

Greening and Cooling Urban Areas: The Open Space System Contribution for Energy Saving and Climate Change Adaptation

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Abstract. Given the urgency in addressing the climate change acceleration, the international community emphasises the relevance to promote both mitigation adaptation measures to achieving climate neutrality by setting binding targets for member countries in terms of emission reductions. One of the main strategies at the local level is to increase resilience through territorial planning and measures aimed at reducing energy consumption and climate adaptation. In this regard, many studies have shown that the physical characteristics of the urban context are significant factors influencing the achievement of these goals. This paper represents a first step in a larger PRIN-funded research project 'Definition of a handbook of guidelines for implementing climate neutrality by improving the effectiveness of ecosystem services in rural and urban areas', aimed at defining an energy-efficient decision support tool based on urban and open space characteristics. In contrast to traditional studies that tend to address the two issues (energy and climate change) separately and at the scale of individual interventions, this research considers the two types of open spaces as a single network and adopts a holistic approach, privileging the urban and neighbourhood scale. The work has a twofold goal: (i) identifying the most significant urban characteristics and the related descriptive variables mainly affecting thermal comfort and energy consumption, by carrying out an extensive scientific literature review and the authors' previous works and (ii) and classifying the surrounding urban context of open spaces based on the relationships among the variables explaining the urban characteristics identified as relevant to investigate the match between homogeneous characteristics and the reciprocal position of open spaces. This second goal was achieved through a cluster analysis focused on the fabric portions influenced by the cooling effect of existing and potential vegetation.

Keywords: Climate Change Adaptation · Energy Saving · Urban Open Spaces · Green Areas

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1 Introduction

With the acceleration of climate change, the international community emphasizes sustainable measures to address climate-related risks, as exemplified by Sustainable Development Goal 13. The European Green Deal aims for a climate-neutral continent by 2050, covering various sectors such as energy efficiency and biodiversity. The European Climate Law commits to achieving climate neutrality, setting binding targets for member countries in terms of emission reductions and legislative measures to be introduced. One of the strategies being adopted at the local level involves increasing resilience by integrating spatial planning actions and measures to reduce energy consumption and promote adaptation to climate change [1, 26]. Current efforts seem to be more oriented towards promoting the use of renewable sources for clean energy production, reducing waste, and adopting energy-efficient technologies [23, 46], paving the way for a more sustainable and resilient future. Regarding this, there are many studies that have demonstrated that both building and urban physical characteristics significantly influence energy consumption [5, 38, 47]. For instance, urban open spaces, both green and built, play a fundamental role in addressing the challenges of reducing energy consumption. In particular, green areas contribute to reducing the negative effects of rising temperatures by, for example, absorbing excess water, mitigating the effects of urban heat islands, and supporting biodiversity. There is much research that has dealt with the effect of green spaces on the improvement of the urban thermal environment from various perspectives [10, 16, 17, 28, 47]. Furthermore, green spaces can contribute to energy efficiency by providing shade, thus reducing the demand for artificial cooling systems during hot seasons. To this end, some studies aim to develop proposals to optimize the presence of green spaces in consolidated urban contexts [19, 40, 49]. In densely built and layered cities, it becomes strategic to resiliently transform the open space system to strengthen its ecosystemic capacities and improve its adaptive capacity to climate change [16, 18, 41]. This open space reorganisation strategy is also promoted by the European Union, which considers open spaces, both built and unbuilt, as components of an integrated system to mitigate urban warming and enable an adaptation approach "based on the return of nature to cities" [24, 36]. Recognizing the interconnectedness of urban ecosystems, we can create urban environments that not only resist the impacts of climate change but also actively contribute to a more sustainable and energy-conscious future. Section 2 identifies the most significant urban characteristics and the relative descriptive variables that mainly influence thermal comfort and energy consumption, carrying out an extensive review of the scientific literature and the authors' previous works, from which to study methodologies and collect data. Section 3 analyses the surrounding urban context and open spaces of the city of Naples, based on the relationships between the variables that explain the urban characteristics identified as relevant to investigate the correspondence between homogeneous characteristics and the reciprocal position of open spaces. The analysis is conducted through a cluster analysis focused on the fabric sections influenced by the cooling effect of existing and potential vegetation. Section 4 includes the final discussion of the results and conclusions. With the above premises in mind, the main goal of this initial research is to contribute to the reduction of energy consumption from fossil carbon sources and, at the same time, address urban challenges posed by climate change through defining the role (new functions?), dimension, and distribution of open urban spaces. In

fact, this work represents a first step of a wider research PRIN-funded "Definition of a guidelines handbook to implement climate neutrality by improving ecosystem service effectiveness in rural and urban area" - aimed at defining a decision support tool that is effective in terms of energy savings, based on urban characteristics and features of open spaces. Unlike traditional studies that tend to address the two issues (energy and climate change) separately and at the scale of individual interventions, this research considers the two types of open spaces as a single network and adopts a holistic approach, favouring the urban and neighbourhood scale. The work was carried out through a (i) literature review to identify the relevant urban characteristics, mainly related to open space system, affecting energy consumption and climate change adaptation and (ii) a cluster analysis to highlight their relationship.

2 Scientific Framework

The scientific community is actively addressing climate change and energy consumption reduction at the urban scale through interdisciplinary and collaborative research. There are an increasing number of studies, which in recent years, are oriented to develop methods and tools to improve the overall organization of urban systems by applying sustainable planning principles and enhancing the presence of greening interventions. The recent research mainly contribute to evidence-based policy recommendations, suggesting regulatory measures and incentives for sustainable practices [6]. In the following paragraphs, the focus will be on a first part of literature review carried out by considering the relationship between urban built environment characteristics and energy saving, in the first part, and climate change adaptation, in the second one.

2.1 Methodology of Literature Review and Research Focus

The literature review process adopted for this study follows a systematic approach aimed at investigating the relation between the urban characteristics, which influences the thermal comfort and energy consumption as described in Fig. 1. The search for relevant literature primarily focuses on the ScienceDirect database, using specific keywords associated with the thermal aspects of urban environments and the impact of urban open spaces, regarding green and built-up areas.

The chosen keywords include "The Cooling Effect In Open Spaces In Urban Areas," "Urban Thermal Comfort," "Climatic Adaptation," "Urban Energy Saving For Climate Change," "Climate Change And Urban Solution," "Green Spaces And Cooling Effect," "Air Quality And Energy Consumption," and "Review Micro-climate Model." The time frame chosen for the literature review ranges from the foundation of the 2030 Agenda for Sustainable Development, adopted by all UN member states in 2015 and the European Green Deal in 2020, to the present [20]. This temporal boundary ensures that the study considers the most recent developments and research in the context of sustainable urban development and climate change mitigation and adaptation. The subject areas covered in the literature review align with the broader theme of sustainable urbanism and include "Sustainable Cities and Society," "Urban Climate," "Urban Greening," and "Urban Planning." Regarding the urban scale, the study encompasses both the city and

Search	Keywords	Time Frame	Subject Areas
ScienceDirect	- The Cooling Effect - In Open Spaces In - Urban Areas - Urban Thermal Comfort - Climatic Adaptation - Urban Energy Saving For Climate Change - Climate Change And Urban Solution - Green Spaces And Cooling Effect - Air Quality And Energy Consumption - Review Micro-climate Model	- 2030 Agenda for Sustainable Development, adopted by all UN member states in 2015 - European Green Deal, founded in 2020 by the European Commission.	- Sustainable Cities and Society - Urban Climate - Urban greening - Landscape and Urban Planning

Urban Scale	Aims	Methodology
- City - Neighbourhood	The aim is to further study the urban microclimate and the evaluation of the thermal effects of urban open spaces, with a focus on green areas.	Methodologies and simulation models to assess the effects of environmental features, urban morphology, green spaces, and other factors on temperature and thermal comfort in urban areas. The methodologies range from using energy balance-based models to numerical simulation approaches like ENVI-met, statistical analyses, and GIS tools.

Fig. 1. Literature Review process.

neighbourhood levels, recognizing that the thermal dynamics of open spaces can vary significantly across different scales [2, 19]. The primary aims of the literature review are to deepen the understanding of urban microclimates and to evaluate the thermal effects of open spaces, with a specific emphasis on green and built areas. In terms of methodology, the review incorporates various approaches, including methodologies and simulation models. These tools are utilized to assess the impact of environmental features, urban morphology, and green spaces on temperature and thermal comfort in urban areas. The methodological spectrum encompasses energy balance-based models, numerical simulation approaches such as ENVI-met, statistical analyses, and Geographic Information System (GIS) tools.

2.2 Definition of the Main Characteristics

Currently, the scientific community is increasingly moving toward a more holistic perspective of the city and its systems [29] with a focus on reducing energy consumption from fossil carbon sources and mitigating the urban impacts of climate change, understanding of the relationships that interact between them and the expected and unexpected shocks they might face, in order to prepare cities to be more flexible and to have the

capacity to bounce back in case of acute shocks [13, 31, 37]. This trend reflects a significant change from traditional approaches, which often addressed energy and climate change issues separately. To this end, the most significant urban characteristics to be considered in the analyses and the corresponding descriptive variables were identified, based on the scientific literature and the authors' previous works, which are those that have the greatest influence on thermal comfort and energy consumption [14, 28, 30, 44] (Fig. 2). In particular, according to S. Bouketta [4], plant cover in urban spaces and bodies of water such as basins and fountains act as devices that reduce overheating, create an urban cooling island effect, and provide outdoor thermal comfort conditions very close to ideal for pedestrians [35, 48]. Tree cover, impervious surfaces, and vegetation structure play a crucial role, but other factors such as the building materials, the distribution of open spaces in the different kind of urban fabrics impact cooling, as well as proximity to distances to rivers, lakes, and bodies of water, [3, 9]. Regarding the urban asset, Wang and Gou [45] demonstrated that urban open spaces surrounded by low-rise buildings and low-built density fabrics exhibit the highest thermal comfort, whereas those encompassed by a combination of buildings and green spaces show the lowest level of comfort.

2.3 Research Selected Characteristics and Variables Definition

In this study the energy issue and climate adaptation are considered in relation to open spaces through a systemic approach and in addition, for each indicator, the relationship with energy saving, UHI adaption and flooding adaption was studied, as shown in the Fig. 3. This approach indicates that all elements of the urban system interact with each other. Therefore, in addition to examining the characteristics of open spaces, we also consider the surrounding context. For example, the distribution of buildings can influence cooling effect due to the presence of vegetation, as building height and distances between open spaces and buildings themselves can determine a barrier effect hindering their positive thermal and energy reduction effects [32]. Based on these systemic interactions, we identify four main categories, explicit in the Fig. 4: open space system, urban context, microclimatic and geomorphological, and socio-economic and demographic characteristics.

We focus on open spaces considering their extent, the presence of vegetation, pavement, and other aspects. It is worth noting that these spaces are part of urban context with various characteristics and relationships. Finally, we take into account the relationships between these characteristics and factors such as temperature, heat islands, energy consumption, and solar radiation, included in the category of microclimatic and geomorphological characteristics. For each of these categories, key variables have been identified and assumed to be significant by scientific studies on the subject. For each characteristic there are variables that can be collected taking into account criteria depending on availability in the study area, reliability of sources, suburban scale and spatial data, this implies that for each case study the variables will change or be measured differently.

Indicators Dataset from Literature Review	(Solecki et al., 2015)	(Cruz et al., 2021)	(Pigliautile et al., 2021)	(Das et al., 2022)	(W. Liu et al., 2022)	(Zhang et al., 2022)	(Ma et al., 2022)	(Nimac et al., 2022)	(Shen et al., 2022)	(Bouketta, 2023)	(Best et al., 2023)	(Darbani et al., 2023)	(Zou et al., 2023)	(Diz-Mellado et al., 2023)	(Couret et al., 2023)	(Roest et al., 2023)	(Wang & Gou, 2024)	(Patle & Ghuge, 2024)
Presence of trees, shrubs, grass, greenery.		x			x	x				x	x	x			x	x	x	x
Proportion of green cover.		x		x	x	x				x	x	x		x	x	x	x	x
Grass and permeable surface			x			x		x			x	x			x	x		
Parks, squares, allotments and vegetable gardens.			x	x						x						x	x	
Street orientation and geometry			x				x					x			x	x	x	
Density of courtyards in urban areas.									x					x	x			
Water bodies			x	x				x		x	x					x		x
Materials used in paved surfaces		x	x		x	x	x	x			x	x	x			x	x	x
Manufacturing, industries, business, food and beverage, retail, residential areas, historical area			x	x				x	x			x		x		x		x
Agricultural land, fallow land, open land, and forest coverage.				x				x	x			x						x
Building coverage ratio, floor ratio		x	x	x		x	x	x	x		x	x	x			x	x	x
Infrastructure details such as public transit, transportation modes	x								x						x			x
Shading systems														x				
Building forms						x	x			x		x	x	x	x		x	
Building material		x					x			x		x	x	x			x	
Neighborhood compactness and layout.	x						x		x						x	x		x
Amount of sunlight and shadows			x	x		x		x		x	x	x	x	x	x			
Global solar radiation and Mean Radiant Temperature (MRT)			x	x		x	x			x		x	x			x	x	x
Energy use	x				x				x				x					
Wind direction and speed		x	x			x	x	x		x		x	x	x			x	
Relative humidity		x	x			x	x	x		x	x		x				x	
Precipitations										x						x		
Average temperatures and Temperature condition index (TCI)				x	x	x	x	x		x	x			x			x	
Physiological Equivalent Temperature (PET)						x	x					x		x				
Temperature variations and Land Surface Temperature (LST)		x	x	x		x				x	x							x
Air quality																	x	
Distance to commercial centre, river, and elevation.								x			x				x			x
Municipal boundaries	x			x												x		
Proximity to different urban features	x										x							
Total population	x								x				x		x			
Age	x																	
City users	x																	
Education	x												x					
Lifestyle									x									
Real estate value	x								x									
Workers													x					
Local governament	x																	
Institutions													x					

Fig. 2. Dataset from Literature Review.

Characteristics	Variables	Indicators Dataset from Literature Review	Energy saving	UHI adaptation	Flooding adaptation
1. Open space system	Vegetation and Greenery	Presence of trees, shrubs, grass, greenery	x	x	x
		Proportion of green cover	x	x	x
		Grass and permeable surface	x	x	x
	Surface Area	Parks, squares, allotments and vegetable gardens	x	x	x
		Street orientation and geometry	x	x	
		Density of courtyards in urban areas	x	x	
		Water bodies	x	x	x
	Pavement Type	Materials used in paved surfaces		x	x
2. Urban context	Land Use	Manufacturing, industries, business, food and beverage, retail, residential areas, historical area	x		
		Agricultural land, fallow land, open land, and forest coverage	x	x	x
	Building Density	Building coverage ratio, floor ratio	x	x	x
		Infrastructure details such as public transit, transportation modes	x		
		Shading systems	x	x	
	Building Layout	Building forms	x	x	
		Building material	x	x	
		Neighborhood compactness and layout	x	x	
3. Microclimatic and geomorphology	Solar Radiation	Amount of sunlight and shadows	x	x	
		Global solar radiation and Mean Radiant Temperature (MRT)	x	x	
		Energy use	x	x	
	Wind	Wind direction and speed		x	
	Temperature	Relative humidity		x	
		Precipitations			x
		Average temperatures and Temperature condition index (TCI)		x	
		Physiological Equivalent Temperature (PET)	x	x	
		Temperature variations and Land Surface Temperature (LST)	x	x	
	Geomorphological features	Air quality		x	
		Distance to commercial centre, river, and elevation		x	
		Municipal boundaries			
		Proximity to different urban features		x	
4. Socio-Economic and Demographic Indicators	Demographic data	Total population			
		Age			
		City users			
	Socio-economic	Education			
		Lifestyle			
		Real estate value			
		Workers			
	Governance	Local governament			
		Institutions			

Fig. 3. Indicators relation with energy saving, UHI adaptation and flooding adaptation.

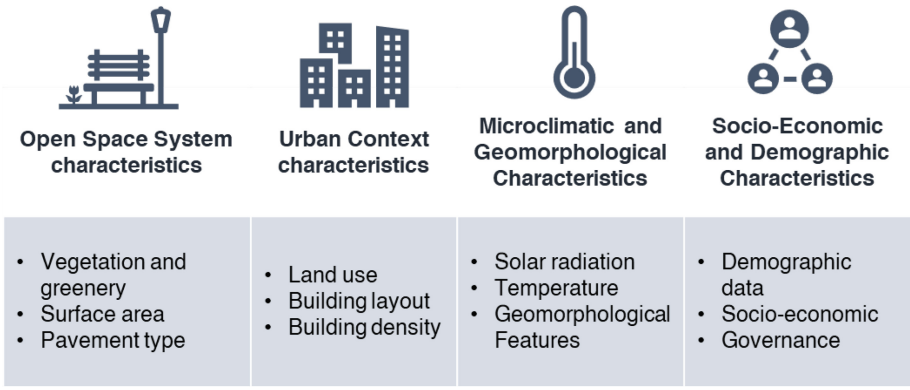

Fig. 4. Definition of urban characteristics.

3 Methodological Process and Data

The aim of this section is to describe the GIS and statistical methodology steps after a literature review, that has enabled the identification of the main dataset addressed in the recent studies, allowing the urban characteristics, the variables, and the indicators to be outlined for input within the analyses. In the next stage, it was necessary to process the data, through calculations and geoprocessing operations, to prepare the dataset for spatial statistical analysis. A cluster analysis was carried out to investigate the match between homogeneous characteristics and the reciprocal position of open spaces, this is focused on the fabric portions influenced by the cooling effect of existing and potential vegetation. This output allows to reach results and conclusions, in order to support decision-makers in defining different greening interventions oriented to energy saving and climate adaptation, according to urban context where open spaces are located. Once the variables of urban characteristics, which emerged from the literature review, have been identified, (a) we proceed to the selection of the indicators describing the data. we need also consider the availability of data for the territorial context under analysis. By first consulting open-source sources, (b) we proceed with the collection, which may involve vector data, raster data or calculation tables. Once the dataset has been collected, it is necessary to make the data continuous and homogeneous, with respect to a single reference unit (census section, buffer area, district, etc.), and normalise it. (c) We will then proceed with correlation analysis, which will identify possible relationships between the indicators and proceed with k-means clustering. (d) This will be concluded by reading the results in the form of both graphs and maps. A summary of the framework methodology is shown in the Fig. 5.

3.1 Case Study Area

The city of Naples (Latitude 40.8517746 and Longitude 14.2681244) is the capital of the Campania Region in Southern Italy with 917.510 inhabitants and covers an area of 117.27 km^2. Naples is one of the oldest cities in Europe, whose contemporary urban fabric preserves the elements of its eventful history. The city has an excessively high

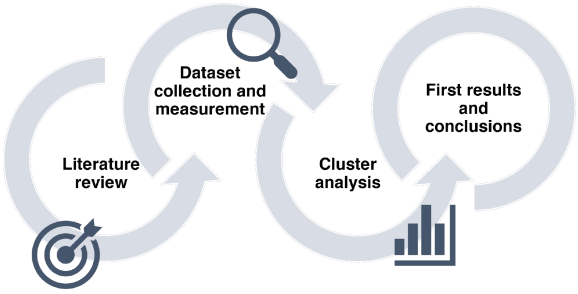

Fig. 5. Methodology framework.

population density, 7,823.91 per km^2, even with reference to the national Fig. (189 inhabitants per km^2). It is marked by a continuous increase in the aging demographic, surpassing national averages [18]. Considering this demographic trend, the impacts on the mobility and well-being of the population, the case study of Naples offers valuable insights. The case study of Naples is also interesting for the heterogeneity of its territory in terms of geomorphologic characteristics, such as its hilly conformation and coastal position, and of urban layouts characterised by densely built-up urban fabrics with different distributions and types of activities. Therefore, as shown in the Fig. 6, the open space system in a densely stratified built city like Naples represents a relevant resource for increasing urban resilience, cooling the built environment, improving stormwater management, and encouraging sustainable mobility.

3.2 Dataset Collection

In this first part of the study, were identified the indicators belonging to the variable's vegetation and greenery, surface area, building density, building layout, temperature, and demographic data, based on the availability of data for the city of Naples. For each characteristic there are variables that can be collected taking into account criteria depending on availability in the study area, reliability of sources, suburban scale and spatial data, this implies that for each case study the variables will change or be measured differently.

They are listened in the Fig. 7 most data utilized for assessing the variables underwent processing within a GIS framework, sourced from open databases such as ISTAT for population data and Urban Atlas for vegetation coverage, greenery, surface area, building density, and layout. Notably, raster image processing was conducted for temperature variables. The indicators specifically concern:

- Open spaces that refer to public spaces with a minimum surface area of 55 m^2 as, below this value, it is no longer a space but an element of street furniture (e.g. a roundabout with vegetation):
  - o Percentage of green cover: considering green urban areas and sports and leisure facilities.
  - o Built spaces: including public squares or courtyards.

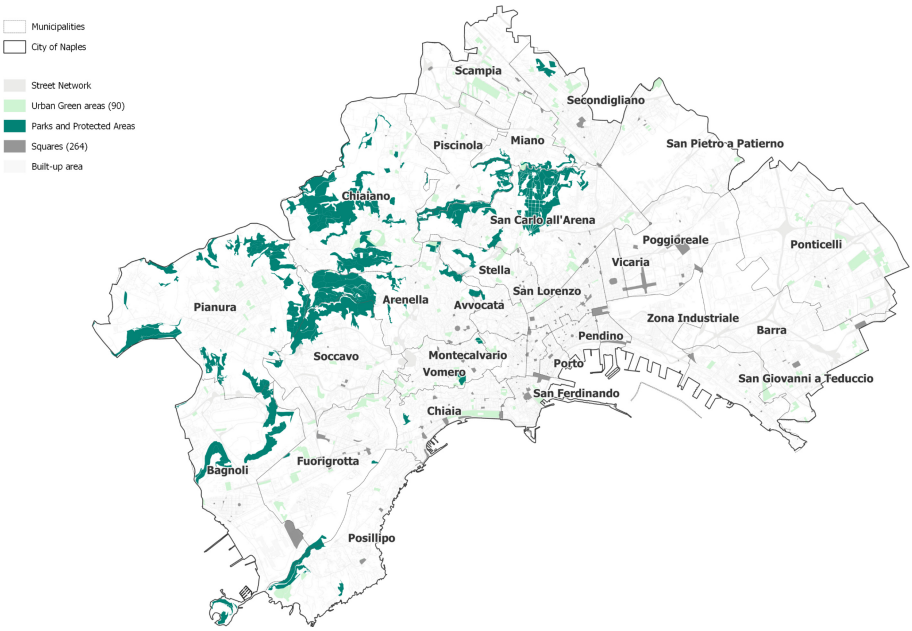

Fig. 6. City of Naples vegetation, street network, open space and built areas.

- Building coverage ratio: that considering the building density.
- Building materials: the number of buildings made of reinforced concrete, masonry, wood or steel, based on ISTAT data.
- Microclimatic and geomorphology: LST and overlapping of cooling areas.
- Demographic data: total resident population.
- Vulnerable population: population that would be most affected by the effects of climate change, i.e. children and the old people [7].

3.3 Indicator Calculation

- Land Surface Temperature (LST)

Measurement of temperature that corresponds urban heat island intensity values necessitated the analysis of multispectral and thermal data obtained from Landsat 8 satellite imagery, accessible via the U.S. Geological Survey website. Specifically, a medium-resolution (30 m/pixel) raster image was analyzed to examine the spatial distribution of air temperatures within the urban canopy layer, spanning from the ground surface to 2 m above, particularly focusing on vegetation cover for the date of July 25, 2022, when a cloud-free image of the study area was available. The variables associated with the land surface temperature (LST), i.e. the radiant temperature measured at the interface between the surface of a material (such as a tree canopy, water, soil, ice or snow) and the atmosphere, influenced by solar reflectance, thermal emissivity and thermal storage capacity; the intensity of the urban heat island effect; the urban area benefiting from

Characteristics	Variables	Indicators Dataset	Measurement	Source	Year	Geometry
1. Open space system	Vegetation and Greenery	Proportion of green cover	mq	Urban Atlas	2018	Polygons
	Surface and built area	Parks, squares, courtyard	mq	Urban Atlas	2018	Polygons
2. Urban context	Building Density	Building coverage ratio, floor ratio	mc/mq	Urban Atlas	2018	Polygons
	Building Layout	Building material	n. of building in reinforced concrete	ISTAT	2011	Polygons
			n. of building in brickwork			
			n. of building in steel, wood, etc.			
3. Microclimatic and geomorphology	Temperature	Land Surface Temperature (LST)	Average °C	Landsat 8	2022	Polygons
		Combined temperature effect*	-	-	-	Polygons
4. Socio-Economic and Demographic	Demographic data	Total population	n. of total residents	ISTAT	2011	Polygons
	Volnurable popolation	Children*	n. of residents 0–9 years old	ISTAT	2011	Polygons
		Old people*	n. of residents over 60 years old	ISTAT	2011	Polygons

Fig. 7. Dataset for measuring the open space system variables in Naples's case study.

the cooling effect due to the presence of green spaces of a particular size. Through the process of evapotranspiration, the energy of solar radiation absorbed by leaves is transformed into latent rather than sensible heat flow, thus reducing the temperature of the canopy and surrounding air. Green areas, especially those characterised by the presence of trees, can also lower the air temperature by intercepting solar radiation, thus preventing the underlying surface from absorbing short-wave radiation, a phenomenon known as the shadow effect. Based on these mechanisms, the air temperature in urban green spaces can be 1–3 °C to 5–7 °C lower than in adjacent urbanised areas, and this phenomenon can also extend to the surrounding environment. The proportion of the urban area that experiences the benefit of cooling due to the presence of green spaces is the result of microclimatic simulations integrated within a GIS environment simulations developed

in previous works of the authors [16–18] and this variable have allowed us to outline the microclimatic behaviour of three common urban fabric types, characterised by various building densities and sizes of green spaces (from 1,000 square metres to 35,000 square metres), typically found in stratified contexts. From the simulations conducted using the ENVI-met software, it emerges that green areas with a size of around 5,000 square metres are the most effective and efficient, capable of reducing the average temperature by about 1 degree Celsius in the surrounding built-up areas within 100–150 m from them [16, 18]. The cooling area represents the size of the urban area that benefits from the presence of green spaces and is the result of integrated microclimatic simulations in a GIS environment. These simulations made it possible to define the microclimatic behaviour of the three most common urban fabric types, characterised by different building density values and different sizes of green spaces (from 1,000 m^2 to 35,000 m^2), which are likely to be found in stratified contexts. After performing simulations using the ENVI-met software, green areas sized around 5000 m^2, which can lower the average temperature by 1 °C on the surrounding built area between 100–150 m from them, were found to be more effective and efficient.

- Cooling Areas

The cooling areas will be the reference unit over which the variables will be distributed, to study correlation and carry out clustering. Specifically, a buffer area of 110 m, 122 m and 146 m will be created based on the surface area of the green area or square. In fact, in the first case, the relationship between actual green areas and urban characteristics will be assessed, and in the second the possible relationship and benefits of covering built open spaces with green areas will be analysed. The buffers will be defined as follows:

– Buffer 110: area < 5000 mq
– Buffer 122: 5000 < area < 30000 mq
– Buffer 146: area > 30000 mq

- Overlapping Effect

Another indicator considered and proposed in the study concerns the calculation of the overlap of the different cooling airs created around green areas. This variable makes it possible to consider the overall, overlapping effects resulting from the proximity of several areas. It can be the context indicator we propose for consolidated cities where it is common for the distribution of open spaces to be ‘concentrated’. At this point was carried out the statistical normalisation, that is the scaling of the distribution of a variable to make comparisons with respect to sets of items and the mean by eliminating the effects of influences. This calculation involved all continuous variables and adjusted to the scale of the cooling areas. Once all variables have been calculated to perform the spatial analysis, it is necessary to merge the normalised indicator fields into a single matrix.

3.4 Cluster Analysis

In the realm of data science, data analysis involves examining, tidying, reshaping, and constructing models with data to unveil insights that guide conclusions and bolster decisions. In this study, cluster analysis was performed, to study the relationship between the spatial variables and to analysing the urban environment near open areas by examining the connections between the factors delineating previously identified urban characteristics, to explore the alignment between similar attributes and the relative positioning of open spaces. Cluster analysis is a statistical method for processing data by grouping the elements of a set, according to their characteristics, into classes that are not assigned a priori. Clustering or cluster analysis is used to classify objects, characterized by the values of a set of variables, into groups. It is therefore an alternative to principal component analysis for describing the structure of a data table. It is used to show relationships among data that are not apparent at first glance, to create homogeneous sets useful for further analysis.

4 First Results and Conclusions

The analysis conducted produced five distinct clusters, whose barycentres are shown in the Fig. 8 and the mapping in Fig. 9, each of which portrays different urban characteristics within the city of Naples. Cluster 1 is characterised by extensive green cover and open spaces, mainly in neighbourhoods object of planned processes, such as Scampia, Bagnoli, Chiaia and Ponticelli. These areas are characterised by mainly masonry buildings, thus of old construction, compared to the other built in more recent periods, with a lower percentage of vulnerable population aged 0 to 9 and over 60. In contrast, Cluster 2 has a high building density, small open spaces and limited green coverage, moreover consistent level of overlapping effect of the cooling areas.as the open spaces are localised in the stratified and consolidated districts of the city, with lower proportion of demographic population and vulnerable population, according to the presence of different urban services and commercial areas. These neighbourhoods, including San Lorenzo, Montecalvario, Pendino and Chiaia, suffer significant urban heat island effects (UHI) due to their consolidated urban fabric. Cluster 3 presents a more balanced distribution between open spaces and green areas, a characteristic common to most neighbourhoods in Naples, with the exception of the central districts. These areas have a lower demographic population, resulting in a lower number of vulnerable individuals. Cluster 4 is characterised by the presence of recently constructed buildings, together with a higher demographic population and a moderate proportion of vulnerable individuals. Mostly squares in established urban fabrics characterized by a medium to high built density value and distributed in different neighborhoods.

Finally, cluster 5 has a substantial proportion of medium-sized green cover and a diverse range of building materials. Despite the dense population, these areas also host a significant percentage of vulnerable individuals and are therefore more exposed to the effects of UHI. Overall, these distinct clusters offer insights into the urban fabric of Naples, providing a holistic understanding of its different neighbourhoods. Such insights are fundamental to the creation of targeted urban interventions aimed at improving the sustainability, resilience and overall quality of life of the city's diverse communities.

N. of elements	31	113	131	82	25	
Cluster	1	2	3	4	5	Average
Land Surface Temperature	0,213	0,381	0,265	0,333	0,256	0,290
Total population	0,366	0,171	0,580	0,628	0,652	0,480
Children	0,073	0,048	0,040	0,185	0,355	0,140
Old people	0,099	0,064	0,062	0,261	0,409	0,179
Brickwork	0,047	0,021	0,080	0,070	0,232	0,090
Reinforced concrete	0,044	0,073	0,048	0,081	0,629	0,175
Steel, wood etc.	0,030	0,005	0,051	0,261	0,246	0,119
Building coverage ratio	0,385	0,631	0,199	0,204	0,207	0,325
Combination effect	0,592	0,689	0,286	0,255	0,405	0,445
Green areas	0,392	0,010	0,075	0,060	0,060	0,119
Squares	0,655	0,961	0,976	0,971	0,986	0,910
Open spaces	0,545	0,027	0,085	0,073	0,066	0,159

Fig. 8. Average Barycentres Pivot Table

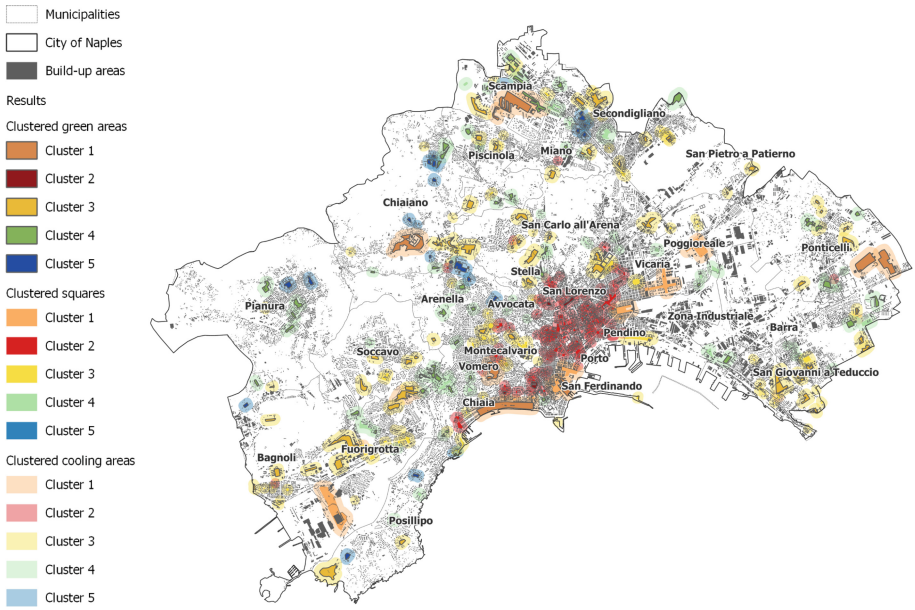

Fig. 9. Cluster Analysis according to the cooling effect areas, green areas, and squares.

These findings are a key step in a broader research effort that focuses on defining guidelines to achieve climate neutrality through increased utilisation of ecosystem services in urban settings. The policy implications of this study are significant, as the paper emphasises the need for integrated approaches to urban planning that simultaneously consider energy reduction and climate adaptation measures. By recognising the role of urban open spaces in increasing resilience, promoting energy savings and improving thermal comfort, policymakers can prioritise investments in green infrastructure and sustainable urban design. By understanding the unique characteristics of different neighbourhoods, policymakers can adapt strategies to improve sustainability and resilience where they are most needed. This approach can help mitigate the urban heat island effect, reduce

vulnerability to climate change impacts and improve residents' overall quality of life. However, it is important to recognise the limitations of this research: although cluster analysis offers valuable insights, it may oversimplify the complexity of urban systems. Moreover, the focus on the city of Naples may limit the generalisability of the results to other urban contexts. Future research should aim to replicate these methods in different cities to validate their applicability in different contexts.

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