Climate Oriented Urban Design. 
Thermal comfort in urban spaces and energy saving potential in built environments

Anastasia Fotopoulou*, Annarita Ferrante, Elena Cattani, 
Riccardo Gulli

Highlights

This research has tested the effects on the urban microclimate of the transformations induced in the outdoor urban spaces and, in parallel, how these modifications effect the reduction of temperature in the confined indoor spaces of the built environments. Open spaces and the surface of urban volumes are considered, measured and evaluated as a unique interacting environment.

Abstract

The volumetric configuration of the urban textures and the materials that constitute the external surfaces, are the main factors that influence the microclimate of a city. Comprehend and being able to transform in an adequate way the urban settings could contribute to the improvement of the thermal comfort in outdoor and indoor built environments. By using as a principal indicator thermal comfort the variation of the external temperatures in an unprecedented collaboration between different scales and different environmental simulation systems, this paper analyses the energy saving potential given by the use of green and passive techniques and shows the synergies that may arise between outdoor and indoor spaces.

Keywords

Volumetric configuration, urban microclimate, thermal comfort, environmental simulation systems, green and passive techniques

1. INTRODUCTION

The issue of the increase of global average temperatures, commonly referred to as overheating, it is one of the most important climate emergencies to protect the entire ecosystem at the global level. The urban districts, especially with high population density, are the sites most directly influenced by the variation of the climatic effects, but at the same time also the primary source of emergency as the absorption and emission of the heat is considerably higher than that produced in rural areas [1, 2]. The understanding and the possible actions of transformation of urban spaces in terms of accessibility for pedestrian use are therefore essential actions in order to increase the external microclimate conditions and performance of buildings, in particular regarding the context of energy consumption [3- 5].

* Corresponding author
Tel.: +39-329-870-9125; 
e-mail: anastasia.fotopoulo2@unibo.it

Anastasia Fotopoulou
DA - Dipartimento di Architettura, 
Università di Bologna, viale Risorgimento 2, Bologna, 40100, Italia

Annarita Ferrante
DA - Dipartimento di Architettura, 
Università di Bologna, viale Risorgimento 2, Bologna, 40100, Italia

Elena Cattani
DA - Dipartimento di Architettura, 
Università di Bologna, viale Risorgimento 2, Bologna, 40100, Italia

Riccardo Gulli
DA - Dipartimento di Architettura, 
Università di Bologna, viale Risorgimento 2, Bologna, 40100, Italia

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Overheating in urban environments compared to areas outside the city, defined by the term “heat island effect,” is the most documented phenomenon of climate change [6]. Its magnitude is mainly related to building density, the specific heat capacity use of the materials in the urban fabric, the geometrical and morphological characteristics of the urban fabric, as well as the presence of green spaces and permeable surfaces, and to the anthropogenic heat production [7]. The heat island has a very important impact on the energy consumption of buildings during the summer period, increases the concentration of pollutants and cause discomfort and health problems [3,4,6,8,9]. The contribution presented here is part of a wider research which aims to verify, first, the effects on the urban microclimate of the transformations induced in the outdoor areas and secondly, to explore how these effects may have an impact on the reduction of temperature in the environments confined. The outdoor thermal comfort is generally studied on the urban micro-scale, which is affected by the Canopy layer heat island (CLHI), and can be described and linked to microclimatic conditions by steady-state assessment methods [10-14]. In general, the climate in the city is characterized by altered values of the ambient temperature by relative humidity and wind velocity and reduced direct solar radiation. The microclimate of an urban area can be modified with the use of passive techniques and natural components: open public spaces covered with green and water zones, such as parks, playgrounds and roads constitute one of the most incisive technical optimization in outdoor environments. In this context there is a growing interest in technologies such as green roofs and green walls especially for the effects that these systems can have to the building’s microclimate [15]. Materials with high emissivity are capable of emitting energy at long wave and are able to fast release the absorbed energy as short wave radiation. Low surface temperatures contribute to reduce air temperatures since the heat transmitted by convection is less. This reduction of temperature can have a significant impact in reducing the average temperature at the urban level, a fact of significant importance in warm climate cities. Previous studies [16] have verified that the density of the tree crown has an impact on the reduction of the air temperature under the tree surface from 2 to 4 °C. When the UHI effect (Urban Heat Island) is compared with the density of the trees in the area under examination, the results show significant correlated relationship [17, 18]. In hot climates, the introduction of vegetation systems can also alter the energy balance of the building as well as the energy demand of cooling due to shading provided on glass surfaces, on walls and on the...
3. METHODOLOGY

Simulation can be defined as the imitation of the reality, a process (theory and prediction) [20] or a situation to verify, find or explain a theory. It is well known that modelling a built environment project may help to visualize its future impact and is an important part of responsible design-making [3]. There are three types of modelling methods used in urban climatology; physical scale models, integrated open-air models, and mathematical models. There is a growing tendency on finding how our understanding of the urban microclimate may be applied in practice for urban planning and design.

The main risk is that by analysing different criteria that affect the microclimate reaches the definition of results contradictory to each other. In any case, the urban microclimate has an effect on the energy performance of buildings and in the open spaces between the buildings implying certain conditions of comfort for the people in confined spaces and people in outdoor environments. For the simulation of various conditions of temperature and comfort parameters, it was used ENVI-met, an environment simulation software that allows to model the micro-climatic conditions in the urban areas considered as ‘empty’ system (open space) and filled (the constructed volumes, etc.) in such a way as to render the interactions between the different elements presented.

The goal is to investigate micro-climatic variations linked to modified parameters and their impact on buildings. The focus of the analysis is, in particular, on the replacement of parking areas with green parks and pedestrian streets, of standard roofs with green ones, of vertical walls to green ones and of the creation of roof shading systems with also the use of photovoltaic system. A packet of simulations has been modelled for the elaboration. They are based on a not real but reliable and plausible, standard contest in Peristeri area in west Athens which was taken as a basic case study due to its urban density and climatic situation [21].

Peristeri is located in the western part of Athens. This area along with the centre presents the highest heat island (HI) intensity of the whole city. Is one of the biggest and one of the denser suburbs of the Attica region. The blocks of buildings considered as the case study of this area, are typical social housing from the 60’s constructed by pillars and beams and as a basic structure material was used reinforced concrete. It is parted by the 3 tower buildings, the 3 double block buildings south north oriented and the four east west
oriented blocks. Focusing on urban areas, the proposed research considers the buildings and the related space as a whole. The urban compound extension is 37'820 m², of which 25'713 (68%) is occupied by building construction and impermeable surfaces (parking areas and streets); the remaining (% 32) is a green open area. The built area represents the 29% (7'504 m²) of the total impermeable surfaces.

Variations in the models concern the replacement of standard roofs with green ones (from 0 to 100%) and the reorganization of the car circulation in order to leave open asphalt areas that become, in a second step, permeable and planted green surfaces. In addition, one of the most important steps for the simulation of the new scenario is the creation of roof shading (from 0 to 100%). Investigations are focused on the thermal variation resulting at the scale of the urban contest. Conclusions drive attention on the interactions between green area and air temperature, but also look at the impacts of these variations on project choices at urban and building level. In order to achieve the goal of zero energy urban settings a strategy of five basic steps has been followed:

- selection, analysis and simulation of a characteristic urban compound with envi-met;
- selection of different urban sustainable designs scenarios, perform new simulations;
- comparison of the results and selection of the best possible scenario for the improvement of the HIE and the microclimate in the urban compound;
- simulation with Design Builder to check the influence of the improvement of the microclimate to the existing buildings;
- analysis and collection of the results for the building energy performance...
after the redesign of the urban compound and the improvement of the microclimate.

For the model simulations, the area of interest has been transformed in a model grid with the dimension 130 x 120 x 30 grids with a resolution of 2 m x 2 m x 3m resulting in a total area of 260 x 240 m in the horizontal extension and with a height of 90m.

The meteorological input of a year period (2014) recorded by the urban climate station in Peristeri plus measurements performed by the university of Athens and the department of Physics (Santamouris, 2014) was applied. For the simulation it was selected the hottest day of the summer of 2014 (9 of July) with mean Temperature in 30 C while the maximum is 35.7 C. The wind is in west direction with an average speed of 3.1 m/sec.

In this next step, it is proposed the analysis and simulation of alternative sustainable scenarios that could help into the improvement of the existing situation and come a step closer to the goal of this research, which is the improvement of the microclimate and the effect that has on the building performance. In a brief these actions are:

• addition of trees and green surfaces on the ground level;
• green roof and green walls;
• shading system with photovoltaic elements on the rooftops;
• reorganization of the parking and creation of pedestrian permeable streets;
• linear park (green roof) on the existing roof of the market.

Experimentations consisted of two brief studies of the area. The following figure 2 visualize the model of the area in different conditions (existing and proposed situation).

The changes reveal the existence of a different microclimate between the as it is scenario and the hypothetical transformation scene. Introducing parks and pedestrian streets in place of asphalted areas lead to a fresher air (temperature decreases generally in a range set from 0.25 to 1.5°C, locally the difference can be 4 °C). Selection of trees and vegetation should be made according to the dry and warm climate of Athens. Plantation with big crown was considered to provide adequate shade but while requiring few water for irrigation. The replacement of standard roofs with green roofs does not seem to lead to significant variations in temperatures, being the maximum decrease equal to 0.7°C; conversely, measurements performed locally, close to one of the buildings with the use of a shading system on the rooftop show a significant decrease (about 2.5°C). Furthermore, by using the simulation tool it is also possible to define areas of thermal comfort. A method of describing thermal comfort was developed by Ole Fanger and is referred to as Predicted Mean
decisioni progettuali di varia natura, sia a livello urbano sia considerando la scala dell’edificio. Per raggiungere l’obbiettivo di comparti urbani verso l’energia quasi zero, è stata elaborata una strategia sviluppata su cinque fasi:

• selezione, analisi e simulazione con ENVI-met di un composto urbano caratterizzati;
• selezione di diversi scenari urbani sostenibili, nuove simulazioni;
• confronto dei risultati e selezione del miglior scenario per il miglioramento della HIE e il microclima nel comparto urbano;
• simulazione con Design Builder per verificare l’influenza del miglioramento nel microclima dagli edifici;
• analisi e raccolta dei risultati di rendimento energetico dell’edificio dopo la riprogettazione del comparto urbano e il miglioramento del microclima.

L’area di interesse è stata trasformata in un modello a griglia (130 x 120 x 30 griglie) costituito da maglie di dimensione 2 m x 2 m x 3m, determinando così una dimensione totale di 260 x 240 m in estensione orizzontale con una altezza di 90 m. I dati relativi alla stazione meteorologica per l’area di Peristeri sono stati inseriti considerando un campione di un anno (2014), inoltre sono stati inserite le rilevazioni effettuate direttamente dall’Università di Atene e il Dipartimento di Fisica (Santamouris, 2014). Per la simulazione è stato selezionato il giorno più caldo dell’anno (9 luglio nel 2014) con una temperatura media di 30°C e temperatura massima di 35,7° C e vento in direzione ovest con una velocità media di 3,1 m/sec. Nella fase successiva, è stata condotta una simulazione di scenari alternativi che potrebbero migliorare il microclima, agendo conseguentemente anche sulle prestazioni degli edifici. In breve, queste azioni riguardano:

• aggiunta di alberi e superfici verdi ai piano terra;
• tetto verde e pareti verdi;
• sistemi di ombreggiamento con elementi fotovoltaici su tetti;
• riorganizzazione dei parcheggi e creazione di zone pedonali permeabili;
• percorso lineare a verde sul tetto esistente della zona mercato.

Le variazioni registrate rivelano l’esistenza di un diverso microclima tra lo stato di fatto e l’ipotetico scenario di trasformazione (Fig. 2). Introducendo parchi e strade pedonali in sostituzione delle aree asfaltate si evidenzia un aumento nel valore di raffrescamento dell’aria (le temperature si riducono da un minimo di 0.25 a un massimo di 1.5 °, mentre la differenza locale può raggiungere picchi di 4°). La selezione degli alberi e dei sistemi di vegetazione dovrebbe essere fatta in relazione alle condizioni climatiche tipiche del luogo, ovvero con temperature elevate e con basse valori di umidità relativa. Le alberature a chioma larga sono ritenute le meglio adatte allo scopo perché forniscono un adeguato ombreggiamento e richiedono poco acqua per l’irrigazione. La sostituzione dei tetti standard con tetti verdi non sembra generare consistenti riduzioni di temperatura a livello superficiale. 
Figure 2. Envi-met: Results of the surface temperature on the ground level (up) and the air temperature (down) of the existing situation (column on the left) and of the proposed scenario at 14.00 pm (column on the right).

Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). The Predicted Mean Vote (PMV) refers to a thermal scale that runs from Cold (-3) to Hot (+3), originally developed by Fanger and later adopted as an ISO standard. After simulating the existing area, it was found that the PMV was above +3, which means that the sensation is extremely hot.

Figure 3 shows a comparison between the surface temperature of outdoor areas and the PMV in the existing situation and the modified setting. The graphs presented, is the comparison between the existing situation (in blue) and the modified scenario (in red) in terms of percentage of outdoor areas with the corresponding PMV values.

In both graphs (T and PMV), the y-axis shows the percentage of the areas, while the x-axis shows the temperature in degrees Celsius (in the graph on the left) and (right) the PMV values.

By the charts, referred to temperature can be observed that more than 60% of the external surfaces in the initial situation has a temperature above 41 °C, while in the modified scenario 60% of the area has a temperature below 35 °C. The PMV graphs indicate that in the existing situation t the 70% of the surfaces presents relative values between 4 and 5, which indicate a situation of extreme discomfort while the corresponding values in the modified scenario show that 70% has a value between 1.4 and 2.2, close to the indices of comfort.
Actually, in the current as-it-is scenario, shade is indeed provided by existing trees in the centre of the courtyards between the buildings. The presence of the trees is assumed to be increased and enhanced by the redesign of external surfaces, increasing the permeable surfaces and reducing the asphalt area as much as possible. A great impact in local decrease in temperature is brought about the linear park and the shading of the new plantation in that area. There is a significant temperature reduction on the surface of the ground level due to the use of new materials and the shading provided by the vegetation. By the measurements around the central building, resulting air temperature reduction is between 0.5 to 2.9 degrees, while a lower reduction is observed to the west and south part. Conclusions put attention not only on the interactions between green area and air temperature, but also at the impact of these variations on project choices at urban and building level.

A further step is needed in the effort of understanding the potential mutual effects of modified external conditions with respect to the energy performance of existing buildings. To provide an idea of the potential of outdoor modifications on the energy performance of existing buildings in this urban compound taking into account the mutual interactions between buildings and open areas, further simulations have been run.

Performed simulations to the building urban complex of Peristeri with the use of Design Builder show the paramount importance of bioclimatic approach in the planning and design to pursue the goal of a low energy consuming built environment. The site, the building orientation and the organization of the blocks play a very important role in determining the energy consumption and its variation.

Notwithstanding the differences between the different buildings in the area...
of Peristeri, a general character among all scenarios derives from the link between the main physical and energy variables. In all the urban contexts the energy performance indexes are variable between 44 and 88 kWh/m² year for heating demand and between 36 and 100 kWh/m² year for cooling demand. In this next step in order to check and evaluate the improvement of the microclimate of the area selected and the effect that the new climatic data have on the energy demand of the buildings, the new climatic data of the area simulated by Envi-met have been used to be intertwined with the simulation by Design Builder, using them as a new input for the re-calculation of the energy performance of the building. At this point, as it is shown at the Fig.4, an area of 4x4x4m around the main central double block building has been identified. A vertical division in 5 critical points was also performed (pilotis level, first floor, middle floor, last floor and 4 meters above the rooftop) so as to subtract results from all the points referred to these elevations.

**Figure 4. The defined area around the double block building for the new climatic data.**

The air temperature of these points has been used for the simulation of the correspondent apartments. South-oriented residential apartments at the first, third and last floor of the double building block B6 of Peristeri have been taken as reference units (Figure 5). Simulations have been performed for the summer period where the HIE is more evident (from 1st June until 31th August).

The standard climatic data used by design builder (IWEC climatic data file) have been modified in two different and opposite ways. On the one side, they have been decreased according to the correspondent value of external temperatures from the Envi-met calculations; on the other side, the same data have been increased as a function of measured data in the correspondent meteorological station of Peristeri [21].
4. RESULTS

Figure 6 reports the results of the energy demand for cooling (kWh) of these apartments, for the whole summer period, as shown, these results are highly variable as a function of external temperatures.

<table>
<thead>
<tr>
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<th>Energy demand for cooling (kWh)</th>
<th>Energy demand for cooling (kWh)</th>
<th>Energy demand for cooling (kWh)</th>
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<tr>
<td></td>
<td>(standard air temperatures)</td>
<td>(air temperatures 10% effect)</td>
<td>(temperatures modified by green)</td>
</tr>
<tr>
<td>Apt 1 (1st floor)</td>
<td>1122.55</td>
<td>1283.45</td>
<td>926.54</td>
</tr>
<tr>
<td>Apt 2 (2nd floor)</td>
<td>990.98</td>
<td>1202.45</td>
<td>874.06</td>
</tr>
<tr>
<td>Apt 3 (6th floor)</td>
<td>1211.22</td>
<td>1483.49</td>
<td>1067.15</td>
</tr>
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</table>

Corresponding values of energy demand for cooling in the selected apartment at the first floor vary from 1348, 37 kWh, (worst condition represented by the scenario considering increased air temperature due to the heat island effect), to the standard scenario, to 1122,55 kWh, down to 926,54 kWh in the improved scenario due to the cooling effect of the green.

Corresponding values of energy demand for cooling in the apartment at the intermediate floor vary between 1202,45 kWh, in the worst condition represented by the scenario considering increased air temperature due to the heat island effect, to 990,98 kWh for the standard scenario, down to 874,06 kWh in the standard scenario.

4. RISULTATI

La Figura 6 riporta i risultati della variazione nella domanda di energia per il raffrescamento (espressa in termini di kWh) di questi appartamenti, per tutto il periodo estivo. Dai risultati è evidente la grande variabilità della domanda di energia interna in funzione della temperatura esterna.

Con Envi-Met, dall’altro le stesse sono state incrementate per meglio rappresentare i valori reali così come rilevato dalla stazione meteorologica corrispondente di Peristeri [21], che considerano anche gli incrementi dati dall’UHI.

La Figura 6 riporta i risultati delle simulazioni fettuate con Design Builder. Le simulazioni sono state eseguite per il periodo estivo, dal 1 giugno al 31 agosto. I dati climatici standard utilizzati da Design Builder (IWEC file di dati climatici) sono stati modificati in due modi diversi e opposti. Da un lato, sono state ridotte le temperature in base al valore risultante dalle simulazioni effettuate con Envi-Met, dall’altro le stesse sono state incrementate per meglio rappresentare i valori reali così come rilevato dalla stazione meteorologica corrispondente di Peristeri [21], che considerano anche gli incrementi dati dall’UHI.
kWh in the improved scenario due to the cooling effect of the green. Corresponding values of energy demand for cooling in the apartment at the last floor vary between 1483.49 kWh of the worst condition represented by the scenario considering increased air temperature due to the heat island effect, to the standard scenario, to 1211.22 kWh, where air temperatures have been supposed under standard condition down to 1067.35 kWh in the improved scenario due to the cooling effect of the green.

The results conclude that a percentage decrement of about the 20% between each scenario can be found. Globally up to about 40% reduction of energy consumption can be observed, demonstrating the huge potential of environmental modification at the urban scale on the energy performance of existing buildings. A very significant, twofold impact on heat island reduction at the urban scale and energy consumption at the building scale can be deducted by shading and addition of green in the urban setting.

The simulation results between the standard setting and the worst scenario due to the increase of temperature are also consistent with the data and the corresponding values reported by Santamouris [22,23] which showed a significant increase in the energy consumption of buildings caused by the intensification of external temperature in metropolitan areas, calculated for the period 1970-2010. Although in the literature are shown comparisons between energy consumption of similar buildings located in urban areas and buildings in rural areas, from existing data can be recorded an average increase for the energy demand of cooling due to the heat island. In particular, in Athens, Santamouris (2014) found that the cooling load is increased from 99.5 kWh / m² / year in 1970 to 124.8% in 2010, while the corresponding heating load has decreased from 39.4 kWh / m² / year in 1970 to 31.7 kWh / m² / year.

5. CONCLUSIONS

It can be concluded that urban settings and buildings in order to reduce the specific impact of urban heat island and global overheating on electricity consumption should be more adaptable to specific climatic conditions considering the built environment in its different scales and conceiving the retrofitting options in the existing built environment and in its urban boundary conditions as a unique system. In fact, energy demand and energy retrofitting options should be observed with the same gravity also to the open spaces and environments of the city and not only in reference on the building block, thus considering the buildings and the related open spaces as the main sector of energy investigation and the consequent global effects that result from the
collaborative strategy and its effects of all the buildings and open areas of the urban environment.

The design of the external surfaces with the use of natural elements - even when the intervention may be limited to the existing buildings in dense built urban areas - is one of the first actions to be considered for the improvement of the urban conditions and as a result to low the energy loads. In other words, the first step to reduce the internal temperatures in existing buildings is the attempt to reduce the external temperature. The results obtained indicate that in fact the alternative design of the outdoor surfaces acts both as an element of modification and optimization of the urban microclimate that of improving the energy performance of buildings.

6. REFERENCES


