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Heat Waves and Adaptation Strategies in a Mediterranean Urban Context

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ABSTRACT

Background: Heat waves can be considered as an emerging challenge among the potential health risks generated by urbanization and climate changes. Heat waves are becoming more frequent, long and intense, and can be defined as meteorological extreme events consisting in prolonged time of extremely high temperatures in a particular region. The following paper addresses health threats due to heat waves presenting the case study of Lecce, a city located in Southern Italy; the Mediterranean area is already recognized in international literature as a hot-spot for climate changes. This work assesses the potential impact of two different adaptation strategies. **Methods**: We have tested the effectiveness of cool surfaces and urban forestry as adaptation approaches to cope with heat waves. The microclimate computer-based model "ENVI-met" was adopted to predict thermal scenarios arising from the two proposed interventions. The parameters analysed consisted in temperature and relative humidity. **Results:** Urban forestry approach seem to lower temperature (that represents the major cause of urban overheating) better than cool surfaces strategy, but relative humidity produced by the evapotranspiration processes of urban forestry has also negative influences on temperature perceived by pedestrians (thermal discomfort). **Conclusion**: Vegetation represents both an adaptation and a mitigation strategy to climate changes that guarantees an improvement of air quality, with consequent psychological and physical benefits. Wide campaigns aimed at planting trees and increasing the urban green coverage should be systematically planned and fostered by national, regional and local institutions preferably with the involvement of research departments, schools and citizens' associations.

KEYWORDS: Heat Waves; Health risks; Adaptation strategies; Cool surfaces; Urban forestry.

1. INTRODUCTION

Worldwide urbanization has been increased since the Second World War [1] and more than 52% of world population currently lives in urban areas, with an expected increase up to 67% by 2050 [2]. The presence of urban areas originates a specific over-heating phenomenon known the Urban Heat Island (UHI), consisting in a thermal environment within the cities characterized by a warmer temperature compared to rural surroundings [3-5]. UHI arises from a mechanism related to surface energy balance, with a huge amount of radiation absorbed by the artificial materials (concrete and asphalt) during the day-time and slowly released (because of the a high thermal inertia) during night-time [6]. This effect is intensified by the global increasing in mean temperature both at surface and atmosphere, which is expected to further grow by the end of this century especially in urban areas [7, 8]. The temperature increase is associated to a higher frequency, intensity and duration of heat waves, consisting in meteorological extreme events prolonged periods of extremely high temperatures in particular regions [9, 10]. There is not a standardized definition of a heat wave: it varies among different countries and national meteorological services. According to the World Meteorological Organization (WMO) a heat wave is a period of five or more consecutive days of prolonged heat in which the daily maximum temperature is higher than the average maximum temperature by 5°C (9°F) or more [11]. All the mentioned factors lead to exacerbation of the thermal heat stress for people living in urban areas [12], resulting also in increased heat-related mortality and morbidity every year [13-15]. The European heat wave occurred in year 2003 had a severe impact on public health [16]: in Northern and Central Europe, about 70,000 deaths exceeding those normally expected have been estimated [17], with 14,802 exceeding deaths reported only in France (2,085 of which occurred in Paris) [18]. High nocturnal minimum temperatures (typical manifestations of UHI) were associated with increased mortality in the centre of Paris [19]. Night temperatures higher than 20°C define "tropical nights" [20], a value often exceeded also in Southern Europe. In England, the Office for National Statistics (ONS) estimated

2,091 exceeding deaths, during the 2003 heat wave, with 616 premature deaths occurred only in London [21]. In Russian federation, the heat wave occurred in year 2010 resulted in about 56,000 exceeding deaths across 44 days. Climatic projections do not usually include UHI, so that its health impacts may be underestimated. Exposure to “hotter-than-average” seasonal conditions compromises the homeothermy of human body, increasing the risk of illness and avoidable deaths even for small changes in average temperature.

Extreme temperatures harmfully affect also birth outcomes, inducing changes in length of gestation, birth weight and neonatal stress. Heat-related morbidity and mortality in newborns is comparable with those produced by malarial febrile seizures. Furthermore, a link between higher temperature and frequency of suicides has been shown, with risk of suicide increased by 1% to 37% for every 1°C rise in ambient temperature [22]. Systematic reviews and meta-analyses about the correlation between heat/heat waves and adverse health effects are reported in [23-27]. Chronic effects on human health associated with heat waves (*Table 1*) led to an increasing interest towards the concept of “urban resilience” [28] in relation to climatic extreme events.

The models of resilient cities towards climate changes include two features: mitigation and adaptation strategies. While mitigation approach is aimed at reducing the greenhouse emissions arising from urban “metabolism” [32], adaptation strategies try to prepare the urban dwellers for climate emergency in all its dangerous aspects [33]. The current fields of adaptation analysis are mainly focused on: (i) smart materials, such as the high reflective ones (the so called ‘cool surfaces’); (ii) green infrastructures, namely urban gardens and parks, pervious pavements, “green walls”, “green roofs”, hedges and trees; (iii) blue infrastructures, especially in those cities where rivers or lakes are present (in addition to fountains and other water-based cooling systems) [34]. Cool surfaces are characterised by materials with high solar reflectance (or albedo) and high thermal emittance, that expresses the ability of specific materials to reflect solar radiation during day-time (known to remarkably heat the urban pavements during summer time), keeping their surfaces cooler than conventional building materials. Green infrastructures make the urban environment cooler through evapotranspiration and shading: water present in the soil directly evaporates or is soaked up by plants and then transpires from the leaves, thus cooling the surrounding air. Shading granted by trees is very effective on the ground, preventing sunlight from raising the temperatures of the soil [35]. Among the green infrastructures, this paper focuses on the urban forestry that consists of increasing trees nearby streets or squares and in urban parks in the perspective of the public good [36]. Blue infrastructures – such as rivers, canals, ponds, wetlands, floodplains, water treatment facilities – allow to decrease the air temperature by capturing and storing heat through the thermal inertia of water.

Table 1. *Major studies (n = 8) on some heat-related chronic morbidities (modified from Ye et al., 2012[37]). Abbreviations: AMI, acute myocardial infarction; ARF, acute renal failure; CD, cerebrovascular diseases; CHF, congestive heart failure; CVD, cardiovascular diseases; RD, respiratory diseases.*

Study	**Location and time**	**Outcome**	**Key findings**
Koken et al., 2003[38]	Denver, CO, United States; July–August, 1993–1997	Hospital admissions for CVD, > 65 years of age	For each 1°C increase, it has been recorded: 17.5% (2.9 to 34.3%), 13.2% (2.9–24.4%), –12.5% (–18.9 to –5.5%), and –28.3% (–38.4 to –16.5%) corresponding increase in incidence of AMI, CHF, coronary atherosclerosis, and pulmonary/heart diseases, respectively. Males showed a higher number of hospital admissions than female.
Green et al., 2009[39]	Nine U.S. California counties; May–September, 1999–2005	Hospital admissions due to CVD, RD, diabetes, dehydration, heat stroke, intestinal infectious diseases, and ARF	For each 10°F increase in the apparent temperature, it has been recorded a 2.0% (0.7–3.2%) excess risk for RD, 3.7% for pneumonia, 3.1% for diabetes, 10.8% for dehydration, 7.4% for ARF, 404.0% for heat stroke, and –10.4% for hemorrhagic stroke. The effect differed by age, with little evidence of modifications due to gender, ethnicity, PM$_{2.5}$ or O$_3$ exposures.
Lin et al., 2009[40]	New York, United States; summer, 1991–2004	Hospital admissions for CVD and RD	1°C increase above the mean temperature resulted in 2.7% (1.25–4.16%) excess risk for RD on the same day and 3.6% (0.32–6.94%) for CD on lag-3 day 1°C increase above the mean temperature resulted in 2.1% (1.1–3.1%) and 1.4% (0.4–2.4%) excess risk for RD on the same day and 1 day later, as well as in 2.5%, 2.1%, and 3.6% for CD at 1, 2 or 3 days later, respectively. Positive interaction between high temperature (> 29.4°C) and humidity was shown.

			Greater increases for CVD and RD admissions in Hispanics, elderly people, and low-income persons were observed
Piver et al., 1999[41]	Tokyo, Japan; July and August 1980–1995	Emergency calls for cases of heat stroke	Daily maximum temperature associated with heat stroke. Greater number of heat stroke cases in males than females; the smallest risk in females 0–14 years of age and the greatest risk in males > 65 years of age.
Ye et al., 2001[42]	Tokyo, Japan; July and August 1980–1995	Hospital emergency transports for CVD and RD > 65 years of age	Except hypertension and pneumonia, daily maximum temperature was not associated with hospital emergency transports. 1°C increase corresponded to +3.8% (2.0–5.0%) in pneumonia cases and -1.4% (0.4–2.0%) decrease in hypertension.
Kovats et al., 2004[43]	Greater London, United Kingdom; 1 April 1994–March 2000	Emergency hospital admissions for CVD, RD, CD, renal disease, ARF, calculus of the kidney and ureter	No relation between total emergency hospital admissions and high temperature; 1°C above the mean temperature resulted in +5.44% (1.92–9.09%) overall excess risk for RD; + 1.30% (0.27–2.35%) for RD; +0.24% (0.02–0.46%) for RD in children <5 years of age, and +10.86% (4.44–17.67%) for RD in adults≥ 75.
Linares and Diaz, 2008[44]	Madrid, Spain; May–September, 1995–2000	Emergency hospital admissions for all causes, RD, and CVD	1°C above the temperature of 36°C resulted in +4.6% (0.9–8.4%) for admissions for all causes in all age groups (lag 0); +17.9% (9.5–26.0%) for all causes in adults ≥75 years (lag 1); +27.5% (13.3–41.4%) for RD among adults ≥ 75 years old (lag 0); no relations between heat (> 36°C) and admissions for CVD in all age groups.
Michelozzi et al., 2009[45]	Twelve European cities; April–September, each city ≥ 3 years during 1990–2001	Hospital admission for CVD, CD, and RD	Negative or null relationship between temperature and CVD or CD; 1°C increase above the mean temperature resulted in +14.5% (1.9–7.3%) for RD in Mediterranean and +13.1% (0.8–5.5%) in North-Continental regions among adults ≥ 75 years of age.

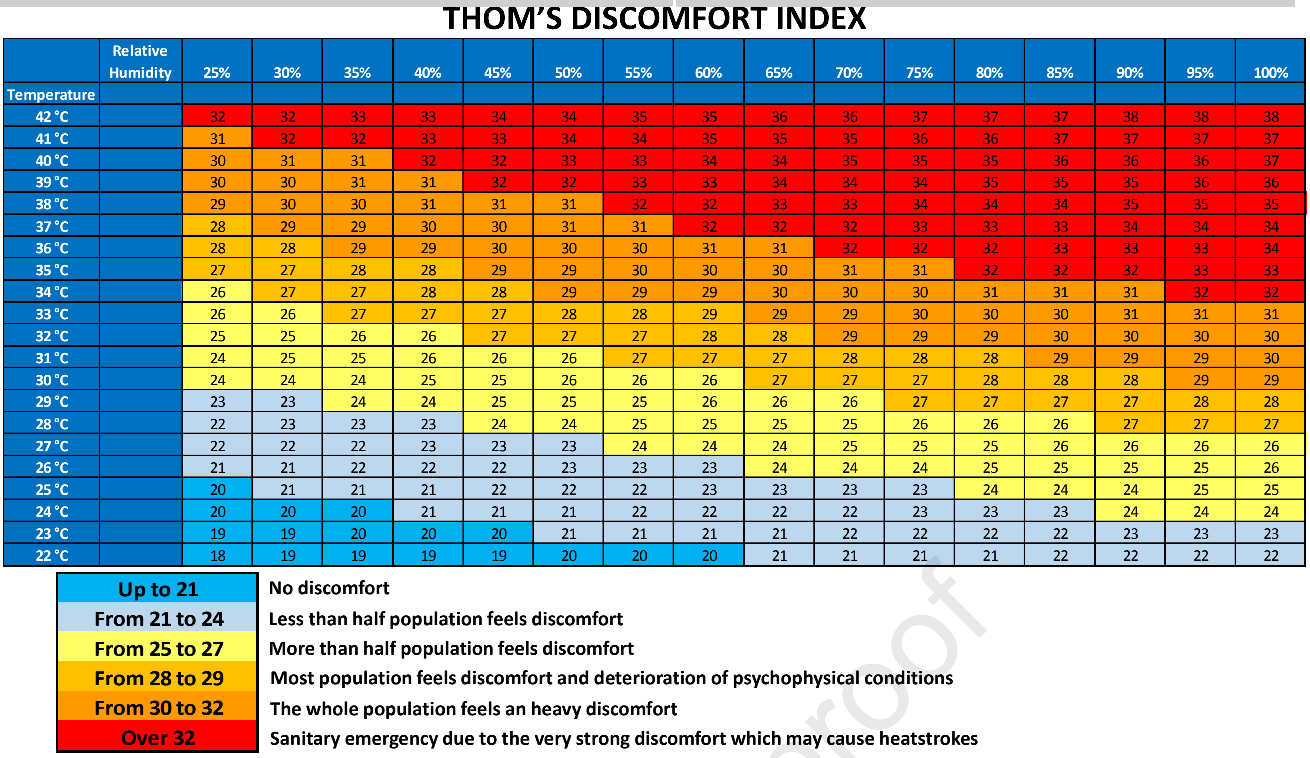
Lowering urban temperatures represents the first step, necessary but not sufficient for public health purposes. During the hottest days, the human bodies use perspiration to maintain the temperature within proper physiological limits. Sweat evaporates, thus limiting the effect of heat and producing a cooling effect on the skin. A high humidity level in the surrounding environment may limits the evaporation process [46] causing thermal discomfort. The purpose of the present paper is to evaluate the effectiveness of two adaptation strategies (cool surfaces and urban forestry) in lowering urban temperatures and improving thermal comfort for citizens. The selected scenario is a heat wave in Lecce, a city of the Mediterranean area recognized as a “Hot-Spot” on the basis of climate projections [47] and characterized by increasing temperatures during summer season [48].

2. MATERIALS AND METHODS

The selected study area is Lecce (UTM coordinates: 40°2107.2400N, 18°1008.900E), a medium size city in Southern Italy, characterized by a Mediterranean climate hot and dry in summer [49]. The modelling studies were conducted adopting the urban micro-climate CFD-based model, ENVI-met 4.0 [49, 50] which is a prognostic non hydrostatic modelling approach composed by a three-dimensional model that solves basic equations forward in time by simulating wind field modifications due to buildings, roads and vegetation. Temperature of the ground surfaces is calculated from an energy balance of the net radiative energy fluxes, turbulent fluxes of heat and vapour and soil heat flux, while the temperature of building facades is computed by taking into account the heat transmission through walls and roofs. The differential equations are solved on a staggered grid system using the finite difference method. ENVI-met requires a configuration file and an area input file in order to respectively provide the meteorological conditions and the geometry of the study area. In the version 4.0 meteorological forcing are available: this feature allows to capture the hourly variations of temperature and humidity through the insertion of observed data in the model dataset. Included into the computational domain, nesting grids are available to reduce the boundary effects. ENVI-met captures, in a holistic way, the surface-plant-air interactions modelling the microclimatic parameters in a complex environment with buildings and surfaces of different materials and green infrastructures (green walls and roofs, parks, trees etc.).

The study site is a popular marketplace situated next to a very busy road of the city (Figure 3a). In the study area, a local and an ethnic market are present: this means that we analysed an area where lot of people stands during summer days. The main physical feature of this site, chosen for the purpose of this study, is the low skyline of the buildings that expose the area to solar radiation for all the day hours with no shadowing.

In order to investigate the human thermal balance, Thom’s discomfort index was evaluated. This index proposed by Thom (1959) is one of the best indices for estimating the temperature perceived by the human body in hot and humid conditions. It represents a physiological thermal stress indicator for people that takes into account the evaporative heat balance (loss or excess) required for thermal equilibrium [51-53] and evaluates the feeling of thermal discomfort in open spaces referring to theoretic average conditions that may be influenced by several individual factors as height, weight and gender, kind of clothes, presence of shade or wind and so on. Extreme values of the index correspond to clinical conditions such as fainting or heat stroke. [54]. The index crosses air temperature and relative humidity that is a ratio, expressed in percent, of the amount of atmospheric moisture present relative to the amount that would be present if the air were saturated. Since the latter amount is dependent on temperature, relative humidity is a function of both moisture content and temperature [55].



THOM'S DISCOMFORT INDEX

	Relative Humidity	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Temperature																	
42 °C		32	32	33	33	34	34	35	35	36	36	37	37	37	38	38	38
41 °C		31	32	32	33	33	34	34	35	35	35	36	36	37	37	37	37
40 °C		30	31	31	32	32	33	33	34	34	35	35	35	36	36	36	37
39 °C		30	30	31	31	32	32	33	33	34	34	34	35	35	35	36	36
38 °C		29	30	30	31	31	31	32	32	33	33	34	34	34	35	35	35
37 °C		28	29	29	30	30	31	31	32	32	32	33	33	33	34	34	34
36 °C		28	28	29	29	30	30	30	31	31	32	32	32	33	33	33	34
35 °C		27	27	28	28	29	29	30	30	30	31	31	32	32	32	33	33
34 °C		26	27	27	28	28	29	29	29	30	30	30	31	31	31	32	32
33 °C		26	26	27	27	27	28	28	29	29	29	30	30	30	31	31	31
32 °C		25	25	26	26	27	27	27	28	28	29	29	29	30	30	30	30
31 °C		24	25	25	26	26	26	27	27	27	28	28	28	29	29	29	30
30 °C		24	24	24	25	25	26	26	26	27	27	27	28	28	28	29	29
29 °C		23	23	24	24	25	25	25	26	26	26	27	27	27	27	28	28
28 °C		22	23	23	23	24	24	25	25	25	25	26	26	26	27	27	27
27 °C		22	22	22	23	23	23	24	24	24	25	25	25	26	26	26	26
26 °C		21	21	22	22	22	23	23	23	24	24	24	25	25	25	25	26
25 °C		20	21	21	21	22	22	22	23	23	23	23	24	24	24	25	25
24 °C		20	20	20	21	21	21	22	22	22	22	23	23	23	24	24	24
23 °C		19	19	20	20	20	21	21	21	21	22	22	22	22	23	23	23
22 °C		18	19	19	19	19	20	20	20	21	21	21	21	22	22	22	22

Up to 21	**No discomfort**
From 21 to 24	**Less than half population feels discomfort**
From 25 to 27	**More than half population feels discomfort**
From 28 to 29	**Most population feels discomfort and deterioration of psychophysical conditions**
From 30 to 32	**The whole population feels an heavy discomfort**
Over 32	**Sanitary emergency due to the very strong discomfort which may cause heatstrokes**

Figure 1 Reproduction of the table of the Thom's discomfort index based on [46]

Validation for air temperature was performed through ENVI-met predictions against measured data [56] for July 7 2019 that is configured as a heat wave. Simulations used a computational three dimensional domain size of 63m x 63m x 51m, meshed by 21 x 21 x 17 square cells of 3m x 3m x 3m plus 5 nesting grids. The study site for the test was "Via Miglietta", in Lecce, next to the meteorological station of property of the Apulian Regional Agency for Prevention and Environment Protection (ARPA Puglia) (Figure 2). Results showed a good correlation with R=0.99 and RQ=0.97. Findings confirm what found in [57] with an underestimation during the hottest hours and an overestimation during the nocturnal hours (Table 2).

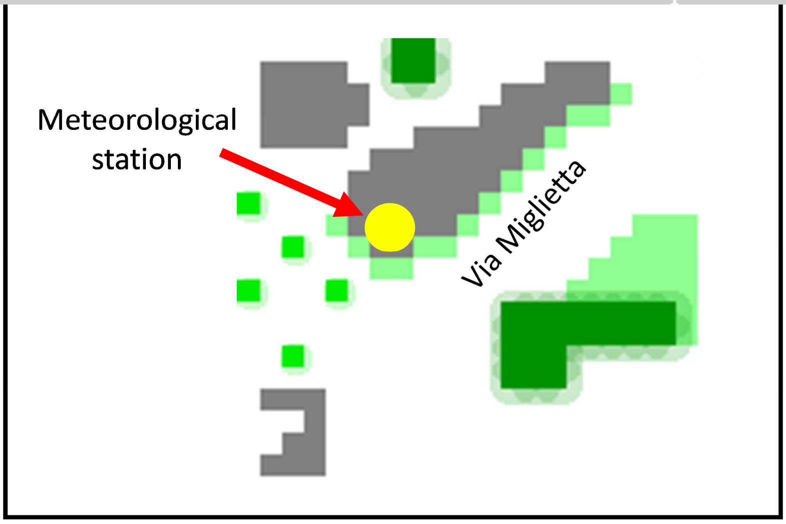


Figure 2 Area input file for the ENVI-met validation Lecce in Via Miglietta: grey elements represent buildings, green elements are vegetation.

HOUR	TEMPERATURE MODELLED (°C)	TEMPERATURE OBSERVED (°C)	TEMPERATURE OBSERVED LESS MODELLED
00:00:00	25.6	25.6	0.0
01:00:00	27.1	25.5	-1.7
02:00:00	26.7	25.1	-1.6
03:00:00	26.4	24.8	-1.6
04:00:00	26.2	24.8	-1.5
05:00:00	26.0	24.7	-1.3
06:00:00	27.4	27.2	-0.2
07:00:00	29.3	29.8	0.5
08:00:00	31.2	32.6	1.4
09:00:00	32.5	34.0	1.5
10:00:00	33.8	35.2	1.4
11:00:00	35.2	36.6	1.4
12:00:00	36.2	37.3	1.1
13:00:00	36.6	37.2	0.6
14:00:00	36.9	37.5	0.6
15:00:00	37.1	37.6	0.5
16:00:00	36.9	37.4	0.5
17:00:00	36.4	37.1	0.6
18:00:00	35.3	35.7	0.4
19:00:00	33.5	33.0	-0.5
20:00:00	32.0	30.9	-1.1
21:00:00	30.8	29.6	-1.2
22:00:00	30.0	28.6	-1.4
23:00:00	29.7	28.5	-1.2

Table 2 Temperature data recorded in Lecce in Via Miglietta and ENVI-met modelled data for July 7 2019.

After the validation stage, ENVI-met ran for the study site using a computational three dimensional domain size of 102m x 219m x 42m, meshed by 34 x 73 x 14 square cells of 3m x 3m x 3m plus 10 nesting grids (Figure 3). Time series are referred to the heat wave of July 7 2019.

Three scenarios were analysed:

1) *base case* with the asphalt in the car parking area (Figure 3b);

2) *cool surface case* where the asphalt was replaced by concrete pavement light, from ENVI-met database, in order to test the potential effectiveness of a surface with albedo higher than asphalt (Figure 3b);

3) *urban forestry case* i.e. the base case plus trees placed to let the cars moving in the parking area. (Figure 3c).

Figure 3 Aerial image of the study site (a) (Source: Google Earth); area input file for the base case and the cool surface case (b): differences between asphalt and concrete pavement light are visible only in ENVI-met database thus no chromatic variations are visible in the figure; area input file for the urban forestry case (c). The yellow circle is the ENVI-met receptor chosen as representative to detect temperature and relative humidity of the study site.

Pinus Pinea was chosen to simulate the *urban forestry case*. Pinus Pinea is a xerophile species able to adapt to thermal excursions and water stresses, particularly widespread along the coastal woods and diffused in the public spaces of Lecce city. It is a characteristic element of the South Apulia landscape in correspondence of the typical “masseria”. The configuration of its crown, similar to an umbrella, guarantees shading during all hours of sunshine hours. In ENVI-met database it is configured with a tall trunk and wide crown and a LAD (Leaf Area Density) comprised within 1.5 and 2.0.

3. RESULTS

Figure 4 shows temperature map of the study site on July 7 2019 at 15:00 (the hottest hour) at pedestrian level (1.5m) during the heat wave experience in Lecce. No substantial differences are visible between the basic scenario and the first intervention scenario (cool surface strategy). At the opposite, a significant temperature decrease was observed in the simulation performed by using the urban forestry strategy, where the increased evapotranspiration and to the shading effect of trees cool the entire area. The evapotranspiration process acts on the latent heat fluxes with plants becoming a kind of “adsorbing sink” for atmospheric heat and the shading is able to reduce surface temperature by acting as a physical filter for solar radiation.

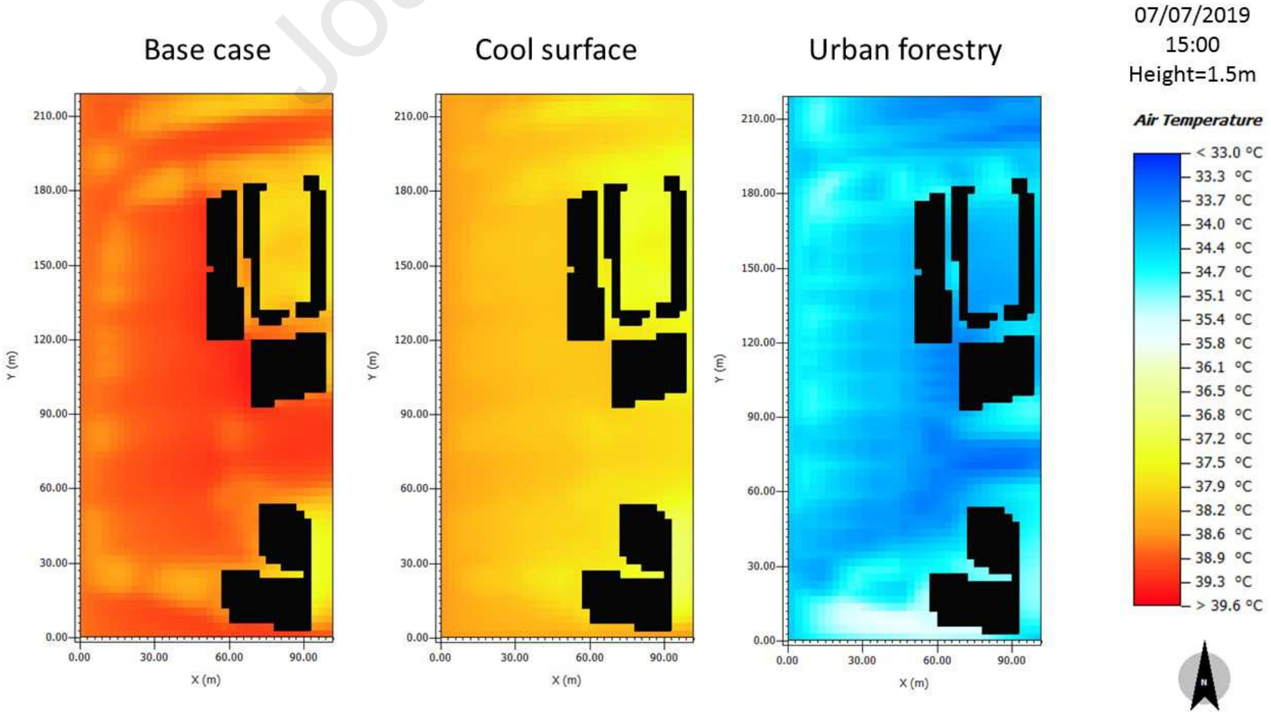


Figure 4 Temperature maps obtained from ENVI-met for the study site on July 7 at 15:00 at pedestrian level (1.5m).

Figure 5 shows temperature maps at 23:00. The basic scenario and the cool surfaces scenario maintains the same features of 15:00, while urban forestry still lowers air temperature but differences with the base case and cool surface scenarios are lower.

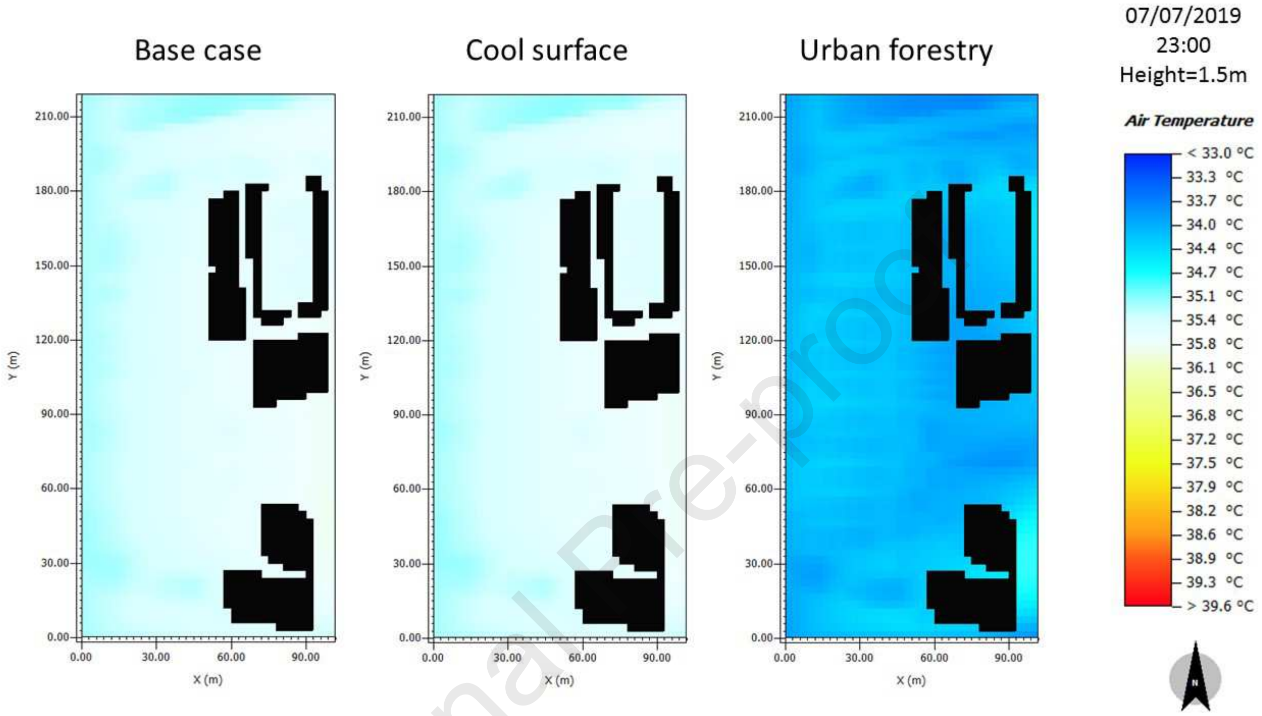


Figure 5 Temperature maps obtained from ENVI-met for the study site on July 7 at 23:00 at pedestrian level (1.5m).

Figure 6 shows relative humidity map of the study site at 15:00 at pedestrian level. Basic scenario and cool surface scenario show the lowest values of relative humidity, while urban forestry shows the increasing of air moisture due to the evapotranspiration.

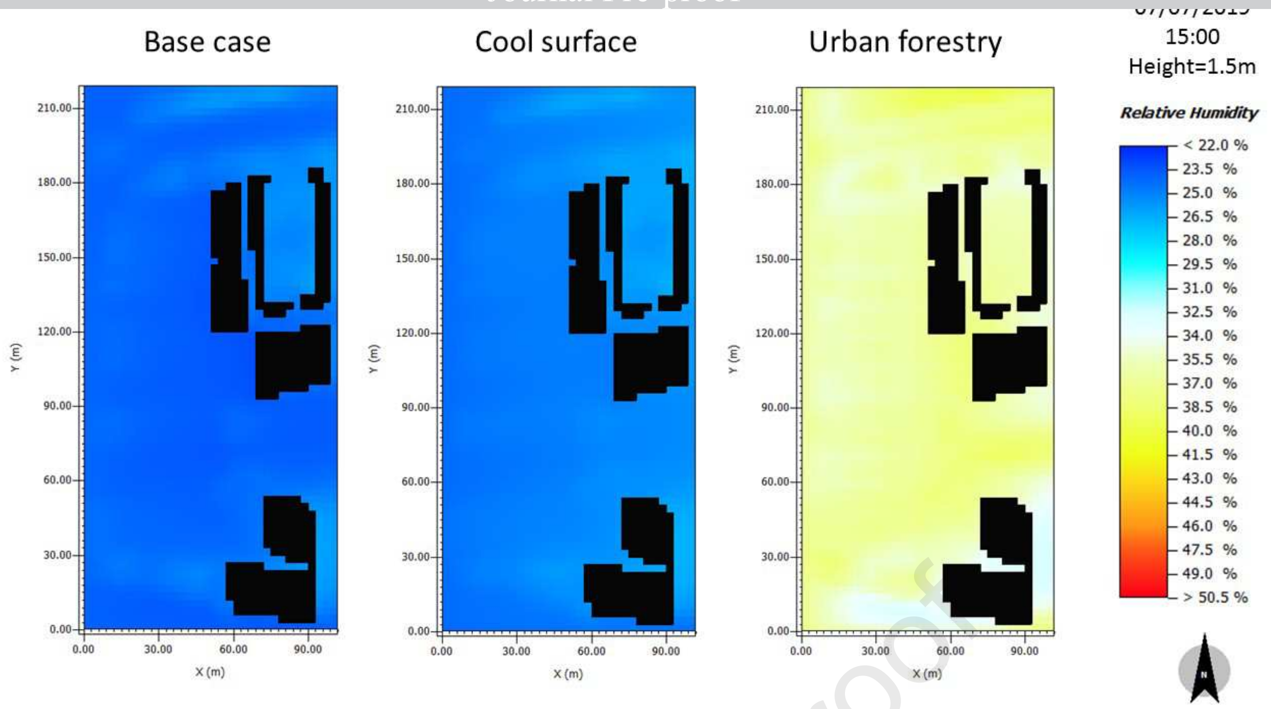


Figure 6 Relative humidity maps obtained from ENVI-met for the study site on July 7 at 15:00 at pedestrian level (1.5m).

Figure 7 shows relative humidity map of the study site at 23:00. Results reveal the same pattern of Figure 6, but an increase of air moisture for all the three cases is evident; this is due to the absence of solar radiation. During the night, the cooling effect of vegetation corresponds to higher values of air moisture.

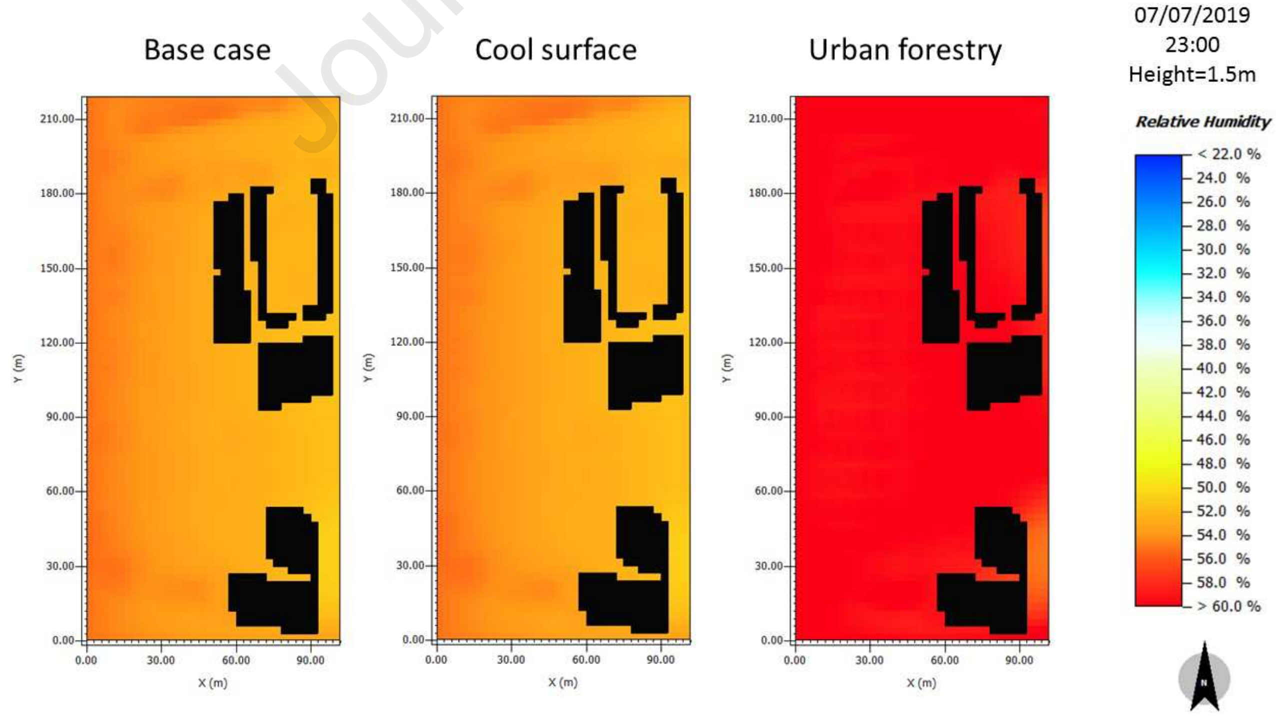


Figure 7 Relative humidity maps obtained from ENVI-met for the study site on July 7 at 23:00 at pedestrian level (1.5m).

Figure 8 represents the graph of the time series of modelled temperature recorded (see Figure 5) from 06:00 to 23:00 on July 7 at pedestrian level (1.5 m). The highest temperatures are observed in the basic and the cool surfaces scenarios for all the hours of the day. The major temperature gap generated by the urban forestry is visible during the diurnal hours from 10:00 to 18:00.

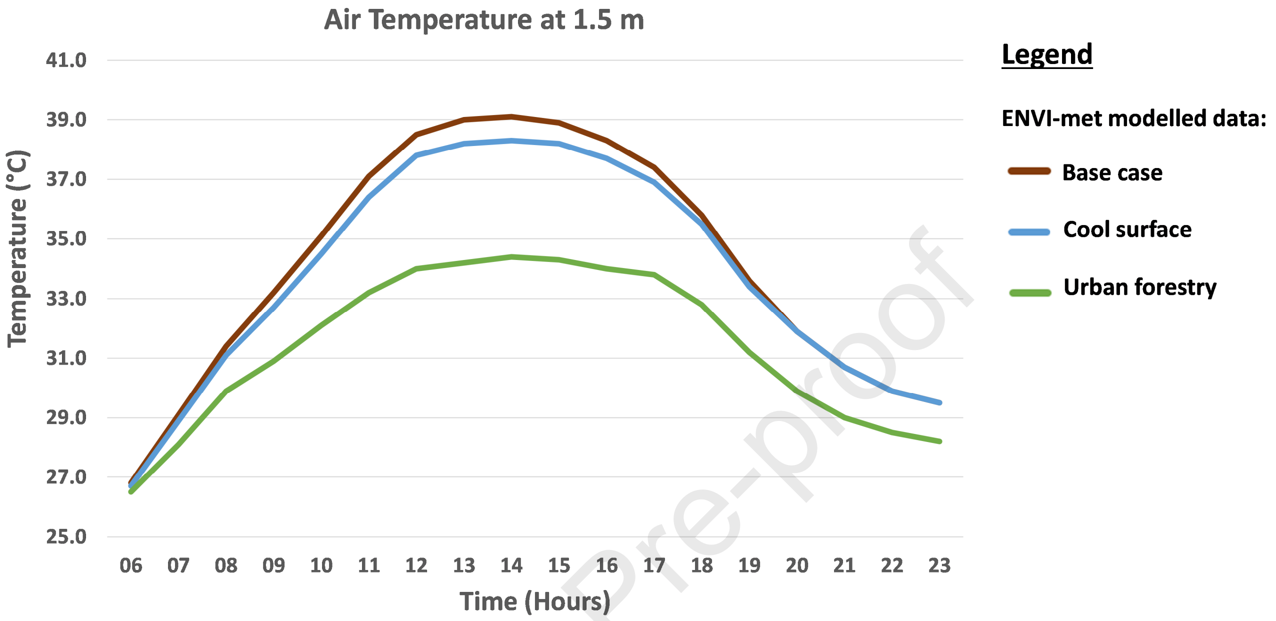


Figure 8 Temperature modelled by ENVI-met from 06:00 to 23:00 of July 7 at pedestrian level (1.5m) at the receptor.

Figure 9 graphically shows the time series of modelled relative humidity temperature recorded from 06:00 to 23:00 of July 7 at pedestrian level (1.5 m). By comparing Figure 9 with Figure 8, the graph shows an expected specular trend with the lowest air humidity during the hottest hours and a constant higher humidity for the urban forestry scenario, confirming the active role of vegetation on latent heat fluxes.

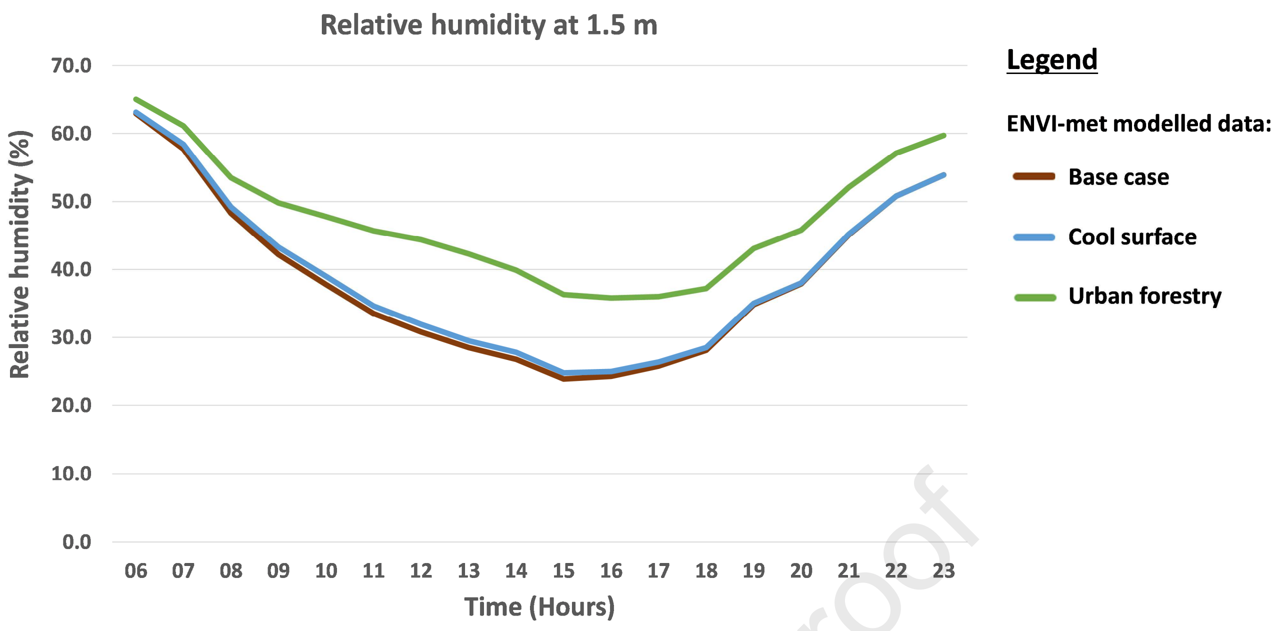


Figure 9 Relative humidity modelled by ENVI-met from 06:00 to 23:00 of July 7 at pedestrian level (1.5m) at the receptor.

During the heat wave occurred in Lecce on July 7, with reference to the Thom's comfort index reported in Figure 1 and comparing temperature and relative humidity values, from 06:00 to 09:00 there are data within the range 25-27 for all the scenarios: more than half population feels thermal discomfort. From 10:00 to 16:00, Thom's index concerning basic and cool surface scenarios is within the range of 30-32 (the whole population feels a heavy discomfort), while the urban forestry scenario shows an index score of 28-29: most population experience discomfort and deterioration of psychophysical conditions. At 17:00 and 18:00 the scenarios corresponded to Thom's Index within the range of 28-29, while urban forestry scenario shows scores of 25-27 at 19:00. The basic and the cool surface scenarios reach these values from 20:00 to 23.00.

Results of ENVI-met simulations show the good performance of urban forestry approach in lowering temperature during the hottest hours of a heat wave. Cool surfaces are not so effective and present problems due to the reverberation of the scattered UV radiation that creates visibility problems toward the pedestrians.

DISCUSSION

The natural environment can affect human health at different levels, following the definition developed by WHO in 1946 and still valid today [58]: physical health, mental health and social cohesion. Heat waves can be considered as an emerging challenge among the potential health risks generated by urbanization and climate changes. Heat waves are becoming more frequent, long and intense, and can occur anywhere and in any period of the year. The common knowledge identifies them with the late spring/summer period: winter heatwaves - also called "warm spells" - are widely recognized as climate anomalies, with a minimal impact on humans, animals and infrastructures. However, as these phenomena are not rare in an era of climate change like the current one, it would certainly be interesting to evaluate the results of the various types of mitigation also in other periods of the year, such as in autumn/winter. Rapid rise in temperature during summer season results in a cascade of illnesses as heat cramps, heat exhaustion, heatstroke and hyperthermia. Moreover, heat induces mental stress and there is the possibility of negative interference with psychotropic drugs or boosting psychiatric symptoms with related increase in hospital admissions for mental and behavioural disorders (including dementia, mood disorders, psychological problems etc.). Mortality attributed to mental and behavioural disorders increases during heat waves, especially in people aged 65-74 and in persons affected by dementia, or schizophrenic disorders [22]. To cope with consequences of climate changes, including heat waves, different adaptation and mitigation strategies have been developed and proposed for implementation at urban level. For this purpose, the Global Covenant of Mayors for climate and energy has been created, and best practices to counteract climate changes are shared between cities and regions. Among those, strategies based on increasing urban greening and forestry represent a valuable approach displayed at international level. Green elements are essential not only for the cooling effect on urban microclimate: a 2017 report by the American environmental organization "The Nature Conservancy" invites to consider trees and green areas as real and proper public health infrastructures [59].

Although the mechanisms underlying these benefits have not yet been clearly defined, there is evidence of how the presence of green areas can be useful in fostering people to practice regular physical activity [60-633], thus increasing quality of life and survival in the older age groups or even reducing mortality rate from cardio-cerebro-vascular diseases [62, 55, 65].

Physical health is also influenced by the improvement of air quality since urban vegetation can contribute in reducing the concentrations of different pollutants, in particular atmospheric particulate matter (PM) [66, 67]. Nevertheless, some vegetal species can generate gaseous secondary metabolites with terpenic or isoprenic nature, thus contributing to air pollution [67-69].

The ecology of urban and suburban areas can then affect the geographical variation of diseases related to pollen, insects and parasites [70, 71]; as for pollens, some plants seem to worsen asthmatic and allergic symptoms, while others may confer a kind of protection from air pollution [72]. The need for preliminary studies concerning plants to choose for a certain urban area is still an open issue and it is necessary to be cautious due to substantial knowledge gaps [73]. Several factors influence the effectiveness of plant in improving urban air quality: street canyon configuration, buildings' height, local prevailing winds, climate conditions and vehicular traffic are to be evaluated all together.

Green spaces can also improve mental health. Several studies demonstrate clear associations between the availability of public green spaces and various psychological, emotional and mental benefits [63, 74]. The access to green areas significantly reduces stress and positively affects the quality of life in urban areas [75-78]. A large epidemiological study carried out in the Netherlands found a positive association between the amount of urban green spaces and people's health perception [79]. A study has found a link between the residential green space in childhood and the onset of psychiatric disorders from adolescence to adulthood [80], thus opening to epigenetic interpretations.

The last aspect considered concerns the social cohesion, that is fundamental for a healthy community and society. Natural characteristics and open spaces in the residential areas can be fundamental in developing interactions between inhabitants [81]. The few studies available on this subject indicate a positive correlation between social cohesion and natural environments [73, 82]. Some researchers also report an association between vegetation in common green spaces and informal social contacts with neighbours [83]. Other studies have shown that inhabitants with less aggressive behaviour, even less prone to commit crimes, belong to greener residential areas [84, 85]. Globally, the research available to date indicates that there is a strong association between natural areas in urban environments and health benefits for humans.

Specifically, with reference to urban heat waves and green infrastructures, more validation studies are necessary to test if positive aspects of lowering temperature by vegetation can overcome the thermal discomfort due to the increasing of air moisture. The choice of the most suitable green infrastructure is linked to the climate conditions of a certain area and has to pursue values of air moisture released by plants acceptable for the human body. Modelling research can offer a powerful tool to test the hypothesis of intervention or not, but limitations in this approach are still present. These are mainly due to the lack of correlation data among many interacting factors (kind of green infrastructure, prevailing wind of the area, building and street configuration, vehicular traffic, health conditions of each individual etc…).

4. CONCLUSIONS

The health effects of heat waves representing a problem of increasing importance in the frame of climate changes. Urban adaptation strategies are useful to cope with this extreme phenomenon in urban environment – where the presence of artificial materials (asphalt, concrete etc.) and the contemporary lack of natural surfaces – exacerbate the thermal effects of heat waves. We have demonstrated possible applications of model simulations performed by using the urban microclimate software ENVI-met to compare the potential efficacy of different adaptation strategies (i.e. cool surfaces and urban forestry) on urban temperature and relative humidity. In our study, adaptation strategies based on cool surfaces appear not very effective as urban forestry in lowering air temperature. Nevertheless, the active role of vegetation in urban forestry increases the moisture rates in the air through the evapotranspiration processes and this effect maintains citizens in a range of thermal discomfort as assessed by Thom’s discomfort index. ENVI-met simulations showed the effectiveness of urban forestry with respect to the basic scenario (i.e. no intervention) and the cool surface one in terms of Thom’s discomfort index. This feature is present during the hottest hours and when the UHI effect is evident, some hours after the sunset. The choice of the most suitable green infrastructure can lead to a further improvement of thermal comfort.Urban forestry represents the first step toward an adaptation approach where there is a hot climate during summer season and no blue infrastructure is available. At the same time, trees represent a radiation shield in urban spaces with a large sky view at pedestrian level. Vegetation represents both an adaptation and a mitigation strategy to climate changes that guarantees an improvement of air quality, with consequent psychological, physical, and social benefits. Some issues are still open and preliminary studies are always recommended to choose the most suitable green infrastructure for a specific urban area. Urban infrastructures are able to address impacts arising from climate changes representing an investment for the health and wellness of citizens. Wide campaigns aimed at planting trees and increasing the urban green coverage should be systematically planned and fostered by national, regional and local institutions preferably with the involvement of research departments, schools and citizens’ associations.

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Highlights:

1. Heat waves represent a health problem of increasing importance at global level
2. Urban climate modelling allows planning adaptation strategies
3. Thermal indices are to be evaluated before intervention on public spaces
4. Green infrastructures are an effective strategy in lowering urban temperatures

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: