Chapter 6
Urban Climate and Building Energy Performance in Compact Cities in Mediterranean Climate

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6.1 Managing Urban Climate in Mediterranean Compact Cities

The shape, structure and colours of many Mediterranean villages, towns and cities reveal an old historical link between climate, architecture and built form in this region. The Mediterranean basin is gifted with one of the most hospitable climates on earth. Mild winters, sunny summers, good amount of precipitation and well-marked seasonal variability allow for a wide range of possibilities for people to thrive. In this context, historic city centres as well as old villages show recurrent characteristics such as high inertia constructions, use of local "cool" materials like light-colour stone and white paints, facades with low window-to-wall ratios and flexible shading systems to control solar radiation and ventilation in summer and winter. The urban fabric is very compact and continuous, and the most common building typology is the courtyard type (Fig. 6.1). The arrangement of buildings and urban blocks generates a dense network of public street canyons and inner courtyards for multipurpose outdoor activities.

All these are characteristic attributes of the "compact Mediterranean city", where compactness here refers to one specific physical characteristic, namely the ratio of building footprints to urban site area (known also as "plan area density" or "site

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M. Palme, A. Salvati (eds.), *Urban Microclimate Modelling for Comfort and Energy Studies*, https://doi.org/10.1007/978-3-030-65421-4_6

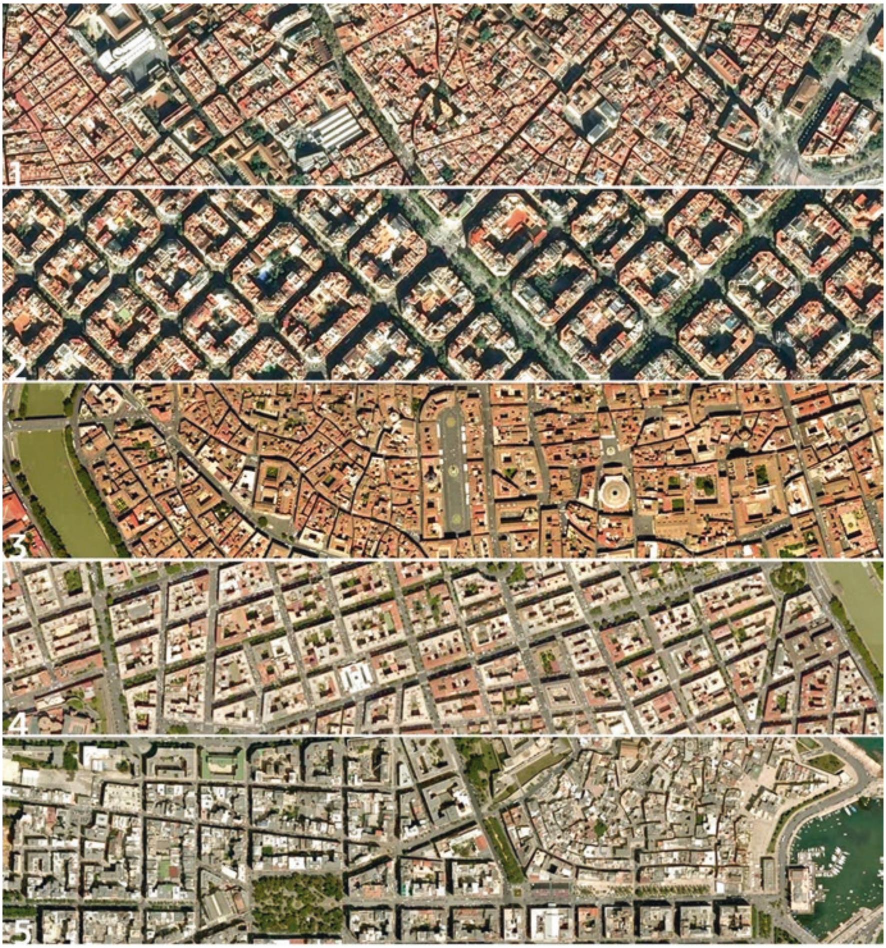

Fig. 6.1 Aerial views of typical urban textures of Mediterranean cities, showing the compactness of the fabric and the recurrent use of courtyard building typologies. (*1*) Barcelona Medieval city centre (Ciutat Vella). (*2*) Barcelona nineteenth-century Plan Cerda development (Eixample). (*3*) Rome Medieval city centre (Campo Marzio). (*4*) Rome twentieth-century development (Prati). (*5*) Medieval core and nineteenth-century development (Murat) in Bari, Italy. (Map data: Google Earth, Landsat/Copernicus)

coverage ratio[1]). Compactness indicates how close the buildings are in the urban fabric. In Mediterranean cities, the ratio of building footprint to the urban site area is normally higher than 0.4 but can be as high as 0.8, meaning that more than 40%

[1] Refer to the chapter "Spatial Metrics to Investigate the Impact of Urban Form on Microclimate and Building Energy Performance: An Essential Overview" by M. Morganti for a complete overview of density parameters (Chap. 18).

and up to 80% of the urban space is occupied by buildings (Morganti 2018). High compactness generates narrow street canyons that provide protection from the excess of solar radiation in summer and from strong winds in winter, improving outdoor and indoor thermal comfort throughout the year. Similarly, at the block and the building scale, compactness is achieved with courtyard building typologies that allow the best control of natural energy resources such as sun and wind to improve indoor thermal comfort throughout the year (Hsie 2008; Natanian et al. 2019; Rojas-Fernández et al. 2017).

In the Mediterranean context, as in any other climate region, the shape and morphology of vernacular architecture show that urban and building form can be designed to create an "artificial climate" that works better than the outdoor climate, protecting people from low and high temperatures, rain, strong solar radiation and winds without the use of active energy systems. Using Rafael Serra's words, a building is indeed "*an artificial refuge, as an island of calm in an un uncomfortable world*[2]" (Serra 1999). Ironically, today we refer to another kind of "island" in relation to climate, the "urban heat island" (Oke 1987; Oke et al. 2017) which is not a refuge, but instead a climate threat to the health and liveability of urban areas. The urban heat island (UHI), namely the increase of temperature in urban areas compared to the rural (or less urbanised) surroundings, is also a form of "artificial climate" resulting from the way buildings and cities are designed. However, this climate modification is not intentional, and, in most of the cases, it is not of help in creating sustainable, healthy and resilient cities.

The increase of temperature in urban areas is strictly linked to the nature of cities themselves, which aims at bringing together people and activities in one place. This needs a substantial modification of the environment, with a substitution of natural surfaces with impervious materials for the efficient run-off of water from precipitation and, above all, the concentration of buildings and functions and consequent energy consumption for climatisation and transportation. All these factors contribute to the increase of surface and air temperature in urban areas.[3]

In the Mediterranean context, the urban heat island intensity may have both positive and negative impact depending on the season. An increase of temperature is advantageous in winter, helping reducing the heating loads of buildings and improving thermal comfort both indoors and outdoors. In summer, the UHI is instead responsible for a rise in building energy demand for cooling and an increase of heat-related health diseases. Due to the intensity of solar radiation, the UHI is normally stronger in summer than in winter in this context, resulting in a net negative impact on the annual energy load of urban buildings (Salvati et al. 2015).

[2] "Los edificios son barreras a la lluvia, al viento y, a veces, filtros sutiles a la luz y al calor. Rodeados de entornos variables, donde cambian el día y la noche, el calor y el frio, el viento y la calma, la lluvia y el sol; se convierten en refugios de artificiales condiciones, como islas de tranquilidad en un mundo incómodo". "Arquitectura y climas" (Serra 1999) p. 7.

[3] A detail explanation of the causes and the characteristics urban heat islands in cities can be found in the chapter "The Energetic Basis of the Urban Heat Island" by G. Mills, J. Futcher and I.D. Stewart (Chap. 3).

In the Mediterranean region, the issue of heat in cities and buildings is becoming more and more alarming in light of global climate change, which is predicted to have strong impact in this region, with significant increase in temperature, decrease in precipitation in summer and increase in frequency, intensity and duration of extremely hot periods known as “heatwaves” (Bastin et al. 2019; IPCC 2014). Therefore, the UHI is a local climate modification that amplifies the negative impact of climate change in urban areas, increasing the exposure and vulnerability of urban population. Studies have shown that even small changes in the average air temperature above certain thresholds may determine an exponential increase in mortality, especially for vulnerable population groups like older people or people with chronic diseases. This threshold temperature depends on the background climate; in Rome, for instance, it is around 27.5 °C (Gasparrini et al. 2015), which is a typical mild daytime summer temperature for this context. In rural areas, the night-time summer temperature normally falls below this threshold even in the hottest days. Conversely, the air temperature may stay above this threshold for many consecutive days in urban areas, due to the night-time UHI intensity.

Considering the high level of urbanisation, the increasing ageing of population and the prediction of an increase in frequency and magnitude of heatwaves, the risk of premature heat-related deaths is considered one of the major threats to public health in the Mediterranean region in the next years (Linares et al. 2020). The risk is obviously higher in cities with strong UHI intensity, where mitigation and adaptation plans are imperative to protect the citizens’ health and well-being and to improve the sustainability of urban areas. For these reasons, the need to effectively integrate urban climate knowledge and modelling into planning and design has never been so urgent to guide the policies and to assess the performance of existing and new buildings and urban spaces.

This chapter intends to provide an overview of the characteristics of urban climate in Mediterranean cities, discussing experimental and numerical studies investigating the UHI intensity in some representative cities in this region. Particular attention is posed on the strong relationships between urban form, urban climate modifications and impact on thermal comfort and building energy demand in typical urban fabric of compact Mediterranean cities. Case studies in Rome and Barcelona are presented in order to highlight the complexity of the phenomena involved at different scales and with different points of view (i.e. outdoor thermal comfort or building energy efficiency). In the last section, design strategies for “heat management” at the urban and building scale are discussed.

6.2 Designing with Climate in a Mediterranean Context

The most characterising feature of the Mediterranean climate is its complexity. The weather conditions change rapidly, over the year and over the day, and both *cold* and *heat* are a problem. Consequently, the design solutions that must be applied in architecture in this region are similarly complex (Coch 1998; Serra 1999).

The variable climatic conditions require the local architecture to have great flexibility in order to cope with periods of both excessive cold and oppressive heat. Moreover, since the changes occur rapidly and at any time of the year, the buildings need to be able to adapt quickly as well. In very short time, the external conditions can change from dry heat to humid heat, from calm to strong wind or from drought to downpours. Therefore, the protection from excessive heat is just one of the functions of buildings in this region, even though one of the more complex to achieve, especially in cities (Coch and Serra 1996; Salvati et al. 2017b).

In Mediterranean climates, the problem of overheating in buildings is a function of solar radiation, humidity and air temperature, in this order.

Intense solar radiation for long periods not only contributes to increased air temperature but, more importantly, also heats the masses of urban structures, which normally consist of heavy masonry buildings in this area. As a result, it is common to find worse environmental conditions indoors than outdoors during some periods of the year. In summer and autumn, for instance, the indoor environment can be very hot due to high internal mean radiant temperatures, even if the air temperature is not particularly high. These are the paradoxical cases in which the saying that “some buildings work worse than the climate” is unfortunately true (Coch 1998).

A similar phenomenon occurs with the humidity of the air. Frequently, although not always nor in all locations, conditions along the Mediterranean coasts are characterised by high humidity combined with relatively high temperatures. It is widely known that thermal comfort zones get narrower as humidity increases, in a way that sometimes one can go from feeling cold to feeling hot without achieving an intermediate comfortable perception. The control of humidity, which we consider to be underestimated in conventional comfort studies, is in fact an important factor for comfort in buildings in such climates. Even in this case, it is true to say that the outside climate is often more comfortable than the interior one, where in many cases there are elements that release humidity.

Finally, the temperature of the air is also important, along with the above parameters. In conditions of dry heat, daytime temperatures in the Mediterranean regions can exceed 35 °C or even 40 °C. In such conditions, the exterior becomes uninhabitable and the interiors are cool refuges because the building inertia enables the temperature of the air to be controlled, although in the night-time that same air temperature becomes uncomfortable.

Considering the above aspects of the Mediterranean climate, the design of buildings should be aimed at controlling these three variables all together to improve the indoor thermal conditions over hot periods. Concerning the issue of excess of heat, each climate variable should be controlled with specific strategies as follows (and in this order).

6.2.1 Control the Entry of Solar Radiation

- Totally blocking the entry of direct sunlight through openings, particularly on the east and west facades and through the roof.

- Controlling and optimising the entry of diffuse radiation through openings on any facade, not only coming from the sky but also from exterior reflecting surfaces: In fact, any excess of light indoors can be detrimental in this climate in summer due to its thermal effect.
- Avoiding the entry of long-wave radiation, both originating from surrounding surfaces heated by the sun and entering the building through its openings and by the energy stored in the walls of the building itself: Both kinds can have noticeable impact at night, long after the sun has set.

These three strategies against radiation should be used together, but we can say that (2) and (3) are of little help if (1) is not implemented.

6.2.2 Control the Humidity of the Indoor Air

- Efficient, controllable indoor ventilation to expel the excess of humidity in humid heat conditions.
- Ventilation in combination with humidification of the air (evaporative cooling) in dry heat conditions.
- Controlled ventilation using previously cooled air, by means of underground ducts and/or conveying air from cooler exterior zones.

The strategies (1) and (2) are conceptually contradictory; therefore, it is essential to find flexible solutions in those cases in which both climatic phenomena are likely to occur.

6.2.3 Regulate the Temperature of the Indoor Air

- High inertia in the interior and the outside walls, in climatic conditions with elevated temperature fluctuations, usually in dry heat climates.
- Reduced ventilation during the hottest part of the day, particularly important in the same cases as in the point above.
- Insulation on the exterior side of walls, thus decreasing the transmission of heat from the outdoors to the indoors over the hottest hours of the day.

It has to be noted that this last group, and the last strategy in particular, is of secondary importance in comparison to the two previous groups of strategies. In Mediterranean climates, the sole control of air temperature would result in just negligible improvement of indoor thermal comfort without first having dealt with the direct, diffuse and long-wave radiation and the humidity issues. As well known, all these climate variables are profoundly modified in urban areas, due to the UHI effect and other urban climate modifications determined by urban morphology, such as solar access, radiation trapping and wind obstruction. Therefore, preliminary study and prediction of the urban microclimate conditions around urban buildings are crucial to develop successful architectural designs, adopting the most suitable passive technologies to improve indoor thermal comfort based on each site-specific climate boundary conditions.

6.3 Measuring and Modelling Urban Climate in Mediterranean Cities

6.3.1 Scale and Purpose of the Analysis

The analysis of urban climate and heat island intensity of an urban area can be carried out with different experimental and modelling techniques, depending on the purpose and the scale of interest. For the purpose of building energy and comfort studies, we are interested in knowing and modelling the "canopy-level urban heat island" (CUHI) and the "surface urban heat island (SUHI)".[4]

Regarding the CUHI, we ideally would need to know the vertical profile of air temperature and wind speed in urban canyons. In fact, the temperature in urban canyons is not uniform and generally warmer near the ground and lower at the top, due to thermal gradient, solar radiation trapping and wind obstruction. However, either measuring or modelling the temperature and wind profiles in urban canyons is not an easy task. Furthermore, building performance simulations (BPS) are performed using weather files with hourly values of the climate variables for the typical meteorological year for the location (normally based on measurements at the city's airport weather station). In order to improve the accuracy of the energy simulations for urban buildings, the "rural" (airport) air temperature can be modified using average canyon air temperatures. For this reason, the experimental studies aimed at measuring urban air temperature for energy performance analysis use sensors installed at approximately mid-height within urban canyons (Kolokotroni et al. 2006; Santamouris et al. 2001; Zinzi et al. 2018), assuming that this is the most representative point to capture the average temperature of urban canyons. Similarly, tools such as UWG,[5] developed for including UHI effects into weather files for building energy modelling, assume uniform air temperature in urban canyons, considering the canyon mid-height point to calculate the values.

Air temperature is less variable on the horizontal plane around a building, since it is the result of the average characteristics of the neighbourhood or, better, the

[4] The different types of urban heat island corresponding measurement methods are described in the chapter "The Energetic Basis of the Urban Heat Island" by Mills, Futcher and Stewart (Chap. 3).

[5] The model is described in the chapter "The Urban Weather Generator Model: Physics-Based Microclimate Simulation for Performance-Oriented Urban Planning" by J. Mao, L. Nordford (Chap. 12).

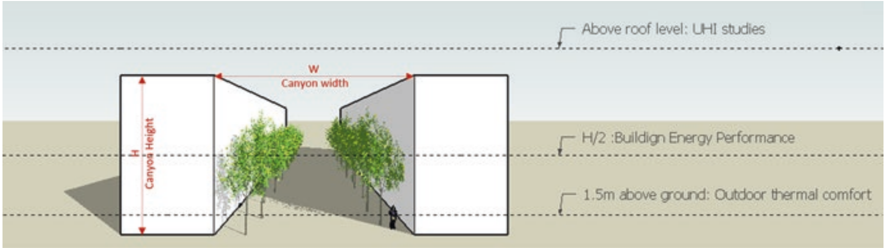

Fig. 6.2 Location of monitoring equipment within urban canyons to measure urban air temperature for different purposes such as the analysis of outdoor thermal comfort, building energy performance or local UHI intensity. (Image elaborated by the authors)

"local climate zone[6]" (Stewart and Oke 2012). As opposite to air temperature, other climate variables such as solar irradiation, surface temperature and wind speed are likely to vary significantly in very short distances, depending on the location within the urban canyon and the detailed three-dimensional geometry of buildings and other urban elements. These variables are crucial for analysing outdoor thermal comfort[7] and their temporal and spatial distribution needs to be carefully assessed using high-resolution microclimate models (i.e. ENVI-met, SOLENE-Microclimat[8] or RayMan-SkyHelios[9]) or using appropriate methods to determine the mean radiant temperature from multiple measurements (Johansson et al. 2014). Therefore, the experimental studies oriented to outdoor thermal comfort in urban canyons are carried out at the street level (1.5–2 m above ground level) and consider both the CUHI and the SUHI, which concur to determine the outdoor thermal comfort sensation.

The studies aimed at assessing the dynamics of the urban energy fluxes and the magnitude of the atmospheric urban heat island at the local and urban scales use equipment located above the roof level, in the roughness sublayer (Fig. 6.2).

In line with the topic of this book, the next sections will focus on representative experimental and numerical studies carried out in Mediterranean cities that provide useful knowledge and tools for improving building energy modelling and thermal comfort analysis in this region.

[6] The concept of the local climate zones is described in "The Energetic Basis of the Urban Heat Island" by Mills, Futcher and Stewart (Chap. 3).

[7] The complexity of outdoor thermal comfort assessments and the variables involved are described in the chapter "Thermal Comfort in Urban Spaces" by M. Nikolopoulou (Chap. 4).

[8] The model is described in the chapter "The SOLENE-Microclimate Model: Potentiality for Comfort and Energy Studies" by Musy et al. (Chap. 13).

[9] The model is described in the chapter "RayMan and SkyHelios Model" by Matzarakis et al. (Chap. 16).

Fig. 6.3 Cities where the UHI has been measured in the Mediterranean basin (map data: Google Earth, Landsat/Copernicus)

6.3.2 Urban Heat Island and Microclimate Studies in Representative Mediterranean Cities

In the last 20 years many experimental and numerical studies of the urban heat island intensity have been carried out in the Mediterranean basin (Fig. 6.3 and Table 6.1), reporting strong UHI intensity both at daytime and night-time and throughout the year. All the cities analysed are classified as Mediterranean climate in the Köppen-Geiger system (Kottek et al. 2006) and are located at latitudes between 43.7° N (Florence, Italy) and 31.2° N (Alexandria, Egypt).

6.3.2.1 Maximum Canopy-Layer UHI Intensity

Concerning energy and comfort studies, both the daytime and night-time UHI intensity are relevant, the former to assess the peak cooling loads of buildings occupied during the daytime (i.e. office buildings), and the latter to assess night cooling ventilation potential and indoor thermal comfort in residential buildings.

The studies carried out in Athens reported that the maximum absolute UHI intensity—namely the maximum observed air temperature difference between the urban fixed stations and the rural one—occurred during daytime, reaching more than 10 °C (Santamouris et al. 2001; Santamouris 2016); at night-time, the maximum UHI intensity is lower than 5 °C at all stations.

The UHI intensity was found to be higher during daytime also in Chania, Crete, reaching a maximum absolute value of 8 °C; in this coastal city, the measurements highlighted that the daytime UHI intensity is quite variable depending on wind speed, while the night-time UHI intensity is more stable, varying between 1.5 °C and 2 °C (Kolokotsa et al. 2009).

Table 6.1 Review of the methods used in UHI and microclimate studies carried out in representative Mediterranean cities

Country/city	Study	Method				
		Air temperature observations				
		Street level	Canyon mid-height	Above roof	Land surface temperature	Numerical study
Greece						
Athens	Santamouris et al. (2001)	×	×			
	Livada et al. (2002)		×			
	Mihalakakou et al. (2001)		×	×		× (data-driven model)
	Mihalakakou et al. (2004)		×			× (data-driven model)
	Giannopoulou et al. (2011)	×[a]	×[a]			
Thessaloniki	Giannaros and Melas (2012)		×			
Chanía (Crete)	Kolokotsa et al. (2009)		×			
Volos	Papanastasiou and Kittas (2012)		×			
Cyprus						
Nicosia	Theophilou and Serghides (2015)	×				
Italy						
Rome	Colacino and Lavagnini (1982)			×		
	Bonacquisti et al. (2006)	×				× (UHSM)
	Cantelli et al. (2011)			×		× (RAMS-LEAF3)
	Pelliccioni et al. (2012)	×		×		
	Cantelli et al. (2014)			×		× (RAMS-STEB)
	Zinzi et al. (2018)		×			
	Salvati et al. (2016)	×		×		× (UWG)
	Salvati et al. (2019)	×				× (UWG)
Bari	Martinelli et al. (2020)	×				

(continued)

Table 6.1 (continued)

Country/city	Study	Method				
		Air temperature observations				
		Street level	Canyon mid-height	Above roof	Land surface temperature	Numerical study
Florence	Petralli et al. (2011)	×				
Spain						
Barcelona	Moreno-Garcia (1994)	×		×		
	Salvati et al. (2017b)	×		×		
	Salvati et al. (2019)			×		× (UWG)
	Serra et al. (2020)				× (MODIS)	
	Martin-Vide and Moreno-Garcia (2020)			×		
Sevilla	Romero Rodríguez et al. (2020)	×		×[a]		
Israel						
Tel Aviv	Saaroni et al. (2000)	×		×		
Egypt						
Alexandria	Hassaan (2008)				× (LANDSAT)	
Algeria						
Constantine	Bourbia and Boucheriba (2010)	×				

[a]The sensor height is not specified in the reference paper

In Bari, the absolute maximum observed UHI intensity reached 6.6 °C in June and was higher than 4 °C for more than 30% of the summer days (Martinelli et al. 2020).

In Barcelona, the maximum UHI intensity measured at the roof level occurred at night-time, with an average monthly maximum of 2.8 °C in winter and 1.7 °C in summer; however at the street level, in summer, the UHI intensity occurred during both daytime and night-time, reaching a maximum intensity of 4.3 °C (Salvati et al. 2017b).

In Rome, a maximum UHI intensity close to 7 °C was detected during daytime in summer in two urban canyons in high-density neighbourhoods (Zinzi et al. 2018). In Sevilla a maximum UHI intensity of more than 7 °C was measured at 06:00 h in the city centre (Romero Rodríguez et al. 2020).

6.3.2.2 Seasonal Variability

Many studies highlighted the seasonal variability of the UHI intensity in Mediterranean cities.

Mihalakakou et al. (2001, 2004) reported the following variation of the maximum average daytime UHI in Athens: +7.5 °C in summer, +5.1 °C in autumn, + 3.7 °C in winter and +4.6 °C in spring. Similar results were found in Thessaloniki, where the maximum observed UHI varied between 2 °C and 4 °C in the warmer months and between 1 °C and 3 °C in the cold part of the year (Giannaros and Melas 2012).

The UHI intensity was found to be higher in summer than in winter also in Rome, where Colacino and Lavagnini (1982) showed that the mean temperature difference between the city centre and the rural area was +4.3 °C in summer and +2.5 °C in winter and a similar seasonal trend was reported more recently by Zinzi et al. (2018). The prevailing anticyclonic conditions for the Mediterranean region in the summer months can explain why the UHI intensity is generally stronger in summer than in winter in most of the cities.

As opposite to the previous cases, the UHI intensity was found to be stronger in winter than in summer in Barcelona. Studies carried out by Martin-Vide and Moreno-Garcia (2020), Moreno-Garcia (1994) and Salvati et al. (2017b) showed a higher UHI intensity in the winter months (+3–4 °C on average) compared to the summer months (+2–2.5 °C on average) in Barcelona. This is most probably due to the thermoregulatory effect of the sea, determining a very small daily temperature range (T_{max}–T_{min}) and reduced peak temperatures in summer (Fig. 6.4). Furthermore, these values are based on roof-level temperatures. A measurement campaign in street canyons showed high UHI intensity in summer at the street level also in Barcelona (Fig. 6.5), during both the daytime and the night-time.

6.3.2.3 Intra-urban Air Temperature Differences Due to Building Density and Land Use

Intra-urban temperature differences due to change in land cover, land use and building density were observed in all the cities.

In Athens, Livada and Giannopoulou (Giannopoulou et al. 2011; Livada et al. 2002) showed that the urban air temperature is lower in areas with high percentage of green areas and it is maximum in the dense city centre and in industrial areas with very low vegetation cover. The mean temperature difference between the hottest and the coolest spots across the city ranged between +3 °C and +5.3 °C during daytime and between +1.3 °C and +2.3 °C during night-time.

In Florence, cold and hot spots were observed across the city, with mean temperature difference of 2 °C and higher differences in summer and autumn (Petralli et al. 2011).

At the street level, in Barcelona, the canyon geometry determines significant air temperature differences from the sunset to the early hours of the morning, with differences up to 2.2 °C in favour of the narrower canyons (Fig. 6.5). The maximum daytime UHI intensity is reached in the low aspect ratio canyons (H/W ~ 0.3), while

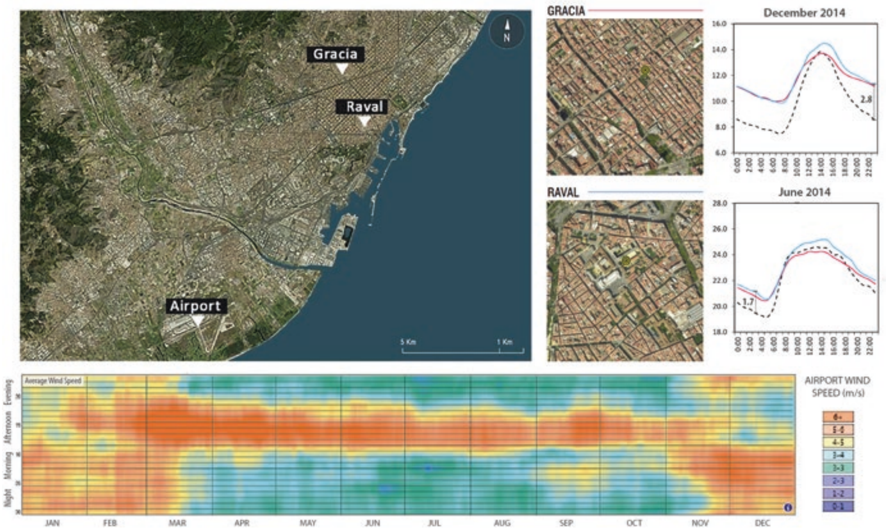

Fig. 6.4 Top: Daily cycle of air temperature in winter and summer months in two dense neighbourhoods of Barcelona; sensors located above roof level at the urban stations (adapted from Salvati et al. 2017b). Bottom: Wind speed at the airport site, showing the consistent effect of the sea breeze from April to October between 12 pm and 6 pm

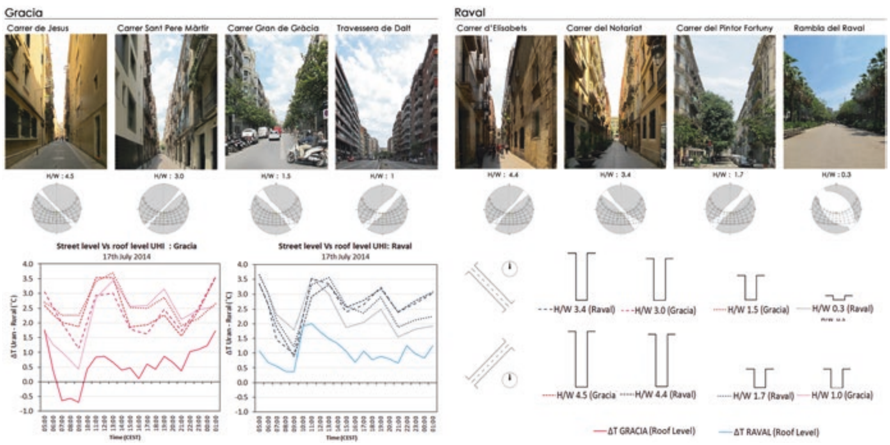

Fig. 6.5 Temperature difference in street canyons compared to the airport measurements at the same time during one hot summer day in Barcelona. (The field measurements have been published by Salvati et al. 2017b)

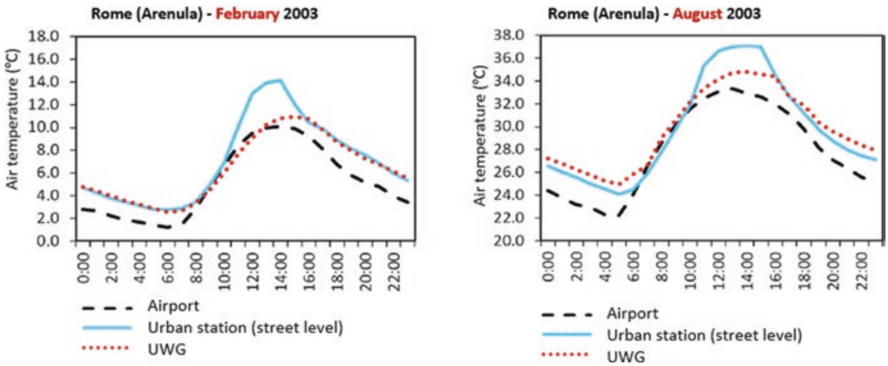

Fig. 6.6 Comparison of the average daily profiles of air temperature calculated by UWG and measured at a street level at a fixed weather station located in Via Arenula in Rome (adapted from Salvati et al. 2019)

the maximum night-time intensity is found in the narrower canyons (H/W ~ 4). Similarly, in Bari, higher daily maximum temperature is observed in the low-density urban areas while higher night-time air temperature in the denser urban areas (Martinelli et al. 2020).

Salvati et al. (2019) carried out a numerical study for Rome and Barcelona using the "Urban Weather Generator" model (Bueno et al. 2013; Mao et al. 2017), validated with air temperature observations from urban fixed stations (Fig. 6.6). The results showed that the variability of urban morphology and anthropogenic heat from air-conditioning systems across the city determines significant intra-urban air temperature differences.

6.3.2.4 Impact of Synoptic Meteorological Conditions and Wind Speed

Some studies analysed the variability of the UHI intensity for varying meteorological conditions.

In Athens, Mihalakakou et al. (2001, 2004) showed that the city's UHI intensity is maximum for high-pressure anticyclonic weather conditions and minimum for south-westerly flow circulation characterised by strong winds (more than 6 m/s).

Strong interactions between meteorological factors and UHI intensity were found also in Chania, Crete, due to the peculiar position of the city, bounded by the Aegean Sea to the North and the White Mountains (about 2000 m altitude) to the south. Here, Kolokotsa et al. (2009) reported that the UHI intensity varies significantly with wind speed and direction; the northern winds expand the UHI front, while the western winds contribute to the UHI mitigation in the city.

In Volos, a medium-size coastal town, the daily maximum UHI intensity was observed to be positively correlated with solar radiation and relative humidity in summer and negatively correlated with wind speed and relative humidity in winter (Papanastasiou and Kittas 2012). In Thessaloniki, the UHI intensity decreases significantly for wind speed higher than 4 m/s (Giannaros and Melas 2012).

In large coastal cities, the moderating effect of the sea is clear in the neighbourhoods close to the shoreline, where smaller diurnal air temperature variation are measured in comparison to more interior urban and rural locations; this was found in Tel Aviv (Saaroni et al. 2000), Bari (Martinelli et al. 2020) and Alexandria (Hassaan 2008). In Alexandria, the moderating effect of the sea on surface temperatures was clear up to about 300 m from the shoreline. Similarly, the moderating effect of the sea was found to vanish at few blocks' distance from the coast in Bari (Martinelli et al. 2020).

In Tel Aviv, the Mediterranean sea breeze (ranging between 3 and 6 m/s on the measurement days) was found to reduce the night-time summer temperatures at the roof level, but not at the street level. This result is similar to what was found in Barcelona, where the daytime summer street-level air temperature in central districts was up to 2 °C higher than the air temperature at the roof level in the same location (Salvati et al. 2017b). The influence of the sea and land breeze circulation on the vertical profile of the boundary layer above the metropolitan area of Rome has also been detected (Cantelli et al. 2014; Leuzzi and Monti 1997) as well as a significant temperature difference between the maximum daytime air temperature observed at roof level and street level in summer (Salvati et al. 2016).

6.3.3 Wind Speed in Urban Canyons

Much less experimental studies on the air circulation in street canyons have been carried out.

An important experimental campaign was carried out in Athens in the summer of 2001 by Georgakis and Santamouris (2005, 2006; Santamouris et al. 2008) for the URBVENT European research project (Ghiaus et al. 2005). The field study was aimed at developing simplified wind canyon models to assess the ventilation potential of buildings in urban context. The wind speed and direction at different points and at different heights within and above urban canyons with aspect ratio between 1.7 and 3.25 were performed. Based on the measurements, semi-empirical models were created to calculate the wind speed at different heights in street canyons, considering the direction and speed of the undisturbed wind and the geometry and orientation of the canyon. These models have been recently applied to assess the impact of urban context on the ventilation potential of buildings located in different areas across Rome (Salvati et al. 2020).[10]

[10] It has to be noted that the URBEVENT empirical models were applied to Rome on the assumption of similarities in climate and urban geometry with Athens, where the measurements were carried out. However, the application of simplified models to calculate the wind flow in cities is very limited, due to the many site-dependant variables involved and the complexity of urban fabric geometry. A complete overview of the topic is provided in the chapter "Air Circulation in Urban Areas" by Di Bernardino et al. (Chap. 10).

6.4 Urban Climate and Building Energy Performance

Many studies highlighted the negative impact of the UHI intensity on the energy demand of urban buildings in comparison to locations out of the city. The negative impact is due to the rise in cooling energy demand due to urban warmth, which is normally higher than the reduction of the heating demand in winter.

Santamouris et al. (2001) used Athens' urban air measurements to perform energy simulations using TRNSYS for an office building with cooling set point of 26 °C and compared the performance with respect to non-urban conditions. The simulations showed a rise of about 120% of the building monthly cooling load and a decrease of the heating load by 38% in the city centre with respect to the suburban location, resulting in a net negative impact of urban climate on building energy demand.

Based on 3-year measurements in four urban sites in Rome, Zinzi et al. (2018) showed that the heating degree days decrease by 18% while the cooling degree days increase by 157% in the city centre due to the urban heat island effect. This entailed a reduction of the heating loads by 18% for office buildings and by 21% for residential buildings, while the cooling loads increased by 53% and 74% for office and residential buildings, respectively. For non-cooled residential buildings, the UHI effect determined a significant increase of the overheating hours as compared to the same building in the countryside, due to the reduced cooling potential of night ventilation in urban context (Zinzi and Carnielo 2017). The study also showed that the cooling energy performance of non-insulated buildings is more influenced by urban climate as compared to insulated ones.

Although many studies analysed the impact of higher urban temperatures on the building energy performance, very few analysed the net energy impact considering other urban climate modifications. In fact, the air temperature increase in urban areas is just one of the urban climate modifications that affect building thermal performance. The complex geometry of the urban fabric determines different kinds of climate modifications, including variabilities in UHI intensity, obstruction of solar radiation and modifications of surface temperatures and wind speed in urban canyons (Fig. 6.7). All these climate modifications have an impact on the building energy performance, by modifying the indoor-outdoor heat transfer through the

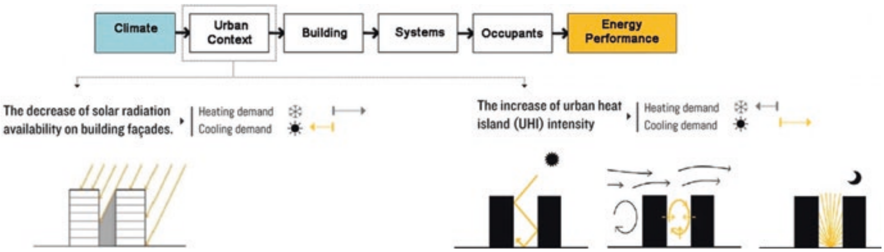

Fig. 6.7 Climate modifications determined by urban context and corresponding positive or negative impact on the cooling and heating energy performance of buildings. (Source: elaborated by the authors based on Ratti et al. 2005)

envelope, the solar gains, the ventilation and infiltration energy gains/losses and the infrared exchange in comparison to an open-rural environment.

Furthermore, these climate modifications have opposite energy impacts. The reduction of solar radiation on buildings' facades in a dense area has a positive impact on the sensible cooling loads and a negative one on the heating loads. At the same time, the air temperature and surface temperature increase and the wind speed reduction in urban canyons have the opposite effect, namely a reduction of the heating and an increase of the cooling demand due to lower outdoor-indoor temperature differences, reduced ventilation rates and reduced infrared radiation exchange with the environment. An example of the net energy balance of these opposite effects is presented in the next paragraphs for residential buildings in Barcelona and Rome.

6.4.1 Urban Morphology and Solar Radiation Availability on Facades and Roofs in Barcelona

Considering the crucial role played by solar radiation in the Mediterranean context, the impact of urban geometry on the solar radiation availability on the building envelope is the first necessary step for a correct assessment of the building energy performance in an urban context.

The solar radiation availability on facades and roofs on the iconic urban blocks of the "Eixample" in Barcelona was analysed by Curreli et al. (2016). The study showed the variability of the *sun factor* (i.e. incident direct solar energy per unit of surface in kWh/m^2) of the different components of the building envelope (roofs, external facades, courtyard walls and residual elements) in that urban texture. The sun factor was calculated with the software Helidon (Beckers and Masset 2011), a tool for solar energy analysis at the urban scale. The results showed a huge difference in the sun factor of vertical surfaces and horizontal ones and also significant differences among the external walls facing the street or the courtyard (Fig. 6.8).

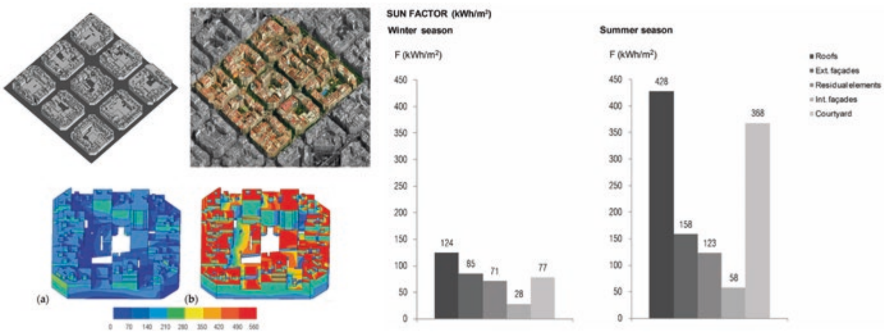

Fig. 6.8 Seasonal sun factor FR (kWh/m^2) for the different components of the building envelope in the "Eixample" district in Barcelona. (Analysis and figures by Curreli et al. (2016), available at https://doi.org/10.3390/en9070544)

The analysis of the *solar gain* (kWh) distribution on the envelope showed the dominant role of roofs compared to vertical surfaces in harvesting solar radiation in such a compact urban structure: roofs collect 33% and 43% of the total radiation incident on the envelope in winter and summer, while the street-facing walls receive 24% in winter and 17% in summer and the courtyard facades 14% in winter and 9% in summer. This also highlights a different interaction between urban morphology and solar radiation in summer and winter, due to the seasonal variability of solar elevations.

6.4.2 Solar Access and UHI Intensity: Assessing the Net Energy Impact on Urban Buildings

The high impact of urban geometry on solar access suggests that the impact of the UHI intensity on the energy demand of urban building may vary depending on the building's solar gains. This was shown by Salvati et al. (2017b), by investigating the relative impact of the UHI intensity on the cooling demand of a residential building in Barcelona for varying solar access conditions. Energy simulations performed using urban air temperatures and airport air temperatures showed that the UHI effect determines a higher relative increase in the sensible cooling demand in the apartments with lower solar gains and higher absolute increase in the apartments with higher solar gains.

The net energy impact of urban compactness considering solar access and UHI intensity was explored for buildings located in different urban textures of Rome and Barcelona in another study (Salvati et al. 2017a). The study was carried out using the Urban Weather Generator (UWG) for the estimation of the UHI intensity and EnergyPlus for the solar radiation availability on building facades and the energy demand calculation of representative apartments. The overall energy impact of the two urban climate modifications on the building heating, cooling and annual energy demand was calculated and correlated to the compactness of the urban textures (Fig. 6.9).

The energy demand was calculated considering a test apartment located at the first floor in four orientations (NW-NE, NE-SE, SE-SW and SW-NW) in the middle block of simplified urban geometry models representative of the real urban textures. In this location, the solar availability on the building facade is reduced by a minimum of 17% in the less dense urban texture to a maximum of 80% in the densest texture compared to an open environment. The simulation performed using UWG showed that the average UHI intensity in summer and winter varies from a monthly minimum of 1 °C in winter in the less compact texture to a maximum of 3.4 °C in summer in the most compact one (Fig. 6.9).

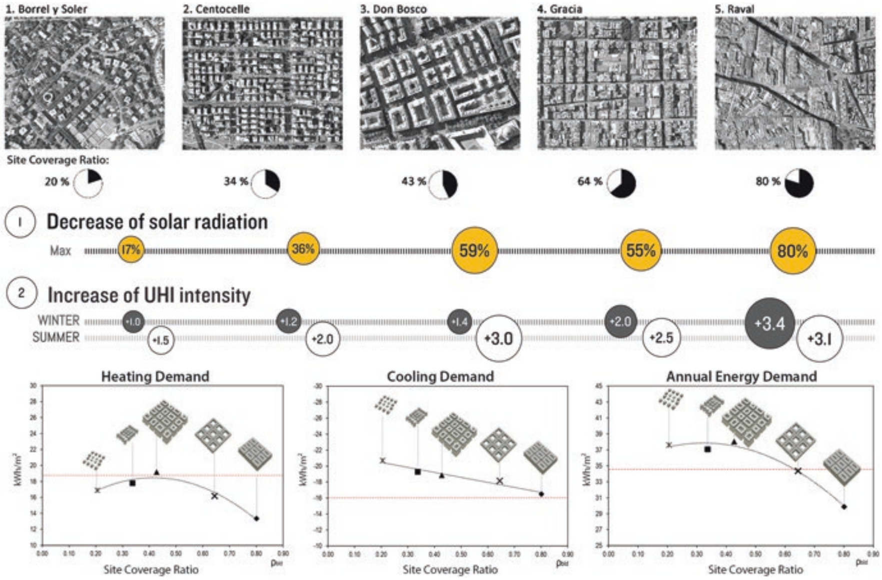

Fig. 6.9 Building heating, cooling and annual energy demand as a function of the urban texture compactness (site coverage ratio—ρ_{bld}), considering the decrease of solar radiation due to shadows and the UHI intensity in winter and summer in the textures analysed. The red line in the graphs is the energy demand of the same apartment in an open-rural context. (Images adapted from Salvati et al. (2016). Originals available at https://doi.org/10.1016/j.egypro.2017.07.303)

The net impact of these two climate modifications on the energy demand of a sample apartment was found to vary significantly with the texture compactness. The results showed a robust (R^2 = 0.95) negative linear correlation between the cooling energy demand and the urban compactness; this means that the building cooling energy demand decreases with the increase of urban compactness, because the obstruction of the solar radiation has a greater positive impact than the increase of the UHI intensity. A non-linear relationship was found between the heating demand and the urban compactness showing that, in winter, the best energy behaviour is found for the texture having medium compactness level. This is explained by the fact that a large reduction of the solar gains in winter has a negative impact on the heating demand but, at the same time, lower level of compactness also entails lower UHI intensity, which is beneficial in winter. The overall annual energy demand resulted in favour of more compact urban textures in this climate context.

6.4.3 Solar Access, Urban Air Temperature, Surface Temperatures and Canyon Wind Speed: Net Energy Impact on Residential Buildings in Rome

A similar parametric study was carried out for Rome, considering the impact of solar access, UHI intensity, urban canyon wind speed and urban surface temperatures on the energy demand of a test apartment in different urban textures (Salvati et al. 2020).

The simulation methodology was based on a chain strategy, using (1) Urban Weather Generator to calculate urban air temperatures and surface temperatures, (2) simplified geometrical models to calculate solar masks on building facades and (3) the URBVENT models for urban canyon wind speed; the set of tools was used to define urban boundary conditions as input to building performance simulations using TRNSYS. The URBVENT models (Ghiaus and Roulet 2004) were slightly modified, as described in detail in Salvati et al. (2020). The URBVENT approach to calculate canyon wind speed is based on the algorithm reported in Fig. 6.10, which allows to select different models based on urban geometry parameters and undisturbed wind speed and direction with respect to the canyon orientation. Five

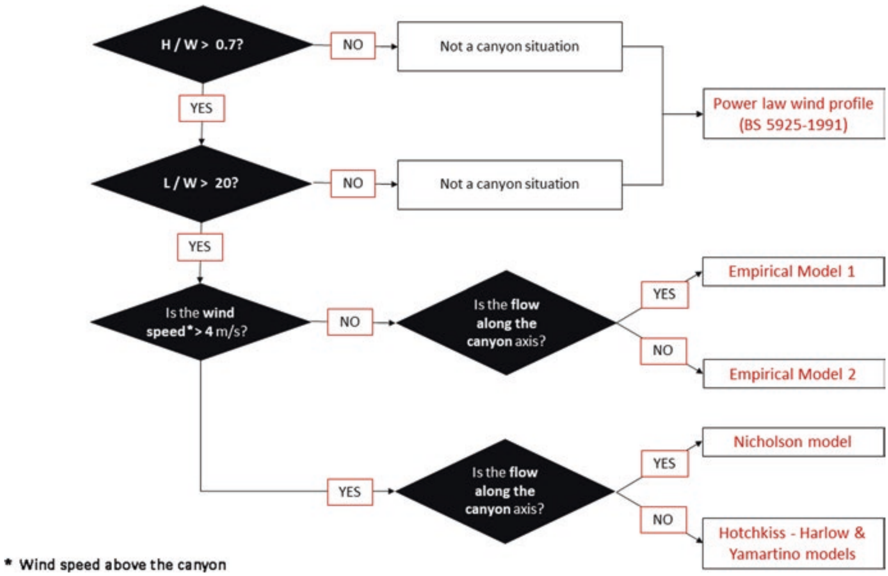

Fig. 6.10 Urban canyon empirical models and algorithm for their application developed for the URBVENT project (Christian Ghiaus et al. 2004). (The figure is from A. Salvati, M. Palme, G. Chiesa and M. Kolokotroni (2020) Built form, urban climate and building energy modelling: case-studies in Rome and Antofagasta, Journal of Building Performance Simulation, 13:2, 209–225, DOI: https://doi.org/10.1080/19401493.2019.1707876, where the models and their applicability are described in detail. The calculation spreadsheet is publicly available at the link https://doi.org/10.17633/rd.brunel.11371272.v1)

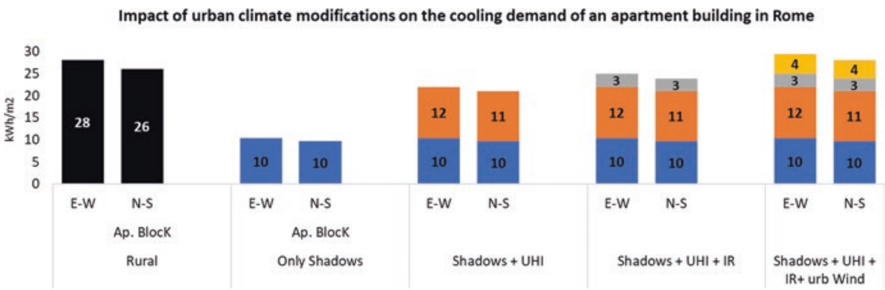

Fig. 6.11 Single impact of different climate modifications determined by an urban context on the cooling energy demand of an apartment building in Rome. (Adapted from A. Salvati, M. Palme, G. Chiesa and M. Kolokotroni (2020) Built form, urban climate and building energy modelling: case-studies in Rome and Antofagasta, Journal of Building Performance Simulation, 13:2, 209–225, DOI: https://doi.org/10.1080/19401493.2019.1707876)

calculation methods correspond to different situations: (1) low-density urban areas (i.e. no-canyon situation), (2) canyon situation with low wind speed parallel to the canyon axis or (3) perpendicular to the canyon axis and (4) canyon situation with undisturbed wind speed >4 m/s parallel to the axis or (5) perpendicular to the canyon axis. This procedure allows to generate hourly urban wind speed data to substitute the undisturbed wind speed values in the weather files for energy simulation.

The microclimate results for the urban context in comparison to an open-rural environment showed that the night-time air temperature is higher, the surface temperature is lower during daytime and higher during night-time and the wind speed is significantly reduced, as well as the solar radiation availability on walls. The energy impact of these climate modifications on the cooling demand of an apartment building located in the city centre is depicted in Fig. 6.11.

The obstruction of solar radiation in dense urban textures determines a significant reduction of the cooling demand (shading systems were modelled for the building in both urban and rural contexts). However, the UHI effect has also a large impact, slightly larger than the reduction due to shadows. A further increase of the cooling demand in urban context is also determined by the reduced infrared exchange with the environment due to higher urban surface temperatures and lower sky view factors and by the reduced ventilation rates determined by lower wind speed in urban canyons. Therefore, the overall energy impact of urban context results to be negative in the summer season, determining an increase of the cooling energy demand. The energy impact of these climate modifications is similar in trend but opposite in sign in the winter season. Therefore, the resulting annual energy demand in urban context is very similar to the one in the rural context, but the share of the heating and cooling demand is quite different, with an increase in cooling and decrease in heating needs in urban context.

Different outcomes can be found for different urban morphologies and locations within the city as well as in different climate regions and depending on the building function (occupancy patterns) and internal gains (Futcher et al. 2013, 2018).

6.5 Heat Mitigation Strategies for Cities and Buildings in Mediterranean Context

To mitigate the UHI intensity in urban areas, three main strategies exist, based on different physical principles: (1) decreasing solar absorption in the urban environment using "cool materials", (2) increasing evapotranspiration using greenery and water and (3) reducing anthropogenic heat from traffic and building air-conditioning systems. The mitigation potential of the different strategies depends on the background climate, namely the amount of solar radiation and precipitation in the hot season and the characteristics of the urban fabric and the buildings' envelope performance (thermal mass and insulation) and HVAC systems. In this last section of the chapter, we briefly discuss how the characteristics of the Mediterranean context, in terms of climate and urban morphology, may influence the potential of some of the UHI mitigation techniques and what strategies should be implemented at the building scale to improve the cooling performance and reduce the need of air-conditioning systems.

6.5.1 Increasing Surface Albedo and Urban Albedo

The first strategy is aimed at decreasing solar absorption in the urban environment by increasing the albedo of surfaces and the global albedo of urban areas. Morini et al. (2018) used the mesoscale Weather Research and Forecasting Model (WRF[11]) coupled with a multilayer Urban Canopy Model to investigate the impact of increasing surface albedo in Rome. The simulations showed that the impact of surface albedo (roofs, walls and paving) on air temperature depends on urban morphology and that, in some cases, increasing surface albedo may have some undesired negative impact on urban microclimate. In fact, urban morphology may reduce the cooling potential of reflective materials due to solar obstruction and radiation trapping phenomena: first, urban morphology decreases the solar radiation upon urban surfaces, roads and facades in particular; as a consequence, the beneficial effect of high-albedo materials is reduced in dense urban textures. Furthermore, urban canyons tend to trap the multiple reflections of solar radiation, vanishing the positive effect of reduced surface temperatures. Studies in the Mediterranean region and other high-radiation regions have found that increasing the reflectivity of building facades and paving may actually increase the mean radiant temperature at the street level, with a negative impact on the outdoor thermal comfort (Alchapar and Correa 2016; Erell et al. 2014; Salata et al. 2015). For these reasons, cool roofs have the highest mitigation potential in compact Mediterranean cities, due to the combined

[11] An overview of the modelling capabilities of WRF coupled with urban canopy models is provided in the chapter "The Coupling of the Weather Research and Forecasting Model with the Urban Canopy Models for Climate Simulations" by Jandaghian and Berardi (Chap. 11).

effect of urban morphology (i.e. elevated roof coverage) and surface albedo in increasing the global urban albedo (Santamouris et al. 2018; Synnefa et al. 2008; Yang and Li 2015). Conversely, the impact of reflective paving and reflective walls should be assessed case by case, as it may vary substantially based on the site urban geometry.

6.5.2 Increasing Vegetation and Comparison Among Different Mitigation Strategies

The second strategy is based on the increase of vegetation and water in urban areas and it also depends on urban morphology and climate background. Due to the dense and compact urban form of Mediterranean cities, the possibility to increase vegetation and trees in a significant amount is scarce, particularly in the historical neighbourhoods. Furthermore, Apreda et al. (2020) showed that increasing vegetation cover does not always determine an improvement of microclimate in Mediterranean climates, depending on the urban morphology. Conversely, in North American cities with similar climate such as Sacramento or Los Angeles, this strategy along with the increase of urban albedo proved to be feasible and successful due to a very different—less compact—urban morphology (Akbari et al. 2001).

In the Mediterranean climate, the mitigation potential of green infrastructure is also limited by the small amount of precipitation and water availability during the summer season, especially in southern dryer locations. In Israel, for instance, it was found that the beneficial effect of daytime temperature reduction is limited to the irrigated green areas (Spronken-Smith and Oke 1998), while large grassy areas can even cause higher daytime temperatures (Potchter et al. 2006) and additional energy expenditures due to the requirement of large quantities of water (Saaroni et al. 2018).

Battista et al. (2019) simulated the impact of urban vegetation, cool pavements, shading systems and water stretch on the outdoor thermal comfort in a square in Rome. The results showed a higher potential of the canopy-shading system to mitigate air temperature, followed by the water stretch, increase of trees and use of cool paving. Interestingly, when the UTCI[12] index was analysed, only the shading system turned out to provide a significant improvement of the outdoor thermal comfort, confirming the dominant role played by solar radiation with respect to air temperature in relation to thermal sensation in this climate zone.

[12] The different thermal indices developed to assess outdoor thermal comfort are described in the chapter "RayMan and SkyHelios Model" by Matzarakis et al. (Chap. 16).

6.5.3 *Reduce Anthropogenic Heat Generation and Increase Passive Cooling Design*

A third, less investigated mitigation and adaptation strategy for urban warmth is the reduction of anthropogenic heat from the buildings' HVAC systems and transport systems. A parametric analysis carried out using UWG showed that the air-conditioning systems may be responsible of up to 1.3 °C rise in urban temperature in summer in the Mediterranean context (Salvati et al. 2017c). Similar findings were found for Singapore (Mohegh et al. 2018), Paris (Tremeac et al. 2012), Phoenix (Salamanca et al. 2014) and Berlin (Jin et al. 2020).

Another parametric study comparing the beneficial effect of different mitigation measures in Mediterranean climates carried out by Palme et al. (2019) confirmed the important role played by anthropogenic heat generation in worsening outdoor thermal comfort.

6.5.4 *Passive Architectural Solutions for Mediterranean Climates*

Looking at the architecture of the past in the southern regions of Europe, many lessons can be learned on how to cope with heat in buildings. The strategies that have been developed over the years in the Mediterranean architecture can take the shape of very different architectural solutions according to local circumstances as regards climate, sociology, available construction technology, cultural tradition and so on. We do not intend to make an exhaustive list of them, but just report a selection of those which best illustrate the wisdom of popular architecture and that should be further developed and applied also in contemporary buildings to improve summer thermal comfort (Coch 1998; Coch and Serra 1996; Coch et al. 1998; Serra 1999):

- Protection from the sun by means of external barriers (vegetation, overhangs, external shutters, louvres and lattices)
- Protection from the sun by means of blinds (*Mediterranean blind*)
- Protection from the sun by means of white finishes on roofs (cold selective surfaces)
- Protection from the sun by means of ventilated air chambers (double roofs)
- Cross-ventilation with continuous openings
- Generated ventilation with wind chimneys, solar chambers or wind conduits
- Treated ventilation with wet surfaces
- Ventilation with underground conduits
- Partial sinking of the building underground
- Opaque, mobile surfaces to block openings
- Insulation in the external side of walls

Another crucial characteristic of any architectural solution to control the indoor environmental conditions is its *flexibility*, which is instead very lacking in contemporary buildings.

As we have already mentioned, temperate climates often have very variable conditions. This complexity can be handled using flexible architectural systems, with elements or combinations of elements that can easily change their environmental action according to the external weather conditions. The most recommended of these flexible systems are:

- Mobile shading systems, such as the typical louvre blind that allows the entry of radiation and ventilation to be controlled simply and conveniently.
- Mobile insulation in the openings, shutters, curtains, etc., which enables the flow of heat and light to be regulated, above all in winter.
- Window types that can be completely opened, permitting maximum control of ventilation and allowing the free passage of air and sunlight when appropriate.
- Intermediate spaces between indoor and outdoor areas, which can generate favourable microclimates: These can also be occupied at different times of the day and the year, thus adding to the building's functional possibilities.

6.6 Conclusion

The many topics discussed in this chapter intended to highlight the complexity of the environmental performance of urban areas, with a specific focus on the peculiar characteristics of compact Mediterranean cities. The aim was to describe the many aspects that need to be considered when approaching the urban scale, even if the objective of the analysis is restricted to "just" the thermal performance of buildings and urban spaces.

In the Mediterranean climate, thermal comfort is a function of solar radiation, humidity and air temperature. These variables are profoundly affected by the dense and compact urban forms typical of this region. Many urban climate studies have been carried out in the last years, bringing more insights on the physics of urban climate phenomena and the correlation with key urban and geographical features. The review of the studies carried out in the Mediterranean climates showed some similarities among the cities in this region. The temperature in urban areas can be significantly higher than surrounding rural areas both at daytime and night-time; the maximum daytime air temperature is often (not always) found in less dense urban areas that have higher solar access, but the maximum night-time air temperature is always found in the densest urban areas in the city centre. Significant intra-urban air temperature differences were observed in all the cities, depending on the location (i.e. city centre or suburban areas or distance from the seashore), the presence of vegetation and, ultimately, the density of the urban area, that plays the major role in most of the cases. Another common finding for large coastal cities is that the moderating effect of the sea and sea breeze on the summer air temperatures is noticeable at the roof level, but it is vanished at the street level at few blocks' distance from the shoreline. Nevertheless, a strong dependence of the UHI intensity on the dominant wind speed and direction was observed in many Mediterranean cities and should be carefully analysed in any future urban climate study.

The UHI intensity, wind reduction and radiation trapping in urban canyons have negative impact on outdoor thermal comfort and building energy performance in this context. The studies presented in the chapter also highlighted that a holistic and multiscale approach is needed to assess the net impact of urban climate on the performance of urban buildings. To this aim, many climate modelling tools already exist, as mentioned throughout the chapter. Due to the complexity of the phenomena involved, there is no complete or perfect tool yet for an effective integration of urban climate modelling into building energy performance analysis and architectural and urban design. Coupling or chaining techniques of multiple simulation tools need to be implemented to investigate the interrelationships between buildings and microclimate in urban areas, with many limitations on the real applicability in the design practice. However, huge advances have been done in the very last years in this field and the knowledge gap between urban climatology and urban and architectural design is shrinking. As architects and building designers, we will keep contributing with our research for the development of more design-oriented tools that could effectively support the work of practitioners in the development of climate and environmentally conscious buildings and cities.

References

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy, 70*(3), 295–310. Retrieved from http://www.sciencedirect.com/science/article/pii/S0038092X0000089X.

Alchapar, N. L., & Correa, E. N. (2016). The use of reflective materials as a strategy for urban cooling in an arid "OASIS" city. *Sustainable Cities and Society, 27*, 1–14. https://doi.org/10.1016/j.scs.2016.08.015.

Apreda, C., Reder, A., & Mercogliano, P. (2020). Urban morphology parameterization for assessing the effects of housing blocks layouts on air temperature in the Euro-Mediterranean context. *Energy and Buildings, 223*, 110171. https://doi.org/10.1016/j.enbuild.2020.110171.

Bastin, J. F., Clark, E., Elliott, T., Hart, S., Van Den Hoogen, J., Hordijk, I., et al. (2019). Understanding climate change from a global analysis of city analogues. *PLoS One, 14*(10), 1–13. https://doi.org/10.1371/journal.pone.0224120.

Battista, G., de Lieto Vollaro, R., & Zinzi, M. (2019). Assessment of urban overheating mitigation strategies in a square in Rome, Italy. *Solar Energy, 180*, 608–621. https://doi.org/10.1016/j.solener.2019.01.074.

Beckers, B., & Masset, L. (2011). *Heliodon 2 documentation*. Retrieved from www.heliodon.net.

Bonacquisti, V., Casale, G. R., Palmieri, S., & Siani, A. M. (2006). A canopy layer model and its application to Rome. *The Science of the Total Environment, 364*, 1–13. https://doi.org/10.1016/j.scitotenv.2005.09.097.

Bourbia, F., & Boucheriba, F. (2010). Impact of street design on urban microclimate for semi-arid climate (Constantine). *Renewable Energy, 35*(2), 343–347. https://doi.org/10.1016/j.renene.2009.07.017.

Bueno, B., Norford, L., Hidalgo, J., & Pigeon, G. (2013). The Urban Weather Generator. *Journal of Building Performance Simulation, 6*(4), 269–281. https://doi.org/10.1080/19401493.2012.718797.

Cantelli, A., Monti, P., & Leuzzi, G. (2011). An investigation of the urban heat island of Rome through a canyon based subgrid scheme. *International Journal of Environment and Pollution, 1/2/3/4*(47), 239–247.

Cantelli, A., Monti, P., & Leuzzi, G. (2014). Development and integration of a subgrid urban surface scheme in a limited area model. *International Journal of Environment and Pollution, 55*(1–4), 230–237. https://doi.org/10.1504/IJEP.2014.065918.

Coch, H. (1998). Bioclimatism in vernacular architecture. *Renewable and Sustainable Energy Reviews, 2*, 67–87. https://doi.org/10.1016/S1364-0321(98)00012-4.

Coch, H., & Serra, R. (1996). Summer comfort solution in Mediterranean areas. *Renewable Energy, 8*, 128–132. https://doi.org/10.1016/0960-1481(96)88831-8.

Coch, H., Serra, R., & Isalgué, A. (1998). The Mediterranean blind: less light, better vision. *Renewable Energy, 15*, 431–436.

Colacino, M., & Lavagnini, A. (1982). Evidence of the urban heat island in Rome by climatological analyses. *Archives for Meteorology, Geophysics, and Bioclimatology Series B, 31*(1–2), 87–97. https://doi.org/10.1007/BF02311344.

Curreli, A., Serra-Coch, G., Isalgue, A., Crespo, I., & Coch, H. (2016). Solar energy as a form giver for future cities. *Energies, 9*(7), 544. https://doi.org/10.3390/en9070544.

Erell, E., Pearlmutter, D., Boneh, D., & Kutiel, P. B. (2014). Effect of high-albedo materials on pedestrian heat stress in urban street canyons. *Urban Climate, 10*, 367–386. https://doi.org/10.1016/j.uclim.2013.10.005.

Futcher, J., Kershaw, T., & Mills, G. (2013). Urban form and function as building performance parameters. *Building and Environment, 62*, 112–123. https://doi.org/10.1016/j.buildenv.2013.01.021.

Futcher, J., Mills, G., & Emmanuel, R. (2018). Interdependent energy relationships between buildings at the street scale. *Building Research and Information, 46*, 829–844. https://doi.org/10.1080/09613218.2018.1499995.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., et al. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet, 386*(9991), 369–375. https://doi.org/10.1016/S0140-6736(14)62114-0.

Georgakis, C, & Santamouris, M. (2005). *Canyon effects: Calculation of wind speed in an urban street canyon with the aid of a semi-empirical model based on experimental data, (May)*. pp. 117–124.

Georgakis, C., & Santamouris, M. (2006). Experimental investigation of air flow and temperature distribution in deep urban canyons for natural ventilation purposes. *Energy and Buildings, 38*(4), 367–376. https://doi.org/10.1016/j.enbuild.2005.07.009.

Ghiaus, C., & Roulet, C.-A. (2004). *URBVENT Natural ventilation in urban areas—Potential assessment and optimal façade design. Workpackage 1: Soft computing of natural ventilation potential. Final Report*. https://doi.org/10.4324/9781849772068

Ghiaus, C., Allard, F., Santamouris, M., Georgakis, C., Roulet, C.-A., Germano, M., … Roche, L. (2004). *URBVENT WP1 final report: soft computing of natural ventilation potential*.

Ghiaus, C, Allard, F., Santamouris, M., Georgakis, C., Roulet, C., Germano, M., … Roche, L. (2005). Natural ventilation of urban buildings - summary of URBVENT project. *International Conference "Passive and low energy cooling for the built environment,"* 1(May), 1109. Retrieved from http://repositorium.sdum.uminho.pt/bitstream/1822/5076/1/Ghiaus_CI_2005.pdf.

Giannaros, T. M., & Melas, D. (2012). Study of the urban heat island in a coastal Mediterranean city: The case study of Thessaloniki, Greece. *Atmospheric Research, 118*, 103–120. https://doi.org/10.1016/j.atmosres.2012.06.006.

Giannopoulou, K., Livada, I., Santamouris, M., Saliari, M., Assimakopoulos, M., & Caouris, Y. G. (2011). On the characteristics of the summer urban heat island in Athens, Greece. *Sustainable Cities and Society, 1*(1), 16–28. https://doi.org/10.1016/j.scs.2010.08.003.

Hassaan, M. A. (2008). Mapping urban heat islands using remotely sensed data Case study: Alexandria city, Egypt. *Bulletin of Faculty of Arts, University of Alexandria*, (October).

Hsie, T.-S. (2008). Achieving Urban Sustainability through Urban Morphology Analyses and Optimum Ventilation. *PLEA 2008—25th Conference on Passive and Low Energy Architecture, Dublin*, (October).

IPCC. (2014). Climate change 2014 synthesis report the core writing team core writing team technical support unit for the synthesis report. Climate change 2014: Synthesis report. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jin, L., Schubert, S., & Mohamed Hefny Salim, C. S. (2020). *Impact of air conditioning systems on outdoor thermal environment during summer in Berlin, Germany (June)*. https://doi.org/10.3390/ijerph17134645

Johansson, E., Thorsson, S., Emmanuel, R., & Krüger, E. (2014). Instruments and methods in outdoor thermal comfort studies—The need for standardization. *Urban Climate, 10*(P2), 346–366. https://doi.org/10.1016/j.uclim.2013.12.002.

Kolokotroni, M., Giannitsaris, I., & Watkins, R. (2006). The effect of the London urban heat island on building summer cooling demand and night ventilation strategies. *Solar Energy, 80*(4), 383–392. https://doi.org/10.1016/j.solener.2005.03.010.

Kolokotsa, D., Psomas, a., & Karapidakis, E. (2009). Urban heat island in southern Europe: The case study of Chania, Crete. *Solar Energy, 83*(10), 1871–1883. https://doi.org/10.1016/j.solener.2009.06.018.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift, 15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130.

Leuzzi, G., & Monti, P. (1997). Breeze analysis by Mast and Sodar measurements. *Il Nuovo Cimento, C, 20*, 343–359.

Linares, C., Díaz, J., Negev, M., Martínez, G. S., Debono, R., & Paz, S. (2020). Impacts of climate change on the public health of the Mediterranean Basin population—Current situation, projections, preparedness and adaptation. *Environmental Research, 182*, 109107. https://doi.org/10.1016/j.envres.2019.109107.

Livada, I., Santamouris, M., Niachou, K., Papanikolaou, N., & Mihalakakou, G. (2002). Determination of places in the great Athens area where the heat island effect is observed. *Theoretical and Applied Climatology, 71*(3–4), 219–230. https://doi.org/10.1007/s007040200006.

Mao, J., Yang, J. H., Afshari, A., & Norford, L. K. (2017). Global sensitivity analysis of an urban microclimate system under uncertainty: Design and case study. *Building and Environment, 124*, 153–170. https://doi.org/10.1016/j.buildenv.2017.08.011.

Martinelli, A., Kolokotsa, D.-D., & Fiorito, F. (2020). Urban heat island in Mediterranean coastal cities: The case of Bari (Italy). *Climate, 8*, 79.

Martin-Vide, J., & Moreno-Garcia, M. C. (2020). Probability values for the intensity of Barcelona's urban heat island (Spain). *Atmospheric Research, 240*, 104877. https://doi.org/10.1016/j.atmosres.2020.104877.

Mihalakakou, G., Flocas, H. a., Santamouris, M., & Helmis, C. G. (2001). Application of neural networks to the simulation of the heat island over Athens, Greece, using synoptic types as a predictor. *Journal of Applied Meteorology, 41*(5), 519–527. https://doi.org/10.1175/1520-0450(2002)041<0519:AONNTT>2.0.CO;2.

Mihalakakou, G., Santamouris, M., Papanikolaou, N., Cartalis, C., & Tsangrassoulis, A. (2004). Simulation of the urban heat island phenomenon in Mediterranean climates. *Pure and Applied Geophysics, 161*, 429–451. https://doi.org/10.1007/s00024-003-2447-4.

Mohegh, A., Levinson, R., Taha, H., Gilbert, H., Zhang, J., Li, Y., et al. (2018). Observational evidence of neighborhood scale reductions in air temperature associated with increases in roof albedo. *Climate, 6*(4). https://doi.org/10.3390/cli6040098.

Moreno-Garcia, M. C. (1994). Intensity and form of the urban heat island in Barcelona. *International Journal of Climatology, 14*, 705–710. https://doi.org/10.1002/joc.3370140609.

Morganti, M. (2018). *Ambiente costruito mediterraneo. Forma densità ed energia*. Monfalcone (Gorizia): Edicom Edizioni.

Morini, E., Touchaei, A. G., Rossi, F., Cotana, F., & Akbari, H. (2018). Evaluation of albedo enhancement to mitigate impacts of urban heat island in Rome (Italy) using WRF meteorological model. *Urban Climate, 24*, 551–566. https://doi.org/10.1016/j.uclim.2017.08.001.

Natanian, J., Aleksandrowicz, O., & Auer, T. (2019). A parametric approach to optimizing urban form, energy balance and environmental quality: The case of Mediterranean districts. *Applied Energy, 254*, 113637. https://doi.org/10.1016/j.apenergy.2019.113637.

Oke, T. R. (1987). *Boundary layer climates* (2nd ed.). London: Taylor & Francis.

Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban Climates*. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781139016476.

Palme, M., Clemente, C., Cellurale, M., Carrasco, C., & Salvati, A. (2019). Mitigation strategies of the urban heat island intensity in Mediterranean climates: Simulation studies in Rome (Italy) and Valparaiso (Chile). *IOP Conference Series: Earth and Environmental Science, 323*(1). https://doi.org/10.1088/1755-1315/323/1/012025.

Papanastasiou, D. K., & Kittas, C. (2012). Maximum urban heat island intensity in a medium-sized coastal Mediterranean city. *Theoretical and Applied Climatology, 107*(3–4), 407–416. https://doi.org/10.1007/s00704-011-0491-z.

Pelliccioni, A., Monti, P., Gariazzo, C., & Leuzzi, G. (2012). Some characteristics of the urban boundary layer above Rome, Italy, and applicability of Monin–Obukhov similarity. *Environmental Fluid Mechanics, 12*(5), 405–428. https://doi.org/10.1007/s10652-012-9246-3.

Petralli, M., Massetti, L., & Orlandini, S. (2011). Five years of thermal intra-urban monitoring in Florence (Italy) and application of climatological indices. *Theoretical and Applied Climatology, 104*(3–4), 349–356. https://doi.org/10.1007/s00704-010-0349-9.

Potchter, O., Cohen, P., & Bitan, A. (2006). Climatic behaviour of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel. *International Journal of Climatology, 26*, 1695–1711. https://doi.org/10.1002/joc.

Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings, 37*(7), 762–776. https://doi.org/10.1016/j.enbuild.2004.10.010.

Rojas-Fernández, J., Galán-Marín, C., Roa-Fernández, J., & Rivera-Gómez, C. (2017). Correlations between GIS-based urban building densification analysis and climate guidelines for Mediterranean courtyards. *Sustainability (Switzerland), 9*, 12. https://doi.org/10.3390/su9122255.

Romero Rodríguez, L., Sánchez Ramos, J., Sánchez de la Flor, F. J., & Álvarez Domínguez, S. (2020). Analyzing the urban heat Island: Comprehensive methodology for data gathering and optimal design of mobile transects. *Sustainable Cities and Society, 55*, 102027. https://doi.org/10.1016/j.scs.2020.102027.

Saaroni, H., Ben-Dor, E., Bitan, A., & Potchter, O. (2000). Spatial distribution and microscale characteristics of the urban heat island in Tel Aviv, Israel. *Landscape and Urban Planning, 48*(1–2), 1–18. https://doi.org/10.1016/S0169-2046(99)00075-4.

Saaroni, H., Amorim, J. H., Hiemstra, J. A., & Pearlmutter, D. (2018). Urban Green Infrastructure as a tool for urban heat mitigation: Survey of research methodologies and findings across different climatic regions. *Urban Climate, 24*, 94–110. https://doi.org/10.1016/j.uclim.2018.02.001.

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., Wang, M., Georgescu, M., et al. (2014). Anthropogenic heating of the urban environment due to air conditioning. *Journal of Geophysical Research: Atmospheres RESEARCH, 119*, 5949–5965. https://doi.org/10.1002/2013JD021225.

Salata, F., Golasi, I., Vollaro, A. D. L., & Vollaro, R. D. L. (2015). How high albedo and traditional buildings' materials and vegetation affect the quality of urban microclimate. A case study. *Energy and Buildings, 99*, 32–49. https://doi.org/10.1016/j.enbuild.2015.04.010.

Salvati, A., Coch, H., & Cecere, C. (2015). Urban morphology and energy performance: The direct and indirect contribution in Mediterranean climate. In M. Cucinella, G. Pentella, A. Fagnani, & L. D'Ambrosio (Eds.), *PLEA2015 architecture in (R) evolution—31st International PLEA conference*. Bologna, Italy: PLEA.

Salvati, A., Coch Roura, H., & Cecere, C. (2016). Urban heat island prediction in the Mediterranean context: An evaluation of the urban weather generator model|Predicción urbana de la isla de calor en el contexto mediterráneo: Una evaluación del modelo generador de tiempo urbano. *Architecture, City and Environment, 11*, 32. https://doi.org/10.5821/ace.11.32.4836.

Salvati, A., Coch, H., & Morganti, M. (2017a). Effects of urban compactness on the building energy performance in Mediterranean climate. *Energy Procedia, 122*, 499–504. https://doi.org/10.1016/j.egypro.2017.07.303.

Salvati, A., Coch Roura, H., & Cecere, C. (2017b). Assessing the urban heat island and its energy impact on residential buildings in Mediterranean climate: Barcelona case study. *Energy and Buildings, 146*, 38–54. https://doi.org/10.1016/j.enbuild.2017.04.025.

Salvati, A., Palme, M., & Inostroza, L. (2017c). Key parameters for urban heat island assessment in a Mediterranean context: A sensitivity analysis using the urban weather generator model. *IOP Conference Series: Materials Science and Engineering, 245*, 8. https://doi.org/10.1088/1757-899X/245/8/082055.

Salvati, A., Monti, P., Coch Roura, H., & Cecere, C. (2019). Climatic performance of urban textures: Analysis tools for a Mediterranean urban context. *Energy and Buildings, 185*, 162–179. https://doi.org/10.1016/j.enbuild.2018.12.024.

Salvati, A., Palme, M., Chiesa, G., & Kolokotroni, M. (2020). Built form, urban climate and building energy modelling: case-studies in Rome and Antofagasta. *Journal of Building Performance Simulation, 13*(2), 209–225. https://doi.org/10.1080/19401493.2019.1707876.

Santamouris, M. (2016). Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change. *Solar Energy, 128*, 61–94. https://doi.org/10.1016/j.solener.2016.01.021.

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A., & Assimakopoulos, D. (2001). On the impact of urban climate on the energy consumption of buildings. *Solar Energy, 70*(3), 201–216. https://doi.org/10.1016/S0038-092X(00)00095-5.

Santamouris, M., Georgakis, C., & Niachou, A. (2008). On the estimation of wind speed in urban canyons for ventilation purposes - Part 2: Using of data driven techniques to calculate the more probable wind speed in urban canyons for low ambient wind speeds. *Building and Environment, 43*(8), 1411–1418. https://doi.org/10.1016/j.buildenv.2007.01.042.

Santamouris, M., Haddad, S., Saliari, M., Vasilakopoulou, K., Synnefa, A., Paolini, R., et al. (2018). On the energy impact of urban heat island in Sydney: Climate and energy potential of mitigation technologies. *Energy and Buildings, 166*, 154–164. https://doi.org/10.1016/j.enbuild.2018.02.007.

Serra, R. (1999). *Arquitectura y climas (I)*. Barcelona: Gustavo Gili, SA.

Serra, C., Lana, X., Martínez, M. D., Roca, J., Arellano, B., Biere, R., et al. (2020). Air temperature in Barcelona metropolitan region from MODIS satellite and GIS data. *Theoretical and Applied Climatology, 139*(1–2), 473–492. https://doi.org/10.1007/s00704-019-02973-y.

Spronken-Smith, R. a., & Oke, T. R. (1998). The thermal regime of urban parks in two cities with different summer climates. *International Journal of Remote Sensing, 19*, 2085–2104. https://doi.org/10.1080/014311698214884.

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society, 93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1.

Synnefa, A., Dandou, A., Santamouris, M., Tombrou, M., & Soulakellis, N. (2008). On the use of cool materials as a heat island mitigation strategy. *Journal of Applied Meteorology and Climatology, 47*(11), 2846–2856. https://doi.org/10.1175/2008JAMC1830.1.

Theophilou, M. K., & Serghides, D. (2015). Estimating the characteristics of the urban heat island effect in Nicosia, Cyprus, using multiyear urban and rural climatic data and analysis. *Energy and Buildings, 108*, 137–144. https://doi.org/10.1016/j.enbuild.2015.08.034.

Tremeac, B., Bousquet, P., de Munck, C., Pigeon, G., Masson, V., Marchadier, C., et al. (2012). Influence of air conditioning management on heat island in Paris air street temperatures. *Applied Energy, 95*, 102–110. https://doi.org/10.1016/j.apenergy.2012.02.015.

Yang, X., & Li, Y. (2015). The impact of building density and building height heterogeneity on average urban albedo and street surface temperature. *Building and Environment, 90*, 146–156. https://doi.org/10.1016/j.buildenv.2015.03.037.

Zinzi, M., & Carnielo, E. (2017). Impact of urban temperatures on energy performance and thermal comfort in residential buildings. The case of Rome, Italy. *Energy and Buildings, 157*, 20–29. https://doi.org/10.1016/j.enbuild.2017.05.021.

Zinzi, M., Carnielo, E., & Mattoni, B. (2018). On the relation between urban climate and energy performance of buildings. A three-years experience in Rome, Italy. *Applied Energy, 221*, 148–160. https://doi.org/10.1016/j.apenergy.2018.03.192.