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# Summer mitigation strategies in an urban renovation area in the south of Italy

Paola Lassandro[1*], Silvia Di Turi[1], M.G. Perrini[2]

[1] Construction Technologies Institute, Italian National Research Council, ITC-CNR, Bari Branch, Via Paolo Lembo 38/B, Bari 70126, Italy
[2] ABITA - Bioecological Architecture and Technological Innovation for the Environment, University of Florence, Via San Niccolò 93, Florence 50125, Italy

Corresponding Author Email: paola.lassandro@itc.cnr.it

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**ABSTRACT**

In urban regeneration process, one of the key components is the environmental and energetic improvement to contrast the negative effects of climate change in modern cities. In fact, temperature increase is exacerbated in more densely built-up urban areas by the phenomenon called “Urban Heat Island-UHI”.
The paper aims at evaluating the influence of buildings and urban interventions on microclimate, through a case study in an urban renovation area in the South of Italy with a particular focus on the effects at pedestrian level.
In particular, this research analyses and compares seven urban scenarios that explore different technical choices involving both buildings and surrounding area, related to the influence on microclimate and outdoor thermal comfort. The considered options are about materials physical properties (albedo), urban fabric morphology, mitigating elements such as water bodies, vegetation and integrated green systems as Green Wall and Roof. The simulations are carried out using the holistic three-dimensional software ENVI-met for urban modelling. The comparative results analysis gives the possibility to individuate the optimal solution for the case study.
The research goal is the definition of an integrated method to assess and compare mitigation strategies for heat stress at micro-urban scale, useful in city planning decision-making.

## 1. INTRODUCTION

In recent years, more attention has been given to environmental problems and particularly to climate changes also linked to the continuing population growth and urbanization. Moreover, the European Union has shown an increasing interest in urban regeneration [1] as strategy that integrates interventions at urban and building levels, in order to restore liveability to cities and, at the same time, to improve buildings energy efficiency [2]. This may be also an opportunity to reduce the vulnerability to climate change in summer, a substantial issue in the modern cities [3]. In particular, the construction sector is one of the main cause of climate change related to greenhouse gases emissions [4]. Moreover, temperature increase is exacerbated in more densely built-up urban areas by the phenomenon called “Urban Heat Island - UHI”.

Cities become more and more vulnerable to current heat waves and extreme heat events. UHI and global warming are positive in winter for the reduction of heating energy need. On the contrary, in summer they induce significant increase of temperature peak respect to peripheral zones [5] and total electricity consumption for cooling purposes. According to Akbari et al. [6], for the 1970–2010 period, the average increase of the cooling demand (23%) overtakes the corresponding average reduction of the heating (19%). This trend is magnified in Mediterranean cities, which show high peaks of summer temperatures and higher average temperatures also in intermediate seasons (spring and autumn), due to climate change.

The urban canyon features that affect mostly UHI and vulnerability of an urban area to hot temperature are: physical properties of materials (albedo, emissivity), morphology of urban fabric (density, buildings’ height, urban canyon), the use of elements such as bodies of water, vegetation and integrated green systems as Green Wall and Green Roof [7-8].

Materials exposed to the solar rays incidence convert the solar radiation into heat, which builds up and is re-emitted over time (especially at night) according to the materials physical characteristics, as a function of conductivity and heat capacity. During the day, in the presence of solar radiation, the characteristic that most influences the thermal behavior of a material is the reflection coefficient or albedo, which depends on color and roughness; instead, during the night, the value of thermal conductivity affects the behavior of materials. In the presence of solar radiation, surface temperatures increase, as the albedo decreases [9]. As it results from previous researches [10], providing for the use of cool materials in the design phase means to contribute to the decrease of surface temperature that is maintained close to air temperature even during the day. Therefore, it copes with UHI phenomenon and heat waves.

The urban morphology and the canyon geometry greatly influence the urban energy balance: they define the surface exposed to the exchange processes, regulate the entrance of the solar radiation, determine an interaction between the urban surfaces and limit the dispersion capacity of the long-wave infrared radiation and air turbulence. The parameters that define the characteristics of the urban settlement are the H/W ratio and the Sky View Factor (SVF) [11], closely connected to each other. An urban regeneration intervention will cause a variation in the height of the buildings (H) and the relative distance (W), even affecting the value of the SVF [12].

Subsequently, the new urban configuration derived from urban regeneration determines a change in the microclimate of the area. Many studies tried to analyze the behavior of urban areas and influence of UHI phenomenon and climate change, focusing on different strategies for mitigation. Morakinyo et al. [13] adopted different scenarios with various urban configurations and green roof type in order to study the outdoor cooling effect of this kind of strategy in cooling demand reduction. Instead, Ali-Toudert and Mayer [14] varied the geometry of the street canyons in order to evaluate comfortable microclimate at street level for pedestrians. Thus, the definition of a method, which aims to define the best mitigating strategies to be adopted, is crucial for sustainable and resilient urban planning and buildings design.

## 2. METHODOLOGY

In order to evaluate the impact of buildings and urban interventions on microclimate, it is defined a methodology with the following steps:

(1) Analysis of climatic conditions (altitude, latitude, degree days, average temperatures in Mediterranean climate) and urban fabric (building density and morphology);

(2) Identification of some representative microclimate indicators for pedestrian comfort (mean radiant temperature, air temperature, relative humidity, wind speed) and urban features (solar radiation, sky view factor). These parameters are influenced by climate change and UHI phenomenon, depending also on the urban fabric configuration.

(3) Identification of urban and building planning factors that mostly influence the local microclimate. The factors considered are about materials physical properties (albedo), urban fabric morphology, mitigating elements such as water bodies, vegetation and integrated green systems as Green Wall and Roof;

(4) Definition of scenarios able to mitigate temperature increase and heat waves, exploring different technical choices involving both buildings and surrounding area, related to the influence on microclimate and outdoor thermal comfort, according to the main factors indicated in the previous point;

(5) Creation of a discretized 3D urban model and simulation of microclimate at urban micro-scale in the most critical climatic condition (the hottest day of summer) through the software ENVI-met.

(6) Development of 2D and 3D maps about microclimate parameters (air temperature, mean radiant temperature, SVF, solar radiation, wind speed etc) in order to compare the seven scenarios;

(7) Output-data comparison, through graphs and diagrams related to in the receptors introduced in the ENVI-met model;

(8) Choice of the best UHI mitigation strategy in summer through the multicriteria analysis of the results of the most critical receptor at pedestrian level. It is based on the Analytic Hierarchy Process (AHP), which allows pairwise comparison of the indicators and, then, of alternatives according to Saaty's preference scale from 1 (minimum importance) to 9 (maximum importance) [15].

### 2.1 Simulation tool

It is necessary to point out that the proposed method analyzes thermal behavior of the studied area through selected indicators and makes use of urban environmental simulations performed through ENVI-met. Like other tools, such as Rayman, it is able to simulate microclimate and interactions between individual buildings, surfaces and plants at urban micro-scale, but in this sense ENVI-met is one of the environmental modeling software at urban level. It is a holistic three-dimensional and non-hydrostatic software, is applied in microclimate analysis in urban area and its models has been validated positively by comparison between field measurements and simulation results [16]. The most critical point is the simulation time that can reach some days. In fact, the finer is the used spatial (available 0.5–10 m) and temporal (up to 10 s) resolution grid, the more the simulation time increases. It includes full 3D Computational Fluid Dynamics (CFD) model [17] based on non-linear equations and computational thermo-fluid dynamic calculation using the standard k− ε turbulence model in closing the Reynold Average Navier-Stokes equations for each grid in space and for each time. A positive application of the software is when greenery is introduced in the model in order to analyze the effects [13], because plants (e.g. trees and grasses) do not result permeable media to wind flow and solar insolation but show in the outputs the interactions with the surrounding environment by energy absorption and evapotranspiration.

Therefore, the tool is fundamental to analyze and compare the chosen different scenarios.

## 3. CASE STUDY AND SCENARIOS

The subject of study is an urban renewal area B/6 according to the Bari's PRG (city in the South of Italy – C Climate Zone 910<GG<1400) of about 12,255m2. The work analysed the main effects at the microclimatic level of the project proposed to the Municipality for the urban fabric regeneration, which is made up of social housing buildings in degradation state.

The study defines a simulation model of the area (150x150x 34 pixels) and requires the settings of new materials (wall with different albedo, green roof, reflective pavements etc.) in the libraries and of climatic conditions of the hottest day in summer. Through this models made-up for seven different scenarios, is possible to analyse the interactions between the different technical choices and microclimatic changes. Hence, this research analyses and compares seven urban scenarios in the hottest day of summer according to the settings in Table 1.

Each scenario explores singularly different technical choices involving both buildings and surrounding area in relation to the influence on microclimate and outdoor thermal comfort.

**Table 1.** Settings in ENVI-met simulations

| | |
|---|---|
| Simulation day | 25.07.2017 |
| Simulation period | 24 h (00:00-23:59) |
| Spatial resolution | 1m horizontally, 1m vertically |
| Wind Speed | 2.6 m/s |
| Wind Direction [N=0, S=180] | 230 |
| Indoor Relative Humidity | 59 % |
| Indoor temperature | 20°C |
| Heat Transmission | 0.314 W/m$^2$K (walls) |

The contemplated data are physical properties of the material (albedo), morphology of urban fabric (density, buildings' height, urban canyon), the use of mitigating elements such as bodies of water, vegetation and integrated green system as Green Wall and Green Roof.

The analysed seven scenarios are:

(1) Base Scenario [BaseS];
(2) Green Roof Scenario [GRoofS];
(3) Green Wall Scenario [GWallS];
(4) Green Scenario [GreenS];
(5) Blue and White pavements Scenario [BlueWS];
(6) White Buildings Scenario [WhiteBS];
(7) Tower Scenario [TowerS].

### 3.1 Base scenario

The Base Scenario is the reference model to which all the following models relate, with the addition of main elements that feature the urban fabric and that affect the microclimate significantly. In fact, the base model is defined by buildings and urban surfaces that use standard materials with non-performing thermo-physical properties.

In particular, the Base Scenario (Figure 1) shows buildings (h=22m) that use external finishing layer with a low value of albedo (about 40%), dark pedestrian and road paving (asphalt albedo about 20%) and has not any green element.

The project of Base Scenario buildings includes wall and roof systems composed of the three following layers: masonry layer (31 cm); extruded polystyrene insulation panels (8 cm) and external finishing layer with 40% albedo (about 2 cm).

There are three different surfaces used in the basic model: asphalt for road paving, concrete for pavement and basalt for public areas as squares.

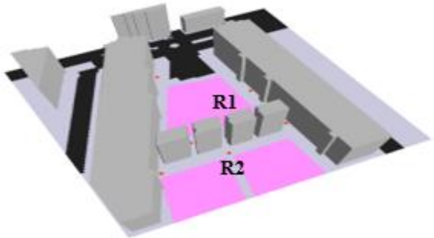



**Figure 1.** Base Scenario 3D model in ENVI-met with the receptors positions

### 3.2 Green roof scenario

**Table 2.** Green Roof characteristics in ENVI-met

| Green Roof | |
|---|---|
| $CO_2$ Fixation Type | C3 |
| Leaf Type | Grass |
| Albedo | 0.20 |
| Plant height [m] | 0.10 |
| Root Zone Depth [m] | 0.20 |
| Leaf Area (LAD) Profile | 0.30 |
| Root Area (RAD) Profile | 0.10 |
| Season Profile | 1.00 |

In the Green Roof Scenario an integrated green system is inserted on the base model roof. This is one of the most important cooling strategies at urban and building level [18]. In the geometric model an extensive green roof is added on the top of buildings [19], according to the data shown in table 2.

The climatic conditions and the other inputs needed in simulation are unchanged.

### 3.3 Green wall scenario

As operated in the Green Roof Scenario, in the Green Wall Scenario a simple plants system is applied on the building wall of the basic model, with the same height of the buildings on the vertical surface without windows.

Thus, it is created a shielding for buildings that prevents the direct incidence of solar radiation on external wall surfaces [20]. The North façade does not show green wall because it is not interested by direct solar radiation.

### 3.4 Green scenario

The Green Scenario preserves the morphological and technological buildings configuration of the Base Scenario, by amending only the urban plan with a green redesign [21].

There are two main typologies of green elements used in the Green Scenario model:

(1) Simple plants: grass uniformly distributed in the area. It is used a simple type of grass with a maximum height of 10cm;
(2) 3D Plants: green punctual elements, trees with medium height (12m) and deciduous leaves.

It is chosen an Acer Campestre, a deciduous tree of modest size, with compact bushy crown and often twisted and branched trunk.

### 3.5 Blue and white pavements scenario

The BlueW Scenario model is characterised by a high albedo material for the urban paving, compared to those used in the Base Scenario.

Furthermore, in order to show the water bodies mitigating effects on the air temperature, a water area is inserted in the centre of the model.

The water cooling effect is related to its ability to maintain the surface temperature lower than air or other materials temperature. Water has also a low albedo value (about 3% in the hours of maximum radiation).

### 3.6 White buildings scenario

As shown in literature, the thermo-physical properties of materials are able to influence the interaction between buildings and climate behaviour. So, in the WhiteBS model cool materials (high value of solar reflectance and thermal emittance) are used for buildings design.

In fact, the use of "cool materials", which can reflect a significant part of solar radiation and dissipate the heat absorbed through radiation, contributes to increase urban albedo, to maintain lower surface temperatures and, thus, to present an effective solution to mitigate UHI [22].

The high reflection capacity of these materials is due to high reflectance pigments in the infrared portion of the solar spectrum. It means that the material does not get hot during the day. The high emittance, instead, allows the material to cool overnight, irradiating the heat absorbed during the day.

Therefore, the difference between the WhiteBS and the Base Scenario models is only the value of material albedo (85%).

### 3.7 Tower scenario

The last model shows changes about the urban fabric: from the linear blocks of the Base Scenario to the tower ones of Tower Scenario. This new urban configuration affects climate indicators, such as wind speed, air temperature and relative humidity. In order to respect the urban standards – in particular distance between buildings – and the design buildings volume, the new urban configuration defines seven 25x25 m isolated blocks, each with a height of 22 m. The materials used in this model and the climatic conditions and the other inputs needed in simulation are the same of those of the Base Scenario.

### 3.8 Simulations

After defining geometric models and the initial settings, the simulation is run for each scenario and takes even longer than 15 days, due to the models completeness and care: grid dimension, vegetation elements, geometric model complexity, number of receptors. The simulation process performed by the software generates a high number of outputs that are divided into eleven destination folders: Atmosphere, Buildings, Inflow, Log, Pollutants, Radiation, Receptors, Soil, Solar access, Surface, Vegetation. Each folder contains two types of output analysed in 10 min time steps. These outputs give information on more than 15 indicators and for the entire height of the model, divided into 30 intervals with a step size of about 1m. From these general tables the data necessary to make comparisons are extrapolated related to:

(1) time: hourly interval;

(2) height: pedestrian level at 1.50mt, the height at which the sensation of pedestrian comfort is detected.;

(3) indicators: mean radiant temperature (Tmrt) [23], air temperature(Ta), relative humidity (Qrel), wind speed (WS).

## 4. RESULTS

The huge amount of ENVI-met simulation outputs needs a reworking through calculation programs and support graphic interface, in order to obtain comparable results. The comparisons are made up through graphs that show the selected climate indicators trend, helpful to the microclimate analysis. ENVI-met graphic support gives a clear and immediate representation in chromatic scale of the analysed climate indicators and of other parameters (e.g. Sky View Factor, solar radiation etc.) for the studied area. The Figure 2 shows, for the BaseS, the critical buildings surface temperatures that cause an increase of the analysed Tmrt and, thus, pedestrian comfort.

### 4.1 Receptors

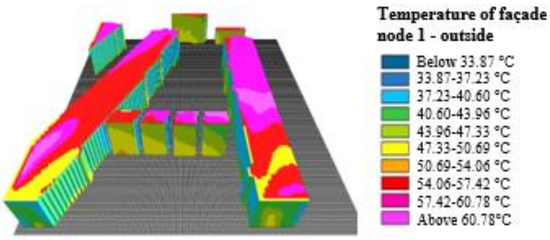



**Figure 2.** Temperature of facades and roofs at node 1 in ENVI-met for the Base Scenario at 13:00

In the Base Scenario six receptors are analysed (see the red points in Figure 1). The results of the most critical ones (R1, R2) are presented below, for brevity.

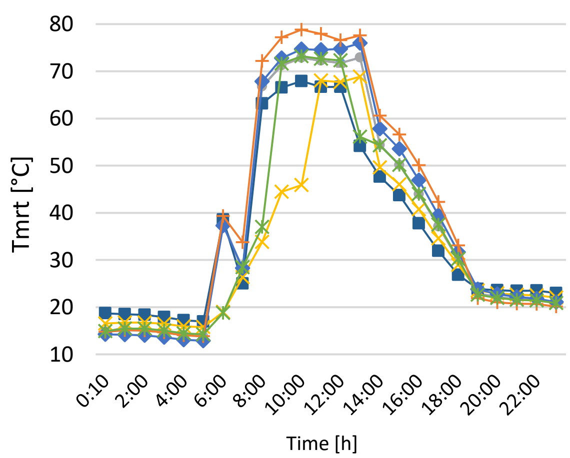
4.1.1 Receptor 1

As regards mean radiant temperature (Figure 3a), the most critical scenario is the WhiteB one: it shows the highest value Tmrt=78.84 °C at 10:00, while the lowest peak values are shown in GWallS (Tmrt,max= 67.93 °C at 10:00) and GreenS (Tmrt,max= 68.87 °C at 13:00).

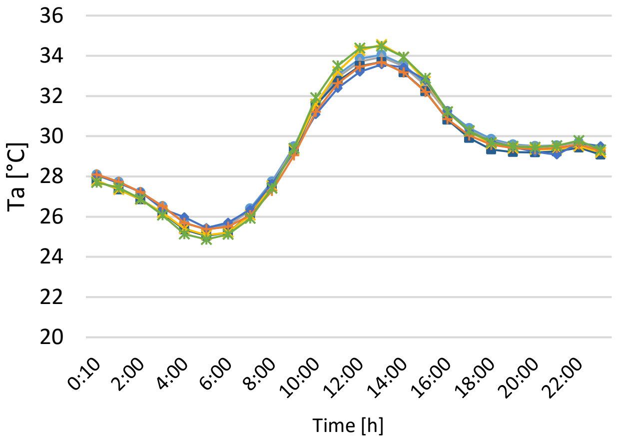
The comparison between these trends highlights the vegetation mitigating effects on the behaviour of Tmrt. In fact, the ΔTmrt between GWallS and WhiteBS is about 11°C, between GWallS and Base Scenario is about 5°C; while comparing GreenS to WhiteBS and then to BaseS, the ΔTmrt is about 10°C and 4°C, respectively. The sudden peak at 6:00 (for almost all the scenarios, except GreenS and TowerS that have a different urban configuration) or the drop at 11:00 (in the GreenS) are linked to the effect of direct solar radiation on the buildings, in particular near the stairwell which is advanced compared to the rest of the construction, or trees that throw shadow. Concerning air temperature, the most critical graphs (Figure 3b) are the BaseS (Ta,max=34.05 °C at 13:00) and TowerS (Ta,max= 34.48 °C at 13:00). The best trend is the GWallS one that reaches the maximum value (Ta,max= 33.69 °C) at 13:00. While, the lowest maximum value of air temperature is reached at 13:00 in BlueWS (Ta=33.32 °C) thanks to the proximity of the analysed receptor to the water. Regarding relative humidity (Figure 3c), the scenarios that show the highest values are: BlueWS (Qrel=63.42 % at 5:00), GWallS (Qrel=60.68 % at 05:00), GreenS (Qrel=60.43 % at 5:00). This trend shows how the greater the green areas, the higher the value of the relative humidity due the phenomenon of evapotranspiration of plants and water surface. As shown, the maximum relative humidity value is reached at 5:00, in correspondence with the lowest temperature value (in fact, there is inverse proportionality between the two quantities) because of the convection currents during the night as a result of the time lag between the cooling of ground and overlying air.

4.1.2 Receptor 2

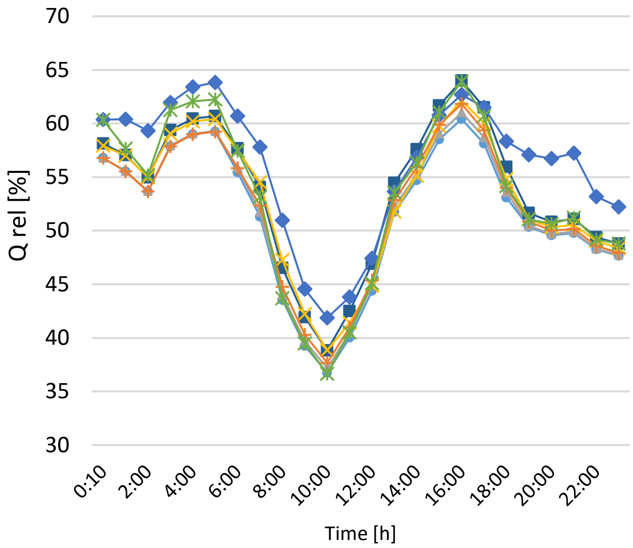
As shown in the previous receptor analyses, the mean radiant temperature (Figure 4) highest value is reached in WhiteBS (Tmrt,max= 79.13 °C at 14:00), while the lowest maximum values are shown in GWallS (Tmrt,max= 72.61 °C at 14:00) and in GreenS (Tmrt,max= 71.22 °C at 14:00).



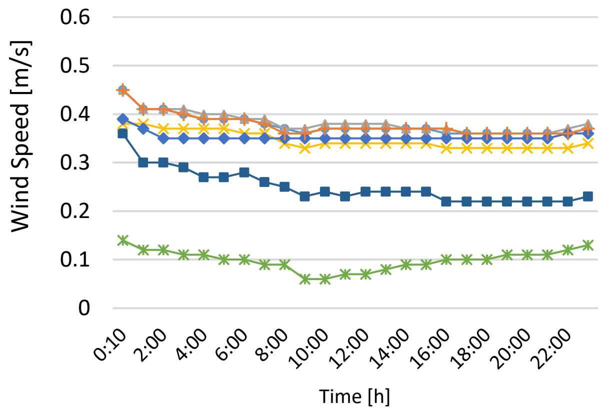

(a) Mean Radiant Temperature in R1




(b) Air Temperature in R1




(c) Relative Humidity in R1




(d) Wind Speed in R1

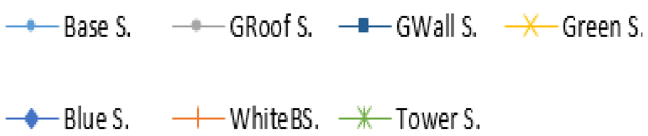



**Figure 3.** Indicators comparison in R1

Regarding air temperature, the most critical graph is the one related to TowerS (Ta,max=34.94 °C at 13:00); however, during the night this model provides lower temperature values due wind mitigating action (Ta,min=23.97 °C at 5:00).

The model with minimum values of air temperature in daytime is the BlueWS (Ta,max=34.01 °C at 13:00); however, in nightime this graph shows rather high values (24.5 °C at 5:00) because of the receptor position is too far from water body.

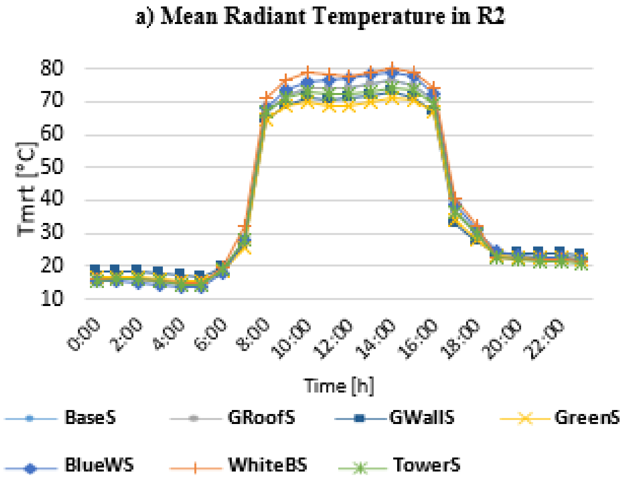



**Figure 4.** $T_{mrt}$ comparison in R2

The highest relative humidity values are reached at 5:00 and 16:00, according to the lowest air temperature values: the lower is the air temperature, the lower is its ability to contain steam and, therefore, the air relative humidity increases. The models with the highest relative humidity value are the GWallS (Qrel= 65.91% at 5:00; Qrel= 68.64% at 16:00) and the GreenS (Qrel= 66.61% at 5:00; Qrel= 67.47% at 16:00); the BlueWS shows the highest Qrel value only at 5:00.

As regards the wind speed graphs, the results of this receptor confirm as shown in the previous analysis: the highest value are reached in TowerS, followed by the triad BaseS – GRoofS – WhiteBS, with values quite similar because the design differences between the three models are not perceptible at pedestrian level.

### 4.2 Environmental performance chromatic maps

The study continues with comparison of chromatic maps at 13:00, the most critical time, and at 1.5 m above the ground, in relation to the most significant environmental parameters.

These maps confirm what the receptors analysis shows. As regards air temperature (Figure 5), the most critical model at 13:00 is the GreenS followed by the BaseS, the GRoofS and the TowerS; while the model that shows the lowest air temperature values is the BlueWS.

Concerning mean radiant temperature, the scenario with the significantly highest values is the WhiteBS (up 75.60 °C).

Regarding the wind speed, Figure 6 shows a better behaviour of the configuration with towers compared to that with linear blocks in relation to the direction and the intensity of the wind.

The maps of direct and diffuse solar radiation do not show any differences between the seven models, while the seven maps related to the reflected solar radiation are different (Figure7) because it depends on thermo-physical properties of materials. In addition to the parameters studied in the analysis of receptors, we consider also the maps of solar radiation and SVF. The most critical models, with the highest reflected solar radiation, are the WhiteBS and the BlueWS (the highest albedo materials); the best one is GreenS. Regarding SVF, the maps (Figure 8) of the two different urban configurations confirm that tower blocks have a higher SVF value than linear ones [24].

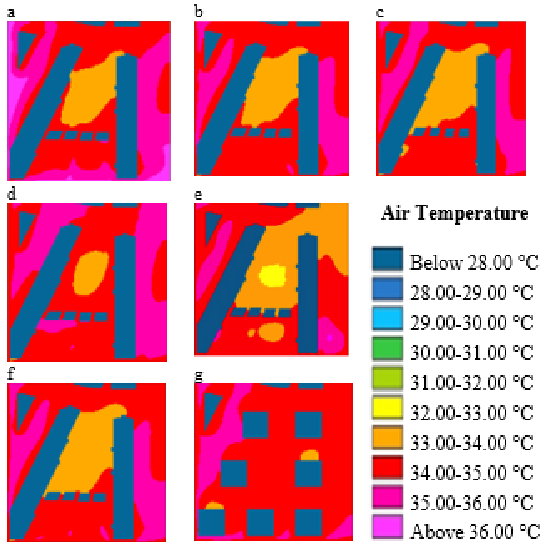



**Figure 5.** Air Temperature [°C] - Scenarios Comparison at 13:00, h=1.5m: a) BaseS, b) GRoofS, c) GWallS, d) Green S, e) BlueWS, f) WhiteBS, g) TowerS

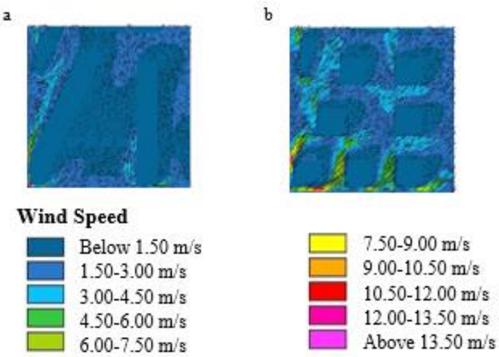



**Figure 6.** Wind Speed [m/s] - Scenarios Comparison at 13:00, h=1.5 m: a) BaseS, b) TowerS

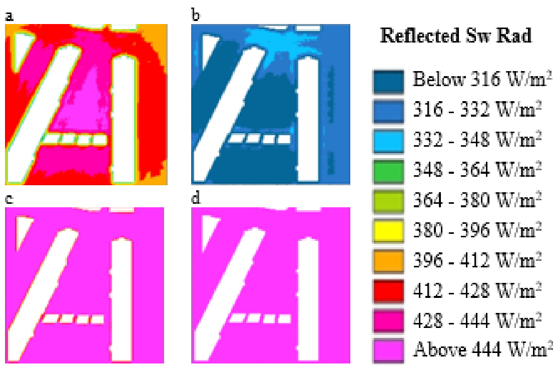



**Figure 7.** Reflected Sw Radiation [W/m$^2$] - Scenarios Comparison at 13:00, h=1.5m: a) BaseS, b) Green S, c) BlueWS, d) WhiteBS

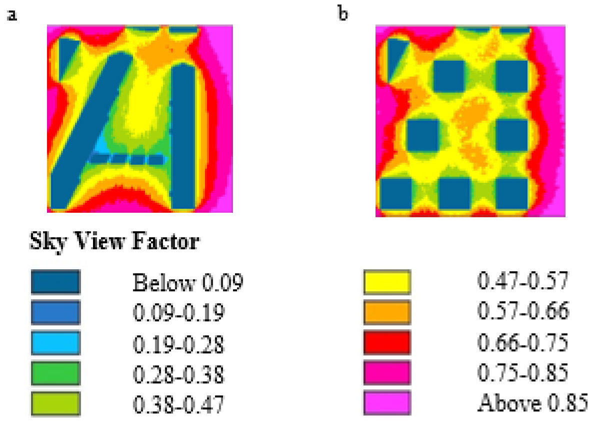



**Figure 8.** SVF - Scenarios Comparison at 13:00, h=1.5 m: a) BaseS, b) TowerS

In fact, the SVF value is about 0.52 and 0.62 in the centre of BaseS and the TowerS, respectively.

### 4.3 Multicriteria analysis of mitigation strategies

After the study of the obtained results, the multicriteria analysis is carried out about the most critic receptors at the hottest hour (13:00).

The AHP method was used. It consists of a pairwise comparisons matrix related to chosen indicators (mean radiant temperature, air temperature, relative humidity and wind speed) in order to identify the most incisive one on the urban microclimate in relation to the analysed area and its use. Then (Table 3), a comparison is made between the seven alternatives (possible scenarios) according to each indicator.

**Table 3.** Comfort indicators comparison matrix

| | Indicators | | | | Local weights | |
|---|---|---|---|---|---|---|
| | Tmrt | Ta | WS | Qrel | | |
| Tmrt | 1.000 | 3.000 | 8.000 | 5.000 | $x_1$ | 0.557 |
| Ta | 0.333 | 1.000 | 7.000 | 3.000 | $x_2$ | 0.274 |
| WS | 0.125 | 0.143 | 1.000 | 0.200 | $x_3$ | 0.041 |
| Qrel | 0.200 | 0.333 | 5.000 | 1.000 | $x_4$ | 0.128 |

In order to build-up the matrix, it is used the Saaty's values scale [range between 1-9]. Through appropriate calculations defined by the AHP method, the local weights are determined (Table 4 shows an example of local weights scores, related to comfort indicators) and then the matrix coherence is evaluated (consistency index CI, random index RI and report consistency CR). Thus, it is possible to obtain the global score vector for each alternative.

The local weight of each indicator (xn) (Table 3) is multiplied by the relative score obtained for the same indicator (according to the reached value) in the selected scenario (yn) (e.g. relative scores for Tmrt in Table 4). Thus, the global score for each scenario is calculated as the sum of the products ($p = x_n * y_n$) obtained for all indicators in the analysed scenario. The results are shown in Figure 9. Hence, the best alternative is the GreenS that reaches the maximum score followed by GWallS and BlueWS.

**Table 4.** $T_{mrt}$ comparisons matrix and relative scores for each scenario

| Mean Radiant Temperature | Tmrt Scores | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BaseS | GRoofS | GWallS | WhiteBS | GreenS | BlueWS | TowerS | |
| BaseS | 1 | 1 | 0.500 | 3 | 0.200 | 2 | 0.500 | $y^1$ 0.088 |
| GRoofS | 1 | 1 | 0.500 | 3 | 0.200 | 2 | 0.500 | $y^2$ 0.088 |
| GWallS | 2 | 2 | 1 | 7 | 0.500 | 6 | 2 | $y^3$ 0.223 |
| WhiteBS | 0.333 | 0.333 | 0.143 | 1 | 0.111 | 0.500 | 0.200 | $y^4$ 0.156 |
| GreenS | 5 | 5 | 2 | 9 | 1 | 8 | 2 | $y^5$ 0.023 |
| BlueWS | 0.500 | 0.500 | 0.167 | 2 | 0.125 | 1 | 0.200 | $y^6$ 0.388 |
| TowerS | 2 | 2 | 0.500 | 5 | 0.500 | 5 | 1 | $y^7$ 0.034 |

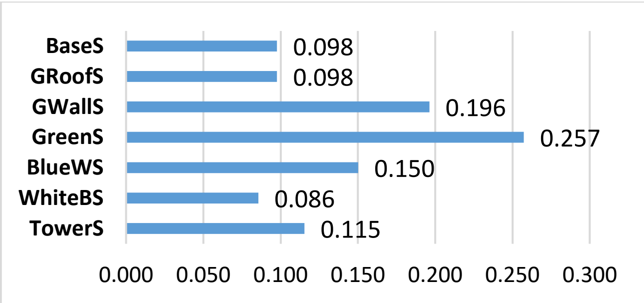



**Figure 9.** Global vector scores in AHP multicriteria analysis

### 4.4 Final Mitigation Scenario

Finally, the paper analyses a final model that shows the best technical-design solutions identified by the multicriteria decision process, in order to obtain an urban fabric able to contrast the stress of summer microclimate. The Final Mitigation Scenario shows a tower morphological configuration with a green wall applies on the facades most exposed to the action of solar rays (South and West facades). The Final Mitigation Scenario uses other summer microclimate mitigation strategies, such as: cool materials apply on building and urban surfaces, insertion of vegetation and green elements (trees, grass etc.).As regards the building surfaces without the green wall (on the North and East facades) two different simulations were analysed: the first one interested by low value of albedo (equal to 40% as in Tower Scenario), the other one interested by high value of albedo (equal to 85% as in WhiteB Scenario). Then, the two models of synthesis are compared to each other. The best solution is the Final Mitigation Scenario with 85% albedo.

## 5. CONCLUSIONS

The defined method represents a useful integrated tool for the evaluation of different strategies at the urban micro-level in relation to the climatic characteristics of the site and to the purposes of urban planning. It is based on the comparison of the results deriving from environmental simulations for the studied urban area and on the multicriteria analysis among the different analysed scenarios. Therefore, it is possible to consider the interaction of all the elements present in an urban canyon in function of the physical characteristics of applied surfaces and materials, the thermal functioning of the envelope and the presence of green.

Furthermore, the analysis of the simulations results makes possible to identify the elements and the solutions of urban and building design that mostly affect the local microclimate. The best mitigation strategies of the heat island phenomenon, exacerbated by climate change, are chosen through a simplified multicriteria analysis process, easily applicable by the various stakeholders (urban planners, municipality technical staff, citizens etc.).

Among the seven scenarios analyzed for the case study, the strategy with green areas, both as distributed elements (grass) and as punctual plants (trees and shrubs), has the greatest influence on the mitigation of the summer climate conditions. In fact, trees allow intercepting the solar radiation, thus lowering the direct energy load; from the analysis, we can see that the mitigation effect is more relevant at low heights (pedestrian level) and decreases as they increase.

In this study, the mitigation action of green is also evaluated in integrated façade and roofing systems. The analysis of data and of decision-making (AHP method) shows that green wall is an effective strategy in terms of microclimate mitigation as it has direct effects on pedestrian level comfort. On the other hand, the green roof does not cause significant variations in the thermal behavior of the buildings in the analyzed area since it mainly influences the microclimate at the roof level and at the upper ones.

The analysis of the results shows how the introduction of cool materials for urban pavements and pools of water (BlueWScenario) determines a greater mitigating action than the Green Scenario in relation to the air temperature trend, thanks to the high reflective ability of these materials. However, the mean radiant temperature has an opposite trend that shows an increase during the day, instead of decreasing. This behavior, also found in the WhiteB Scenario, in which high albedo finishing layers are used for buildings, is nevertheless predictable: the greater reflectance of the materials that have replaced the surfaces of the Base Scenario (current state) increases the part of reflected energy, rising the Tmrt. The reflected radiations increase determines a reduction of the absorbed heat and, therefore, allows surfaces to reach lower temperatures, which, at night, guarantee higher levels of comfort and reduced effects on the heat island. Moreover, the change of the urban morphology (from linear blocks to tower blocks) brings benefits especially for the wind speed and the mean radiant temperature as a function of the reduction of the barrier effect and the incidence of solar radiation, respectively. The final proposed solution (Final Mitigation Scenario with 85% albedo) summarizes the contemporary use of the best-analyzed strategies: use of green walls, high albedo surfaces, plants and tower building morphology. In this way, the study indicates some effective mitigation proposals that can be considered guidelines in the decision-making processes of city planning. However, extending the application of the method to different climatic and urban contexts can provide further reference mitigating solutions for both buildings and urban fabric.

## REFERENCES


[1] European Commission. (2014). An introduction to EU Cohesion Policy 2014-2020. http://ec.europa.eu/regional_policy/en/policy/what/investment-policy/

[2] European environment Agency (EEA). (2012). Climate change, impacts and vulnerability in Europe. An indicator-based report. Report n. 12/2012, TH-AL-12-012-EN-C. https://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012

[3] Lassandro P, Di Turi S. (2017). Façade retrofitting: from energy efficiency to climate change mitigation. Energy Procedia 140: 182–193. https://doi.org/10.1016/j.egypro.2017.11.134

[4] Intergovernmental Panel on Climate Change (IPCC). (2014). Summary for policymakers in "Climate Change 2014: Impacts, Adaptation, and Vulnerability". Working Group II contrib. to 5 Assessment report of the IPCC University Press, Cambridge, United Kingdom and New York, NY, USA: 1–32. http://www.ipcc.ch/report/ar5/syr/

[5] Evola G, Martella L, Cimino D. (2018). Weather data morphing to improve building energy modeling in an urban context. J Mathematical Modelling of Engineering Problems 5(3): 211–216. https://doi.org/10.18280/mmep.050312

[6] Akbari H, Cartalis C, Kolokotsa D, Muscio A, Pisello AL, Rossi F, Santamouris M, Synnefa A, Wong NH, Zinzi M. (2016). Local climate change and urban heat island mitigation techniques - the state of the art. J Civ Eng Manag 22: 1–16. https://doi.org/10.3846/13923730.2015.1111934

[7] Martins TAL, Adolphe L, Bonhomme M, Bonneaud F, Faraut S, Ginestet S, Michel C, Guyard W. (2016). Impact of Urban Cool Island measures on outdoor climate and pedestrian comfort: Simulations for a new district of Toulouse, France. Sustainable Cities and Society 26: 9–26. https://doi.org/10.1016/j.scs.2016.05.003

[8] Georgakis C, Zoras S, Santamouris M. (2014). Studying the effect of "cool" coatings in street urban canyons and its potential as a heat island mitigation technique. Sustainable Cities and Society 13: 20–31. https://doi.org/10.1016/j.scs.2014.04.002

[9] Akbari H, Kolokotsa D. (2016). Three decades of urban heat islands and mitigation technologies research. Energy and Buildings 133: 834–852. https://doi.org/10.1016/j.enbuild.2016.09.067

[10] Santamouris M, Synnefa A, Karlessi T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Solar Energy 85(12): 3085–3102. https://doi.org/10.1016/j.solener.2010.12.023

[11] Wang Y, Akbari H. (2014). Effect of sky view factor on outdoor temperature and comfort in Montreal. Environmental Engineering Science 31(6): 272–287. https://doi.org/10.1089/ees.2013.0430

[12] Wang Y, Akbari H, Chen B. (2016). Urban geometry and environmental urban policy development. Procedia Engineering 169: 308–315. https://doi.org/10.1016/j.proeng.2016.10.038

[13] Morakinyo TE, Kalani KWD, Dahanayake C, Ng E. (2017). Temperature and cooling demand reduction by green-roof types in different climates and urban densities. A co-simulation parametric study. Energy and Buildings 145: 226–237. https://doi.org/10.1016/j.enbuild.2017.03.066

[14] Ali-Toudert F, Mayer H. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Building and Environment 41(2): 94–108. https://doi.org/10.1016/j.buildenv.2005.01.013

[15] Saaty TL. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.

[16] O'Malley C, Piroozfar P, Farr ERP, Pomponi F. (2015). Urban Heat Island (UHI) mitigating strategies: A case-based comparative analysis. Sustainable Cities and Society 19: 222–235. https://doi.org/10.1016/j.scs.2015.05.009

[17] Huttner S, Bruse M. (2009). Numerical modelling of the urban climate - A preview on ENVI-met 4.0. The seventh International Conference on Urban Climate (ICUC-7), Yokohama, Japan.

[18] Vijayaraghavan K. (2016). Green roofs: A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews 57: 740–752. https://doi.org/1016/j.rser.2015.12.11910

[19] Silva CM, Gomes MG, Silva M. (2016). Green roofs energy performance in Mediterranean climate. Energy & Buildings 116: 318–325. https://doi.org/10.1016/j.enbuild.2016.01.012

[20] Jaafar B, Said I. (2013). Impact of vertical greenery system on internal building corridors in the tropic. Procedia Social and Behavioral Sciences 105: 558–568. https://doi.org/10.1016/j.sbspro.2013.11.059

[21] Lobaccaro G, Acero JA. (2015). Comparative analysis of green actions to improve outdoor thermal comfort inside typical urban street canyons. J. Urban Climate 14 (Part 2): 251-267. https://doi.org/10.1016/j.uclim.2015.10.002

[22] Lassandro P, Di Turi S. (2017). Energy efficiency and resilience against increasing temperatures in summer: The use of PCM and cool materials in buildings. Int J of Heat and Technology 35(Sp.1): S307–S315. https://doi.org/10.18280/ijht.35Sp0142

[23] Thorsson S, Lindberg F, Eliasson I, Holmer B. (2007). Different methods for estimating the mean radiant temperature in an outdoor urban setting. International Journal of Climatology 27(14): 1983–1993.

[24] Taleghani M, Kleerekoper L, Tenpierik M, van den Dobbelsteen A. (2015). Outdoor thermal comfort within five different urban forms in the Netherlands. Building and Environment 83: 65–78. https://doi.org/10.1016/j.buildenv.2014.03.014