Chapter 8
Mitigation of and Adaptation to UHI Phenomena: The Padua Case Study

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Abstract Elaborating solutions to counteract UHI effects can represents a relevant challenge for spatial planning and urban design. A specific experimentation has been developed on the city of Padua, analysing different scenarios of urban warming and using specific monitoring tools (Lidar/aerial survey) to define a DIM (Digital Surface Models) providing local situation in terms of green quality and extension, solar incidence/radiation, sky view factors, building materials. This chapter reconstruct the methodology followed during the survey and the elaboration of specific solutions to counteract UHI accordingly different scenarios.

Keyword Urban planning • Local plans • Digital surface models • Climate adaptation

8.1 Introduction

The test developed by the Veneto Region and by the working group of the Iuav University of Venice as part of the European project "UHI – *Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Islands phenomenon*" is based on the territorial peculiarities of the Veneto region's lowlands, mostly characterized by small sized historical centers and the widespread settlements that have developed around them over the last 40 years. This urbanization occurred without strategies or rules as a summation of individual initiatives that amalgamated residential forms and functions with large thoroughfares, as well as production and commercial areas (Selicato and Rotondo 2003).

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In some ways, this process broke the environmental balance of the medieval towns (which were designed keeping in mind local microclimate regulation) often creating an artificial barrier around them, suffocating them, and contributing greatly to raise the amount of impermeable surfaces to the detriment of permeable ones. In recent years, the relationship between urban planning and architecture paid a price for the rigidity dictated by Local Strategic Plans conforming to homogeneous and repetitive rules rather than adapting to the peculiarities of the various land areas (Samonà 1980). As a result, we are dealing with areas that are already rigid and intensely anthropized, with a paucity of characterizing settlements, whose development in the near future may be expected to involve mostly the transformation of the existing tissues. Our test focused on the connection between local climate, urban structure and the emergence of the urban heat island effect, with the purpose of providing land management guidelines for the near future (Musco et al. 2014). Within this framework, we singled out a section of Padua's metropolitan area for analysis and planning, with the intent of applying the results of our tests to the rest of Veneto's central area. Often, the cause for urban heat islands are specific factors (such as large paved areas), which are directly connected to widespread systemic factors (such as the nocturnal dispersion of the heat absorbed by peripheral urban tissues, or pollution from production areas, again located in the suburbs). Such a plurality of causes leads to studying heat islands from different points of view, which are both horizontal and vertical.

Oke's model (2006) approaches this phenomenon by analyzing different urban climate scales, where diverse climate events occur that influence each other:

- Horizontal scale: Microscale, Local scale and Mesoscale;
- Vertical scale (according to different UHI types): *Air* UHI (*Urban Canopy Layer* UCL, and *Urban Boundary Layer* UBL), *Surface* UHI, and *Subsurface* UHI.

The *Urban Boundary Layer* (UBL) encompasses the urban cover layer above the average height of buildings, whereas the *Urban Canopy Layer* (UCL), encompasses the urban cover layer below the average height of buildings. After considering the goals of our projects, namely to analyze the causes of this phenomenon at the microscale level with the intent of coming up with accurate mitigation measures, we proceeded by considering the heat island on the vertical scale encompassed between ground level and the average height of buildings, that is, in the *Urban Canopy Layer*.

This microscale level can help verify the relationship between urban form, roofing materials and UHI, with particular reference to the vegetative cover, soil permeability and albedo of materials. Within this context, the following factors influence microclimate at different urban scales in a significant way: orientation of buildings, surface covering, Sky View Factor (SVF), solar incidence, materials used, and shape of buildings. For example, where building facades are too close to each other, temperatures are affected by the SVF, i.e., they heat up more than other facades located on more open and ventilated roads (which are perhaps no more than thirty or forty yards away).

A recent study shows how urban microclimate affects the functions of buildings in terms of thermal performance, proving that urban form has an effect on the UHI phenomenon (Wong and Chen 2009). Speaking specifically of Italian cities, heat islands are not caused by the anthropogenic heat produced by human activities, but rather by the heat stored by urban surfaces (buildings, roads, parking lots) during the day and then released gradually at night. This effect generates a nocturnal heat island, insofar as the heat released does not allow the city to cool down as much as the rural environments external to it.

The complexity of the UHI phenomenon is directly related to the relationship between city and atmosphere; urban climate and atmospheric climate affect and influence each other (Oke 2006b).

Usually, the aspects that influence climate, generating an urban microclimate that is different from the climate of the atmosphere, (Shahmohamadi 2012) are the following:

– amount of grass, permeable soil, trees, asphalt, and concrete;
– artificial heat released from buildings, air-conditioning systems, cars, and production areas;
– surface water storage and lamination in favor of underground canals and drains;
– air pollution;
– urban ventilation.

Urban heat islands arise from extensive anthropization, or rather, it could be said that the fewer the ecological properties of a city, the greater its heat island will be. It is no coincidence that this effect had already been observed by meteorologist Luke Howard for the first time in 1818, in London, at the height of that city's expansion. At the time, it was not identified as a heat island[1]; the term "island" was coined when isotherms were used to map the city. When air temperatures are mapped through isotherms, the city appears like an island compared to the surrounding rural areas, which are differentiated by lower temperatures. On these bases, we started our project by studying the different behaviors of the urban heat island of pilot experiment city Padua vis-à-vis its different urban contexts. We chose this area also taking into account our purpose of drafting an urban planning manual for the Veneto Region to be delivered to municipal administrations in order to support their future strategic choices in terms of mitigating the UHI phenomenon and adapting vulnerable urban areas to climate changes. Therefore, we picked this area for our study also because it conforms to the urban and spatial characteristics of other cities and areas of the Veneto region.

To conduct urban heat island effect analyses and surveys, we then went on to selecting five pilot areas in the municipality of Padua, based on their location with respect to a survey transect crossing the city along the north-west/south-east axis

[1] The term "urban heat island" was coined in 1958 by Gordon Manley in an essay found in the *Quarterly Journal of the Royal Meteorology Society*.

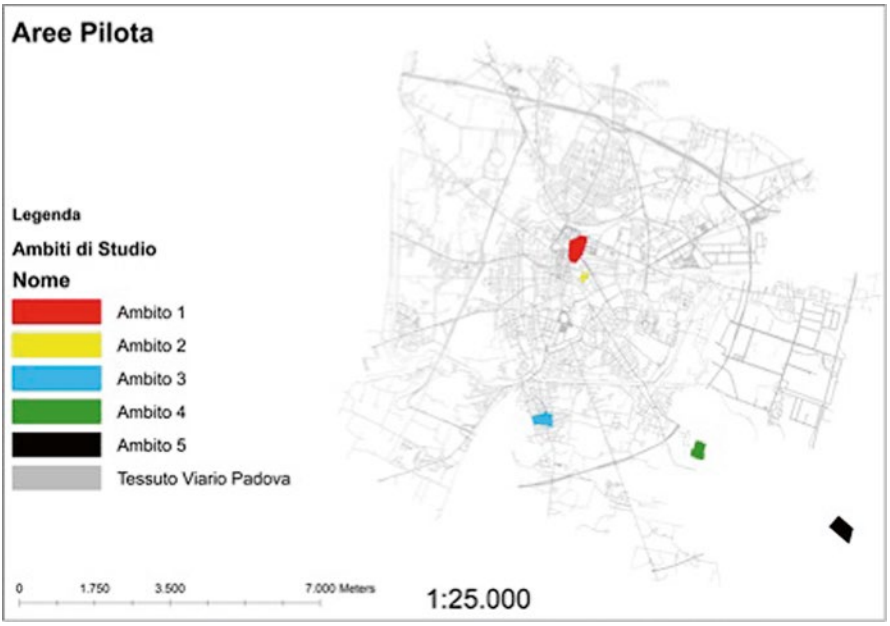

Fig. 8.1 Pilot Areas in Padua

and the intrinsic features of their settlement structure. These features are the following (Fig. 8.1):

Area 1, a dense urban area located inside the medieval historical center;
Area 2, a mixed-use area, ranging from a major river to a large parking lot;
Area 3, a "high density" residential area built in the 60/70s;
Area 4, a "low density" residential area, also built in the 60/70s, located in the first outer ring of the city and consisting of free-standing 1–2 storey buildings;
Area 5, a production area located outside the municipality of Padua.

8.2 Analysis Methods: Traditional Surveys and Remote Sensing

The first part of our project concerned the implementation of an efficient urban heat island study method. We focused our attention right away on producing an urban planning manual that could be used by other municipal administrations. With this in mind, we sought to adopt simple but effective methods. An ideal process of analysis would require atmospheric temperature readings throughout the urban environment.

Temperature represents an important descriptor of UHI behavior; unfortunately however, detectors often are not spread evenly through the urban environment. In Italian cities, the location of temperature and humidity detection devices is often

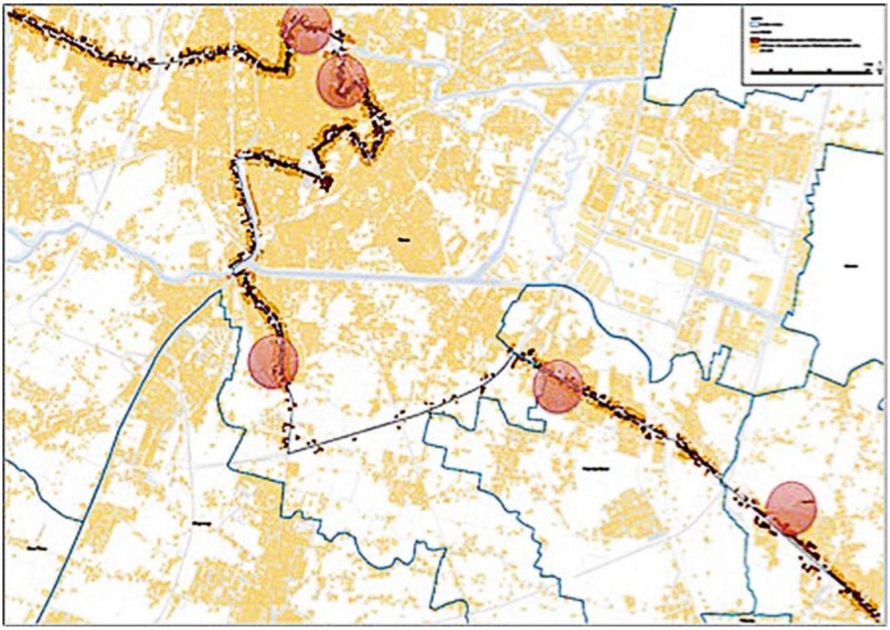

Fig. 8.2 Urban transect used for UHI survey

organized around the monitoring of pollution rather than the microclimate. Due to this lack of information, it was not possible to build a homogenous framework capable of bringing out the causes of urban overheating for the various scales. In addition, some land management data usually available to public administrations do not consider the variables used to identify this phenomenon. As part of our project, the University of Padua research unit measured urban environment atmospheric heat, working to determine the heat island within the city by paying specific attention to the five selected areas described above (Fig. 8.2).

The picture that emerged from our analysis revealed a significant difference in nocturnal temperature between the urban area and the rural area peripheral to the city. A nocturnal heat island that becomes more intense as dawn approaches is already a strong indicator of the causes of urban overheating, mainly due to its morphology and surface types.

Scientific literature (Oke 1982; Santamouris 2005) states that heat islands are caused by anthropogenic factors when developing gradually from late afternoon to night time (namely, resulting from human activities), whereas if they are detected during the night, their formation factors are dependent on the ratio between permeable and impermeable surfaces, materials used and urban ventilation (Papadopoulos 2001).

It was therefore clear from the outset that our analyses and possible strategies should address built-up areas rather than the human activities in and around them.

Our analysis of the existing urban fabric followed the guidelines of the Technical University of Vienna, which has proposed a number of indicators for weighing and quantifying the various UHI production factors (Table 8.1).

We quantified these indexes and compared them to our temperature readings to obtain cogent results that would approximate the real state of things. Thanks to this approach we were able to evaluate the various urban microclimates of the selected areas and single out incidence factors.

For example, the first area that we analyzed showed that heat island production factors are mostly ascribable to the low ratio between permeable – impermeable surfaces and the sky view factor, whereas the fourth area (which we later picked as final pilot area) showed that heat production is mostly ascribable to the type of materials used for buildings. Therefore, it seems obvious that mitigation strategies (and the urban planning tools for implementing project interventions) must be different for the two areas in question.

In order to ensure and maintain the high effectiveness of the proposed interventions and solutions, it is essential that the different overheating causes and issues of each area be carefully identified so as to come up with site-specific strategies. The necessary information for evaluating (and then monitoring) the resilience of an urban area to heat waves were the following:

Paved surface areas;
Permeable surface areas;
Built up surface;
Sky View Factor (SVF);
Urban compactness;
Solar incidence;
Reflectance/albedo of materials;
Thermal conductivity of materials;

Due to the great number of details provided by all this information, we had to come up with an appropriate data collection method for our analysis. Two alternative methods were used; one was a traditional analysis on the field that classified ground covering and building types as well as the height of buildings, the other used remote sensing and three-dimensional data processing from LiDAR[2] and very high resolution orthophotos.

The traditional method allowed us to map the urban tissue and determine the types of materials of all the surfaces, as well as their thermal properties. This activity required a lot of time, spent mainly on the field, but yielded a complete and current set of facts for the area.

[2] Il LiDAR (Laser Imaging Detection and Ranging) performs remote sensing to determine the distance of an object or surface through the emission of high frequency laser pulses by a flying sensor (plane or drone). The distance of an object is given by the length of time elapsed between emission and reception. Very high frequency pulses bouncing from objects or the ground are converted into geo-referenced and dimensioned points, thus giving rise to a “point cloud” from which the exact reconstruction of an area can be created in the form of three-dimensional digital models.

Table 8.1 Main physical parameters and indexs to analyse UHI phenomena

Geometric properties	Symbol	Unit	Rage	Definiation
Sky View Factor	Ψ_{sky}	–	0–1	Mean value of the fraction of sky hemisphere visible from ground level
Aspect ratio	H/W	–	0–3+	Mean height-to-width ratio of street canyons, consider length of streets as a weighting factor
Built area fraction	A_b/A_{tot}	–	0–1	Ration of building plan area to total ground area; fraction of ground surface with building cover
	A_b: building plan area [m^2]			
	A_{tot}: total ground area [m^2]			
Unbuilt area fraction	$1-A_b/A_{tot}$	–	0–1	Ratio of unbuilt plan area to total ground area; fraction ground surface without building cover
Impervious surface fraction	A_i	–	0–1	Ration of unbuilt impervious plan area (paved, sealed) to total ground area
Pervious surface fraction	$A_p=(A_e+A_g+A_{H2O})$	–	0–1	Ration unbuilt impervious plan area (bare soil, green, water) to total ground area
	$A_{e: earth}$	–	0–1	Bare soil area
	$A_{g: green}$	–	0–1	Green area
	$A_{H2O:water}$	–	0–1	Water bodies area
Mean building	I_c	M	–	Ration of built volume (above terrain) to total building plan area
	$I_c=V_b/A_b$[m^3/m^2]			
	V_b: built volume [m^3]			
Built surface fraction	A_s/A_b	–	>1	Ration of total built surface area (above terrain) of building (walls and roofs) to total built area
	A_s: total built surface area [m^2]			
	A_W/A_b	–	>1	Walls
	A_W: total wall area [m^2]			
	A_R/A_b	–	~1	Roofs
	$A_R=(A_{R,i}+A_{R,p})$			
	A_R: total roof area [m^2]			
	$A_{R,I}/A_b$	–	~1	Impervious roofs
	$A_{R,I}$: total impervious roof area [m^2]			
	$A_{R,p}/A_b$	–	~1	Pervious roof
	$A_{R,p}$: total pervious roof area [m^2]			
Mean sea level	H_{sl}	m	–	Average height sea level

(continued)

Table 8.1 (continued)

Surface/material properties	Symbol	Unit	Range	Definition
Reflectance/albedo	P_{sw}	–	0–1	Mean value of albedo (shortwave)
Thermal conductivity	$\lambda=(\lambda_i+\lambda_p)$	$W.m^{-1}.k^{-1}$	>0	The property of a material's ability to conduct heat
	λ_i: impervious surface	$W\text{-}m^{-1}.k^{-1}$	>0	Thermal of a material's ability to conduct heat
	λ_p: pervious surface	$W.m^{-1}.k^{-1}$	>0	Thermal conductivity of pervious surface
Specific heat capacity	$c=(c_i+c_p)$	$J.kg^{-1}.k^{-1}$	>0	The amount of heat required to change a unit mass of a material by one degree in temperature
	C_i:impervious surface	$J.kg^{-1}.k^{-1}$	>0	Specific heat capacity of impervious surface
	C_p:pervious surface	$J.kg^{-1}.k^{-1}$	>0	Specific heat capacity of pervious surfaces
Density	$\rho=(\rho_i+\rho_p)$	$Kg.m^{-3}$	>0	The mass density of a material is its mass per unit volume
	ρ_i:impervious surface	$kg.m^{-3}$	>0	The mass density of impervious surfaces
	ρ_p: pervious surface	$Kg.m^{-3}$	>0	The mass density of pervious surfaces
Anthropogenic heat output	Q_F	$W.m^{-2}$	>0	Mean annual heat flux density from fuel combustion and human activity (traffic, industry, heating and cooling of buildings etc.)

Proposed variable for the specification of an urban unit of observation (U2O)
DOCUMENT WP5-UHI-01_112012
WP 5, authors: A, Mahdavi, K. Kiesel, M. Vuckovic (November 5th, 2012)
Main reference:

Mahdavi, A., Kiesel, K., Vuckovic M. (2013). *A framework for the evaluation of urban heat island mitigation measures.* SB13 Conference, Munich, Germany.
Stewart, I. D., & Oke T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*.
Unger, J., Savic, S., & Gal, T. (2011). Modeling of the annual mean urban heat island pattern for planning of representative urban climate station network. *Advances in Meteorology, 2011*, 1–9.
Hens, H. (2007). *Building physics – Heat, air moisture.* Ernst & Sohn, Berlin.

The remote sensing method required less time to collect the data and yielded useful information to describe and map the phenomenon. Depending on the information, computers and technology available to individual local administrations, this method could be applied easily and quickly to the whole of the Veneto region.

Remote sensing analyses require LiDAR data and high resolution orthophotos (0.2–0.5 m per pixel), preferably including the infrared band, for the entire administrative area.

For each selected area, this methodology allowed us to find out the sqm of vegetation (divided by height), the ratio between permeable and impermeable surface, the incident solar irradiation, and the sky view factor (Berdahl and Bretz 1997). Technically, the analysis involved the creation of three-dimensional digital models of the terrain, DSM (Digital Surface Models) and DTM (Digital Terrain Models), which made it possible to identify and inventory the composition of urban surfaces. By adding the DEM (Digital Elevation Models) obtained by processing the LiDAR data with the multispectral orthophotos, we also got to an automatic breakdown of the horizontal surfaces of the city by type and height, resulting in an atlas of surfaces composed of green spaces, with their respective heights, and impermeable spaces (buildings, roads, parking lots).

Next, we used software like *LAStools*, *Saga Gis* and *eCognition* to produce sky view factor and solar irradiation maps, which most importantly provide essential information to determine the specific areas that require intervention, in addition to which interventions should be performed to mitigate the UHI phenomenon and adapt the urban environment to climate changes.

The key strength of these innovative analysis techniques is that they can be replicated over very extensive urban areas, whose level of detail would require months to obtain with traditional topographical detection methods. However, we must realize that not all areas are equipped with LiDAR or similar detection devices, which means this methodology is still used in limited areas despite the fact that it is innovative and efficient (Figs. 8.3, 8.4, 8.5, 8.6, 8.7, 8.8 and 8.9).

The collected information, converted into vector format, can be queried using height and covering type data. Breaking down the city in all its three dimensions, we can identify the areas that are most vulnerable to heat waves, and also adapt portions of the city to the extreme weather phenomena, suggesting some possible strategies to achieve that goal. So as to test and evaluate the efficacy of the interventions, we then proceeded to build four different transformation scenarios of the area under study.

The four scenarios, and their specific interventions, which resulted from the integration of accurate temperature readings and the indicators research, were then processed using the *ENVI-met* software, which simulates air temperature changes based on the physical changes proposed within a selected area. It can therefore verify and indicate mitigation strategies for the UHI phenomenon by showing the results of the proposed interventions. For example, this simulator can show what benefits would be derived from adding trees to an actual area or modifying the albedo of some of its surfaces. *ENVI-met* can not only verify the effectiveness of an intervention but also the optimal location for its application.

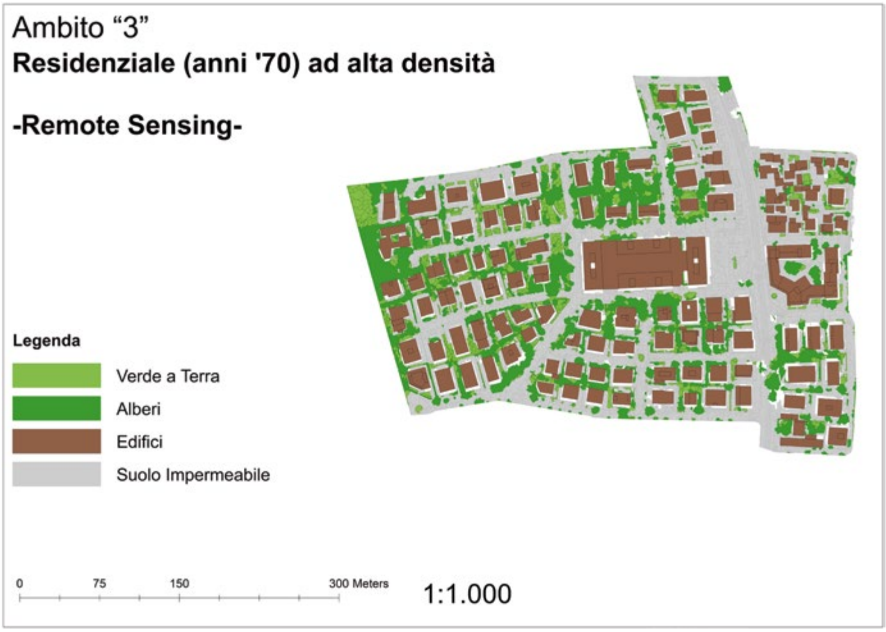

Fig. 8.3 Hight desnity residential building neighbourhood (1970's) Remote sensing survey (green areas, trees, buildings, surfaces)

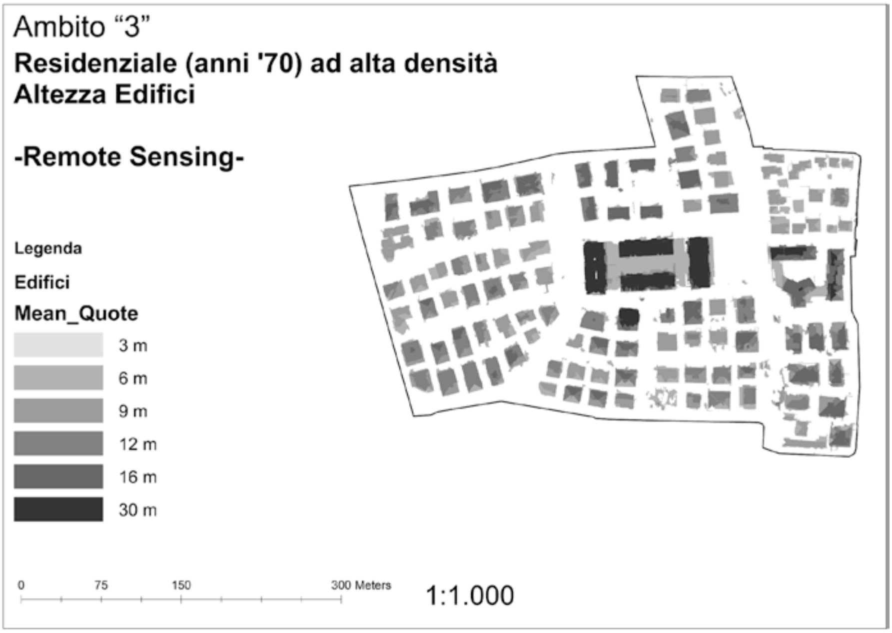

Fig. 8.4 High density residential neighbourhood (1970's) Bulding Height

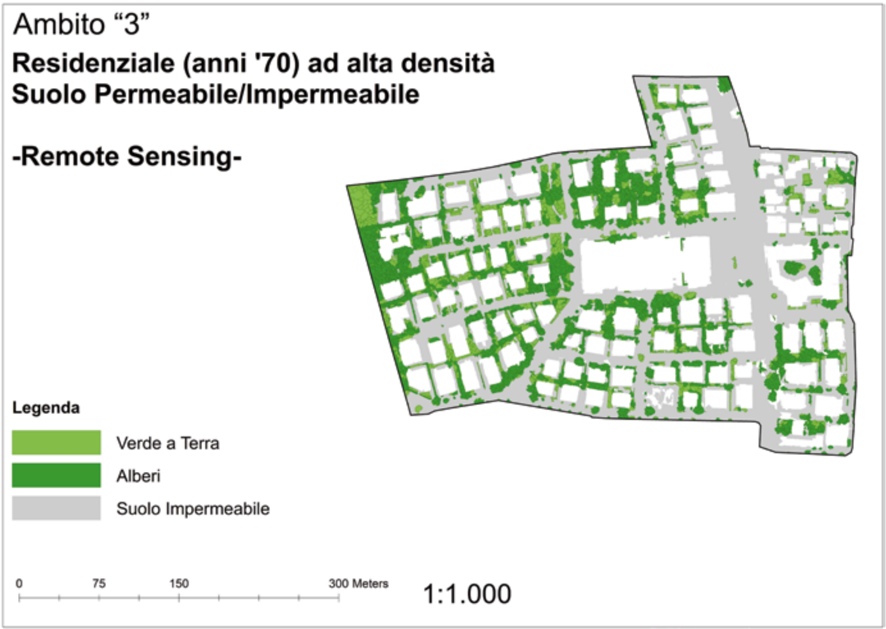

Fig. 8.5 High density residential neighbourhood (1970’s) Permeable/Water proof surfaces

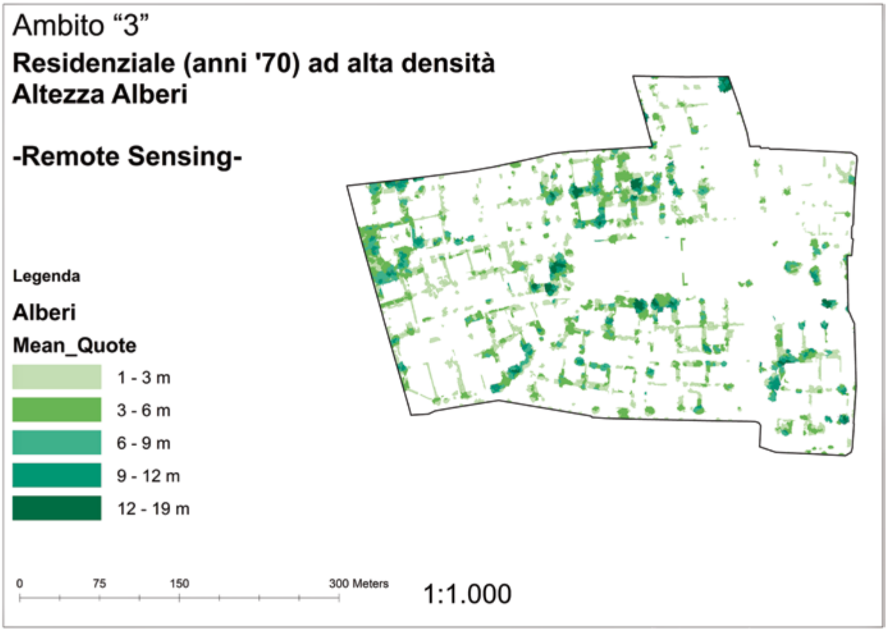

Fig. 8.6 High density residential neighbourhood (1970’s) Trees Hight

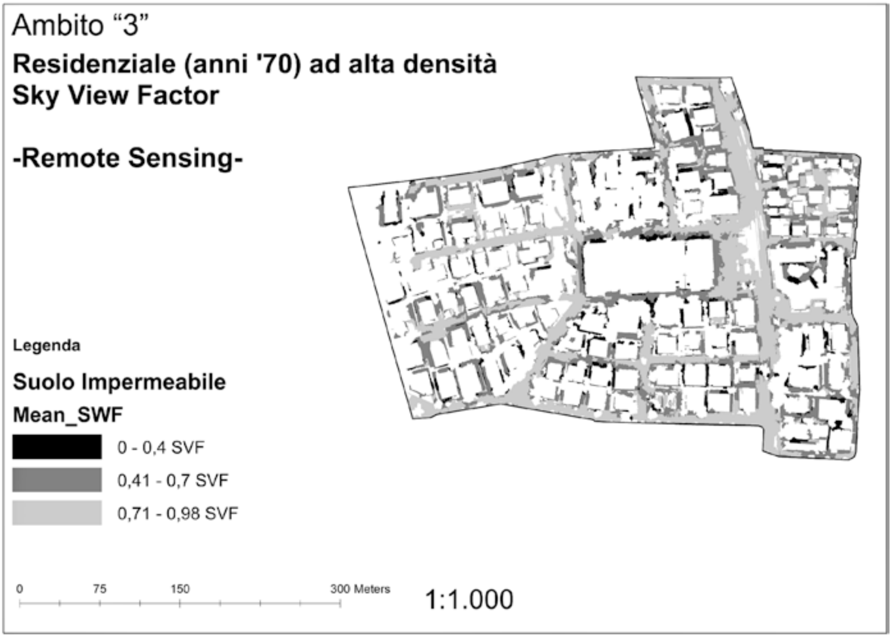

Fig. 8.7 High density residential neighbourhood (1970's) Sky view factor

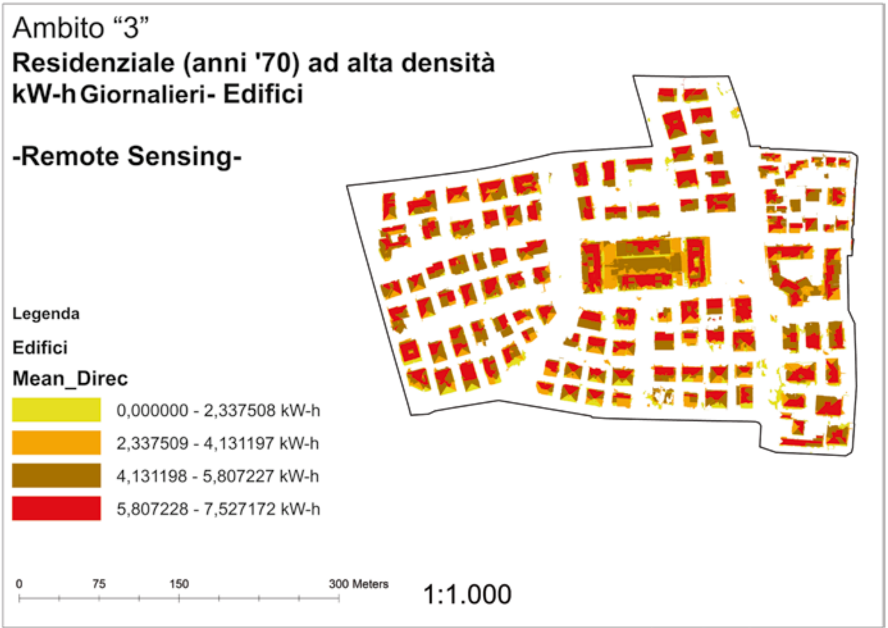

Fig. 8.8 High density residential neighbourhood (1970's) Daily kW/h/buildings

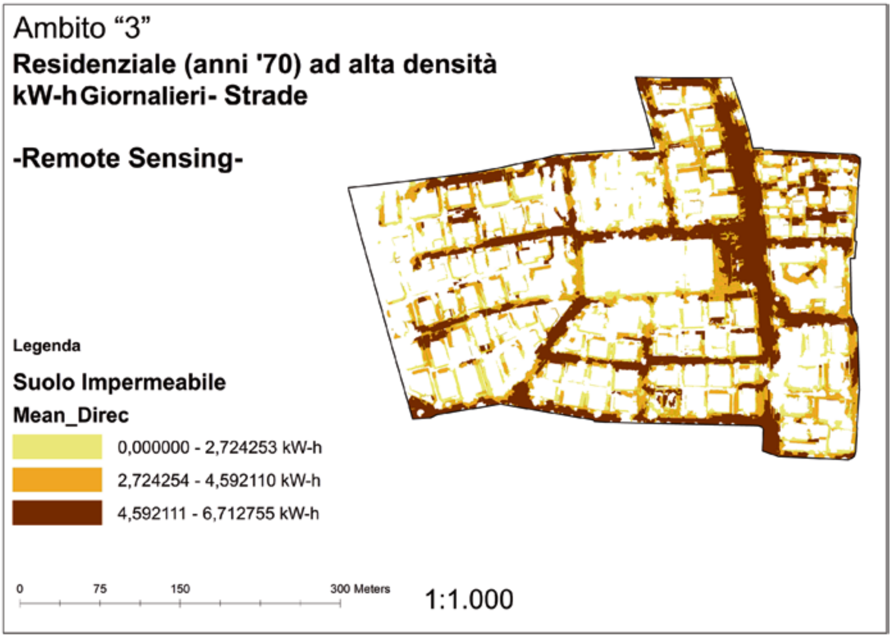

Fig. 8.9 High density residential neighbourhood (1970's) Daily kW/h/roads

8.3 Feasibility Study

After processing the data pertaining to the areas inside the survey transept, it became necessary to understand what mitigation and adaptation interventions should be considered based on the morphological aspects of this specific neighborhood of the city of Padua, including buildings, outdoor public spaces, and private spaces.

The integration of these sets of interventions produced the "transformation scenarios" that were later tested for effectiveness with the *ENVI-met* software.

Through this process, we initiated an actual project for the pilot area, by adapting to it specific mitigation measures that until then had been generic proposals for other areas. As a result of the preliminary project test performed inside the pilot area, we came up with four different project scenarios as follows:

"green ground": **a scenario where the permeable surface of the area is increased (from 18 % to 23 %) by turning a paved parking lot into a grass surface and planting 10 m tall trees along the main roads of the area;**

"cool pavements": **substituting the traditional paving material (0.2 albedo) and concrete (0.4 albedo) used on streets and sidewalks with high albedo (0.5) "cool" materials;**

"cool roofs": **substituting the traditional tile or covered flat roofs with "cool" materials (0.3 to 0.6 albedo);**

"green ground + cool pavements": **a scenario that adopts both these mitigation interventions simultaneously.**

The precision of the digital terrain model, obtained through the use of *LiDAR* and orthophotos data, made it possible to increase the number of details with which to perform the effectiveness measuring simulations in terms of temperature reduction, using the various mitigation interventions considered for each of the four scenarios.

The subsequently performed simulations allowed us to close the working cycle through the virtual testing of the interventions under consideration, thereby assessing the best strategies for the pilot area.

The fourth scenario, *"green ground + cool pavements"*, tested with the *ENVI-met* software, provided the best results from the point of view of temperature reduction. Based on this, we used this scenario for our project.

8.4 The Pilot Area as Testing Ground for the Veneto Region

The scenario we selected for the pilot area is aimed at increasing resilience to negative externalities caused by climate variability. This urban green infrastructure plan becomes a driving force for the adaptation of urban and regional systems to climate changes.

A network of natural and semi-natural areas has a good ability to make the land more resilient; if well designed, green infrastructure can mitigate the effects of floods and the increasing droughts, improve water and air quality, effectively promote soil protection, and oppose hydrogeological instability. In addition, it ensures air filtration, erosion protection, water flows regulation, coastal protection, soil structure maintenance, and carbon storage.

The multiple benefits of green infrastructure are also set forth in the European strategy for green infrastructure published last year (EU 2013). For example, trees and green areas may prevent flooding in cities while reducing air pollution and noise levels. Furthermore, the use of natural systems can often be cheaper and more durable than a hard artificial structure.

However, we have yet to understand how to apply these changes to a real area. Veneto's central area, having been greatly transformed over the last 40 years, mostly through a series of small spread out interventions, requires a specific design approach. By the same talking, the pilot area transformation project produced by our feasibility study can be implemented through small interventions that will be made presumably over a period of about 20 years.

Our project and its graphical representations provide a potential scenario that can presumable be striven for. Its mitigation measures against the heat island effect can be effectively used in the first place through the adoption of appropriate land and urban management and planning tools that can implement the new adaptation priorities arising from climate changes.

Based on this, in order to make our mitigation measures as applicable as possible, our work group performed a survey of the existing land management and planning tools, linking each measure to a potentially modifiable planning tool (Table 8.2).

Table 8.2 Ordinary urban planning and management tools: possible UHI moderation interventions

GROUND SURFACES	Intervention	Main regulating body	Tool (for urban planning or managment)	Indication type	Notes
Management of the Reflectance and Emissivity of impermeable surfaces for public and private spaces	(1) Pigmentation type	Municipal Administrations	Municipal urban plan (the name will change according to the specific regional legislation)	Indications on the surfaces of each ordinary transformation area	The pigmentation of existing pavements should be modified gradually
	(2) Material type				New surfaces should employ materials that combine greater reflectance and a low impermeabilization rate
			Ordinary and extraordinary maintenance plan	Reflectance parameters of existing surfaces	
			Infrastructure plan	Reflectance parameters of new infrastructure surfaces	
			Building regulation	Reflectance parameters of surfaces of new private and public buildings	

Source: *IUAV data processing, 2014*

8.5 Possible Transformations of the Pilot Area

The possible transformations/interventions proposed below refer to the previously analyzed *"green ground + cool pavements"* scenario. We took the basic pattern used for *ENVI-met* modeling and came up with a number of potential transformations for the pilot area.

These possible interventions are not part of a single urban planning project, but they are structured rather as small interventions to be implemented through the use of the urban planning tools analyzed above (see Table 8.2).

It should be noted that the proposed interventions can be effective on their own in mitigating the heat island effect; however, more specifics are needed on the areas they are going to be applied to, so as to make effective and cost effective decisions. Maximum effectiveness can be reached when all of these interventions together become part of a general strategy of adaptation to climate changes combined with the more important urban and/or socio-economic concerns of a given area.

Intervention 0 actual conditions + summary of intervention 0 actual conditions.

8.5.1 Outdoor Public Spaces

The first intervention posits an increase in the reflectance of the road surface. This can be done by means of several types of materials. Two technical options may be considered: the more immediate one would be acting on the pavement's coloration/pigmentation, the other would involve a more structured approach of asphalt type modification. This type of intervention can be planned on a municipal scale over a set period of time, for example, the years it would take to pave everything over and remanufacture some types of streets signs. For the sake of economic sustainability, it would make sense to prioritize such interventions by area with the aid of specific maps. For larger cities, the mapping process can be integrated with urban heat studies, using direct readings or indirect photogrammetric data processing. Municipalities that do not have access to complex analyses of urban heating phenomena can prioritize their most densely occupied areas, and also apply the indexes suggested by the University of Vienna for this specific project (Figs. 8.10 and 8.11).

The second intervention also concerns the reflectance of impermeabilized urban surfaces; however, in this case, the spaces considered – sidewalks, parking lots, and city squares – do not involve car traffic. These surfaces, like the ones we just discussed, need to be approached according to a set of urban planning priorities. Modifications will necessitate the application of street furniture programs that will include reflectance limits to the repaving of city squares and sidewalks. For the application of this intervention inside the pilot area, we considered also parking lots and street side parking areas, which are normally paved, and which will have to be handled using a different approach, like more permeable materials for improved absorption of rainwater (Fig. 8.12).

Fig. 8.10 Intervention 1 + summary of intervention 1
Modify the albedo of streets. Modify the reflectance of the road surface

Fig. 8.11 Intervention 2 + summary of intervention 2
Modify the albedo of sidewalks and parking lots. Modify the reflectance of sidewalks and parking lots

Fig. 8.12 Intervention 3 + summary of intervention 3
Add *green areas* on the ground of public spaces in addition to public trees

8.5.2 Public Green Spaces: Create New Traffic Islands and Plant New Trees

The third intervention focuses on increasing public green spaces. Here too, we are not talking about great new parks or large green areas; these are micro interventions that can be applied in a city with a consolidated infrastructure. Practically speaking, it is about creating new traffic islands and planting new trees. These interventions necessitate an innovative approach based on a new public space management vision. At present, for most Italian cities to add new trees and traffic islands in urban areas where everything has already been built could involve an increase in maintenance costs and a loss of needed urban space (for car, bicycle, and pedestrian traffic, parking, etc.). This is why this new approach would have to be adopted as part of a strategic paradigm shift in the general management of city spaces. Creating new green spaces inside the context of a built up city entails changing one's perception of street space as just for transit, parking, and car maneuvering. A new paradigm for the use of public green spaces requires a strategic rethinking of urban greenery, insofar as what it can offer in terms of the urban ecosystem adapting to climate changes. Going down this road means understanding and valuing the gamut of services that green spaces can offer to mitigate the heat island effect in addition to other negative externalities due to weather phenomena: lamination for the containment of water during extended rainfall, reducing air pollution, helping to reduce the speed of urban traffic, and even a general improvement in the environmental and aesthetic quality of public spaces. New traffic islands were added inside the pilot area along the streets whose width could reasonably be reduced or that could be switched from two-way to one-way traffic. We also added a green area on a space used as a square along Via Guizza.

8.5.3 Private Outdoor Spaces

The management of private outdoor spaces is also a major factor in determining the occurrence and intensity of urban heat islands. Depending on the type of settlement, a significant portion of Veneto's cities that is not covered by buildings is private property; in the case of Padua's pilot area, private property covers more than 1\3 of the total surface.

It is obvious that the management of these surfaces is greatly relevant to the mitigation of the heat island effect. However, in this case, even a simple technical solution (increasing the green surface and the reflectance of impermeable surfaces) must be justified at the management and legislative level; a cogent response is necessarily based on a general strategic vision that can harmonize individual management needs with the understanding of the importance of adapting to climate changes. Private outdoor spaces can easily be handled when it comes to new buildings, where building codes can set new extension and surface type parameters, but they require a much more thorough consideration for consolidated urban areas, as is the case of the pilot area, since it is more difficult to find legislative levers or incentives to modify already built property.

In these cases, implementation can be achieved through the following:

- come up with education programs for the city's inhabitants, so that the more sensitive section of them may be stimulated into performing ordinary maintenance of their private spaces;
- coordinate with the water department to establish incentive policies where bill payments reflect how much of a property is impermeabilized.

Within the pilot area, we proposed to modify only the reflectivity of the private surfaces currently impermeabilized by asphalt, concrete or the like with intervention 4, whereas with intervention 5 we proposed to replace them with greenery (Figs. 8.13 and 8.14).

8.5.4 Post-scenario Intervention

The last project intervention on the pilot area takes a step beyond the interventions encompassed by the feasibility study, proposing a more incisive transformation that involves buildings as well.

Fig. 8.13 Intervention 4 + summary of intervention 4
Albedo on private paved surfaces. Modify the reflectance on private surfaces

Fig. 8.14 Intervention 5 + summary of intervention 5. Put greenery on private surfaces
Add green areas on private surfaces

Fig. 8.15 Intervention 6 + summary of intervention 6. *Green roofs*: extra scenario intervention

This intervention pictures a gradual transformation of the roofs of private buildings, first by modifying the reflectance of flat surfaces and then by turning them into green roofs. A real expansion of green roofs can only occur if our cities will understand and assess their value in terms of the services that they can offer to the community: mitigation of the heat island effect, lamination of rainwater, improvement of air quality, and last but not least, recreational use.

This final scenario is not meant to offer a new utopian vision of what a city should be like, but it is rather an attempt to propose the application of solutions that would adapt the current state of affairs to a no longer so remote future of rapid climate changes.

To increase concretely the resilience of our urban system to climate changes, such as in the case of heat island mitigation demonstrated by this project, we must utilize several approaches: in-depth climate evolution studies on the regional and local scale, the use of climate modeling, the use of new technologies as a support for urban planning, the research of new building materials, the revision of the urban governance system, and above all the creation of a new strategy to review and harmonize all the aspects of the matter (Fig. 8.15).

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Focus A: Energy and Urban Form

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Nowadays, the population which can be considered an urban population exceeds 50 % of the total with areas where the percentage reaches 80 %. This process of urbanization of the population, combined with the potential impacts of climate change induced by the anthropogenic component (IPCC 2007), provides a new impetus to efforts to understand how the forms, functions and resources interact within urban environments. In some cities, energy consumption per capita has grown at approximately the same rate as spatial growth (Baynes and Bai 2009). From a point of view of urban metabolism, energy therefore represents one of the most critical resource flows for the life of a city, since it is a primary factor in supporting physical and economic systems (Alberti 1994). Considering then that the growing global contribution to GHG emissions of cities (Bai 2007), addressing global climate change bringing it down to an urban level acquires strategic interest, as it provides greater effectiveness of intervention: energy consumption, urban form, density and morphology if correctly associated, may provide the opportunity to address the issue of climate locally. Much of the literature available, for example, Williams et al. (2000), Jenks and Burgess (2000) and Foley (2005), Oke (2006),

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focus on the issue of mitigation considering it a driver of urban sustainability. Better planning, better design of spaces and urban forms, should be able to both mitigate climate change, and ensure a gradual process of adaptation to reduce the direct and indirect impacts of climate change on cities.

The approach to mitigation carried out so far to reduce GHG emissions, has been focused primarily on the production of energy from renewable sources, energy savings of buildings, "green" technologies for industrial production, alternative fuels with a higher efficiency for vehicles, and an increase in public transport. It has focused less on the study of urban form and the role it plays in an energy strategy for the conservation and efficient use of this resource.

The globalization of the construction industry and the total delegation of the indoor systems and plants has in fact determined, in the last century, an increasingly pervasive realization of approved buildings and urban structures barely related to their climatic context, cultural material. "The same buildings can be found from Stockholm to Nairobi, from Shanghai to Sao Paulo, with age-old design principles simply eliminated" (Butera 2004): a challenge for nature set by man, to prove that he can live indifferently in any context and in any climate.

If we take a broader view, which embraces and considers the territory as a geometric area of energy consumption (Olgyay 1951), we must consider that urban planning aimed at energy saving and sustainability must be sensitive to local conditions and able to exploit the resources that the environment provides. The end result of this approach is expressed naturally in architectural forms and urban structures, contextualized by morphology, type, use of materials. This does not necessarily mean that they should be vernacular or traditional, given that typological, morphological and technical-constructive solutions evolve over time as new requirements emerge and new materials and new building systems are introduced. We must also take into account on the fact that the use (and waste) of energy does not only depend on the use of the individual buildings and their systems, but often on the way in which these have been designed and arranged in relation to each other. For example, the layout of a building on the land, its position in relation to the prevailing winds, the path of the sun and the reciprocal relationship with other surrounding buildings can prevent the sunlight needed from reaching it, creating barriers to hot winds and vice versa channelling the cold winds, leading to an inefficient use of energy. It is very rare that building regulations or urban-building standards for the implementation of planning regulations contain directives aimed at ensuring environmental conditions which are conducive to energy saving for temperature regulations.

Therefore, urban planning policies that are sensitive to reducing energy consumption and comfort, related to the use of the spaces within a city, must be based on a bioclimatic approach, which aims to simultaneously control three interconnected levels: environmental-climatic, typological and

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technical-constructive which, if studied in sufficient detail, can provide the following information:

- with regards to the control of aspects relating to the relationship between a building and the environment, planning and architecture (especially that related to temperate climates) have always had to deal with a climate characterized by significant seasonal changes (temperature, humidity, wind, solar radiation) which therefore encourages and imposes solutions capable of adapting to these seasonal variations. In addition to the climate, individual buildings must also respond to the microclimate of the area, i.e. the specific features of individual sites also in relation to the shape of the urban constructions or landscape (which influence, and sometimes change, the typical climatic conditions such as temperature, humidity, wind speed and solar radiation, distinguishing a single context with local conditions).
- with regards to the control of the typological aspects, buildings must be characterized by a search for balance between a compact form in winter (based on the more advantageous ratio between surface and volume in relation to heat loss) and a more open form in the summer (based on the possibility of favouring natural ventilation), with “open-closed” structured spaces for winter/summer use (porches, balconies, patios, filter spaces). For example, the typical Mediterranean building is a home with a patio, compact but “porous” (Olgyay, 1998). The in-line or terraced type house is equally effective, allowing compactness to be favoured (seen as support-type housing), but also to identify two preferable exposures, namely south facing (so that sunlight can be exploited in the winter months) and north facing (to have a “cool” side in the summer triggering the natural ventilation throughout the building).
- for the control of the technical-constructive aspects, an urban structure must be characterized by the passive use of energy thanks to the exploitation of sunlight both directly (windows) or indirectly (heat storage units) and by the presence of an adequate capacitive mass (and thermal inertia) to retain heat and mitigate temperature peaks (reducing and off-setting the introduction of the thermal wave) in the summer. Therefore, building orientation, building shape and cladding characteristics are the aspects on which designers should focus more carefully. A building which exploits the characteristics surrounding it is defined as “passive”, which should be distinguished from those buildings which artificially (and therefore “actively”) construct comfort within the rooms (not to be confused with the term “*passivhaus*”, which refers to an energy standard). A passive urban structure combines the ability to use favourable climatic factors (capturing solar energy in winter, directing air flows in the summer) with the ability to maintain favourable conditions (storing heat in winter and night-time cold in summer) and hamper unfavourable conditions without resorting to costly and energy-intensive additions to the system.

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It is therefore the designer and/or planner who, on different levels, who is called upon to deal with the issues related to the regulations, the shape of the urban structures, the orientation of the buildings, the cladding and systems, and therefore work towards reducing energy consumption and ensuring suitable living comfort.

Therefore, designing buildings today, with a climate which is changing constantly, means understanding the reasons related to the microclimate, resources and local materials. Planning in these geographical areas does not require a strict adherence to architectural shapes of traditional buildings, but rather an innovative reinterpretation of the reasons which have "naturally" driven construction for centuries.

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Focus B: Using Aerial Photogrammetry for Urban Sustainability Analysis

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The ongoing climate change and energy issues are among the most important challenges that city planning, zoning, and architecture are now facing.

Limited resources and the economic crisis aggravate the difficulties of intervention, forcing one to identify multifunctional interventions for combined solutions to different problems and needs (Musco et al. 2013).

In recent years, there has been considerably growing interest in alternative and renewable forms of energy supply (Pearce 2002); at the same time, the difficulties experienced by cities in resisting the effects of climate change are steering Public Administrations toward formulating integrated policies in order to decrease CO_2 production and simultaneously increase the land's resilience to climate change (Musco 2008).

The ensuing difficulties lead one to analyze urban environments using the most advanced technology and the best tools available.

We introduce an example of applied methodology, where, using a point cloud generated by a photogrammetric technique, we will consider what buildings are most suitable for installing a PV system and which areas are most affected by solar incidence (Wilson et al. 2000).

Thanks to recent advances in photogrammetry Hardware and Software (Hirschmüller 2008), by using stereoscopic techniques it is possible to make 3D point clouds[3] and digital models of a terrain comparable in definition to those produced by active sensors (e.g., LiDAR). But unlike LiDAR data,[4] a

[3] These point clouds consist of geo-referenced and dimensioned points, with an average density of 12 points per m^2, which thus render the photographed area (or detected, in the case of LiDAR processing) in digital form and in three dimensions. Available algorithms, including through open source software, are able to analyze both geographically organized and dimensioned points, and render an exact 3D urban composition in numerical form.

[4] LiDAR (Laser Imaging Detection and Ranging) performs remote sensing to determine the distance of an object or surface through the emission of high frequency laser pulses by a flying sensor (plane or drone). The distance of an object is given by the length of time elapsed between emission and reception. Very high frequency pulses bouncing from objects or the ground are converted into geo-referenced and dimensioned points, thus giving rise to a "point cloud" from which the exact reconstruction of an area can be created in the form of three-dimensional digital models.

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point cloud created with the Dense Image Matching (DIM) method has a much lower cost, making it more accessible to Public Administrations.

To assess the solar incidence impacting the slopes of buildings and horizontal urban surfaces, we trace a methodology composed of three steps.

Step One

In order to transform the point cloud generated by the stereoscopic technique, the first step is to transform it into a DSM[5] (Digital Surface Model), which is a raster file whose pixels contain the average dimensions of the points of the cloud.

The very high density of the cloud has allowed us to create a DSM with a 0.5 m^2 per pixel resolution. The conversion can take place with the aid of various software tools; for the prototype we used LAStolls. This application has a very simple command line interface, developed by Martin Isenburg for LiDAR data, but which could be used for this specific operation on photogrammetric data in the LAS format.

The command for the operation is the following:

```
las2dem -i name_file_input.las -o name_file_output.tif -step 0.5
```

By using this command on Command Prompt, the software automatically transforms the point cloud into the desired DSM.

Step Two

The second step consists in producing information pertaining to solar incidence and the inclination angles of roof slopes. This operation was performed with the Open Source Software System for Automated Geoscientific Analyses (SAGA GIS). SAGA GIS has many algorithms, one of which can calculate the inclination angles of surfaces (by Olaya 2004), and another the potential solar incidence of surfaces (by Conrad 2010).

The information layer pertaining to the inclination angles of roof slopes will be crucial in the classification of roofs, as for the study in question it is important to distinguish flat roofs from sloping roofs. The inclination angles of roofs are also essential in selecting and suggesting an installation type.

[5] DSM is a digital elevation model in raster format. Each cell of the model, called pixel, holds a height number. Therefore, DSM represents the spatial distribution of the dimensions of an area or surface.

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The calculation of the solar incidence uses the three-dimensional knowledge acquired automatically by SAGA GIS from the input raster file: knowing the latitude and longitude supplied by the georeferenced raster file, the algorithm simulates the height of the sun and considers the dimensioned urban elements, projecting shadows, and thereby calculating the potential solar incidence for each pixel.

The output will therefore still be a raster file with a 0.5 m^2 per pixel resolution, where each pixel contains the information in kWh. The process has the option to choose the time of year to be analyzed (January rather than July), and the number of days (1–365).

Step Three

The final step of the analysis compares the information obtained so as to identify the urban areas vulnerable to strong solar radiation, in order to come up with more accurate mitigating and/or adaptive solutions.

Making use of any GIS Software (for this example we used Quantum GIS) it is possible to analyze quantitatively the two dimensions under study.

As for identifying the roofs most suitable for a photovoltaic or solar thermal installation, one can simply evaluate information such as solar incidence, inclination angle, and slope size.

As for identifying hot urban areas (with greater solar incidence), one can simply ask Quantum GIS for the location of areas vulnerable to solar incidence (it will be better to convert the raster file into vector format for this purpose). The resulting zoning information will be of great help in choosing an intervention, where, depending on land area type (square, parking lot, sidewalk, intermodal station, etc.), this can be done with greater accuracy and solutions pertaining to shading in conjunction with renewable energy production can be easier to find.

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Focus C: Urban Sprawl and Measures for Environmental Sustainability

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Keywords Urban sprawl, Urban growth, Carbon dioxide emissions, Welfare policies

Urban Sprawl: Characteristics and Impacts

The contemporary city has increasingly been characterised by certain distinctive features, in particular by a progressive urban fragmentation and by a polarisation and specialisation of some functions and services outside the urban centres, which resulted in a growing increase of mobility.

The phenomenon, known as *urban sprawl*, is generalised and extended and has been studied extensively in its social, economic, cultural, political and institutional components[6] as well as in its causes, impacts,[7] formal expressions and local specificities, which have led to different manifestations of the phenomenon according to the different territorial and geographical contexts.

[6] About the effects of local scale regulations and sprawl and about the relationship between administrative fragmentation and sprawl increase, see: Pendall R. (1999), "Do Land-Use Controls Cause Sprawl?", *Environment and Planning B*, vol. 26/4, pp. 555–571.

[7] Between the various studies, see Ewing R., Pendall R., and Chen D. (2002), *Measuring Sprawl and Its Impact*, Smart Growth America/U.S. Environmental Protection Agency, Washington, D.C.

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Research has highlighted the close relationship between low-density of settlements and sprawl, as well as new needs, consumption and lifestyles impose high-impact territorial choices with high land use rates.

A topic that over time has become important in research on the effects of the sprawl is the one linked to the quantification of the collective[8] and social costs related to mobility[9] and more recently, the health care costs that the sprawl imposes. Some recent studies in fact highlight the connection between a sprawl and the health of individuals: «The study, *Relationship Between Urban Sprawl and Physical Activity, Obesity, and Morbidity*, found that people living in counties marked by sprawling development are likely to walk less and weigh more than people who live in less sprawling counties. In addition, people in more sprawling counties are more likely to suffer from hypertension (high blood pressure)»[10] as well as the need to act, regulating and limiting the development of sprawling so as to allow improvement the people's quality of life.

Research on the sprawl is also characterised by an approach which takes ever more the form of planning and is ever more linked to identifying common tools, policies and measures that are primarily aimed at limiting land use. The latter is considered the most evident criticality and the one with the larger impact since it is associated with the erosion of natural, environmental and

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[8] On this subject, reference should be made, by way of example, to the numerous studies conducted in the United States of America on the *social* and *environmental* costs of sprawl since the 70s: Real Estate Research Corporation (1974), "The Costs of Sprawl" (US Environmental Protection Agency, Washington, DC); Ladd H. (1992), Population growth, density, and the costs of providing public services, *Urban Studies*, 29; Carruthers J., Ulfarsson G.F. (2003), "Urban sprawl and the cost of public services", *Environment and Planning B: Planning and Design*, 30. In the case of Europe and Italy, the amount of research is more restricted: Camagni R., *et al.* (2002), *I costi collettivi della città dispersa*, Alinea, Firenze; Caperchione E. (2003), "Local Government accounting system reform in Italy: A Critical Analysis", *Journal of Public Budgeting, Accounting and Financial Management*, 15(1); Hortas-Rico M., Solé-Ollé A. (2008), "Does Urban Sprawl Increase the Costs of Providing Local Public Services? Evidence From Spanish Municipalities", *Urban Studies*, 47(7); Travisi C.M., *et al.* (2009), "Impacts of urban sprawl and commuting: a modelling study for Italy", *Journal of Transport Geography*, 18(3); Fregolent L., *et al.* (2012), "La relazione tra i modelli di sviluppo urbano dispersi e i costi dei servizi pubblici: un'analisi panel", in Cappellin R., Ferlaino F., Rizzi P. (editors), *La città nell'economia della conoscenza*, Franco Angeli, Milan.

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[10] McCann B., Ewing R. (2003), "Measuring the Health Effects of Sprawl: A National Analysis of Physical Activity, Obesity, and Chronic Disease", Smart Growth America and Surface Transportation Policy Project, Sep., p. 1.

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landscape resources, and soil sealing.[11] Waterproofing is the result of the strong anthropization caused by the urbanisation processes and leads to the degradation of the ecosystem functions, the alteration of ecological balance, and a series of negative impacts on the environment such as a strong pressure and water resources with consequent decrease in rainfall absorption; loss of biodiversity; impact on food safety; increase in solar energy absorption due to dark asphalt or concrete surfaces, which contribute significantly along with the heat generated by air conditioning and cooling systems, and the heat produced by traffic, to the so-called 'Urban Heat Island' effect.

The evolution of the sprawl phenomenon and the quantification of its impacts have therefore pushed scholars and researchers and then also administrators and politicians to search for the measures to adopt and the possible actions to be implemented through specific and sectoral policies as well as careful planning.

The urban and regional planning may limit the sprawl also by means of infrastructural and transport regulation measures which foster a reduction in greenhouse gas emissions and allow to direct the growth and form of the urban space. In fact, density, functional *mixité*, re-compaction of the urban space, infrastructure design and the promotion of public and collective transport are the principles for developing guidelines for sustainable planning that regulates the urban space in such a way to control and reduce CO_2 emissions. This is how the form of the urban settlement and the planning aimed to regulate its growth that can make an important contribution to climate protection,[12] and this is why even at a European level, one of the major pushes is heading for intervention on the urban form, the compaction of the urban space, and the re-use of abandoned and dismissed areas.

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[11] On this subject, please refer to the documents produced by the EU, in particular the Soil Thematic Strategy (COM(2006) 231); and on the measures that may be adopted to mitigate the phenomenon: European Commission (2011), *Report on best practices for limiting soil sealing and mitigating its effects*, Technical Report, 2011-050, Apr., available at: http://ec.europa.eu/environment/soil/pdf/sealing/Soil%20sealing%20-%20Final%20Report.pdf

[12] See: Intergovernamental Panel on Climate Change – IPCC (2014), "Human Settlements, Infrastructure and Spatial Planning", in Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.), *Climate Change 2014: Mitigation of Climate Change*, *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, cap. 12, Cambridge, Cambridge University Press, United Kingdom and New York.

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8.1.1 Measures and Tools for Sprawl Containment

The European Union has long been committed to the promotion of a culture of sustainability which over the past two decades has helped to increase attention towards environmental issues and is now a leader with respect to the major environmental issues, from combating climate change[13] to the protection of biodiversity.

As for land and its protection – with special reference to the land use – the measures proposed by the EU collide again with the constraints stemming from the fact that land planning is a matter for the competence of the individual Member States. But other policies that affect to a greater or lesser degree, the land transformation processes and the issue of non-sustainable consumption and soil sealing, are the focus for a number of European Institutions (European Commission, European Environment Agency, and Eurostat), who initiated monitoring programs, research and awareness, although we continue to wait for a specific directive on land that is difficult to achieve.

As previously mentioned, planning is one of the strategic tools identified by the EU for a new enhancement of the city and the control of urban growth to take place in a sustainability manner, because sustainability means a transdisciplinary perspective on phenomena that requires different approaches, opinions and observations, which planning can combine and intersect in order so as to develop effective solutions. For this reason: «The majority of the EU Member States have established the principle of sustainable development in their key spatial planning regulations, referring to economic use of land resources and avoidance of unnecessary urban sprawl. However, the existence of relevant regulations does not give any insight on the effectiveness of implemented measures».[14] In addition, the actions taken by several European

[13] On this subject, a first assessment can be made of the planning measures adopted in the USA: "The first generation of state and local climate change plans reflects increasing consciousness of this, and these plans have begun to take important steps, such as measuring emissions. But much stronger action is needed. Instead of pursuing slow, incremental policy changes, governments at all levels must adopt a *backcasting* approach, setting goals for both mitigation and adaptation based on the best available scientific knowledge, and working backward from these targets to develop plans and programs capable of achieving them. The initiatives would then be regularly reviewed and revised to ensure progress at an appropriate rate" (Wheeler S.M. (2008), "State and Municipal Climate Change Plans. the first generation", *Journal of the American Planning Association*, vol. 74/4, pp. 481–496).

[14] Soil Thematic Strategy (COM(2006) 231); and on the measures to be adopted to mitigate the phenomenon: European Commission (2011), *Report on best practices for limiting soil sealing and mitigating its effects*, Technical Report, 2011-050, Apr., available at: http://ec.europa.eu/environment/soil/pdf/sealing/Soil%20sealing%20-%20Final%20Report.pdf.

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countries and aimed at sustainability-oriented planning are based on: «Quantitative limits for annual land take exist only in six Member States: Austria, Belgium (Flanders), Germany, Luxembourg, the Netherlands, and the United Kingdom. In all cases the limits are indicative and are used as monitoring tools”,[15] for example: «In England, 10 % of the total land area, which includes country roads, is urban and, according to the Department for Communities and Local Government (2008), over 70 % of new development is taking place on this previously developed land (i.e., brownfield) at high densities to conserve greenfield land. This is a highly restrictive land use policy, constraining the supply of new houses and limiting lifestyle choice».[16] Similar rules have been adopted in other European countries: in Germany, measures were introduced for progressive control of land consumption with the goal of reaching zero consumption in 2050, by envisaging re-use of brownfield sites, requiring new urbanization to only occur in areas accessible by public transport and urban development plans to be designed in such a way to enhance compact urban centres and provide them with services, such as Active City and District Centres (2008). In France, the “Schémas de la Cohérence Territoriale” (SCOT) – large-scale plans which serve as a guide for the local plans - allow to determine perimeter of the protected natural and urbanized spaces. The SCOTs impose the principle of “extension limitée de l’urbanisation” which establishes limits to the urbanisation of non-anthropized areas and the realization of large commercial spaces.

Different regions in Italy are preparing urban regulations aimed to control land consumption: Regione Veneto is working on a draft law on the reduction of land consumption through urban regeneration; this work began at the end of 2013 but the draft law is still under discussion. Regione Toscana is engaged in reviewing its Regional planning law with the introduction of specific measures to contain land use; Regione Puglia, which has already passed a law to encourage and facilitate access of youth to agriculture and combat the abandonment and consumption of agricultural land.

In addition to planning, the most common tools for urban growth control are greenbelts and urban growth boundaries, applied in different cities around the world (London, Berlin, Portland, Beijing, Singapore, etc.) with the aim of defining and delimiting the physical boundary between the city and the countryside, with the contribution also of fiscal and regulatory measures and other indications such as the re-use of dismissed areas and buildings to encourage

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[15] op. cit.

[16] Echenique M.H., Hargreaves A.J., Mitchell G., and Namdeo A. (2012), “Growing Cities Sustainably. Does Urban Form Really Matter?”, *Journal of the American Planning Association*, vol. 78/2, pp. 121–137.

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the upgrade of that which is already in existence, and the start of urban regeneration processes in order to prevent consumption of non-anthropized land, to allow construction works to take place on free land only when all dismissed or under-used land is recovered, and when re-use of areas already compromised has been verified to be impossible. In any case the use of free land should be linked to real needs; regulating land use through regulatory restrictions and adopting different local taxation systems for the different areas and uses.

The outcomes of these measures in the various contexts of application were different, and this demonstrates that there is no solution or single measure able to minimize the sprawl but that the measures to be taken must be different and applied in different ways, but all within an unambiguous reference framework to be determined by the planning.

The adjustment and implementation of policies aimed at governing urban transformation must take place at different scales of intervention with a focus on the large-scale and/or metropolitan scale, because this allows understand, contextualize, and find solutions to phenomena that occur on a local scale.

Planning plays a key role, especially on a vast or regional scale, since the processes of urban sprawl affect large areas of land - several municipalities and provinces mutually adjacent. This scale also enables to address issues such as pollutant gas emissions, resource management, reduction of land consumption, protection of natural ecosystems, and also enables to implement welfare policies[17]; and an integrated approach to urban development policies is the only key to implementing the *European strategy for environmental sustainability*.

[17] Wheeler S. (2009), "Regions, Megaregions, and Sustainability", *Regional Studies*, vol. 43/6, pp. 863–876.