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UHI effects and strategies to improve outdoor thermal comfort in dense and old neighbourhoods

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Abstract

Modelling techniques have received growing attention as a tool to investigate the thermal comfort within a city, on the basis of which decision makers can set-up appropriate mitigation strategies. This research aims at studying the effectiveness of strategies for reducing the urban heat island-associated effects in dense and old neighborhoods considering, in particular, green roofs, cool roofs, cool pavements, green areas and urban renewal actions. Computer simulation was selected as the major methodology in this research; ENVI-met software was used under different scenarios for a case study consisting in an old neighborhood in the city of Avola. The investigation focused on evaluating the efficacy of each strategy for a condition corresponding to a typical summer heat wave. The results highlight that the cool pavements allow relevant improvements at the height of 1.50 m, with a temperature decrease up 1.15°C, whereas the other scenarios, given the relatively high density of the buildings, are able to improve outdoor conditions only at higher elevations. Reported results represent a guideline for the choice of UHI mitigation method that can help stakeholders involved in new urban assessment of old neighborhoods in Mediterranean climate.

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1. Introduction

Climate change will have relevant consequences, especially in Southern Europe and North Africa where the effects of Urban Heat Island can be extremely severe for human health. Mediterranean cities are mainly characterized by a very dense urban structure that poses considerable difficulties in implementing sound and cost effective adaptation strategies.

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For this reason, the selection of the appropriate adaption strategies requires the application of a set of integrated tools, including land use policies and modeling techniques for investigating the outdoor comfort. Several studies have been carried out on this topic [1, 2] and literature overviews are reported in [3, 4].

Moreover, in recent years, the mutual influence of UHI and urban layout [5] or thermal comfort [6, 7] has been analyzed, along with mitigation technologies. In particular, solar reflectance, or albedo, influences the development of the urban heat island effect, as it determines how solar-energy is reflected, emitted, and absorbed by a surface. Solar reflectance of building envelopes and urban pavement represents an important property for the characterization of building energy performance for cooling and to mitigate the summer UHI effect [8, 9].

Several researches have focused on reflective envelopes [10, 11] and roofs [12, 13] as strategies to mitigate UHI. On the other hand, several techniques to mitigate the urban heat island effect can be implemented [14].

Prognostic models, such as ENVI-met, based on the fundamental laws of fluid dynamics and thermo-dynamics, represent one of the possible approaches that have the main advantage of allowing comparative analyses of different scenarios. Though simulations require several simplifications, as the physics underlying the urban microclimate is very complex, they are able to provide useful predictions on specific scenarios that cannot be easily derived by observational studies. In fact, several applications of ENVI-met have been proposed for urban assessments [15, 16] considering cool material [17, 18] or vegetation [19, 20]. This research aims at proposing possible solutions that can be implemented by planners, designers, and urban decision makers in order to contrast the effects of UHI and, in particular, for assessing a strategy to mitigate urban hotspots.

The proposed approach has been focused on a case study, consisting in a dense settlement in the fringe of the historic center of the city of Avola, in the South-Eastern part of Sicily. The oldest part of the settlement dates to the beginning of XX century (before 1912) even if the majority of the buildings have a very low architectural quality. The urban fabric is typical of many small and medium towns of Mediterranean Countries, with narrow blocks, almost entirely built up and with a very limited availability of permeable soil and green areas. Several examples of this type of urban fabric are present around the Mediterranean basin in countries like Tunisia, Spain and Greece. Public realm is limited to the surface of narrow roads (4-6 meters) between the built blocks.

Moreover, the analyzed area is decaying, being its poor urban quality one of the main reasons. In fact, several buildings are abandoned or underused and the adoption of a set of renewal actions is required. This study aims at identifying a set of measures that can improve the general quality of the public realm, verifying, at the same time, their effects in improving the thermal comfort. In particular, two kinds of approach have been proposed based on the nature of the actions. The first approach is based on the evaluation of specific localized solutions on the superficial properties and on the urban green of either the actual building stock or the public realm; the second approach, instead, identifies a possible scenario based on the definition of a new urban plan that specifically accounts for UHI mitigation.

2. Methodology

A crucial element in the assessment of thermal comfort is the use of a powerful comfort index, which appropriately reflects the comfort sensation of a person in a given situation. Several indices have been proposed in the literature and among them it is possible to cite the Fanger Indices (PMV, PPD) [21] and the Physiological Equivalent Temperature (PET) [22]. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) calculation schemes were developed by Fanger (1970) on the basis of empirical laboratory comfort research in indoor environments, under steady-state conditions. PMV and PPD are calculated on the basis of mean radiant temperature (T_{mrt}), air temperature, humidity, and air speed as well as for a given activity level and clothing. Fanger's indices are implemented in many international standards (ISO 7730, 2005; ASHRAE Standard 55, 2010) and, currently, their adoption is extended to evaluate the thermal comfort in external environments. Many studies are applying and comparing Fanger´s models, trying to adapt them to the diversity of these environments, considering the dynamic conditions and other influencing factors, such as direct solar radiation, T_{mrt} and different human activities profiles [23, 24, 25].

Another important parameter is represented by the physiological equivalent temperature (PET), which is defined as the air temperature of a reference environment in which the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions in the environment to be assessed.

All previous indices are influenced by T_{mrt} which is the most important variable affecting human thermal comfort in an outdoor urban space. For this reason, it is fundamental to model radiant heat transfer between human body and the built environment. The analysis of T_{mrt} is not very easy because it varies in time and space in the urban environment, where surfaces interact with radiation, reflecting, absorbing and emitting radiant energy at numerous wavelengths.

Since measuring the T_{mrt} in a dense urban environment is not an easy and low-cost operation, it is usually preferred to simulate T_{mrt} with software tools such as RayMan and ENVI-met; however, these software tools have some limitations. RayMan is easy to use but it allows calculating only T_{mrt} at one point at a time, it displays significant errors when solar angles are low and it does not take into account the reflected short-wave radiation [9].

On the other hand, ENVI-met can compute T_{mrt} on a continuous surface but it has other important limitations: the lack of assessment of anthropogenic heat emissions (i.e.: traffic, air conditioning systems, etc.), the use of homogenous parameters for the entire model (i.e.: same temperature in all the points of the building), etc.

In this study, in order to evaluate the effectiveness of some strategies for improving thermal comfort in a dense and old neighborhood, ENVI-met software and RayMan software were utilized, obviously aware of the software limitations. The urban microclimate, the PMV and the PPD were calculated by ENVI-met which is a freeware and prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. In particular, this software allows the evaluation of several phenomena, such as the heat flux around and between buildings, the heat and steam exchange at soil level and between walls, turbulence, the thermo-hygrometric exchange in green areas, the fluid dynamics of small particles and polluting species. Based on the simulation of these phenomena, it also provides the evaluation of the interrelation between buildings, vegetation and various surface coverings, and of their effects on the perceived microclimate. The values of Fanger's indices calculated by ENVI-met are based on the modified Fanger heat balance equation developed by Jendritzky and Nubler for outdoor conditions [26]. In addition, in order to have further information on the pedestrian stress, the results of the calculation performed by means of ENVI-met are then fed to the RayMan software. It is a numerical tool developed by the Meteorological Institute of the Albert-Ludwigs University at Freiburg, that allows the calculation of radiation fluxes in simple and complex environments [27, 28, 29]. Therefore, RayMan was adopted in order to estimate T_{mr} which, in turn, was used to calculate thermal bioclimatic indices, and, more specifically, the PET.

This study is articulated as follows:

- preprocessing the geometric and physical features of the urban area, object of this study, through the Q-GIS software;
- importing the data elaborated in Q-GIS to ENVI-met;
- simulating the urban climate at the current state,
- selecting different suitable design scenarios;
- analyzing the results and detecting the most effective strategy in terms of attenuation of the urban heat island, overall improvement of the urban microclimate and thermal comfort.

In particular, Q-GIS, a GIS software, was used firstly to create a GIS dataset of the neighborhood. Information is available at the address/building level including floor surface, number of storeys, dwelling type, number of rooms, year of construction, building material, type of roof.

Then, ENVI-met allows selecting an atmospheric model, vegetation model, soil model and the bio-meteorological model. As ENVI-met is a prognostic model, it only requires to define the meteorological data such as temperature, wind speed, wind direction, and humidity. ENVI-met allows to carry out simulation using numerical models for describing atmosphere, vegetation and soil energy balances, as well as the same meteorological conditions because it has a CFD package such as the model Navier-Stokes equation for wind flow, E- e atmospheric flow turbulence equations, energy and momentum equation and boundary condition parameters. The Envi-met allows simulating built environments from the microclimate to local climate scale at any geographic location, nevertheless Tmrt due to uncalculating soil heat storage [30], global radiation overestimation by day and underestimation of nocturnal by night [31]. As regard the meteorological conditions, they were chosen to be representative of a typical heat wave situation, in order to analyze the effects of thermal stress on human health. Ngl et al. [32] as well as the ENVI-met® guide, stated that the best time to start a simulation is at sunrise and that the total running time should be longer than 6 h, in order to overcome the influence of the initialization.

Results of the simulation under different proposed scenarios were compared to analyze the effects of each proposed mitigation action.

3. 1. Case Study

The case study investigates the urban climate of a neighborhood called Priolo, that is part of the downtown of the city of Avola, and characterized by a typical urban canyon layout with narrow roads and tall buildings, resulting in aspect ratios H/W (building height/road width) varying between 2 and 3.5. An undeveloped area adjacent to Priolo district has been included (the zone shown in Fig .1.b without buildings), taken into account to evaluate its effect on outdoor comfort condition

Fig. 1. a) Avola city – b) Priolo district

The climate of Avola is warm and temperate and has much more rainfall in the winter than in the summer. The climate is classified as Csa according to Köppen and Geiger [28] with an average temperature of 17.6 °C while the yearly average rainfall is 468 mm. In August, the hottest month of the year, the average temperature is 25.2 °C, while with an average temperature of 11.3 °C, January is the month with the lowest temperature of the year.

The meteo-climatic data, from 2013 to 2015, were obtained by the urban climate station of Noto (36°53'28" N, 15°4'12" E). Figure 2 shows the mean daily solar radiation and temperature during the month of August 2014.

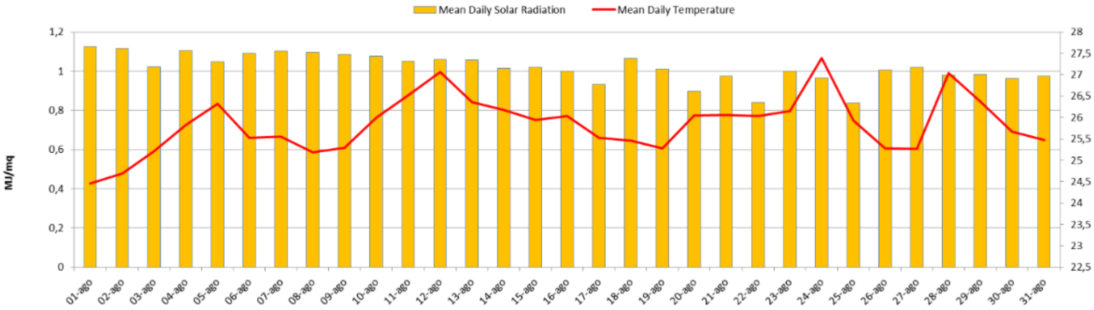

Fig .2: Mean daily solar radiation and temperature (August 2014)

The city of Avola is a typical Eastern Sicilian agro-town [29], rebuilt after the 1693 earthquake. Living conditions of these settlements are rudimentary, corresponding to the needs of the peasant population up to the 1960s. These conditions are not considered acceptable nowadays, consequently parts of the urban fabric are being progressively abandoned and neglected. On the other hand, this condition opens up the opportunity of strong urban renewal actions that can be based on consideration that include the upgrading of thermal comfort.

ENVI-met simulations were performed under the meteorological conditions recorded on 24 August 2014, which was the hottest summer day during the years 2013-15 and has been assumed as representative of a heat wave state (intense solar radiation and absence of cloudiness). The starting temperature and humidity were assumed to be uniform.

The modelled area has an extension of 65,100 m^2, 310 m in width and 210 m in length. This area has been rendered with a grid of calculus of 189,000 cells, 70 × 90 × 30 (x-y-z), keeping the following dimensions: dx = 3.00 m; dy = 3.00 m. The resolution is an average within the suggested values (minimum 0.5 m – maximum 10 m) [26] and is a reasonable compromise between accuracy and calculation time. The grid has a fixed spacing at the x and y axis, while it is telescopic in the z axis (1.50 m is a mean value), with a thicker grid near the ground, allowing a better accuracy for edge effects. The height of the investigated domain is of 60.0 m. This value largely satisfies the rule to be at least twice as high as the height of the tallest building in the model, which is 12.0 m, to achieve numeric stability. A total of 480 buildings were defined in the model, many of them having common walls. Figure 3 shows the 3D Model of the investigated area. In this area, five receptors have been placed: two of them are located along Nino Bixio street (X_2 and X_4), other two are set along Nuova street (X_1 and X_3), while X_5 is placed area not yet covered with buildings.

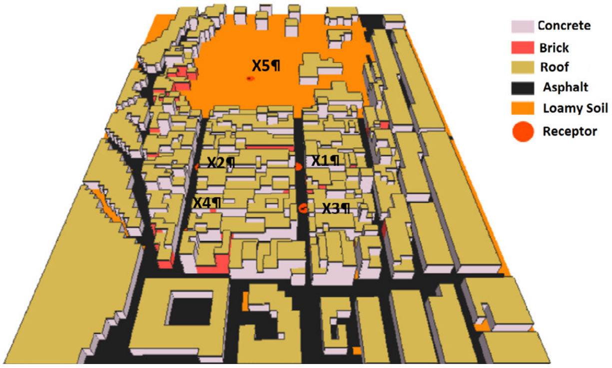

Fig.3: 3D Model with receptors at 1.5 m

3.1 Scenarios based on localised actions

All current studies agree that the most-promising strategies that help to reduce the UHI effects are: urban green (trees and vegetation), cool roofs and cool pavements. The benefits of vegetation are obvious since it provides shadow, it introduces a cooling effect thanks to the evapotranspiration, and increases the overall albedo thanks to the foliage.

Cool roofs are roofing systems that use high reflective and high emissive materials, which are able to reflect the solar radiation keeping the exposed surfaces cool. The cool roofs improve the building comfort and decrease the energy consumption. The cool pavements refer to innovative technologies and materials that tend to store less heat and may have lower surface temperatures compared with conventional pavements [33],[34].

There are many strategies to keep the pavement cool: increase pavement surface reflectance; increase pavement emissivity; increase pavement surface convection; reduce pavement heat capacity, etc. For evaluating the impact of possible actions that can be carried out to diminish the adverse microclimate effects, different mitigation actions have been evaluated, which consist in the adoption of cool roofs, cool pavements, green roofs and in the realization of a green area.

Table 1: Solar properties of construction material used in the urban models.

	Case	**Albedo walls**		**Albedo roofs**	**Albedo Green**	**Albedo Asphalt**
		Brick	**Concrete**			
1)	**Base**	0,4	0,3	0,3		0.2
2)	**Cool Roof**	0,4	0,3	0,83		0,2
3)	**Cool Pavements**	0,4	0,3	0,3		0.83
4)	**Green roof**	0,4	0,3	-	0,26	0,2
5)	**Green Area**	0,4	0,3	0,5	0,20	0,2

In this study, only materials with high albedo were considered, in order to keep cool both pavements roofs as well as to reduce the temperature below the surface; in some cases, these materials could induce glare problems [35], but this issue is not considered in this study. Table 1 indicates the albedo values for each proposed action. The base case considers standard characteristics of urban environment, especially with respect to the radiant properties. In comparison with the Base Case, in the proposed scenarios single specific modifications of the radiant proprieties were assumed, while all other main parameters were left unchanged; this allowed to evaluate the effect of each specific action on the outdoor urban microclimate. Therefore, the cool roof case considers all the roofs covered with high-reflectance materials; the cool pavements case considers all the pavements covered with high-reflectance materials; the green roof case consists of an average density 50 cm tall grass applied to all buildings with flat roof; the green park consists in dense vegetation of deciduous trees in the undeveloped area.

In accordance with the literature, the simulation start time was set at 06:00 on 24 August and the end at 06:00 on 25 August 2014. The meteorological inputs are wind speed 0,5 m/s at 10 m above ground, wind direction 225°, initial temperature 292 K, relative humidity 64% . The solar radiation was calculated with atmospheric model considering the geographic location. The results data were stored at 10 min intervals.

3.2 Scenario based on a new urban plan

Finally, a last scenario that foresees a novel urban configuration, motivated by the idea of improving living conditions of the neighborhood, has been tested. The proposed new layout is aimed at increasing the existing amount of public realm, that in the present condition includes only asphalted roads. (Table 2.)

Table 2: Current Land Uses

High density Built Up (m^2)		**Other Uses ((m^2)**	
Abandoned	1,392	New Developments	9,421
Commercial	416	Public Buildings	10,554
Garages	1,861	Undeveloped	12,360
Residential	18,320	Roads	4.793
Total (A)	**21,989**	**Total (B)**	**37,128**
Total (A+B)	**59,178**		

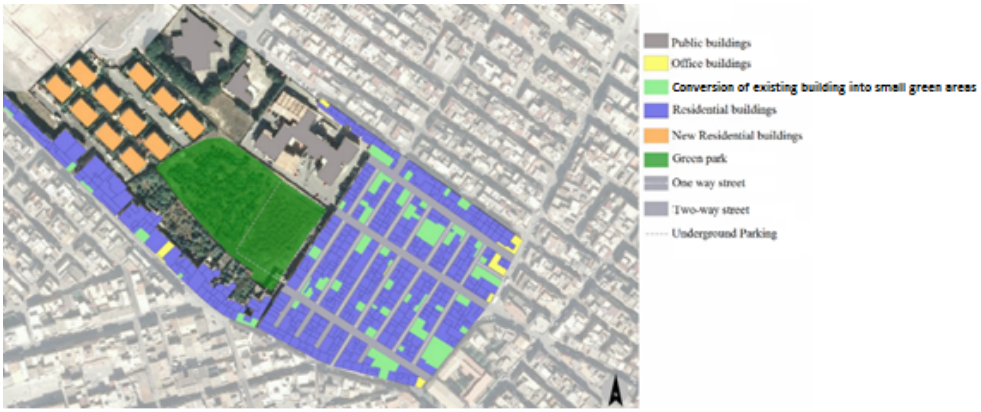

Fig. 4: novel urban configuration "Green park" and Small Green Areas

The proposed creation of livable public spaces is aimed also at reducing the intervention in the urban texture. In order to reach this goal, increasing at the same time the acceptance of these urban changes, the proposed scenario includes the substitution of few dilapidated ground floor-houses and garages with comfortable outdoor green spaces. Buildings to be demolished have been chosen considering their present condition and property value.

To compensate the loss of parking space, due to the demolition of existing garages the construction of an underground car park in the green area has been planned. This last option can be defined according to a detailed land use master plan, as stated by the new general master plan that is currently under review. Figure 4 shows the proposed new urban configuration with a green park (7,265 m^2) and small green areas resulting from the demolition of garages and abandoned buildings (3,253 m^2).

4. Results and Discussion

In this section the results of the simulations are reported and discussed for the different scenarios. In particular, Fig. 5 shows the thermal maps of the analyzed area at Z = 1.5 m in the current state (base case) and in the case of intervention on the undeveloped area (green park) and cool pavements at 13:00.

In the base case, it is evident that the air temperatures are between 31.0 and 32.0 °C in a large part of the investigated area. The increase in temperature within the urban canyon, if compared to the undeveloped area, is not evident. In the case of green roof, distributed urban vegetation influences the urban micro-climate and consequently the outdoor pedestrian comfort levels, but its influence is highest in the case of the green park for point X_5 and for all receptors for cool pavements.

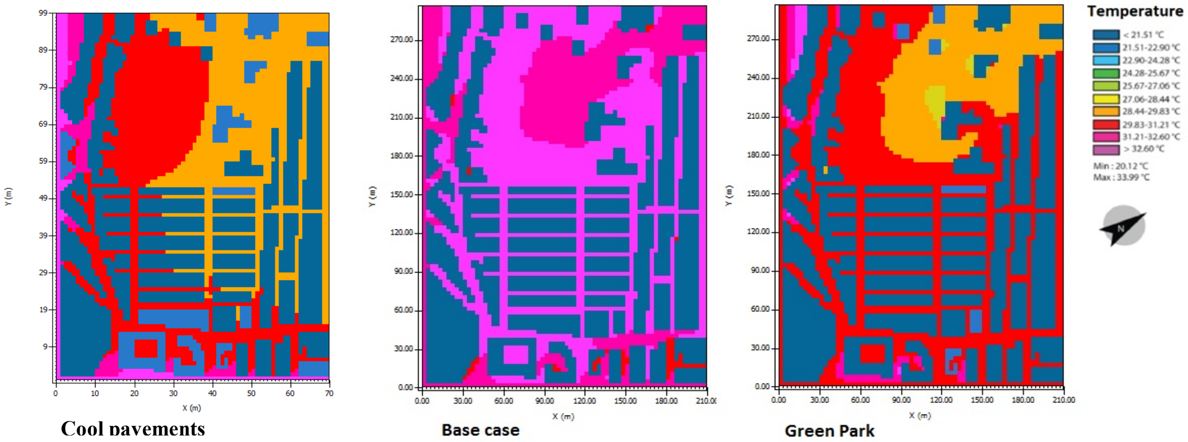

Fig. 5. Thermal maps and section at Y=150 m for the various scenario at 13:00

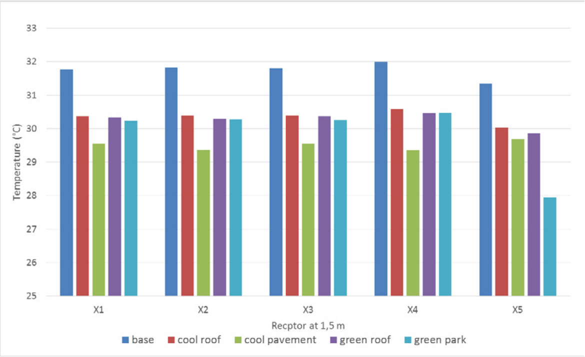

Fig. 6: temperatures in receptors at 1.5 m for the various scenarios at 13:00 o'clock

On the other hand, Fig. 6 shows the temperatures calculated in the five receptors fixed at 1.5 m at 13:00 o'clock. With respect to the general efficacy evaluated in all of the observation points, it can be noticed that the scenarios called "cool roof" and "green roof" provide approximately the same efficacy, with a reduction of temperature of about 1.5 °C. In particular, with respect to all of the considered scenarios, the "cool roof" is the less efficient as it allows the lowest temperature reduction, of about 1.0-1.5 °C, with respect to the base traditional dark materials, and has the lowest influence on the outdoor comfort of pedestrians in the considered dense urban context.

The best performances is obtained with the "cool pavements" scenario, which allows for a reduction of the ambient air temperature of over 2.0°C with respect to the base scenario. Such results point out that urban road, which are usually paved by dark and impermeable materials, significantly contribute to the heat island effect by warming up in the sun and releasing the stored energy to their surroundings during the evening and overnight.

As regards the action named "green park", it deserves a specific discussion as it provides non-uniform performance with respect to the various observation points. In fact, its predominant effect is obviously observed in the surroundings of the area in which the plants are implanted, allowing to obtain at position X_5 a decrease of temperature of over 3.0°C.

Together with the temperature, the urban climate associated with each examined scenario has been compared in terms of heat stress calculating PET and TRM in the five receptors (Fig. 7).

Figure 7 points out that in the base case the urban climate is characterized by conditions that cause strong heat stress. The adoption of the mitigation actions allows reducing the adverse effects of the warm temperatures determining slightly improved PET values, which means moderate heat stress (Fig. 7.a). These results confirm that the cool pavements have a greater impact than other materials on the outdoor comfort and, hence, on the wellbeing of citizens. If looking at PMV values (Fig. 7.b), all scenarios allow to shift from "Warm" to "Slightly warm", while the green park even makes PMV "Neutral" in point X5. In fact, in case of heat wave, the local energy and moisture balances of green areas allow to guarantee a fairly comfortable global thermal perception. Moreover, it is worth noting that the implantation of trees in the urban context not only helps to mitigate the thermal stress and the urban heat island effect, but also has effects on CO_2 emissions which are both indirect, by reducing the demand for cooling energy, and direct, by balancing CO_2 emissions through photosynthesis.

Moreover, it also contributes to reduce noise pollution as a consequence of the attenuation effects of trees.

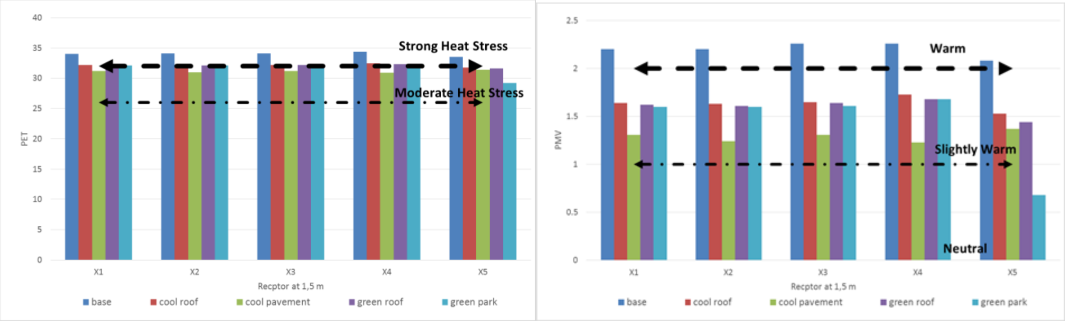

Fig. 7: a) PET, b) PMV in receptors at 1.5 m for the various scenarios at 13:00 o'clock

The implementation of all the proposed scenarios (green roofs, green park, cool roofs and cool pavements) requires to involve either householders (green and cool roofs) or the city administrations (green park and cool pavements). For boosting such processes, public administrations should promote grant or fees incentivizing these kind of actions. Figures 8 and 9 show the temperatures and the comfort indexes that may be reached with this new urban configuration, considering the same albedo value and meteo-climatic input data

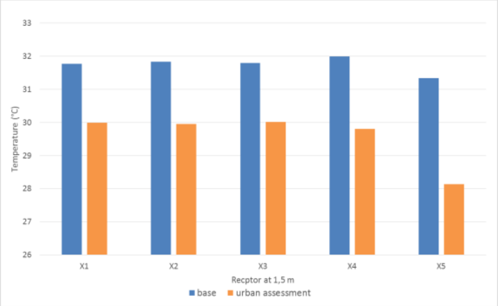

Fig.8: temperatures in receptors at 1.5 m for the urban scenarios.

In particular, Fig. 8 shows that in the "urban scenario" the temperature decreases from 1.5 °C (receptor X1) to 3.5°C (receptor X_5). The improvement of wellbeing conditions is confirmed by Fig. 9, from which it is possible to observe that the PET and PMV values indicates "slightly warm" conditions under the occurrence of heat wave days.

The new urban intervention is more suitable and grants higher performances with respect to the other proposed scenarios.

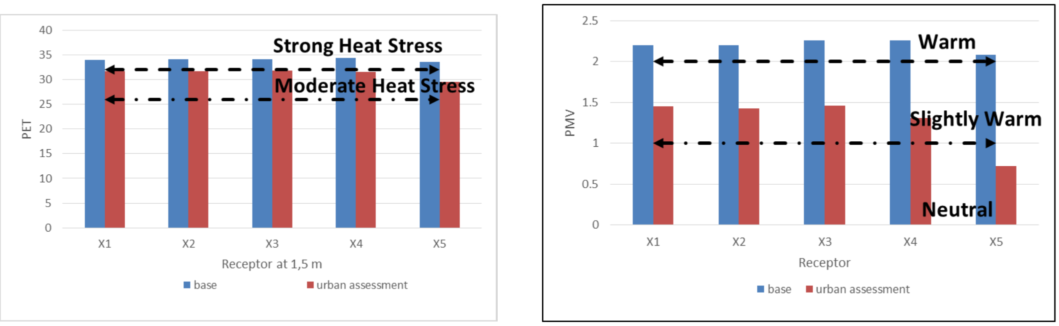

Fig. 9: a)PET; b) PMV in receptors at 1.5 m for the urban scenarios.

5. **Conclusions**

The study of UHI effects requires many competences in many subjects such as urban planning, landscape, architecture and building material science. Prognostic softwares, such as Envi-met, can help to evaluate the relationships between buildings and the surrounding outdoor environment for controlling and mitigating urban microclimate and assess new urban configurations.. In this study, in order to evaluate the strategies for improving thermal comfort in a dense and old neighborhood, ENVI-met software and RayMan software were utilized. These software tools were used to simulate microclimatic conditions in a part of the city of Avola.

Two approaches have been proposed based on the nature of the actions. The first approach is based on the evaluation of specific localized solutions on the superficial properties and on the urban green of either the actual building stock or the public realm; the second approach, instead, identifies a possible scenario on the basis of a new urban configuration that specifically accounts for UHI mitigation.

The analysis of mitigation scenarios by using green roofs, green park, cool roofs and cool pavements have given improvements comparable to the values available in literature. In particular, with respect to all of the considered scenarios, the “cool roof” is the less efficient one, as it allows the lowest temperature reduction, of about 1.0-1.5 °C, with respect to the base traditional dark materials, and has the lowest influence on the outdoor comfort of pedestrian in the considered dense urban contest. The best performance is obtained with the “cool pavements” scenario, which allows for a reduction of the ambient air temperature of over 2.0°C with respect to the base scenario. Therefore, the results highlight that the adoption of reflective materials can be beneficial outdoor mean air temperatures. However, it is necessary to highlight that the results are affected by errors due to the several limitations of software and uncertainty of many input variables, so this software can be considered only a tool for a preliminary assessment of possible strategies of urban microclimate planning.

Finally, further studies, surveys, and monitoring will be carried out in dense and old neighborhoods in order to developed methodologies for decrease the uncertainty of simulations.

References

[1] Taha, H. Urban climates and heat island: Albedo, evapotranspiration, and anthropogenic heat. Energy Build. 1997, 25, 99–103.
[2] Akbari, H. Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation; Lawrence Berkeley National Laboratory: Berkeley, CA, USA, 2005.
[3] Santamouris, M. Heat island research in Europe—the state of the art. J. Adv. Build. Energy Res. 2007, 1, 123–150.
[4] Santamouris, M. Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy 2014, 103, 682–703.
[5] Taleb, D.; Abu-Hijileh, B. Urban heat islands: Potential effect of organic and structured urban configurations on temperature variations in Dubai, UAE. Renew. Energy 2013, 50, 747–762.

[6] Carfan, A.C.; Galvani, E.; Teixeira Nery, J. Study of thermal comfort in the City of São Paulo using ENVI-met model. Investig. Geogr. Bol. Inst. Geogr. UNAM 2012, 78, 34–47.7.

[7] Olivieri, F.; di Perna, C.; D'Orazio, 7. M.; Olivieri, L.; Neila, J. Experimental measurements and numerical model for the summer performance assessment of extensive green roofs in a Mediterranean coastal climate. Energy Build. 2013, 63, 1–14.

[8] Pisello A. L., Pignatta G., Castaldo V. L. and Cotana F., "Experimental analysis of natural gravel covering as cool roofing and cool pavement," Sustainability, vol. 6, no. 8, pp. 4706–4722, 2014

[9] Santamouris M., Gaitani N., Spanou A. et al., "Using cool paving materials to improve microclimate of urban areas—design realization and results of the flisvos project," Building and Environment, vol. 53, pp. 128–136, 2012.

[10] Santamouris M., Synnefa A., and Karlessi T., "Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions," Solar Energy, vol. 85, no. 12, pp. 3085–3102, 2011.

[11] Yuan J., Emura K., and Sakai H., "Evaluation of the solar reflectance of highly reflective roofing sheets installed on building roofs," Journal of Building Physics, vol. 37, no. 2, pp. 170–184, 2013.

[12] Akbari H. and Touchaei A. G., "Modeling and labeling heterogeneous directional reflective roofing materials," Solar Energy Materials and Solar Cells, vol. 124, pp. 192–210, 2014

[13] Akbari H. and Matthews H. D., "Global cooling updates: reflective roofs and pavements," Energy and Buildings, vol. 55, pp. 2–6, 2012

[14] Mirzaei PA, Haghighat F. Approaches to study Urban Heat Island – Abilities and limitations. Build Environ 2010;45:2192–201

[15] Middel, A.; Häb, K.; Brazel, A.J.; Martin, C.A.; Guhathakurta, S. Impact of urban form and design on a mid-afternoon microclimate in Phoenix Local Climate Zones. Landsc. Urban Plan. 2014, 122, 16–28.

[16] Yang X.; Zhao L., Bruse, et al.. An integrated simulation method for building energy performance assessment in urban environments. Energy Build. 2012, 54, 243–251

[17] Huttner S. ,Bruse M., Dostal, P., Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities. In Proceedings of the 5th Japanese-German Meeting on Urban Climatology, Albert-Ludwigs-University of Freiburg, Freiburg, Germany, October 2008;

[18] Mayer H., Matzarakis, A., Eds.; Meteorological Institute Albert-Ludwigs-University of Freiburg: Freiburg, Germany; pp. 307–312.

[19] Ng, E.; Chen, L.; Wang, Y.; Yuan, C. A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. Build. Environ. 2012, 47, 256–271.

[20] Fahmy M., Hathway A., Pattacini L., Elwan, A., Environmental thermal impact assessment of regenerated urban form: A case study in Sheffield. In Proceedings of the World Renwable Energy Congress 2011, Linköping, Sweden, 8–11 March 2011.

[21] Gagliano A., Nocera F, Patania, F., Moschella, A., Detommaso, M., Evola, G. (2016). Synergic effects of thermal mass and natural ventilation on the thermal behaviour of traditional massive buildings . International Journal of Sustainable Energy, vol. 35 (5) , p. 411-428,

[22] Fanger, P.O., (1970). Thermal comfort. Analysis and applications in environmental engineering. McGrawHill. ISBN:0-07-019915-9

[23] Dessi V., Evaluation of Microclimate and Thermal Comfort in Open Urban Space. Proc. 18th Passive and Low Energy Architecture (PLEA) International Conference, Florianópolis, 2001. pp. 373-377

[24] Katzschner L.,Bosch U., Röttgen M., Behavior of people in open spaces in dependency of thermal comfort conditions. Proc. 19th Passive and Low Energy Architecture (PLEA) International Conference,. Toulouse, 2002. pp. 411-415

[25] Gagliano A., Detommaso M., Nocera F, Berardi U. The adoption of green roofs for the retrofitting of existing buildings in the Mediterranean climate, 2016, International Journal of Sustainable Building Technology and Urban Development

[26] Jendritzky G. , Nübler W. , A model analysing the urban thermal environment in physiologically significant terms. Arch. Met. Geoph. Biokl., ser. B., 29, 31: 313-326.

[27] Höppe, P. (1999) The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. Int. J. Biometeoroi, 43: 71-75.

[28] Matzarakis A, Mayer H (1996) Another kind of environmental stress: thermal stress. WHO Newsl 18:7–10

[29]Matzarakis A, Mayer H (2008) Importance of urban meteorological stations – the example of Freiburg, Germany. Ber Meteorol Inst Univ Freiburg 17:119–128

[27] ENVI-met®! Available online: http://www.envi-met.com (accessed on 20 August 2015).

[28] Koppen, Avaible online https://www.britannica.com/science/Koppen-climate-classification

[29] Blok A., South Italian Agro-Towns, Comparative Studies in Society and History, Vol. 11, No. 2 (Apr., 1969), pp. 121-135

[30] Spangernberg J., Shinzato P., Johansson E., Durate D., Simulation of the influence of vegetation on microclimate and thermal comfort in the city of Sao Paulo. In Rev. SBAU, Piracicaba, 3(2) (2008), 1–19.

[31] Ali-Toudert F., Dependence of outdoor thermal comfort on street design (Ph.D. thesis), University of Freiburg, Freiburg, Germany, 2005

[32] Ng E., Chen L., Wang Y., and Yuan C., "A study on the cooling effects of greening in a high-density city: an experience from Hong Kong," Building and Environment, vol. 47, no. 1, pp. 256–271, 2012

[33]Rossi F., Castellani B., Presciutti A., Morini E., Filipponi M., Nicolini A., Santamouris M. , Retroreflective façades for urban heat island mitigation: Experimental investigation and energy evaluations, Applied Energy, Volume 145, 1 May 2015, Pages 8-20

[34]Rossi F., Castellani B., Presciutti A., Morini E., Anderini E., Filipponi M., Nicolini A., Experimental evaluation of urban heat island mitigation potential of retro-reflective pavement in urban canyons, Energy and Buildings, Volume 126, 15 August 2016, Pages 340-352

[35] Rosso F., Pisello A. L., Cotana F., Ferrero M., On the thermal and visual pedestrians' perception about cool natural stones for urban paving: A field survey in summer conditions, Building and Environment, Volume 107, October 2016, Pages 198-214