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MODERN SOLUTIONS IN ENGINEERING

Edited by
Dorota Anna Krawczyk
Ewa Szatyłowicz
Anna Justyna Werner-Juszczuk
Dorota Gawryluk

Politechnika Białostocka

FACULTY OF CIVIL ENGINEERING
AND ENVIRONMENTAL SCIENCES
BIALYSTOK UNIVERSITY
OF TECHNOLOGY

ASSOCIATION
OF SANITARY ENGINEERS
AND TECHNICIANS

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Evaluating buildings and urban external layout green retrofitting to improve micro-climate conditions at district level

Keywords: sustainable retrofitting; ENVI-met; environmental redevelopment; residential buildings; green urban district

Abstract: In the context of sustainable cities and communities, to meet the European aim of a carbon-free economy by 2050 and to tackle current climate change, the retrofitting of Italian residential building stock as well as the green regeneration of urban districts is essential. The research aims at assessing the influence of some cooling strategies applied in a defined hypothetic but realistic urban grid located in 3 different Italian cities (Milan, Florence and Palermo) evaluating multistorey, tower and courtyard building types respectively. Using ENVI-met software several micro-climate parameters are evaluated. The most significant outcomes are related to the substitution of the current dark asphalt (reference case) with cool pavements as cool improvement strategy. This measure results in a reduction of external air temperature (~ 1.2°C). Additionally, the application of green façade technology on buildings noticeably impacts both the wall surface temperature (Milan, Florence and Palermo: reduction of around 10°C–12°C) and the wall energy balance with respect to traditional external wall configurations. For the city of Palermo the cool redevelopment measures results in a slight improvement in terms of micro-climate parameters compared to other cities.

Introduction

According to the Enerdata report [1] in Europe buildings are responsible of 43% of final energy consumption and only 15% is satisfied by renewables [2]. Households account for 2/3 of this need for energy, equaling to about 240 Mtoe in 2019 [1]. At the Italian level, residential building stock is nowadays aged and obsolete. This is because 25% of Italian houses were built before 1950 [3] without meeting any standards concerning energy saving or emissions reduction. According to the ENEA report of 2020 in Italy a total of 40% of primary energy demand is needed in fact for civilian use [3] and the households' energy consumption accounts for about 31 Mtoe (data from 2019) [4]. Twenty six percent of Italian residential building stock is classified as energy efficiency class lower than C (1.2 $EP_{gl,nren,rif,standard(2019/21)}$ reference building global energy performance index for non-renewable < global energy performance index for non-renewables $EP_{gl,nren}$ < 1.50 $EP_{gl,nren,rif,standard(2019/21)}$) [5]. Moreover, natural gas is always the main source (50%) for energy production while electricity accounts only for about 18% [4]. In fact, Carpino et al. [6] demonstrate through a survey of about 80 Italian families that 60% of heating systems of their apartments is characterized by a traditional gas boiler.

Lack of use of renewables for heating and cooling is not only an Italian issue. Due to climate change, Tootkaboni et al. [7] affirm that a significant increase of about 255.1% for cooling demand will occur in the near future for densely built existing residential districts. Zinzi et al. [8] mention a monitoring campaign in Rome (Italy), in line with previous cited research, which demonstrates that the urban environment and heat island effect noticeably influence the cooling demand of existing residential buildings. In this context, retrofitting of Italian residential building stock is essential to meet the European aim of a carbon-free economy by 2050, as well as increasing energy efficiency up to 32.50%, as called for by the European 2030 climate and energy framework.

Urban environment design and especially the use of effective cooling strategies (such as implementation of flowerbeds or cool pavements for the external neighborhood environment or introduction of trees etc.) can tackle climate change and the rise in external air temperature, avoiding an increase in energy needs during the summer season and overheating effects inside buildings. Moreover, some efficient cooling strategies to reduce the heat island effect can be applied also on buildings, on both green façades and roofs. In the literature, many studies demonstrate that a properly designed urban environment and appropriate micro-climate condition positively affect human comfort and wellbeing. For instance, Yldiz et al. [9] developed a model to demonstrate the relationship between the built urban environment (for instance in terms of providing open spaces, landscaping, sustainable pedestrian routes, layout of buildings and streets etc.) and social sustainability, highlighting that accessibility and quality of social life have the most weight (33%). Abdallah et al. [10] observed that cooling strategies applied in both deep and shallow canyons can improve the outdoor thermal comfort for people in terms of PET (Physiological Equivalent Temperature) for urban districts located in hot humid climates.

The research discussed in the chapter aims at assessing the influence of implementing both green roofs and façades (as retrofitting measures for existing residential buildings in urban districts) and some single external cooling strategies, as well as a combination of them on micro-climate conditions at both building and urban level using ENVI-met software [11]. The main goal is providing useful indications for the designers to choose the most suitable and effective retrofitting strategy for green urban redevelopment interventions in the context of the European SDGs (Sustainable Development Goals) concerned with sustainable cities and communities.

State of the art

In the literature there are many studies concerning a systematic review on ENVI-met software to validate its use in the evaluation of some micro-climate parameters typical of the urban environment and affecting both users' external thermal comfort and building energy performance. For instance, Ouyang et al. [12] validate the performance of ENVI-MET software using full forcing meteorology and considering several thermal-radiative parameters (such as air temperature and mean radiant temperature). For validating the model, they perform in situ measurements for different kinds of scenarios. Crank et al. [13] tried to test the effectiveness of the software to calculate external air temperature in presence of urban mitigation strategies such as high albedo materials and trees. According to this study, Tsoka et al. [14] performed a systematic review to estimate the suitability of the ENVI-MET model to calculate changes in external air, surface and mean radiant temperature due to the use of urban greenery and cool materials for pavements. As regard to ENVI-MET validation, Perini et al. [15] performed a comparison between ENVI-MET and TRANSYS to evaluate the mean radiant temperature in a typical canyon between 2 row buildings, considering the insertion of trees. A reduction in mean radiant temperature equal to 20°C occurs as a result of the insertion of trees and the ENVI-MET software allows for the evaluation of the design of trees and their influence on humans' external comfort and wellbeing.

The air temperature parameter is one of the most evaluated to measure the possible reduction of the heat island effect. Liu et al. [16] with a detailed literature review affirm that the external air temperature is the most used and suitable parameter to evaluate human external wellbeing. They also advise to consider a parameter related to solar radiation and one concerning ventilation. Faragallah et al. [17] proposed the use of external cool pavements to reduce outdoor temperature and consequently the heat island effect during the summer season. They point out that this improvement is the most effective and a decrease in external air temperature by 3.5°C occurs. In line with previous researchers, to tackle climate change, Cortes et al. [18] propose a combination of three green retrofitted measures (increase in the number of trees, grass-covered areas and green roofs in buildings) that results in a reduction in external air temperature in a range between 0.5°C and 0.8°C for a zone characterized by warm summer.

In general, 52% of researchers considered the PET parameter to evaluate the level of humans' external comfort [19] but also the evaluation of the mean radiant temperature is frequently performed as well. In regard to PET, Karimimoshaver et al. [19] point out that for an urban context both the buildings height (H) and the distance between buildings in the urban district (W) affect external micro-climate parameters. An increase in the ratio H/W results in a decrease in PET. For instance, they conclude that if the H/W parameter varies in a range between 1 and 1.5 the PET drops by about 2°C. In line with that, Wai et al. [20] highlight that a decrease in heat-stress at pedestrian level can be obtained by the reduction of buildings length and minor density.

Finally, in regard to the integration of active strategies to produce energy from renewable sources, Vassiliades et al. [21] perform studies dealing with the influence on urban thermal comfort with the possible installation of photovoltaic (PV) systems on urban factories. They compare the solution with and without the active strategy in terms of PET. They point out that in the spring season with the installation of a PV system there is a reduction of the thermal stresses and so an improvement in pedestrians' comfort.

Methodology

The methodology to assess the possible configuration for a green redeveloped urban district or a new one is the following:

- Identification of a possible typical scheme of an Italian urban district. An urban grid of 80 m X 80 m was outlined in ENVI-met spaces and located in Milan, Florence and Palermo that belongs to 3 different Italian climate zones. Milan is located in northern Italy; it is characterized by subcontinental climate and 2404 Heating Degree Days (HDD). Florence is sited in central Italy and the climate is a temperate and sub-coastal climate with 1415 HDD. Finally, Palermo, located in southern Italy, has 751 HDD with a Mediterranean climate characterized by hot and arid summers. For each location, the maximum outdoor air temperature registered for the simulation day selected (14th of July) was assumed at 31°C, 36°C and 37°C respectively. The district configuration is assumed as invariant.
- Definition of 3 different residential building types to be introduced into the delineated urban grid: multistorey, tower and courtyard buildings. (Figure 1). For the multistorey buildings a configuration characterized by lower density (Figure 1) is considered to evaluate the influence of distance between buildings on the external micro-climate parameters.

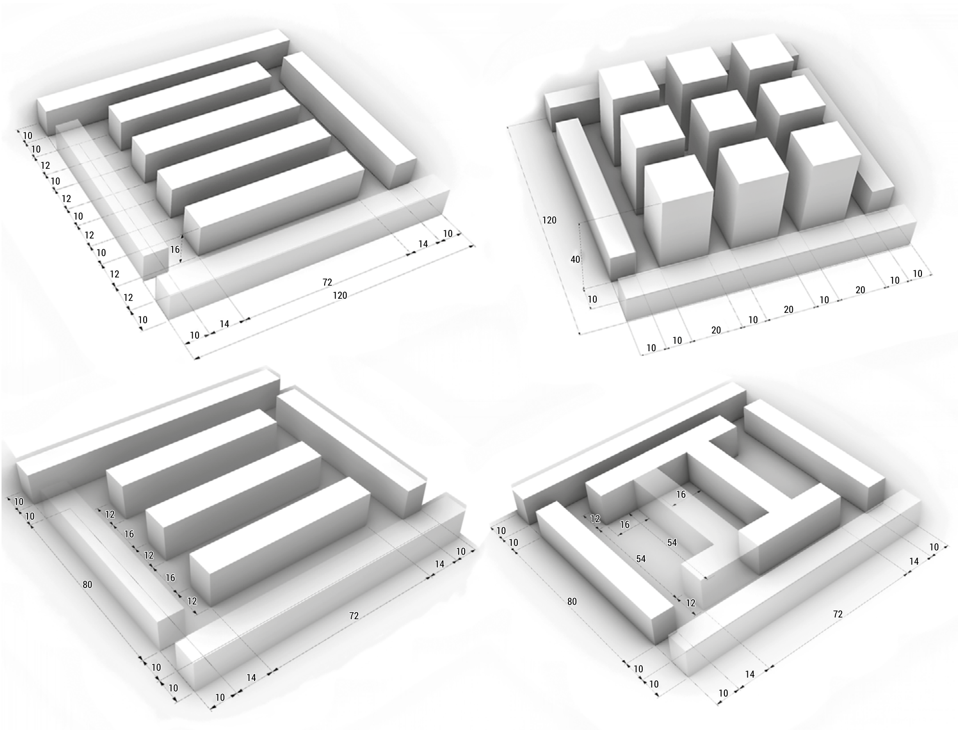

FIG. 1. Sketch of the 4 considered urban layouts for simulation tasks
SOURCE: own elaboration

- Outlining of different cooling strategies at both buildings and urban level. For the former, the use of vertical greenery for South oriented walls combined with green roof technological solutions is proposed. Green façades for buildings are used in different configurations with changing degrees of greening: for multistorey buildings 20%, 30% and 50% of greenery with respect to the total southern wall surface are investigated while for tower buildings only 50% of greenery is considered characterized by a height of 10 m and 30 m.

Various green urban strategies are evaluated in the different configurations of the outlined typical urban district considering the 3 residential building types (Table 1). In the initial solution, asphalt pavement for the whole urban grid surface is considered.

TAB. 1. Characteristics of Green Strategies considered the different residential building types. In the table below the percentages refer to the whole surface of the considered urban grid without buildings. The low-density configuration obviously permits more trees to be included in the urban grid

Green Strategy	Residential building type			
	High density Multistorey	Low density Multistorey	Tower*	Courtyard**
Flowerbeds [%]: grass 25 cm thick	46.7%	47%	31.5%	57%
Flowerbeds and trees [number of trees]: rancho trees 8.63 m height	56	150	58	120
Cool pavements [%]: concrete pavement light	100%	100%	100%	100%

*For tower buildings due to the high density of the built environment the same number of trees are provided but the flowerbeds are lower.

**For courtyard buildings the number of trees is higher because of the shape of the building and to overcome the decrease in flowerbeds.

SOURCE: own elaboration

In Table 2 the main characteristics of the different kind of pavement for both the base solution and the cool one is defined.

TAB. 2. Main characteristics of reference case pavement (asphalt road) and cool pavement (concrete pavement light)

Pavement	Albedo	Emissivity
Asphalt road	0.20	0.90
Concrete pavement light	0.80	0.90

SOURCE: own elaboration

- Evaluation of different micro-climate parameters with respect to the different strategies modeled: external air temperature, relative humidity (RH), wall surface temperature, external temperature outside the wall and energy balance (last 3 only for greenery strategy).

For ENVI-met set up, the climate files created by Italian CTI (Italian Thermotechnical Committee) referencing the different cities are used. In addition to the nesting grids already set up by the software (5 grids), 3 empty grid rows (6 m) are added on each side of the model area to avoid errors related to uncertainties in boundary conditions. The buildings are modeled according to typological features widely spread in the Italian context, in terms of geometry and envelope characteristics (Table 3).

TAB. 3. Main characteristics of the materials used for the different technological solutions

Exiting external wall					
Material	**Thickness [m]**	**Conductivity [W/mK]**	**Specific Heat [J/kgK]**	**Absorption [%]**	**Reflection [%]**
Bricks – plaster	0.12	0.84	829.84	42	45
Air	0.08	0.03	1006.00	–	–
Aerated bricks	0.08	0.30	840.00	–	–
Green façade					
Material	**Thickness [m]**	**Emissivity**	**Conductivity [W/mK]**	**Transmittance [W/m^{2}K]**	**Albedo**
Greening	0.10	–	–	0.30	0.20
Substrate – Sandy loam	0.05	0.98	–	–	0.20
Styrofoam	0.01	–	0.10 W/mK	–	–
Air gap	0.08	–	–	–	–
Existing roof					
Material	**Thickness [m]**	**Conductivity [W/mK]**	**Specific Heat [J/kgK]**	**Absorption [%]**	**Reflection [%]**
Roofing tiles	0.02	0.84	800.00	50	50
Insulation	0.08	0.07	1500.00	–	–
Reinforced bricks	0.24	1.10	840	–	–
Green roof					
Material	**Thickness [m]**	**Emissivity**	**Conductivity [W/mK]**	**Transmittance [W/m^{2}K]**	**Albedo**
Greening	0.10	–	–	0.30	0.20
Substrate – Sandy loam	0.15	0.98	–	–	0.20
Styrofoam	0.08	–	0.10	–	–

SOURCE: own elaboration

Results and discussion

ENVI-met performed the analysis for over 2400 points in the meshed analysis grid considering 4 hours (10:00 – 14:00) of 14th of July. The results reported in this section refer to noon. The graph in Figure 2 relates to the number of points [%]

and the corresponding value of external air temperature for the city of Florence and multistorey building types (high density). The results highlight that for the reference case, distinguished by the presence of dark asphalt for the whole external pavement, about 8% of points (highest and so representative value) are characterized by a temperature equal to 27.86°C. In this case the higher value of the external air temperature is calculated for the external points in the nesting grid where there are no shadows cast by buildings. This happens for all considered cooling strategies.

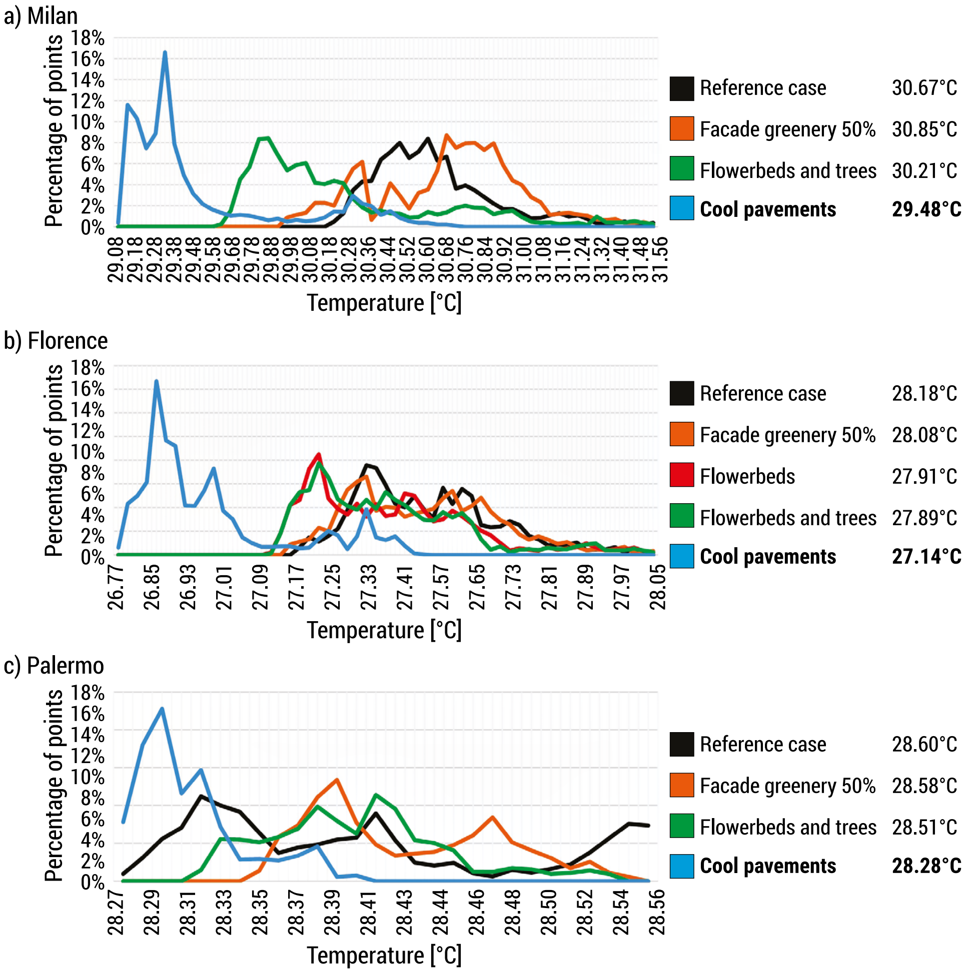

FIG. 2. Percentage of points with respect to the external air temperature considering different cities and different intervention scenario. On the right the average of the external air temperature for each analysed cooling strategy

SOURCE: own elaboration

The configurations with the presence of flowerbeds and the latter combined with trees do not result in a significant decrease in the average of external air temperature. In fact, about 8% of points are characterized by a temperature equal to 27.61°C with a slight reduction of 0.6°C with respect to the reference case. This is probably related to the evaluation point of the external air temperature fixed at 1.5 m (man-height to evaluate urban external comfort) while trees are about 9 m tall.

It is worth highlighting that the most significant result is related to the layout characterized by cool pavements. This solution is the most advantageous considering the external air temperature parameter. The decrease in the average external air temperature is equal to about 1°C and as previous graph shows (Figure 2) 15% of points (representative amount) have a temperature equal to 26.93°C. Consequently, a significant reduction of about 1.5°C occurs. Even according to literature [22] the use of cool pavements is the most advantageous cool strategy also with respect to the introduction of green flowerbeds. This should be analyzed and verified also in terms of CO_2 emissions.

As for the city of Florence and the city of Milan, the introduction of cool pavements is the most effective green strategies to reduce the average external air temperature by about 1°C. In this case, 16.6% of points is at a temperature equal to 29.3°C while in the reference case 8% of points is at 30.5°C. Furthermore, the cool pavements result in an increase in relative humidity by about 4%. Otherwise for the city of Florence there is a slight increase in RH (~ 0.6%) with cool pavement improvement strategy. It is worth to notice that in the case of Milan the use of the combination of flowerbeds and trees causes a higher reduction in external air temperature compared to Florence. The decrease in air temperature is about 0.6°C. In regard to the green façade the most significant result is related to the relative humidity that increased by about 1%.

Regarding the city of Palermo, it is worth to notice that green improvements only slightly influence the micro-climate parameters compared to the other 2 cities. For instance, the decrease in external air temperature with cool pavements is lower by 0.4°C even if most of the points (about 23%) are at 28.3°C. The same occurs for the relative humidity: the introduction of the green façade for southern orientated walls results in a low decrease of RH of about 0.4%.

In regards to the results concerning the variation of the relative humidity for the different cooling strategies adopted for the analysed urban grid, it is proved that the vertical greenery (50%) on the façade is the most influential (Figure 3). In fact, an increase in relative humidity of around 1.6% occurs with respect to the reference case (65.50% average of RH). This is probably due to the evapotranspiration of the green façade. The other cooling strategies are comparable in terms of the relative humidity parameter.

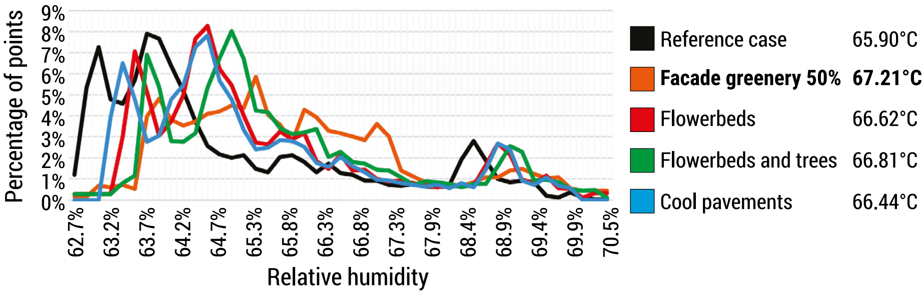

FIG. 3. Percentage of points included in the urban grid with respect to relative humidity considering the city of Florence and the high-density multistorey building types. On the right, the average relative humidity for each analysed cooling strategy is shown

SOURCE: own elaboration

Finally, as for low density multistorey buildings included in the grid, the results show that the increase in distance between buildings and the reduction in covered area significantly influences the value of relative humidity rather than external temperature. In fact, even if the temperature is lower than the high-density configuration, only a slight decrease occurs. In this configuration, relative humidity rises by 4% compared to the high-density grid. Compared to the other models, in this one the most advisable configuration for both temperature decrease and relative humidity increase is the redevelopment of the area with cool pavements.

Figure 4 shows the variation of the external air temperature in the outlined urban grid considering the different analyzed cooling strategies (on top of the figure) applied for the high density multistorey grids located in 3 cities (Florence, Milan and Palermo). For instance, regarding the city of Florence, this result confirms the previous results. In fact, in the last grid (Figure 4 on the right) characterized by cool pavements most of points are characterized by an average temperature below 26.91°C. This significant reduction in temperature by adopting a cool pavement redevelopment strategy occurs also for Milan (~ 1.2°C). For Palermo it is less noticeable, as specified before (~0.4°C).

It is important to highlight that the vertical greenery on façade (50%) does not significantly affect the value of external air temperature at the height of 1.5 m. Consequently, to evaluate the benefit of these buildings' redevelopment intervention, the surface temperature and other parameters deal with the buildings are considered.

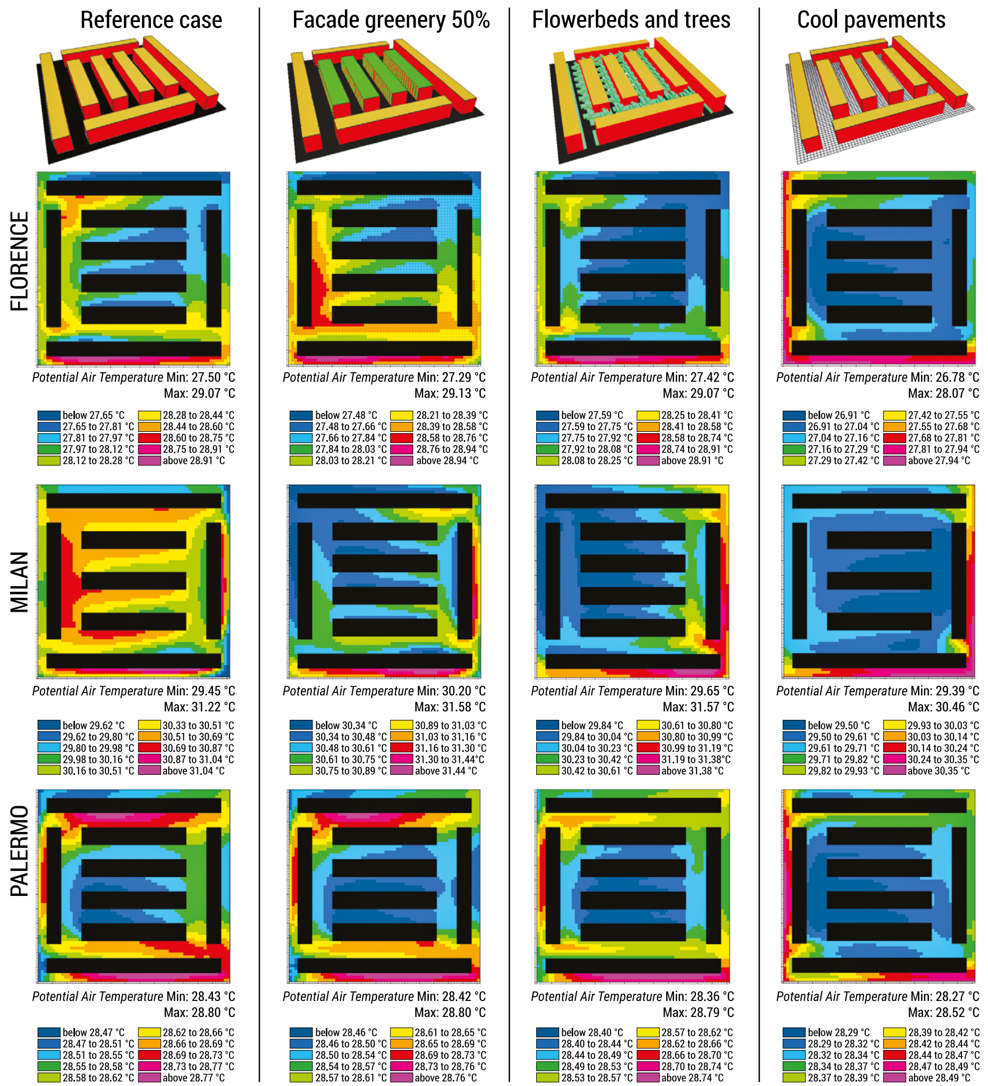

FIG. 4. **Variation of external air temperature in the considered urban grid with the different cooling strategies and different locations**

SOURCE: Own elaboration

Figure 5 illustrates the results related to the variation of the buildings' surface temperature (southern wall), the energy balance [W/m^2] with respect to incoming long-wave radiation (LW_{in}) and outcoming (LW_{out}) by the southern wall and the external air temperature outside the wall, considering different possible locations.

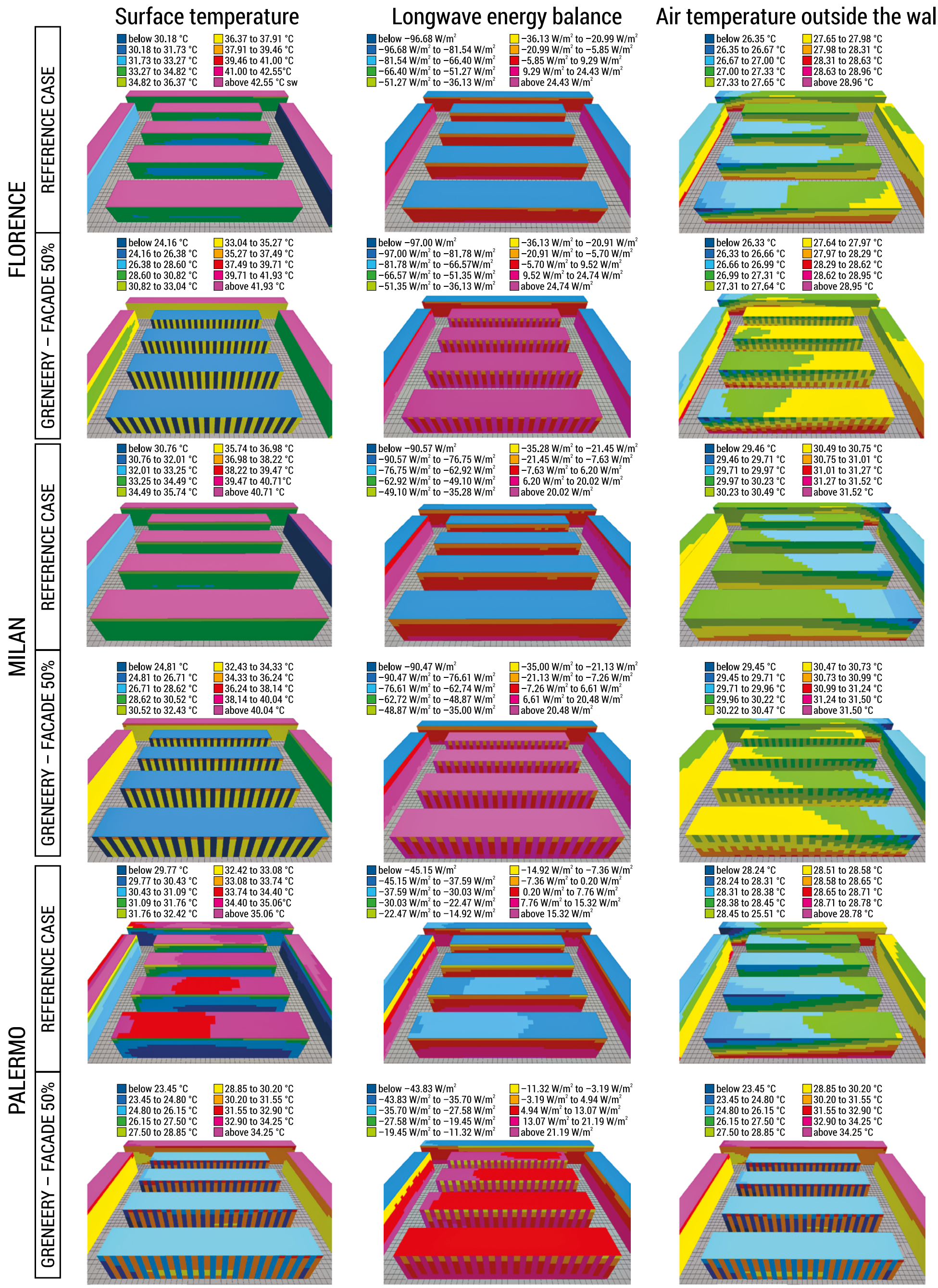

FIG. 5. Distribution of surface temperature [°C], longwave energy balance [W/m2] and air temperature outside the wall [°C] (southern) for both reference and vertical greenery at 50% cases in all cities considering multistorey buildings

SOURCE: own elaboration

For the city of Florence, regarding the southern wall surface temperature, green portions are characterized by a temperature of 22.26°C while for traditional façades it amounts to 34.31°C. At the same time, an observation related to the roof surface temperature is needed. In the central buildings, where the green roof technology is applied, the roof surface temperature varied between 26.53°C and 28.47°C. While for the other buildings, with traditional roof stratigraphy, the temperature significantly increases above 42°C. Both green façades and roofs inevitably affect the users' indoor thermal comfort and the buildings energy performance, especially considering cooling energy needs during the summer season.

As for energy balance, a significant decrease (~40 W/m^2) in the LW_{in} parameter occurs between green and traditional façades. The results show that the difference between LW_{in} (~414 W/m^2) and LW_{out} (~390 W/m^2) for a green façade is equal to about 24 W/m^2. It is worth to notice that if the southern wall total surface is considered (1152 m^2) a reduction in energy balance of about 14 kW occurs for 50% of green surface while for southern walls with 20% or 30% green surface, a slight decrease of around 5.5 kW and 8 kW happens respectively. Furthermore, if the variation of LW_{out} is considered along the wall height, the solution with green façade is less affected by variation of emitted radiation (~1 W/m^2). Finally with respect to the external air temperature outside the wall it is worth to notice that they are lower for a larger area considering vertical greenery at 50%.

As in Florence, as far as Milan is concerned, a significant decrease in wall surface temperature occurs, equal to 10°C. For the roof surface temperature, the same effect as in Florence occurs, and the value of roof surface temperature of both cities are comparable. With the green façade at 50% coverage, the incoming longwave radiation reduces to 22 W/m^2. This avoids 12672 W of incoming radiation when considering the whole southern façade surface. Another interesting result related to Milan deals with the energy balance, because with the introduction of a green façade at 50% there is a noticeable increase in building performance and the energy balance changes from –5 W/m^2 in the reference case, to 30.70 W/m^2 in the improved version. Compared to the reference case, Milan is the worst case compared to Florence and Palermo. Obviously, this result is affected by the choice of materials and the stratigraphy of the wall.

For Palermo, the most significant result is related to the value of the roof surface temperature. Even if the external air temperature is slightly higher than the same value related to Florence, the external roof surface temperature is lower by about 7°C and equal to 35°C. This is probably due to the wind velocity that significantly influences the micro-climate parameters as reported also in the literature. In fact, the wind speed (sea breeze) in Palermo is equal to 5 m/s at 18 m height while in Florence it is 0.83 m/s, and this inevitably affects the value of the surface temperature on the roof. To validate this result, another simulation is performed considering the building located in Lecce (HDD = 1153). In this case the wind speed is lower than in Palermo (3 m/s) and the distance from the sea is higher. In this case, the roof surface temperature is above 43°C, as it should be expected. As for the energy balance, the LW_{in} is 438.63 W/m^2 and the LW_{out} is 434 W/m^2. So, also in this case, the previous results are confirmed: the introduction of the green façade at 50% increases the energy performance of the buildings and positively affects the internal thermal condition and occupants' comfort.

As for multistorey buildings, for tower buildings the substitution of dark asphalt with light asphalt is the most advantageous retrofitted measure for the urban external layout, considering buildings located in Florence. This improvement results in a decrease in average external air temperature of about 1.5°C (cool pavements average external air temperature equal to 27.04°C). In this case it is worth to highlight that the introduction of trees combined with flowerbeds leads to a reduction in external air temperature by about 0.6°C (average temperature equal to 27.77°C), unlike in the case of multistorey buildings. With respect to the vertical greenery on façade at 50% coverage, the solution with the highest value of RH is the one with a height equal to 30 m. A value equal to 67.73% is registered with an increase of 5% compared to the reference case. In an urban grid characterized by both higher buildings and higher density value, the cooling strategies have a greater effect on microclimate parameters.

For tower buildings, due to the computational time required by the calculation of micro-climate parameters related to the building's height, only the simulation considering the grid located in Florence was performed. All the different cooling redevelopment measures were considered.

Finally, in regard to courtyard buildings, the most significant results are illustrated below (Figure 6). They refer to the city of Florence. In this case, the microclimate parameters are measured at 1 m of height because of the ENVI-MET mesh construction. The average external air temperature for the reference configuration is comparable to the other ones. This occurs in all climate zones considered for the analysis. For the city of Florence, the average external air temperature is equal to about 28.12°C in the case of courtyard buildings. The most noticeable result in this case is related to the introduction of both flowerbeds and trees as redevelopment strategies. It results in a reduction of about 1.5°C in average external air temperature, comparable to other layout configurations. A simultaneous increase in RH occurs with the combination of flowerbeds and trees equal to 2%.

Compared to other studied cases in this configuration it is interesting to analyze the microclimate parameters inside the courtyard.

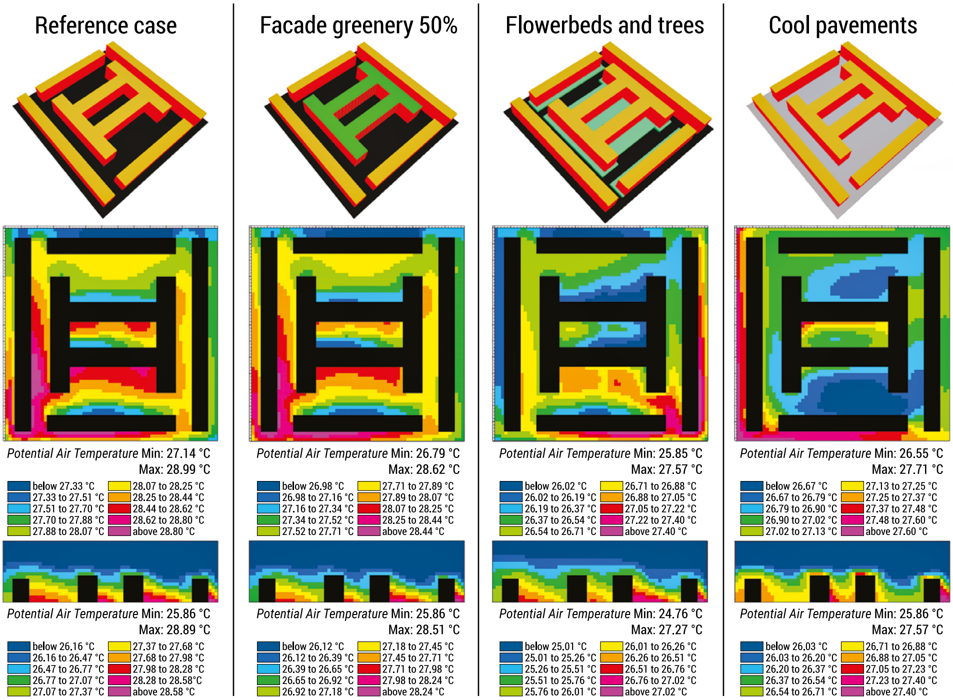

FIG. 6. Variation of external air temperature for courtyard buildings located in Florence in both plant and vertical section visualization

SOURCE: own elaboration

As for the reference case as well, the value of the external air temperature is different when comparing the inside and outside of the courtyard (Figure 9), while also considering building height. The southern houses facing the courtyard, from the first floor of the building, certainly have better energy performance with respect to the same height apartments facing the street. This is because the value of the external air temperature inside the courtyard is lower than on the outside. Moreover, compared to other building types, it is worth to notice that the use of cool pavements in the courtyard is not so advantageous because there is not as much air recirculation due to the lack of wind, being that the courtyard is laterally closed.

The most effective way to reduce external air temperature within the courtyard occurs with the use of flowerbeds combined with trees. In this case the reduction of average external air temperature is equal to about 1.9°C. This is obviously due to the shadow provided by the trees and the lack of wind inside the courtyard.

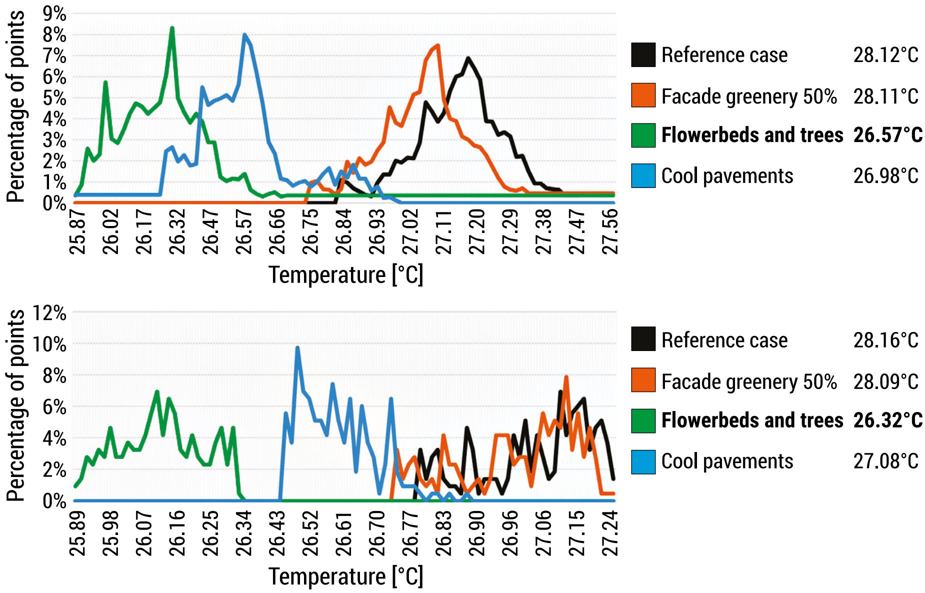

FIG. 7. Comparison of external air temperature for courtyard buildings outside (on the top) and inside (on the bottom) the courtyard with the indication of related average external air temperature (on the right column)

SOURCE: own elaboration

Conclusions

In conclusion, different building types on a typical Italian urban grid were analyzed with respect to some sustainable and cooling improvement strategies for both buildings and urban layouts considering different micro-climate parameters. The most advantageous and effective redevelopment measure proves to be the substitution of dark asphalt with a lighter one. This occurs for all cities and for multistorey and tower building types. This results in a significant decrease in average external air temperature of about 1°C for multistorey buildings and 1.5°C for towers. The only exception is for courtyard buildings where the most effective redevelopment measure is the introduction of flowerbeds and trees for both inside and outside the courtyard. This is inevitably affected by the higher number of trees that can be included in the urban grid due to the buildings' layout. In regards to Palermo it is worth to notice that the cool redevelopment measure has less impact on external micro-climate parameters (for instance on external air temperature).

If a low-density configuration is considered, for instance in a multistorey buildings urban grid, the results show that the increase in distance between buildings and the resulting reduction in covered area significantly influences the value of relative humidity rather than the average external temperature.

Furthermore, the application of greenery on southern façades mostly affects the surface temperature and the energy balance of buildings rather than external air temperature. For multistorey buildings located in Florence the vertical greenery at 50% coverage leads to a reduction in LW_{in} equal to about 14 kW, due to the difference of external surface temperature equal to 34.31°C and 22.26°C for green and traditional façade respectively. This certainly influences the cooling demand of the building. Considering the other 2 cities, for the reference case condition Milan is the worst case compared to others. In fact, the energy balance for the reference case is equal to –5 W/m^2. This result is obviously related also to the materials chosen for the external envelope stratigraphy.

In conclusion, for future developments, a real Italian district should be considered, also taking into account different kinds of cooling redevelopment measures and several building types. The parameters related to pedestrian comfort (such as the PMV – Predicted Mean Vote) should be considered when comparing different cooling strategies.

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