



i
a
f
o
r



Zhaoqing: A Study-Case of Energy-Saving Urban Design
Giovanni Marco Chiri, Ilaria Giovagnorio

0149

University of Cagliari, Italy

The Asian Conference on Sustainability, Energy and the Environment

Official Conference Proceedings 2012

Abstract:

The guidelines of many international organizations (such as the European Commission) and contemporary scientific studies have called attention to the importance of city-scale planning with regard to energy-saving and environmental responsibility. The urban shape, as attested by the history of town planning, collaborates in reaching these goals: Scholars have shown how settlement morphology is related to environmental comfort and the city's energy urban balance via important 'physical' relationships (H/W ratio). In this way, architects and planners have improved both environmental behaviour and urban quality of living standards via typo-morphological solutions and the use of environmental data from the beginning of the urban design process.

In order to verify this theoretical approach, a case study from China has been used herein as a starting point. One of several projects for an academic course involving the development of a new train station area of Zhaoqing (P.R.C.) has been analysed and then modified through a three-step process. This modification has focused on the relationship between the original morphology and the corresponding urban microclimate, altering initial spatial and typological configurations to improve environmental performance.

The outcomes, shown via the software used, have confirmed the prominent role of good urban form in enhancing comfort standards and reducing energy needs of settlements. In addition, as many international organizations have advised, urban design must be considered a useful tool in planning the 'sustainable' city of the future, overthrowing the energy-related 'hidden costs' of bad design which can affect environmental and energy performance of buildings after their construction.

1. Introduction.

Despite the fact that today most energy-saving and environmental policies are pertinent to individual buildings, the instructions and guidelines provided by the ONU and EC in recent years have situated the city at the centre of such considerations. In 2006, the European Commission declared in its policy document 'Thematic Strategy on the Urban Environment': «[...]Urban areas play an important role in delivering the objectives of the EU Sustainable Development Strategy» (EU, 2006). This centrality of city-scale planning is encouraged by the city's size, positioned between region and building. The necessity of a switchover from a building-scale to a city-scale frame of reference has also been affirmed by scholars who have attested to the impact of city shape on both energy and environmental performance. Research carried out in recent years has demonstrated the necessity of making a leap in order of magnitude from the edifice to the entire urban organism to improve environmental comfort and energy efficiency. «A significant share of energy is, in fact, linked to the physical and functional relationships which are established, or may be established, among the various elements of the settlement, and which determine the city's shape and organization» (De Pascali, 2008).

Over the past century, this one-to-one deep link between urban morphology and energy supplies has determined the mutual development and decline of each, as testified by the history of architecture and planning, such that now one must wonder what the future of city shape holds, and more importantly, how the current urban form can be made to collaborate in building the future 'renewable' city.

Prominent studies on the relationship between urban morphology and its energy-environmental consumption have been ongoing since the 70s, after the oil crisis (S. Owens, 1986; R.L. Knowles, 1974; R. G. Stein, 1977). Results have highlighted the importance of certain 'physical' parameters on which designers and planners can work to improve urban comfort. This awareness has assigned relevant capabilities to urban design, already highlighted in 2004 by the European Commission, who declared urban design the ideal tool through which to intervene in spatial configurations to build more efficient urban forms.

This instrument also allows us to take into consideration the entire settlement, or an even broader area, overcoming the sectorial, piecemeal view of the city in favour of a more holistic approach which considers «the whole [...] greater than the parts» (Scandurra, 1995).

2. The H/W ratio in urban morphology.

Among the physical parameters affecting the weather-environmental behaviour of settlements, scholars have identified the importance of H/W ratio (H= building height; W= façade width). According to these studies, values under this parameter affect urban energy balance, especially with regard to air temperature differences in the city centre, wind speed variation in the urban canyons, and the rate of solar radiation at ground level.

The main consequences of the aspect ratio on the weather-environmental performance of the settlement can be summarized as follows:

- H/W ratio and the urban heat island
according to the T.R. Oke equation:

$$[dt = 7,54 + 3,97 \ln(H/W)]$$

Thus, the aspect ratio is directly related to the intensity of the 'urban heat island' (UHI). The UHI phenomenon refers to the increased air temperatures in central areas of the city, which spark a vicious cycle based on increased use of air conditioning systems and confounding

effect of their heat and gas emissions (Fig. 1). The high temperatures of the center city, in fact, have a tremendous impact on building energy consumption based on cooling needs. An Athens-based case study, carried out by M. Santamouris in 2001, found that electric energy requirements reached values three times higher than normal based on the UHI effect. Several studies performed in the USA (NASA and L.B.L.) (Santamouris, 2001) have studied urban temperature trends in several American cities. For example, the Los Angeles case study revealed a temperature gap during the last decade of 0.8 F, with a difference in cooling degree days equal to 92% more (1941-1970).

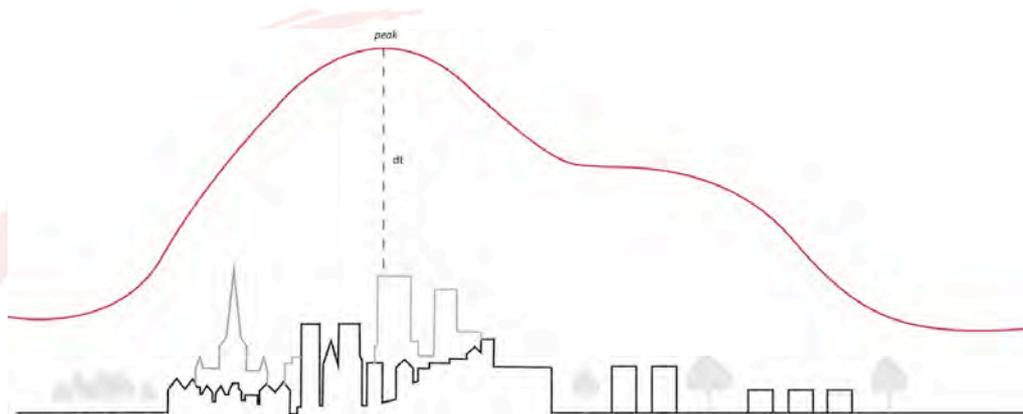


Fig.1. The urban heat island.

- H/W and the *urban airflow*

The roughness of a settlement influences wind flow inside the urban canyon. According to Oke, building geometry obstructs natural air movement, defining two different *layers* located above and below roof level (*boundary layer*; *urban canopy layer*).

Within the *urban canopy layer*, the relationship between urban geometry and wind direction impacts average wind speed and, consequently, the natural ventilation of the fabric. The orientation of the urban grid with regard to the main wind direction and the urban geometry identifies various wind regimes.

In the case that the canyon axis is oriented perpendicular to air flow, the secondary flow at ground level is strictly related to the aspect ratio, such that it will be reduced at greater values (> 0.65). «Naturally, this condition provides greater shelter to pedestrians from undesirable wind, but at other times may impede necessary ventilation of the urban space» (Erell, Pearlmutter, Williamson, 2011).

Differently, when the urban array axis is oriented parallel to wind flow, the secondary airflow circulation is a function both of width and façade distance. According to E. Neg: «For the air path to be effective, the width of the air path at the windward side should be at least, and on average, 50 per cent of the total widths of the buildings on both sides. The width needs to be increased when the heights of the buildings increase» (Ng, 2010).

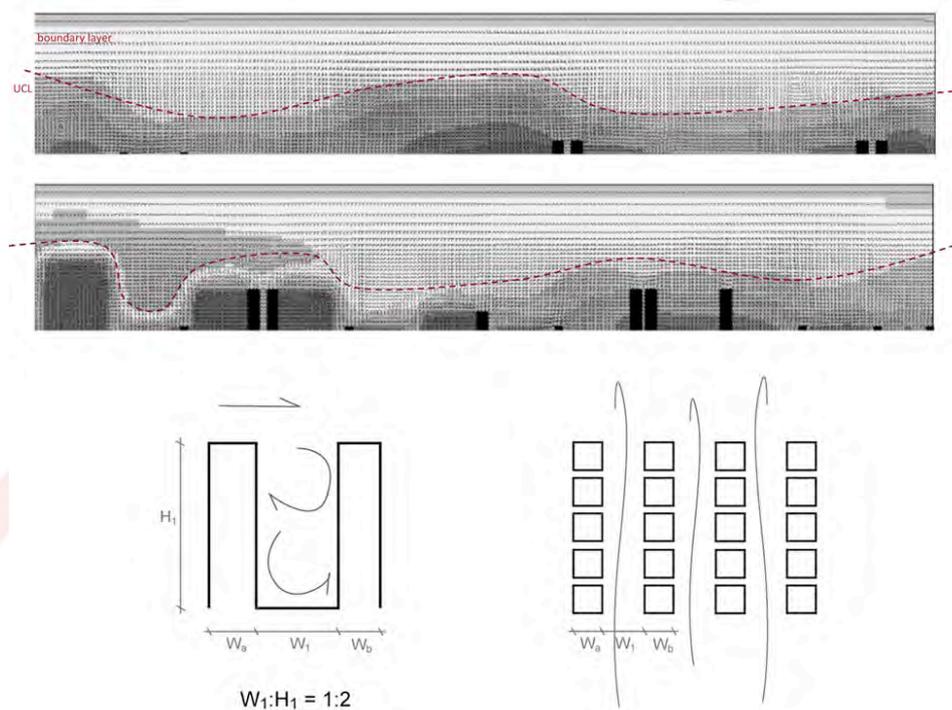


Fig.2. Urban airflows.

- *H/W and solar radiation access*

Regarding solar radiation access within the urban canyons, in addition to the H/W ratio, the location of settlements plays a prominent role in controlling daylight and sunlight. On the one hand, greater distance between building façades fosters the natural lighting of indoor and outdoor spaces, and improves building healthiness and citizen psychophysical well-being. On the other hand, in hot regions, greater distance may contribute to overheating of building surfaces, increasing indoor and outdoor air temperatures.

Research developed by A. Tsangrassoulis in 2001 (Santamouris, 2001), concerning the need for exploitation of natural lighting, linked urban geometries to latitude. The results suggested that designers should decrease H/W ratio in relation to increases in latitude, advising a practice already within the know-how of “good construction techniques”.

Specifically, Tsangrassoulis identifies three optimal H/W ratio values with relation to three different latitudes, as reported in Table 1.

latitude	H/W ratio
40°	0.7
45°	0.58
50°	0.46

Tab.1. The conventional criterion of daylighting; A. Tsangrassoulis.

3. The Zhaoqing case study.

The impact (or potential) of urban form with regard to control and improvement of the urban microclimate has herein been tested via a case study regarding the northeast expansion of Zhaoqing City.

The main goals of the proposed work can be summarized as follows:

- To assay a potential practical method for bringing a site's weather and environmental data back into the urban design process from the initial stages;
- To devise a repeatable protocol which complements the design process. This tool joins the process throughout its complete *iter* via a continuous checking and monitoring of design performance, emerging from the early phase of main project criticalities.

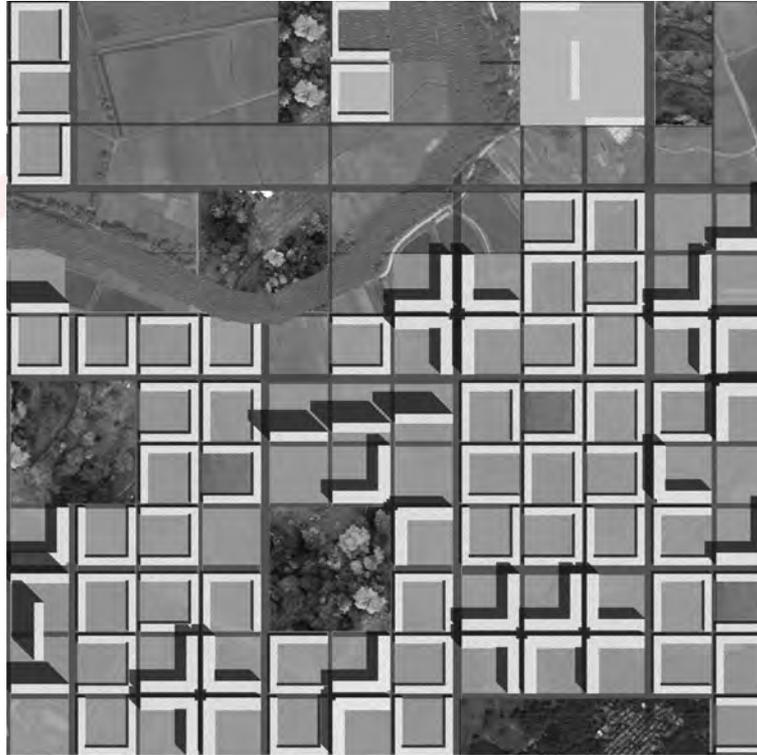


Fig.3. The initial urban design of Zhaoqing's new satellite town.
The master plan has been developed by F. Carta, M. Casu, C. Gaddari, M.A. Pani and F. Pinna.

3.1 The new satellite town.

The case study is in the preliminary stages of the urban design process in the construction of a new 45.000 inhabitant satellite town near the new high-speed train station in Zhaoqing, Guangdong Province (R.P.C.). The area under consideration is located in the city's north-east along the major infrastructural axis connecting the western China territories with the Pearl River Delta, China's economic and productive centre.

This work was developed by the Cagliari Faculty of Architecture in 2011 during a six-month academic design course, and was positively evaluated by an international jury.

The project divided the space on a square grid with sides 95m long, such that it covers a total area of about 1.4 km² (1.200x1.200m). The grid gives with the terrain, breaking off and changing its size where it meets pre-existing local environmental and historical features, as it structures the urban space into macro-blocks with sides of 300m long. Each such block contains office and residential functions in accordance with the direction of the city plan, integrating the necessary services to satisfy the needs of the new expansion.

3.2 methodology of study.

The work is structured in a three-step process through which initial spatial configurations of the project have been analyzed, modified and then re-analyzed to estimate their weather and environmental behaviour.

The evaluations of the iteration between urban form and local features were carried out taking into consideration the two most critical days of the year (the summer and winter solstice) in relation to four environmental parameters:

- wind speed (m/s) and direction;
- temperature (K);
- relative humidity (%) and
- solar radiation (W/m²).

This analysis was developed with the help of two software: ENVI-met and Heliodon. Despite its limitations, ENVI-met allows the designer to evaluate the performance of the first three environmental parameters for each hour of the day through easy-to-understand thematic graphical maps.

Heliodon, by contrast, evaluated access to solar radiation, the shading phenomena and the sky view factor both for the building envelope and outdoor spaces, taking into account a simplified 3D model.

The local weather data were provided by the International Weather for Energy Calculation (IWEC). Although data were for Guangzhou city, the proximity of these two cities, approximately 98 km, allows us to approximate the weather conditions for Zhaoqing City. In the table n.2 are reported the average data for June and December.

	Temp. (K)	Rel. Humidity (%)	Wind speed (m/s)	Wind direction
June	299	80	2.4	S
Dec.	288	60	2.5	N

Tab.2. Average weather data (Guangzhou). IWEC.

3.3. The three-step process.

Step 1. The urban design was analysed taking into account two macro-areas of study: the typo-morphological solutions of the project and their consequences on urban microclimate.

With regard to the first area of analysis, an abacus was built which yielded the main dimensional features of the three basic typologies used and of their spatial aggregations.

These latter can be summarized as follow:

- the “C” typology—9-12-15m—used to house residential functions. The aggregation of these buildings determined inner courts with sides equal to the grid dimension (95m).
- The “L” typology, 30-60m high. These buildings contain offices and business and financial functions.
- Rectangular towers, 100m high. Executive and office districts are also housed in these towers.

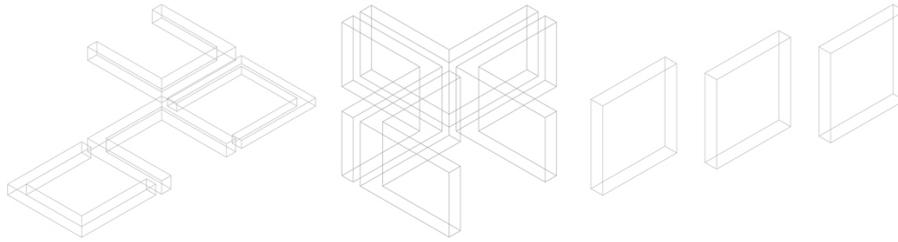


Fig.4. Basic typologies and spatial aggregations.

As we have seen above, values assigned to the aspect ratio have a significant impact on the urban microclimate. To better evaluate the consequences of the H/W ratio, the main urban spatial configurations and their aspect ratio values were analyzed and synthesized, as shown in the figure below.

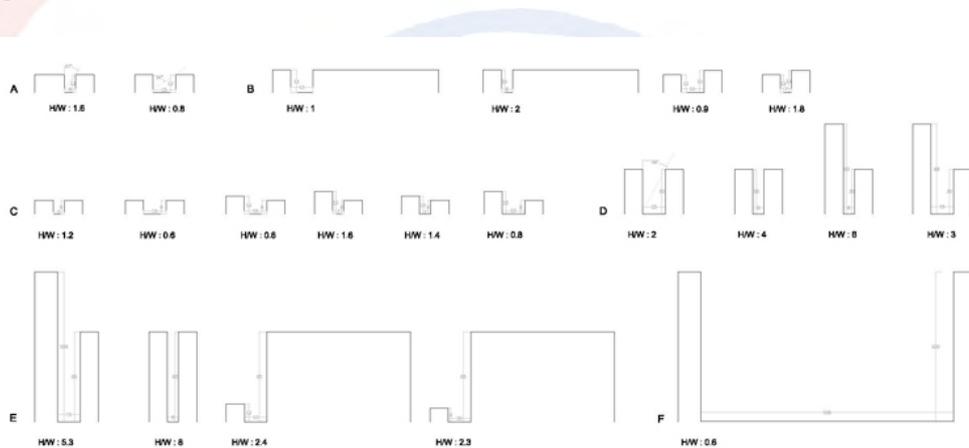


Fig.5. The aspect ratio values of the original project.

The main critical point which emerged during the first phase of analysis of the project can be summarized as follows:

- The grid's size and the use of a typology closed on three sides ("C" typology) obstructs the penetration of air flow into the urban texture, especially for building heights greater than 9m.
- The juxtaposition of buildings over 30m (60-100m) creates a barrier to air, especially along the southern side. The cross-shaped group arrangement hinders sunlight penetration with consequences in terms of both indoor natural lighting and shadowing. The latter phenomenon affects both the building envelope and the outdoor public spaces.
- Both the above points affect humidity levels, very high in the summer (80-95%).
- The road axis, oriented N-S along the direction of the prevailing winds, is able to channel air only for the H/W ratio contained in value 2.
- The sunshine of both the inner courtyards and the vertical surfaces improves if the C typology buildings are oriented along the N-S axis and the "L" typology buildings along a N-E/N-W axis.
- In some areas, the H/W ratio reaches very high values, between 4 and 8, unfavourable for both natural ventilation and lighting of indoor/outdoor spaces.

Step 2. The initial choices of the urban design which had been critically evaluated for environmental comfort were changed with the intent of improving design performance. The

modifications were studied in order to comply with certain general settings of the original project such as the utilization of the square grid and the north–south orientation, strictly linked to the local traditional culture.

The interventions were aimed at implementing the penetration of air flow into the urban fabric with the purpose of reducing the humidity level, which can be particularly high in a tropical context such as that in Zhaoqing. To achieve these goals, this case study worked primarily on typological solutions and spatial configurations. It reduced maximum building heights (Roaf, 2010), favoured continuous front chipping, and guaranteed paths for air path flow. The new design worked on buildings defining three main layers characterized by different altitudes:

0-9 m: this first area features a base which redefines the spatial relationships between indoor and outdoor building spaces. The building arrangement maintains internal courtyards that double each building's size, and, where possible, orients these along the N-S direction of the prevailing winds.

9-40m: this second area overlaps the previous base, and is designed with particular attention to the ventilation and shading of adjacent spaces. The ratios established are constantly checked for both surrounding buildings and open spaces.

Finally, the square towers are at a height of 54m. These answer the dual purpose of absorbing missing volume and of reintroducing «prominent nodes» (Lynch, 1960) to facilitate citizens' orientation in the urban space.

Phase 3. This last step repeats the initial analysis process of the previous urban proposal to evaluate its behaviour and to compare it to the original plan. The weather–environmental analysis takes into consideration the most disadvantageous time of the year which emerged in step 1: the summer solstice.

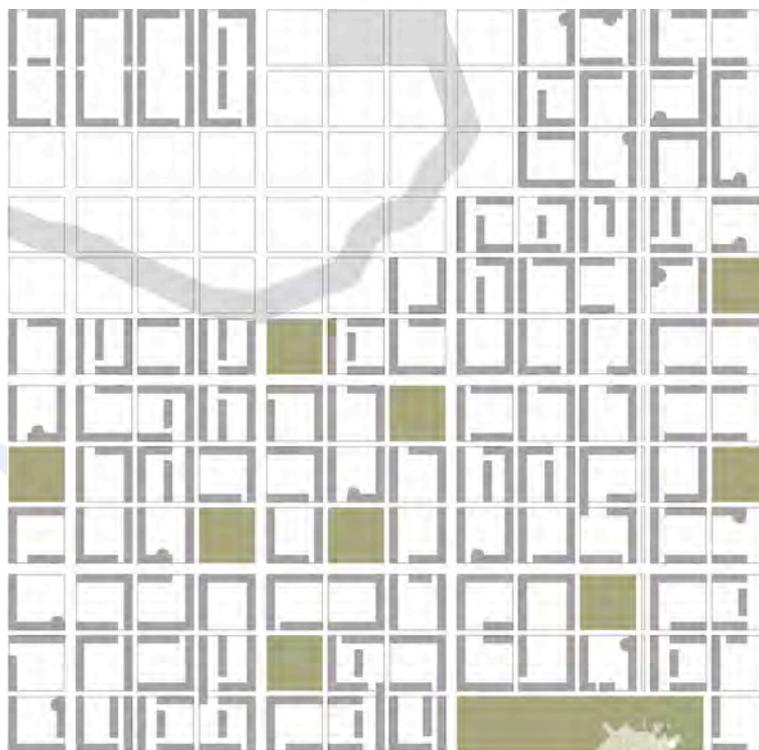


Fig.6. The second urban design proposal.

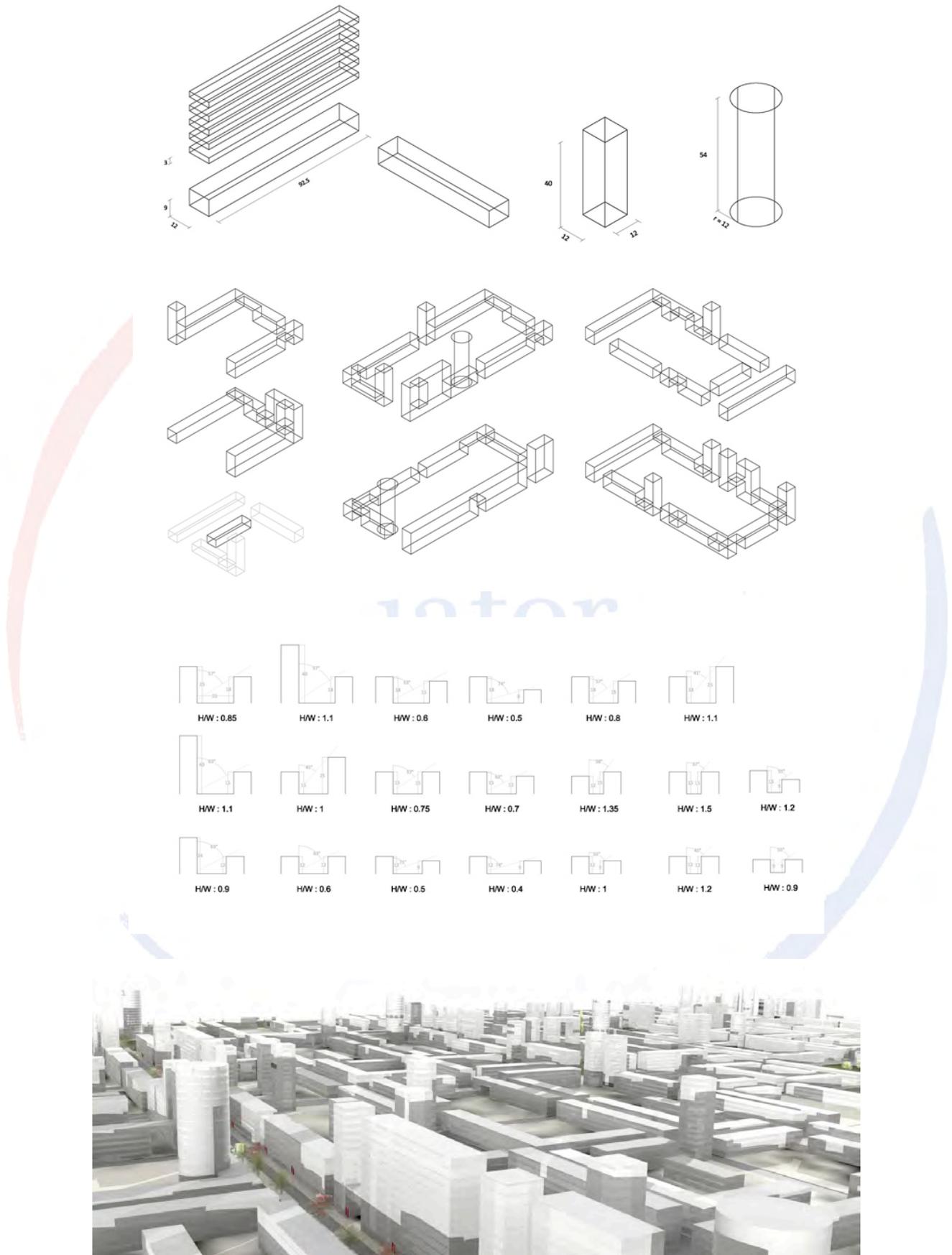


Fig.7. The second round of typomorphological solutions and spatial configurations.

Below, the new aspect ratio values and an overall view of the project.

4. The results of the intervention.

The results obtained in the third phase and performed after the changes to the original design confirmed the validity of the transformations.

The main benefits are summarized below:

- The natural ventilation in the urban fabric has improved: on the street the wind speed remains up to 1.5–2 m/s. According to Givoni, a wind speed of 1.9m/s over the body is enough to ensure a neutral thermal sensation condition at 28°C (Ng, 2010). The overall reduction in building heights and the increase in courtyard size have both improved the natural ventilation of the blocks, guaranteeing a minimum wind rate of between 0.5-1.5 m/s.

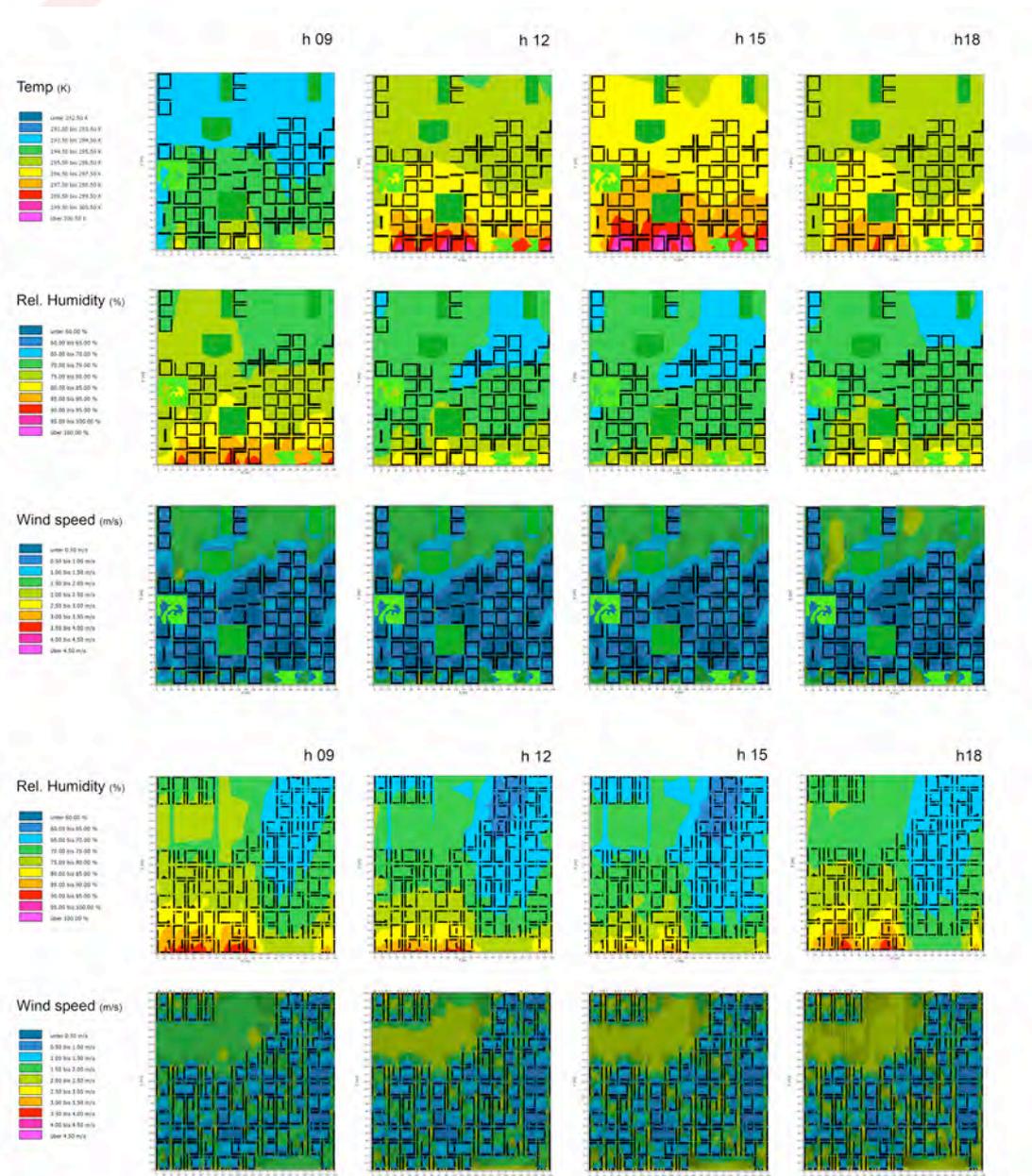


Fig.8. ENVI-met results for the original master plan (upon) and the new proposal (below). Maps show the parameter trends during the prime hours of 21st June.

- Similarly, with regard to relative humidity, the levels achieved during the day have been improved, especially in the east part of the project, where values have been decreased by 10–15% compared to the initial situation.
- The increase in the built area of approximately 15% has produced an increase in daily solar radiation of 30% on the 21st of June. This result can be explained in part based on the major attention paid in the design process both to surface orientation and to building façade relationships (H/W ratio).
- The continuous monitoring of this ratio has successfully contained its values below the maximum threshold of 1.5 for the analysis.

Microclimatic information in relation to the two planning solutions, provided by software, has been incorporated into the bioclimatic chart of V. Olgyay to evaluate degree of comfort. The environmental parameters entered are relevant to the 21st of June. As may be noted, the two distinct spatial configurations correspond to two microclimate conditions that, even if similar, reaffirm once again the effectiveness of design transformations. In fact, microclimate performance arising from new typo-morphological solutions approaches the comfort zone, assuring comfortable conditions during some hours of the day and an overall improvement as compared to the original proposal.

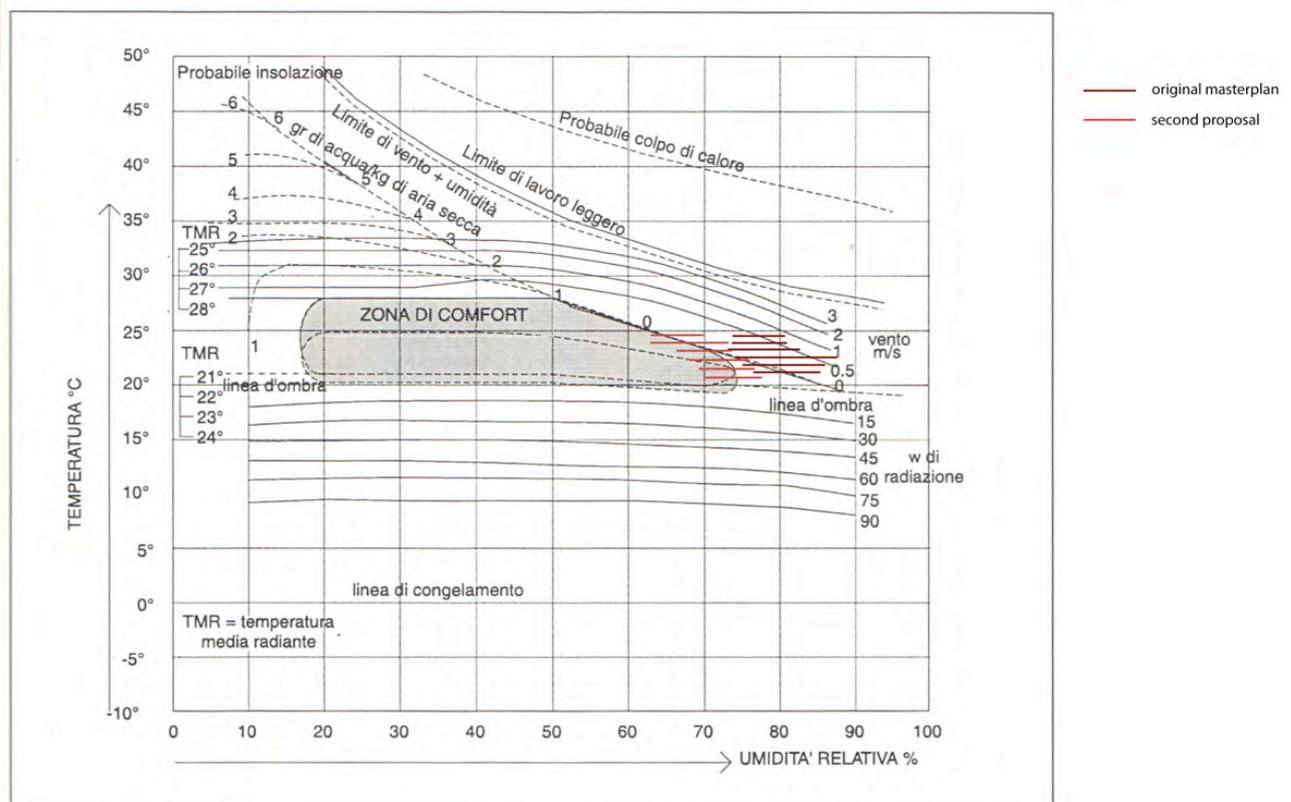


Fig.9. The bioclimatic char of V. Olgyay.

5. Potential renewable energy.

The increase in daily solar radiation on surfaces makes it possible to convert a portion of that radiation to satisfy the electrical energy requirements of buildings. Considering the difficulties of energy data retrieval for offices and services, we focus on residential energy production and consumption. The aim of this work is to ascertain whether the direct solar radiation

received on residential building roofs is sufficient to satisfy the energy requirements of the building's residents.

Building	Area (m ²)	direct solar radiation (kWh/year)	fattore rid.	Tot. direct solar radiation (kWh/year)
H9	68.928,50	129.792.960	0,32	41.533.747
H54	4.657,80	9.262.356	0,32	2.963.954
H40	23.457,60	44.119.591	0,32	14.118.269
H25	17.232,40	33.240.013	0,32	10.636.804
H18	27.835,10	52.333.094	0,32	16.746.590
H15	69.379,10	130.380.786	0,32	41.721.851
H12	89.111,90	169.381.520	0,32	54.202.086

Tab.3. Annual direct solar radiation on building roofs.

Tot. Building area (m ²)	Annual direct solar radiation (kWh/year)	Annual direct solar radiation/m ² (kWh/m ² year)
300.602	181.923.302	605

Tab.4. Annual direct solar radiation on the roof per square meter.

The solar radiation received on the roof was measured by Heliodon for one year (365 days). Results obtained considering a clear sky the entire time of measurement have to be decreased by a reduction factor of 68%. This factor has been determined based on a comparison of the average IWEC monthly direct radiation statistics with those of Heliodon.

According to the initial choices of the urban design, the residential functions are mainly held in "C" typologies of 9-12-15m height; total roof surface and energy consumption are summarised in Table 5. Energy consumption evaluations have taken into consideration the ClimateHouse A categories, which attest to consumption of 30 kWh/m² year for buildings of the A class in Italy. Multiplying single consumption first for the building floor area and secondly for the number of floors, we can evaluate the global residential energy requirements for each typology (9-12-15m).

Building	floor area (m ²)	floor n.	area (m ²)	ClimateHouse A standard (kWh/m ² year)	Tot. house energy consumptions (kWh/year)
H9	68.929	3	206.787	30	6.203.610
H12	89.112	4	356.448	30	10.693.440
H15	69.379	5	346.895	30	10.406.850

Tab.5. Annual energy requirements for residential buildings.

The energy production, on the other hand, has been evaluated taking into account the total direct solar radiation on a residential roof. Considering the total energy stored over 365 days and the total roof area of the buildings, we found a direct flux equal to 605 kWh/m² year. This figure has been multiplied to account for the total roof surface of each typology, yielding a direct potential solar radiation of about 137.500.000 kWh/anno.

The current photovoltaic technologies active on the market are capable of capturing and transforming into electricity only a small portion of the received direct solar flux, between 10% and 20%. This gap depends on *pv* panel materials and features: an amorphous silicon panel requires less energy to be produced than a monocrystalline/polycrystalline silicon one, but its energy conversion ratio fluctuates between 10 and 14%. On the other hand, the monocrystalline or polycrystalline silicon panels are more energy-intensive to produce, but their efficiency reaches 20-22%.

Building	roof area (m ²)	Annual dir. solar rad./m ² (kWh/m ² year)	Roof dir. solar rad. (kWh/year)	<i>pv</i> panel efficiency (13%) (kWh/year)	BOS efficiency (85%) (kWh/year)	% energy requirement compensation
H9	68.929	605	41.702.045	5.421.266	4.608.076	74%
H12	89.112	605	53.912.760	7.008.659	5.957.360	55%
H15	69.379	605	41.974.295	7.555.373	6.422.067	61%



<i>pv</i> panel efficiency (18%) (kWh/year)	BOS efficiency (85%) (kWh/year)	% energy requirement compensation
7.506.368	6.380.413	1%
9.704.297	8.248.652	77%
7.555.373	6.422.067	62%

<i>pv</i> panel efficiency (20%) (kWh/year)	BOS efficiency (85%) (kWh/year)	% energy requirement compensation
8.340.409	7.089.348	1,15%
10.782.552	9.165.169	85%
8.394.859	7.135.630	69%

Tab.6. Annual electric energy production by three different *pv* panels.

The calculation of potential renewable energy produced by building roofs has taken into account both kinds of *pv* panel: an amorphous silicon panel with 13% efficiency and two polycrystalline silicon panels of 18-20%. Results are shown in Table 6. Obviously, the amorphous silicon type produces less electricity than the others, but it is both energetically and economically less expensive and is able to satisfy at least 55% of the residential buildings' consumption needs (H 12). In the case of the H9 building, by contrast, this value improves, accounting for 74% of the total one-year energy consumption.

With regard to the polycrystalline silicon panels, the difference made by the higher energy production efficiency of between 18% and 20% is especially noticeable for the 12m buildings, improving energy production by 8%, and covering between the 77% and 85% of annual energy requirements. The H9 buildings, by contrast, would produce a one-year surplus of +1–1.15%.

Any such energy surplus could be channelled into the urban electricity network and be used to feed other buildings and services. The energy requirements of office and service industry buildings are not easy to define. Though no definite annual figure can be proposed, requirements can be supposed to exceed residential levels; recent research of the ENEA R.S.E. (2009) assumed for Italian offices a consumption standard of 80 kWh/m² per year, a value three times higher than residential requirements. The size of the energy requirements noticeably reduced the potential solar energy contribution of office and service industry roofs to the annual energy balance.

This reflection suggests, once again, that designers should broaden their attention to encompass how buildings of various sizes may function in the City through the “smart grid” system. Through such a system, the building’s energy production is brought into the urban electric network and channelled in real time where requested. In this way, we can suppose that we may move, during the day, a portion of the renewable energy produced by residential buildings to offices and business districts, and vice versa, thus meeting a greater share of energy requirements.

In fact, on the strength of scholarly findings, we may say that renewable sources will allow a switchover from a territorial centralized system to a new, dispersed and consumed-on-the-spot form of energy production. Thus, cities (or urban blocks) may transform themselves into self-sufficient islands able to produce their energy requirements autonomously. Energy surplus in the ‘island’ may be poured into an urban smart grid system and simultaneously used by other consumers or stored. According to L. De Santoli, «each isle could be connected with other islands to form an “energy district”. All this changes the design approach into the urban design size and different urban, spatial configurations».

6. Conclusion.

The positive results obtained via this three-step process confirmed not only the validity of the project interventions, but the effectiveness of the design procedure. The integration of a continuous check system, operating hand in hand with the design process, assists the designer in selecting and editing typo-morphological solutions to allow for the definition of a more efficient urban form even in the early stages of the project.

Although energy-saving policies today mainly address individual buildings, such measures on their own are unable to ameliorate the discomfort caused by an inefficient urban design which rebounds upon itself, raising energy and environmental costs.

The assistance rendered by the software used in this study confirms it to be an extraordinary tool by which to qualitatively assess trends stemming from initial choices, directing the design towards the overall improvement of its performance. Despite the software’s relevant limitations, the results demonstrate the method’s validity and its applicability in diverse forms and contexts.

Finally, the potential for increased use of renewable energy also calls designers’ attention from the building to the city scale, confirming the necessity of overcoming a sectorial view of the settlement in favour of a vision of a more holistic “smart city”.

7. Acknowledges.

This work is sponsored by the Sardinia Region with funds from PO Sardinia FSE 2007-2013 (L.R.7/2007) “Promotion of scientific research and technological innovation in Sardinia”.

References

- Breheny, M., (1996) The search for a sustainable urban form, in *The Compact City: A sustainable urban form?*, ed. M. Jenks, E. Burton and K. Williams, London, E&FN Spon.
- De Pascali, P. (2008) *Città ed energia. La valenza energetica dell'organizzazione insediativa*, Franco Angeli, Milano.

- De Pascali, P. (2011) Governance e tecnologie per il piano della smart city, in Valutazione e pianificazione delle trasformazioni territoriali nei processi di governante ed e-governance, edited by C. Zoppi, Franco Angeli, Milano.
- De Santoli, L. (2005) Energia e Architettura, Ed. Kappa, Roma.
- D'Olimpio, D. (2008), La progettazione del microclima urbano, Ed. Kappa, Roma.
- Erell, E., Pearlmutter, D., Williamson, T., (2011) Urban Microclimate. Designing the space between buildings, Earthscan, London.
- European Commission, (2004) Towards a thematic strategy on the urban environment, Brussels.
- European Commission, (2006) Thematic Strategy on the Urban Environment, Brussels, http://europa.eu/legislation_summaries/environment/sustainable_development/128171_en.htm
- Lynch, K., (1960) The image of the city, The MIT Press.
- Knowles, R.L., (2003) The solar envelop: its meaning for energy and buildings, in Energy and Buildings n.35, pp.15-25, in www.elsevier.com/locate/enbuild.
- Ng, E. (2010) Designing high-density cities for social and environmental sustainability, Sterling Earthscan, London.
- Owens, S., (1986) Energy, planning and urban form, Pion, London.
- Rogora, A., Dessì, V., (2005), Il comfort ambientale negli spazi aperti, EdicomEdizioni, Gorizia.
- Santamouris, M., (2001) Energy and climate in the urban built environment, James & James, Londra.
- Scandurra, E., (1995) L'ambiente dell'uomo. Verso il progetto della città sostenibile, Etaslibri, Milano.
- Serra Florensa, R., Coch Roura H., (1995) L'energia nel progetto di architettura, Città Studi Ed., Milano.
- Welbank, M., (1996) The search for a sustainable urban form, in The Compact City: A sustainable urban form?, ed. M. Jenks, E. Burton and K. Williams, London, London: E&FN Spon.