Effect of Urban Greenspaces on Residential Buildings' Energy Consumption: Case Study in a Mediterranean Climate

Carmela Gargiulo, Ahmed Ayad, Andrea Tulisi and Floriana Zucaro

Abstract The paper is part of the scientific research sector concerning the government of urban transformations in order to promote efficiency and reduction of energy consumption in urban areas. In this study, urban greenspaces (green areas) are proposed as a strategy for cities to achieve both urban sustainability and resilience while addressing the issues of energy reduction and climate change adaptation. The study investigated the microclimate impact of greenspaces on the cooling energy needs of residential buildings in Naples, Italy, given different urban fabric characteristics by coupling the microclimate model ENVI-met with the building energy model EnergyPlus. The charts resulted from the study could represent an useful decision support tool for urban planners and policy-makers to locate and size greenspaces based on their effectiveness in terms of energy consumption reduction. The study found that—in general—a medium-size green area (4900 m^2) would reduce the cooling energy consumption by 9.20% which is more than double the effect of a large green area (32,400 m^2).

1 Introduction

Since the 1987 Brundtland Report defined sustainable development and pointed out that cities should be pivotal to this development as the majority of the world's population will live in urban areas (Brundtland 1987), the concepts of sustainable cities and urban sustainability have gained much attention with an increasing interest

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in the role of cities in addressing global environmental challenges such as climate change (Bulkeley and Betsill 2005).

This role was further emphasized in the 1992 United Nations Conference on Sustainable Development where local authorities worldwide were encouraged to develop plans for applying sustainable development (Bulkeley and Betsill 2005).

In order to achieve urban sustainability, a set of goals and strategies matching the urban context of the city has been developed in collaboration with the practitioners responsible for applying them (National Academies 2016).

Nevertheless, as cities continue to grow, challenges like: climate change, economic fluctuations, etc. started to be increasingly pressing, causing cities to struggle to provide basic urban services to its residents and making achieving urban sustainability alone not enough (Harter et al. 2010; Da Silva and Moench 2014). In this context, the concept of urban resilience has emerged to work hand-in-hand with urban sustainability plans to achieve rational urban development that can help cities adapt and transform in the face of the challenges (Papa et al. 2014a; Zhang and Li 2017).

Therefore, building urban resilience requires a holistic view of the city and its systems to have a good understanding of the interacting relationships between them and both expected and unexpected shocks they might face, in order to prepare cities to be more flexible and have the ability to bounce back in case of acute shocks (Papa et al. 2014b; Gargiulo and Lombardi 2016; 100 Resilient Cities 2017).

This challenge is even more complex if we consider that cities are not just the victims of the consequences of climate change but one of the main causes. In fact, urban environments have a significant impact on climate change since 35% of global greenhouse gas emissions are produced in urban areas (excluding urban transport); one of the main consequences is the global warming (van der Heijden 2014) which emphasizes the negative impact of the UHI phenomenon by increasing the number of heat waves affecting most of the cities worldwide, determining an increased death rates due to heat peaks in urban areas compared to rural areas (Tan et al. 2010; Echevarria Icaza et al. 2016).

Furthermore, urban environments also affect global energy consumption which is expected to increase by 48% in year 2040 compared to 2012 (U.S. EIA 2016). Between 60 and 80% of this consumption happens within cities (Grubler et al. 2013) and is mainly consumed by buildings which is considered the largest energy consuming sector in the world (IEA 2013).

The issues of energy consumption and climate change are strongly related since increased energy consumption in urban areas and the associated CO_2 emissions intensify the greenhouse effect leading to increased warming of the climate which can be considered one of the main reasons for climate change. On the other hand, increased global warming due to climate change will cause a bigger energy demand mainly due to an increased cooling needs (Sharifi and Yamagata 2016).

In light of the previous discussion on the challenges facing the world and the recognition of the need for a more sustainable city that reduces its impact on the environment while being more resilient to natural and man-made stresses, there is an urgent need to facilitate the transition of cities towards less dependence on energy and other resources and producing fewer greenhouse gases (van der Heijden 2014).

This transition can only be achieved through, clear goals and specific—applicable—strategies (Papa et al. 2015). In this context, urban greenspaces (green areas) such as parks, street trees, etc. can be proposed as a strategy for cities to achieve both urban sustainability and urban resilience while addressing the issues of energy and climate change.

In a previous study done by the authors (Gargiulo et al. 2016, 2017), the urban greenspace cooling effect and its influence on the urban microclimate was investigated as a proposed mitigation measure to UHI and climate change. In that study, the main goal was to establish greenspace dimensions threshold values which influence the urban microclimate by lowering the temperature given the challenging space constraints provided by the need for a more compact city.

In the current study, this work was further extended by adding the dimension of building energy consumption with the aim to investigate the impact of the cooling effect of urban greenspaces on the energy consumption of the surrounding buildings, given different building density and green area size contexts. This study—along with the previously mentioned study—can provide a more comprehensive evaluation of the effectiveness of urban greenspaces as a mitigation measure to both climate change and global energy consumption increase which can help to derive planning and design guidelines for urban greenspaces and verify its efficiency in achieving urban sustainability and resilience. The study focuses on the cooling energy needs for the residential buildings in the Municipality of Naples (referred to in the rest of the study as Naples), the capital of the Metropolitan City of Naples located in Campania region in the south of Italy which is characterized by a Mediterranean hot climate. The choice to focus only on residential buildings was due to the fact that they consume about three-quarters of the total global energy used in the buildings sector (the largest energy consuming sector worldwide) (IEA 2013). Also, while heating needs dominate the residential energy use worldwide, cooling needs was chosen as the focus of this study since it is projected to more than double worldwide by 2050 (IEA 2013) and also due to the hot nature of Naples climate which requires more cooling than heating (Palombo et al. 2012).

2 State of the Art

Various approaches have been used to link the microclimate effect of green areas and the energy consumption of buildings. These approaches include: descriptive case studies, mathematical modelling, analytical modelling, empirical modelling, and remote sensing (Skelhorn 2013; Papa et al. 2014c). Since mathematical modelling was chosen as the methodology for this study (see Sect. 3), only these studies were reviewed with a focus on the ones that utilized the coupling of a microclimate model with a building energy model.

By reviewing literature, it appeared that very few studies have used modeling-based methodologies supported by the coupling of microclimate and building energy models to investigate the impacts of the cooling effect of urban greenspaces on building energy consumption. Among these studies, (Akbari and Konopacki 2005) produced summary tables to estimate the potential of heat island reduction (HIR) strategies (i.e., solar-reflective roofs, shade trees, reflective pavements, and urban vegetation) to reduce cooling energy use in buildings in all U.S. cities based on a meteorological simulation model developed by Taha et al. (2000) and the DOE-2.1E building energy simulation model. Although this study was comprehensive as it addressed all U.S. cities and presented the results in tabular formats for easy interpolation, one drawback was that the effect of urban vegetation alone was not identified because the study assumed that all HIR measures have been fully implemented. The same methodology of including vegetation among a set of other HIR measures was followed in (Bouyer et al. 2011) where a dynamic simulation platform was developed and tested on a real urban context to study the effect of vegetation (shading and cooling effect), nature of the soil and building coatings on the energy consumption of a theoretical office building with no particular focus on the effect of vegetation alone. The platform developed relied on the coupling of: (1) Fluent, a commercial CFD software and (2) Solene, a simulation tool to compute a comprehensive thermoradiative balance of the urban surfaces with a building thermal sub-model developed by the authors.

As for the studies that investigated the effect of vegetation—alone—on building energy consumption, (Gros et al. 2016) evaluated the effect of two cooling strategies: vegetation (trees, green walls and roofs) and high albedo values (cool roofs and façades) on the cooling energy demand of two urban blocks located in Part-Dieu, in Lyon (France). Two indices, Energy Performance Index (EPI) and Ambient Temperature Mitigation Index (ATMI), were defined to evaluate the efficiency of each strategy. The evaluation was done through the coupling of microclimate and building energy models (EnviBatE, SOLENE & QUIC). Although the study was unique in its approach of defining indices to evaluate the efficiency of vegetation, the study used sophisticated software and models that cannot be easily used by urban planners. Another study that investigated the effect of vegetation in isolation was (Skelhorn et al. 2016) in which the impact of shading, air temperature, and wind effects of trees on commercial buildings' cooling energy consumption in Manchester, UK was studied. The study modeled microclimate changes due to different types of greenspace and then used the results in combination with measured UHI intensity results to develop customized weather files for building energy modeling. The used models were ENVI-met for microclimate and IES-VE for building energy simulation. One issue of this study was the quality of data inputs for the model since numerous datasets were used that were not developed by the authors and hence complete accuracy cannot be guaranteed.

It was interesting to see that only two studies coupled the ENVI-met microclimate model with the EnergyPlus building energy simulation model despite each of these models is considered the best in its field (Crawley et al. 2008; Roset and Vidmar 2013). One of these studies (Pastore et al. 2017) explored the benefits of vegetation for microclimate mitigation and thermal comfort improvement in a case study of neighborhood renewal design in the city of Palermo (Italy). The study focused only on the effect of vegetation on residential building's indoor thermal comfort without considering its effects on the building's energy consumption. The other study (Fahmy et al. 2017) investigated how the application of green cover (trees, green roofs and green walls) can affect the residential buildings' energy consumption in present and future by conducting two case studies located in different climatic zones in Egypt (New Borg El-Arab and 6th of October cities). One innovative aspect of the study was that the weather data used to simulate case studies' site conditions were developed not only for the present but also for the future (2020, 2050 and 2080) using the Climate Change World Weather Generator tool in order to verify the efficiency of green cover as an adaptation measure of Egyptian urban communities for climate change. Also, pedestrian thermal comfort (PMV) and air temperature (Ta) maps were developed for both case studies. While the study showed innovative approach for investigating the relationship between vegetation and building energy consumption by including the dimension of climate change, the focus of the study on real case studies that represent specific urban contexts make it difficult to generalize the results and derive guidelines from it.

In the context of the reviewed literature, the research presented in this paper contributes to the knowledge of the impacts of the cooling effect of urban greenspaces on residential buildings' energy consumption by providing simple design guidelines (in the form of charts and general rules of thumb) that can empower urban planners and policy makers to make decisions related to the appropriate green area size and location for a certain urban context with taking into account the effects of that decision on the energy consumption of the surrounding residential buildings. To the authors' knowledge, this study is the first to address the impacts of vegetation on building's energy consumption in a Mediterranean climate and the only one that investigated the combined effects of building density and green area size on building's energy consumption.

3 Methodology

Empirical studies and modelling are frequently used in investigating the effect of urban greenspaces on building energy consumption (Skelhorn 2013). Given the aim of this study, modelling was more appropriate as it allowed the flexibility to change the size of the green area and the building density surrounding it. This wouldn't be possible in an empirical study because an empirical study is restricted to the characteristics of the case study selected for measurement. Also, choosing modeling facilitated the connection to the previous research work done by the authors (Gargiulo et al. 2016) upon which this study was based. A four-step modeling-based methodology was developed by coupling the microclimate model ENVI-met with the building energy model EnergyPlus since there is no software package that is capable of modeling both the microclimate effect of vegetation and the impact of that effect on building's energy consumption (Skelhorn 2013).

3.1 Step 1: Identifying a Typical Neapolitan Residential Building

It was necessary to start the study by investigating the residential building stock in Naples in order to come up with a conceptual building representative of that stock to be used in building energy simulations. Based on the classification of Italian residential buildings into three main categories: Single-Family Houses, Terraced Houses, Multi-Family Houses and Apartment Blocks proposed by (Corrado et al. 2012), It was assumed that the conceptual building used in this study was an apartment block. Then, the general characteristics of the building in terms of the building type (reinforced concrete or load-bearing wall) and the construction period were investigated.

Building Type Although 51.13% of the residential buildings in Naples are constructed using the load-bearing wall system (ISTAT 2011), the conceptual building was assumed to be built using reinforced concrete (RC). This assumption was based on that, while the total number of load-bearing wall residential buildings is higher than the RC buildings, since 1946 the number of RC buildings built each year is higher than that of the load-bearing wall buildings (Fig. 1) which reflects the tendency of the Neapolitan building stock to abandon the load-bearing wall buildings and shift towards the RC buildings.

Construction Period Around half of the RC residential buildings in Naples (49.8%) were built in the period from 1961 to 1980 (ISTAT 2011) and hence it was assumed to be the construction period of the conceptual building.

After the general characteristics of the conceptual building were determined, it was then necessary to determine the characteristics of each apartment in the building. The most important characteristic was the area of the apartment. More than half of the apartments in Naples (51.1%) have an area from 60 m^2 up to 99 m^2 (ISTAT 2011) and so the apartments in the conceptual building were assumed to have an average area of 80 m^2. For the number of rooms, the highest percentage of apartments in Naples have 4 rooms (ISTAT 2011) and hence it was assumed that each apartment in the conceptual building has 4 rooms that serve the basic needs of the occupants (i.e. bedroom, living room, bathroom and kitchen).

3.2 Step 2: Creating Building Energy Model

In this step, a building energy model was created for the conceptual building identified in Sect. 3.1 using DesignBuilder software. DesignBuilder is a user-friendly modelling

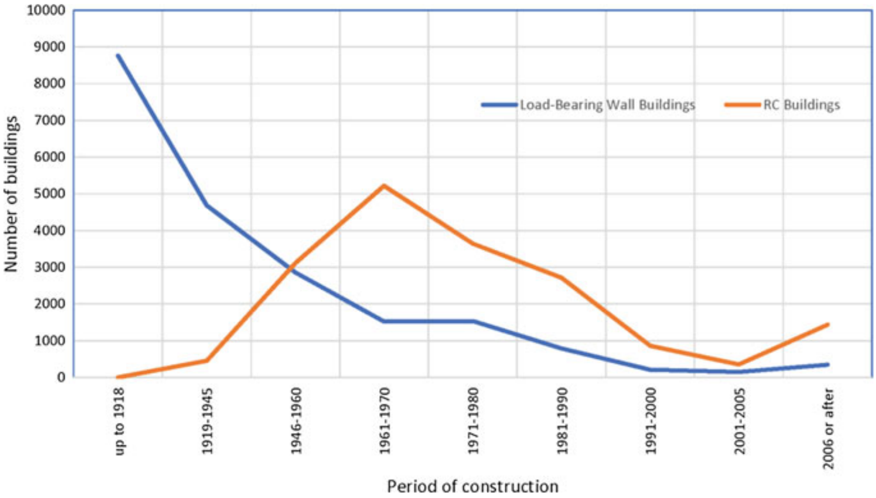

Fig. 1 The construction trend of for the load-bearing and RC residential buildings in Naples (ISTAT 2011)

environment that provides various environmental performance data such as: energy consumption, carbon emissions, comfort conditions … etc. (DesignBuilder 2017). DesignBuilder is based on the building energy simulation engine EnergyPlus which was developed by the Lawrence Berkeley National Laboratory and others for the U.S. Department of Energy and is considered the most accurate and bug-free energy simulation engine available due to the various tests and industry standards it passed (EnergyPlus 2017). In this study DesignBuilder version 5.0.3.007 was used which was equipped with EnergyPlus version 8.5.

Building Geometry The first part of the model is to define the building geometry. Because this study is based on the microclimate model conducted in (Gargiulo et al. 2016), the dimensions of the building energy model had to be the same as the ones used in the microclimate model. The dimension of the building in the microclimate model was 20 m × 20 m. In this study, the 20 m × 20 m area was assumed to contain two similar adjacent buildings to reduce in the running time of the model as only one building will be simulated and its results will be multiplied by two. As for the height of the building, it was dependent on the building density with the low building density being represented by a nine-meter-high building (three floors) while the medium and high building densities were represented by a 24-meter-high building (eight floors) according to (Gargiulo et al. 2016). Figure 2 shows the two building energy models used to represent different building densities with each model containing two adjacent buildings, while Fig. 3 shows a floor plan for one of the buildings showing the different rooms (zones).

Building Orientation To determine the building orientation, multiple energy simulation trials were performed on the two building models shown in Fig. 3 to test the different alternatives available (north-facing building, south-facing building,

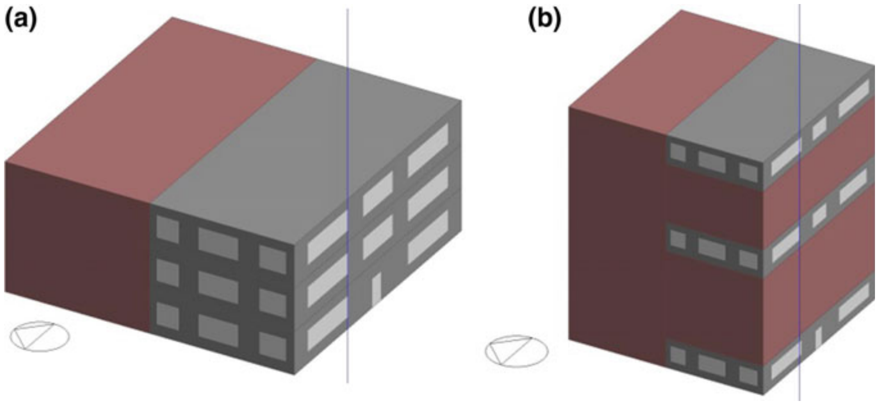

Fig. 2 **a** Nine-meter-high building (three floors) to represent low building density, **b** 24-meter-high building (eight floors) to represent medium and high building densities

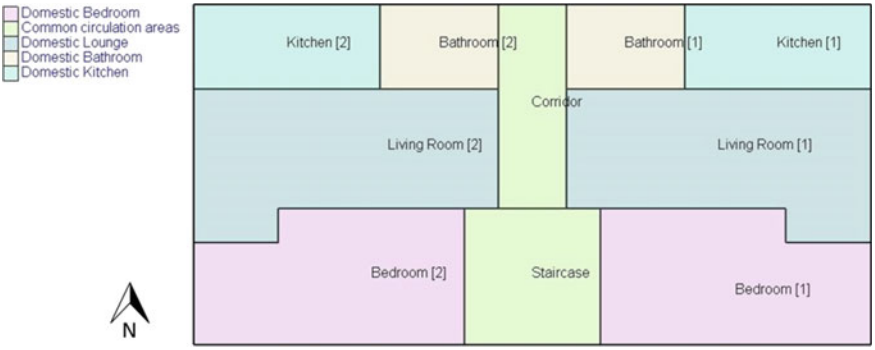

Fig. 3 Floor plan of the building used in energy simulation

east-facing building and west-facing building). These trials have indicated that the highest energy consumption in summer (the period considered for building energy simulations in this study) is for the south-facing building and hence the south orientation was chosen as the worst-case scenario upon which the influence of the cooling effect of green areas on the building's energy consumption will be much apparent.

Building's Location Relative to The Green Area Each green area has a maximum cooling distance—which is dependent upon the size of the green area—beyond which the effect of the green areas to reduce the air temperature is not sensible (Gargiulo et al. 2016). So, it was necessary to locate the building at a distance within the maximum cooling distances of the different green area sizes included in this study (see Sect. 3.3 for the classification of the green area sizes used in the study). In this study, it was assumed that the modeled building was located 50 m away from the green area. This distance is less than the maximum cooling distance of all the green area sizes considered in the study and hence the building was within the cooling effect of the green area.

Model Parameters The data warehouse of the 2011 population and housing census produced by the Italian National Institute of Statistics (ISTAT), Naples Sustainable Energy Action Plan (SEAP)—Annex B, and the National Scientific Report on the TABULA activities in Italy (ISTAT 2011; Corrado et al. 2012; Palombo et al. 2012) were used to define building occupancy, the elements of the building envelop, and the HVAC system used while the Italian standards (UNI/TS 11300-1:2014) and (UNI EN 15251:2008) were used to define the indoor environmental conditions (temperatures, ventilation rates … etc.).

Model Calibration To keep the model as simple as possible while still maintaining sufficient accuracy and since the objective of this study was to conduct a comparative energy modeling to report the percentage of savings in building energy use due to the cooling effect of urban greenspaces with no interest in the actual energy use of the building in absolute terms (predictive energy modeling), a forward engineering model was created using DesignBuilder software. The forward engineering model eliminates the need for calibration as its results are validated through the verification status of the simulation engine used (EnergyPlus) and is more suitable for comparative energy modeling (IBPSA-USA 2012; Fumo 2014).

3.3 Step 3: Utilizing TeMALab Urban Microclimate Model for Naples

The microclimate model discussed in (Gargiulo et al. 2016) was utilized in this study. This model was conducted for Naples by the authors as a part of *Smart Energy Master for the energy governance of the territory (SEM)* research project undertaken by the Laboratory of Territory, Mobility and Environment (TeMALab) in University of Naples Federico II, Italy (Papa et al. 2016). In (Gargiulo et al. 2016), the study area was divided into three main urban fabric typologies representing low building density (2.084 m^3/m^2), medium building density (8.482 m^3/m^2) and high building density (13.280 m^3/m^2) areas. Also, the green areas located in the study area were divided into small green areas (900 m^2), medium green areas (4900 m^2) and large green areas (32,400 m^2). This classification resulted in nine different scenarios that were simulated in ENVI-met software. In this study, the results of (Gargiulo et al. 2016) were used to calculate the reduction in air temperature due to the cooling effect of green areas (*ΔT for Building Energy Simulation*). Then—for each modeling scenario—the relevant temperature difference (*ΔT for Building Energy Simulation*) was subtracted from each hourly value in the original weather file for Naples and a set of nine weather files were created using the "Weather Data Analysis Tool" available in DesignBuilder software. It should be noted that this process was based on the assumption that *ΔT for Building Energy Simulation* was the same for each

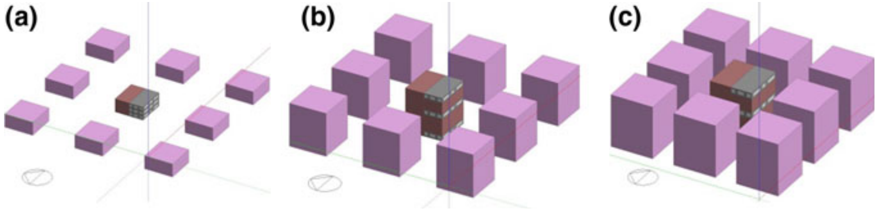

Fig. 4 Building energy models created in DesignBuilder: **a** low building density, **b** medium building density, **c** high building density

hour in the day for each day in the year which is not true as the it should vary from hour to hour but this assumption was made for simplification.

3.4 Step 4: Building Energy Simulation Scenarios

In this step, the coupling of the microclimate model ENVI-met with the building energy simulation model EnergyPlus was achieved. The coupling procedure was performed in the following two steps:

1. Three building energy models that represent different building densities were created in DesignBuilder software as shown in Fig. 4.
2. Nine building energy simulation scenarios—that reflect the different combinations between building density and green area size—were run using DesignBuilder software. Each of these scenarios utilized one of the building energy models to represent the building density (in terms of the shading effect) and one of the weather files created in Step 3 (see Sect. 3.3) to represent the effect of the green area size and the building density on the outdoor air temperature. In addition to these nine scenarios, three other scenarios that reflect the different building densities were run using the original weather file for Naples to calculate the energy consumption of each scenario in the absence of the green areas.

In Naples, the HVAC system is normally switched on in the period between the 1st of June and the 15th of September (Palombo et al. 2012) and hence this was chosen as the period for running the building energy simulation scenarios.

4 Results & Discussion

Since a *forward engineering model* was chosen for the building energy simulations (as discussed in Sect. 3.2), it was necessary to present the results in a comparative form that report the percentage of savings in cooling energy use due to the cooling effect of the green areas as shown in Table 1. In order to calculate these saving percentages,

Table 1 Reduction in cooling energy consumption due to the cooling effect of urban greenspaces

Modelling scenario		Cooling energy consumption reduction (%)
L.B.D.[a]	S.G.A.[b]	2.05
	M.G.A.	3.72
	L.G.A.	6.50
M.B.D.	S.G.A.	2.18
	M.G.A.	3.68
	L.G.A.	5.96
H.B.D.	S.G.A.	0.38
	M.G.A.	16.72
	L.G.A.	3.66

[a] L.B.D.: Low building density/M.B.D.: Medium building density/H.B.D.: High building density
[b] S.G.A.: Small green area/M.G.A.: Medium green Area/L.G.A.: Large green area

the cooling energy consumption of each modeling scenario was compared to the base case scenario (with no green area).

We can see from Table 1 that in both low and medium building density scenarios, the larger the green area, the more the effect it has on reducing the energy consumption. However—in high building density scenario—the medium green area has significantly higher energy reduction effect compared to the small and large green areas. These interesting findings indicate that there is a relationship between the effect of the green area on reducing the cooling energy consumption of the buildings and the urban morphology in which the green area is located. In order to understand this relationship, it was necessary to include the distance from the green area as an important factor in the analysis.

By referring to the reductions in cooling energy consumption reported in Table 1, it is important to note that these reductions were based on the assumption that the modeled building was located at a fixed distance of 50 m away from the green area (see Sect. 3.2). In order to see the effect of varying this distance, two possible methods were proposed: the first method was to rerun the nine building energy simulation scenarios where each scenario would be run multiple times at different distances from the green area (a different weather file—reflecting the distance—will be used in each time). The second method was to predict the reduction in cooling energy consumption when the distance from the green area is varied using statistical analysis. In order to vary the distance from the green area at a minimum of 5 m steps to provide sufficient accuracy, the simulations would be run more than 200 times and thus the first method was considered impracticable due to the huge amount of time, effort and computing power needed to rerun the simulations and the second method was used.

In the second method, the relationship between the reductions in cooling energy consumption reported in Table 1 and the reductions in outside air temperature (*ΔT for Building Energy Simulation*) calculated in Sect. 3.3 was analyzed using regression analysis for each building density. In all building densities, the relationship was linear with an R-squared value of 0.99 for low building density and 1.00 for medium and high building densities. The distance from the green area was varied at 5 m intervals and the corresponding *ΔT for Building Energy Simulation* was calculated using the microclimate model results from (Gargiulo et al. 2016). Then, the reductions in cooling energy consumption expected to result from each *ΔT for Building Energy Simulation* were calculated based on the linear regression equations. Figures 5, 6 and 7 show the relationship between the reduction in cooling energy consumption and the distance from the green area in each building density.

From the figures, we can see the strong influence the distance from the green area has on reducing the cooling energy consumption. In low building density (Fig. 5), the results show that up to 32.7 m distance, the medium green area has higher effect in reducing the cooling energy consumption than the large green area. This is reversed for distances more than 32.7 m. Regardless of the distance, the small green area always has the lowest effect compared to the other sizes.

In medium building density (Fig. 6), it is obvious that the large green area has a higher effect than the medium green area regardless of the distance. This effect remains up to a distance of 160 m away from the green area—after which the large green area has no effect. The small green area was neglected from the analysis because it has nearly no impact on lowering the air temperature as reported in (Gargiulo et al. 2016) and hence it would have no effect on reducing the cooling energy consumption. In high building density (Fig. 7), the medium green area appears to has significantly higher cooling energy consumption reduction effect compared to both large and small green areas. This remains true up to a distance of 115 m away from the green area after which the large green area has a higher effect but this effect remains only to a distance of 190 m.

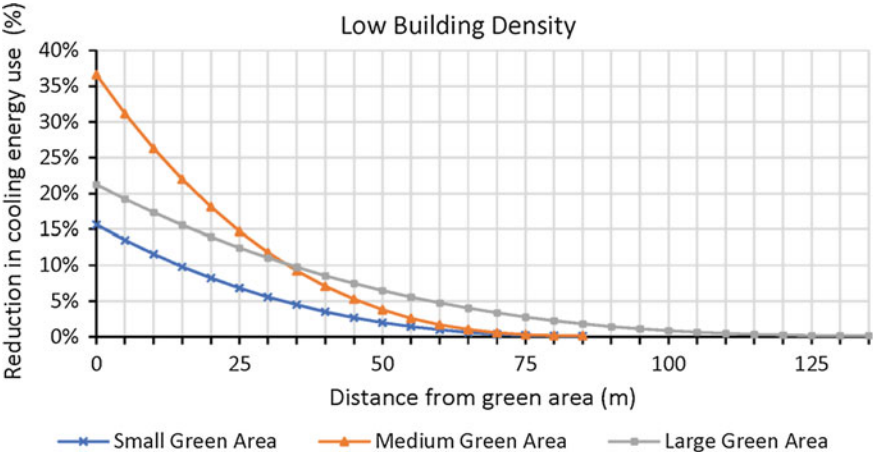

Fig. 5 Relationship between the reduction in cooling energy use and the distance from the green area for different green area sizes located in a low building density

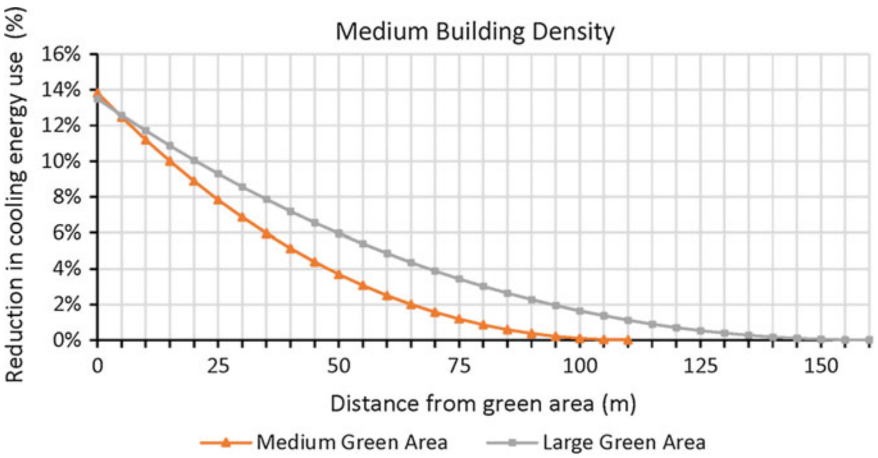

Fig. 6 Relationship between the reduction in cooling energy use and the distance from the green area for different green area sizes located in a medium building density

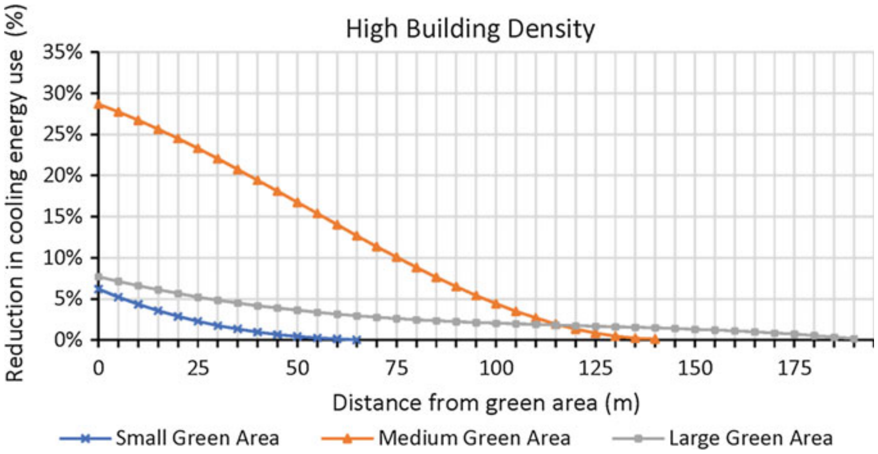

Fig. 7 Relationship between the reduction in cooling energy use and the distance from the green area for different green area sizes located in a high building density

By averaging the results for all the building densities and all the possible distances from the green area, the medium green area appears to has the highest effect in reducing the cooling energy consumption (9.20%) followed by the large green area (4.43%) and the small green area (2.98%) as shown in Fig. 8.

The results of this study conforms with the results of (Gargiulo et al. 2016) in terms of the influence range that each green area size has and in that—in general—the medium green area has the highest effect followed by the large and small green areas respectively. But in terms of which green area size has the highest effect and which has the lowest when the distance is varied, it appears at first glance that

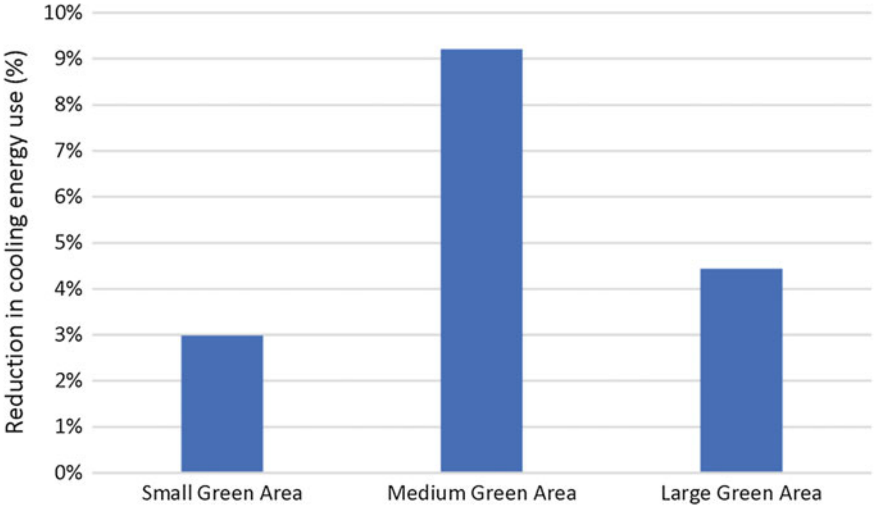

Fig. 8 Percentage reduction in cooling energy use due to the cooling effect of different green area sizes

there is a discrepancy between the results of the two studies (for example, the results of (Gargiulo et al. 2016) showed a higher effect for the medium green area located in a medium building density when compared to a large green area located in the same density which is reversed in the results of the current study). This discrepancy can be explained by referring to that each study looks at the topic from a different perspective, while (Gargiulo et al. 2016) investigated the cooling effect of the green area in terms of the difference between the air temperature and the green area temperature to determine the maximum influence range of each green area size, this study investigated the same effect but in terms of the difference in air temperature in the presence and absence of the green area and the effect of that on the building's cooling energy consumption. So, there is no conflict between the results of the two studies but rather each study integrates with the other to give a better understanding of the complex relationship between green area size, building energy consumption, and urban morphology.

5 Conclusion

This study was aimed at investigating the effect of urban green areas on the energy consumption of the surrounding residential buildings. One important aspect of the study was the inclusion of the urban morphology defined by building density and building characteristics in Naples as an important factor in the investigation. Also, the study proposed an innovative technique for the investigation by using a modeling-based methodology which facilitated the analysis which would be difficult to achieve using empirical studies.

The charts introduced in this study (Figs. 5, 6 and 7)—along with the charts from (Gargiulo et al. 2016)—can help in defining standards and guidelines for Naples to locate and size new green areas taking into consideration the effects on the urban microclimate and on the residential buildings' energy consumption as these charts can be easily used to select the optimal green area size given its distance from the built environment and the building density in which it would be located. Also, the study introduced a general rule of thumb for the optimal green area size in Naples regardless of the building density or the distance from the green area by confirming that using a medium-size green area (4900 m^2) would reduce the cooling energy consumption of the surrounding residential buildings by 9.20% which is more than twice as much as the effect of a large green area (32,400 m^2). This general rule would be useful in the initial urban planning stages where the urban fabric is still not clearly defined.

The complex nature of the interactions between the processes of evapotranspiration and the numerous physical characteristics of urban areas, suggests further development for this research work, by investigating how changes in the climate type and the urban morphology would affect the relationship between the green areas and the energy consumption of the residential buildings; for this reason, it is planned to extend this study in the future by conducting new case studies in different cities with different climate conditions and different urban fabric than Naples.

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