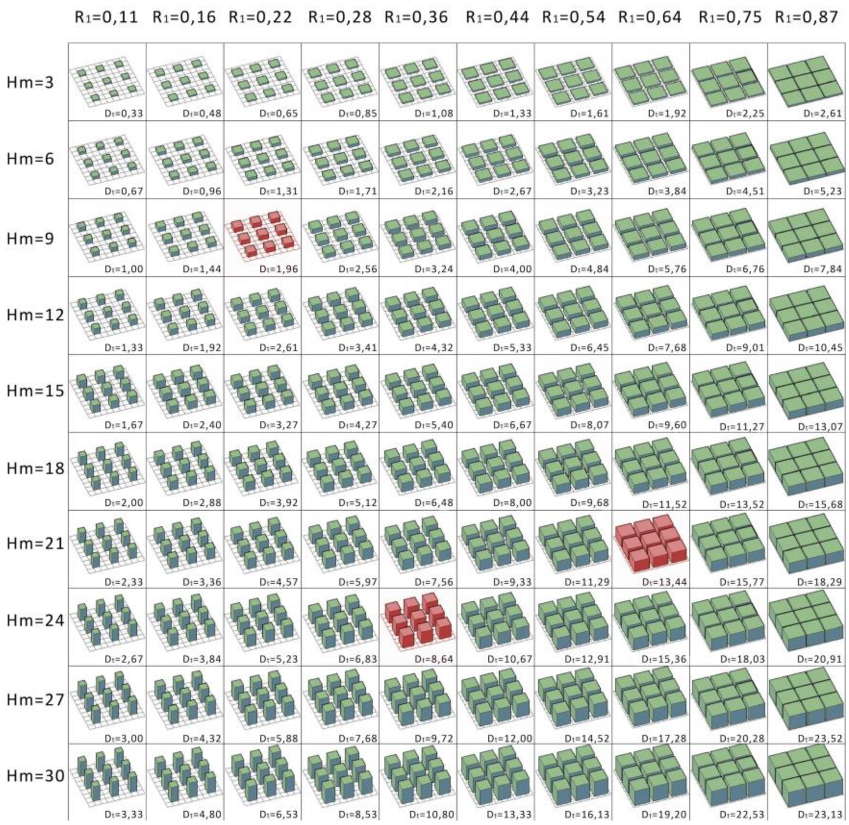
Class	Area (sqm)	Average value
1	0,151 – 2559,488	839,61
2	2559,489– 8661,508	5043,48
3	8661,508 – 128223	32847,1

Source: Self-elaboration.

The values of settlement density and the green surfaces to be simulated were chosen from the density and green areas classes found in the SEM research project (Tables 1 and 2). The three settlement density values considered represent the three main different urban fabric typologies found within the study area (Figure 1):

- Low-density areas: settlements with a low density, buildings on average 8 meters high, and with ample open spaces.
- Non planned areas: settlements with buildings on average 23 meters high and with a medium coverage ratio.
- Historical compact areas: compact and planned settlements with a high density and buildings on average 24 meters high.

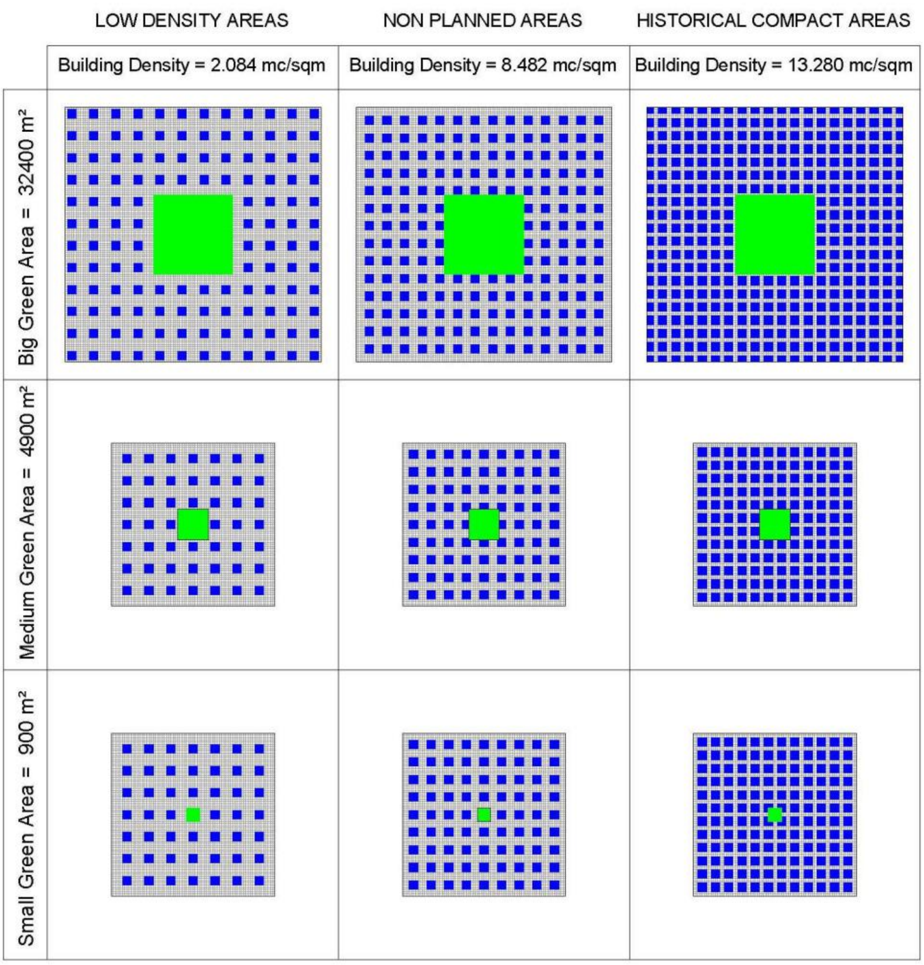
Figure 1**. Grid of 100 settlement patterns made of a combination of coverage ratios (columns) and building heights (lines). The red modules represent the three settlement configurations considered**



Source: Self-elaboration.

Modular elements were defined placing the green areas in the center (Figure 2). Vegetation on the ground is made of a mix of trees (15 meters height) and grass. The size of the volumes distributed in the grid, on which to build the grid, and the total area simulated were defined according to the calculation and simulation capacity of the software. In fact, the smaller the basic element, the more accurate the simulation result, but longer the simulation times. Therefore it was necessary to preliminary choose the size of the green spaces to simulate. We chose a 5 meters element. Choosing the size of the base was necessary to *transform* the value of the surface of the green area in a square whose side was a multiple of 5. This operation has therefore determined the following approximations: 839,61 ≈ 900, 5043,48 ≈ 4900 and 32847,1 ≈ 32400.

Figure 2**. Table of modular patterns used for the green areas simulation**



Source: Self-elaboration.

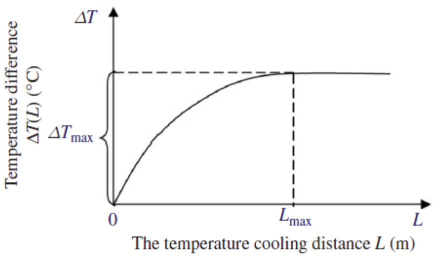
In the simulated patterns, the distance between the squares representing the green area and that of the entire simulated area varied (150, 170 and 200 m.) taking into account both the calculation ability of the software, and the values of the maximum cooling distances found in the scientific literature. Completed the simulations with the software ENVI-met, for each of the 9 patterns, potential temperature averages for each hour in the time range 18-24 hours have been extrapolated, with a 5 meters pace from the green area, along a horizontal section. The time range considered was chosen in agreement with the studies on the subject, according to which the evaporative cooling during daytime hours has a very limited impact on air temperatures, at ground level, unlike what happens from sunset onwards, when the green area behaves as a *cold island* (Spronken-Smith, 1994). The differences (ΔT) between the calculated medium temperature at each 5 meters interval and the calculated temperature of green area were graphed to determine the maximum influence range in each of nine studied cases. To determine the cooling distances the work (Chen et al, 2012) was used, according to which the maximum distance beyond which the effect of cooling of the green areas in not sensible (Ri), corresponds to the point where the tangent to the cubic polynomial curve which approximates the sequence of the detected points is horizontal, and therefore where the first derivative of the function is cancelled:

$$R_i = \frac{-b \pm \sqrt{b^2 - 3ac}}{3a} \qquad (1)$$

$$aL^3 + bL^2 + cL \qquad (2)$$

The horizontal course of the curve indicates, in fact that no other change in temperature is found; condition that corresponds, in practice, with the range at which the green space becomes uninfluential (Figure 3).

Figure 3**. Model of the effect of cooling of the green areas where L_{max} is the radius of influence of the green areas**



Source: Chen et al. (2012).

3. Results

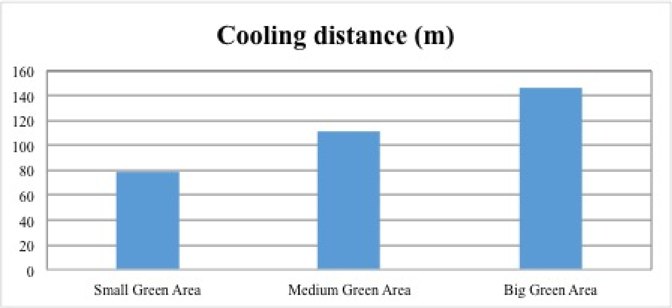
Analyzing the simulation results, averaging the values between the three different densities per green area size to determine exclusively the influence of size (tab. III - Average values) we can make the following first considerations:

- The range of influence increases with the size of the green spaces but not proportionally (Figure 4).
- In every case the green area determines a cooling effect.

The largest temperature variation occurs in the presence of green areas of medium size: about 1,5 °C. The change in temperature is almost irrelevant, instead, in the presence of small green areas, while with the large green areas the variation is slightly higher than 1°C (Figure 5), even if the influence range is bigger (Figure 4, 146 vs. 111).

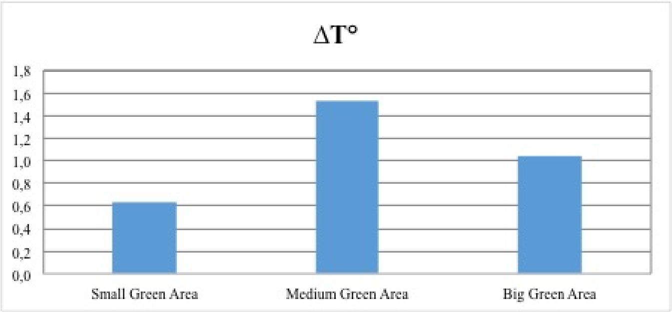
The values thus obtained confirm that the size of the green space is the most relevant in terms of potential cooling effect, is the medium one.

Figure 4**. Cooling distance varying the size of the green areas**



Source: Self-elaboration.

Figure 5**. Potential cooling in terms of lowering the temperature varying the size of the green areas**



Source: Self-elaboration.

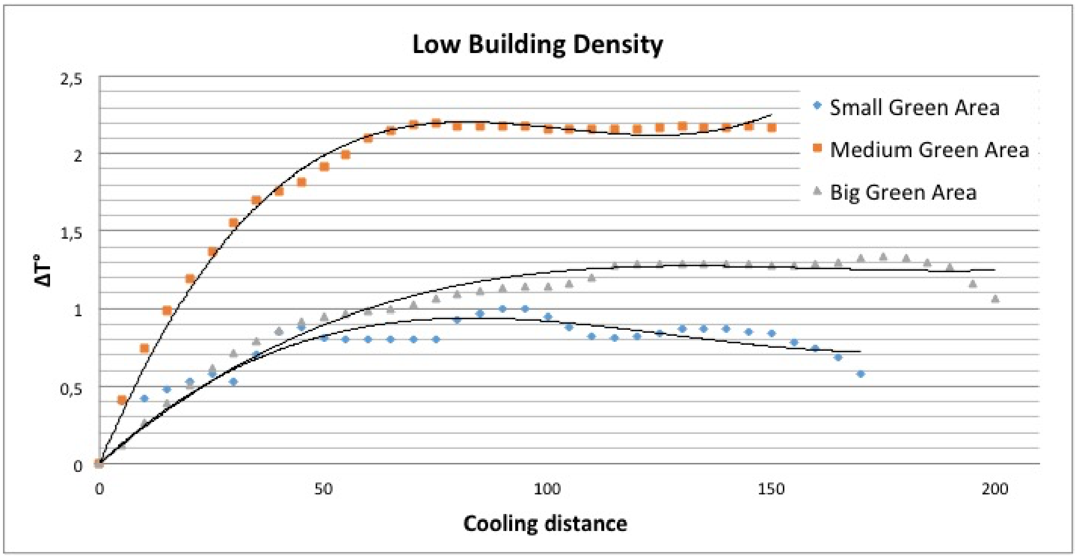
One aim of this work was to understand the link between green areas and building density, in order to suggest how to localize green spaces, depending on the type of urban fabric. Therefore, the analysis of the results was carried out not only in absolute terms, but also in terms of the three building density values (Figures 6, 7 and 8).

For *low density areas* the Ri of the small and medium green areas are very similar, respectively 83 and 82 meter. Large areas, instead, present a Ri of 132 meter. The greater drop in temperature is related to the medium green area and is higher than 2°C. In this case, the presence of small green areas, of about 1.000 square meters, can be significant in terms of cooling. However, as seen in Figure 6, it may be more efficient to use 5.000 square meters green areas, in order to benefit of a greater cooling effect.

In *non-planned areas*, small green areas appear to have no impact in terms of lowering the temperature (Figure 7). At constant ΔT between the medium and large green areas, the one that appears to be characterized by a higher Ri is the largest green area. However, in *non-planned areas* it can be difficult to have a large green space, given the rapid urban growth processes in place.

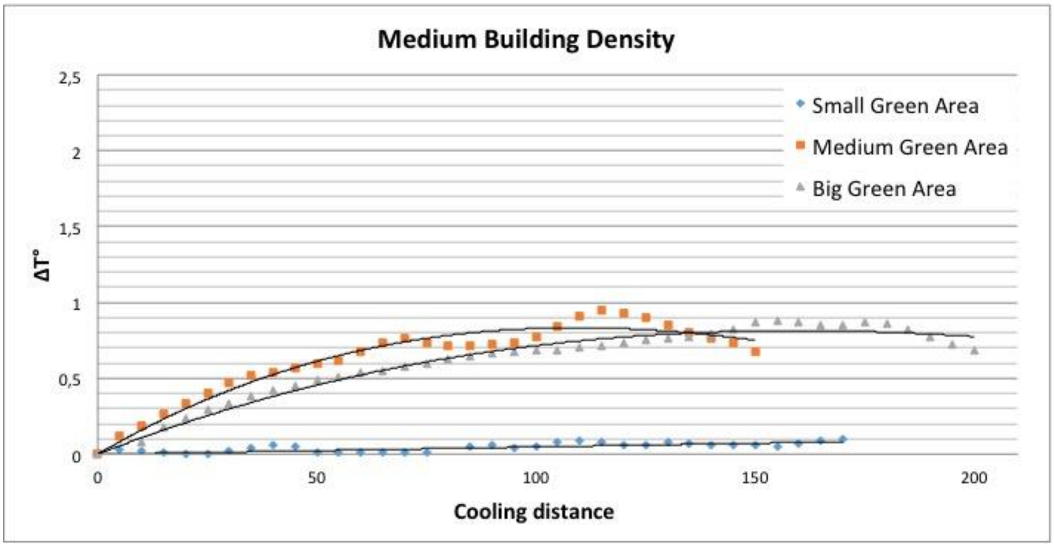
Finally, regarding the case of *historical compact areas*, small green areas, as in the case of *non-planned areas*, are irrelevant, since the ΔT is equal to 0,33°C (Figure 8); this is probably due to the barrier effect, that reduces the benefits of evapotranspiration process in a compact built environment. This barrier effect appears uninfluential on the cooling distances of green areas of about 5.000 square meters.

Figure 6**. Image data for the effect of the green areas on low building density areas showing on the abscissa the distance (m) of the point of measuring the temperature and on the ordinate the relative ΔT(°C). The continuous line represents the cubic polynomial which approximates the sequence of points detected**



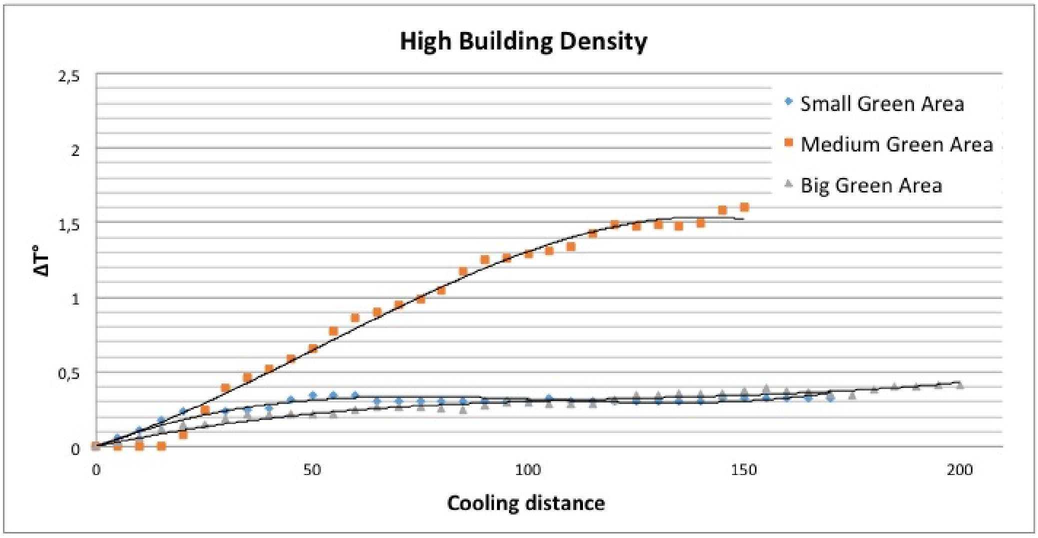
Source: Self-elaboration.

Figure 7**. Effect of the green areas on medium building density areas**



Source: Self-elaboration.

Figure 8**. Effect of the green areas on high building density areas**



Source: Self-elaboration.

Within the *historical compact areas* the creation of 5.000 square meters green areas can be, even more than in other cases, the right balance between effectiveness in terms of cooling and the limited availability of open space to be allocated.

Table 3. **Values of the cooling distances (r_i) and ∆T accordingto the values of building density and green areas simulated**

	Low density areas		**Non planned areas**		**Historical Compact Areas**		**Average value**	
	∆T(°C)	Cooling distance (m)	∆T(°C)	Cooling distance (m)	∆T(°C)	Cooling distance (m)	∆T(°C)	Cooling distance (m)
Small Green Area	0,940	83,32	0,15	5	0,33	73,46	0,638	78,39
Medium Green Area	2,21	81,90	0,83	109,24	1,54	140,69	1,526	110,61
Big Green Area	1,28	132,55	0,81	159,43	0,41	>200	1,045	145,99

Source: Self-elaboration.

4. Conclusions

The study was aimed at defining strategies and protocols to localize, dimension and distribute green spaces effectively, to reduce energy consumption, CO2 and improve environmental comfort. This work, in the field of studies dealing with the effects of the green areas on the urban microclimate, presents some innovative aspects. The first is related to the measurement of the effects on the microclimate of urban smaller green areas, more congenial to densely built urban fabric. A further innovative aspect is the identification of the Ri values of green areas depending on the type of urban fabric defined by density values of the built environment (Table 3). Based on these elements, the first result is the threshold values of the green areas size. These thresholds are the first suggestions to position green spaces within different density built environments. In particular, the 5.000 square meters size represents the most effective solution in terms of both cooling and feasibility of intervention, especially in highly built urban contexts.

Notwithstanding the identification of this threshold value we cannot propose a universal rule since other parameters such as climate conditions, latitude, types of greenery, etc., influence the results. The complex nature of the interactions between the evapotranspiration processes and the multiple physical characteristics of the urban spaces, suggests interesting further developments of this research work. For example, an aspect that could be analyzed further is the inclusion of other environmental descriptors such as aspect ratio and the orientation of the road axis.

Furthermore this study can be useful for the application of green space standards in order to define them not only on the basis of the amount of minimum facilities allocation per capita, but according to new parameters related to climatic and environmental factors.

In conclusion, these examples show that the different urban and environmental elements can be designed and coordinated to achieve maximum benefits in a sustainable way or to reduce the problems caused by urban densification.

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