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Effect of facade reflectance on outdoor microclimate: an Italian case study

Abstract:
Global warming affects the built environment with relation to its own characteristics, form, density. Heat waves effects would have limited effects if most of the cities would not be affected by Urban Heat Island that strongly increase their impacts (particularly on urban population). Does the choice of façade colours and materials contribute to this issue?
The paper reports a research on a case study in Italy that tries to answer to this question comparing the trend in outdoor temperature increase closed to the building façade with relation to its colour and reflectance variations modelled by using Envi-met software. The outcomes point out that there is a correlation between the building façade reflectance and the temperature trend but this has a very limited influence on outdoor microclimate in open spaces as it varies in a range of less than 1°C.

Keywords
Outdoor thermal comfort; reflectance; facade colour; Envi-met; building facade

1 Introduction and literature

Global warming is nowadays a consolidated issue in the scientific literature and research: a number of initiatives and policies have been launched, both at international and local level, to reduce the current level of CO_2 emissions involving very different sectors from industry to agriculture, from circular economy to material recycling and of course to a massive adoption of renewable energy sources, as outlined in the last IPCC Report (IPCC, 2018) and policy decision as Clean Energy Act (European Commission, 2017). In this general framework, the built environment and contemporary cities play a central role considering at least two main relevant perspectives.
On the one hand, most of the population is living and will live in the future in the cities, spending a relevant part of their time inside buildings or in the space in-between them (the so called public open space). Therefore ensuring adequate level of indoor and outdoor comfort is becoming a more and more relevant priority strictly related to the potential effects of climate change and global warming as many studies have already evidenced (Kristian Fabbri, Di Nunzio, Gaspari, Antonini, & Boeri, 2017) (Jacopo Gaspari, Fabbri, & Lucchi, 2018) (J. Gaspari & Fabbri, 2017) (K. Fabbri, Di Nunzio, Gaspari, Antonini, & Boeri, 2017) and as specific research papers on outdoor microclimate report in the dedicated scientific literature (Almhafdy, Ibrahim, Ahmad, & Yahya, 2013),(Santamouris & Kolokotsa, 2015) (Sözen & Koçlar Oral, 2019), (Fong, Aghamohammadi, Ramakreshnan, Sulaiman, & Mohammadi, 2019), (Battista, Carnielo, & De Lieto Vollaro, 2016), (Sharmin, Steemers, & Matzarakis, 2017).
On the other one, the peculiar characteristics of building materials, paving solutions and vegetation can strongly influence the microclimate of the urban fabric and may contribute to phenomena such as Urban Heat Island (UHI). Kruger et al. explain the impact of sky-vie-factor (SVF) and urban geometry on urban climate simulation (Krüger, Minella, & Rasia, 2011), Tseliou & Tsiros (2016) contributed with a research on urban microclimate and thermal sensation in outdoor area in Athens with some improvements scenarios , Santamouris and Kolokotsa analysed the correlation between overheating and fuel poverty (Santamouris & Kolokotsa, 2015). Heat Waves (HW) are well described in the literature review by Ward et al (Ward, Lauf, Kleinschmit, & Endlicher, 2016) and Moriti et al (Morini, Castellani, De Ciantis, Anderini, & Rossi, 2018). UHI/HW mitigation measure in central European cities (Vuckovic, Maleki, Kiesel, & Mahdavi, 2015) have been investigated with relation to façade reflectance especially by Mauri et al. (Mauri, Battista, de Lieto Vollaro, & de Lieto Vollaro, 2018) as well as by Alchapar and Correa who report a useful classification of building materials to mitigate UHI effect (Alchapar & Correa, 2016).
Thus a targeted field of research has been developed dealing with the role of building materials (Castaldo et al., 2017), (Kyriakodis & Santamouris, 2018), (Santamouris & Kolokotsa, 2015),(Lai, Liu, Gan, Liu, & Chen, 2019), of green spaces, of urban forms (Sharmin et al., 2017) and more generally dealing with the role of the built environment on the outdoor comfort (Yang, Zhao, Bruse, & Meng, 2013) (Sun et al., 2017).

In a built environment, solar radiation mainly impacts on horizontal surfaces and on those belonging to the building envelopes, whose characteristics influence the reflectance.
Since architects and urban planners usually perceive the material's functional and aesthetic features as more relevant, they primarily focus the design choices accordingly, paying less attention to thermo-physical performances despite their crucial role in influencing the outdoor comfort.
Several research found in the literature confirm this relevance, although focusing more on the effects on horizontal surfaces, like roofs (Schabbach, Marinoski, Güths, Bernardin, & Fredel, 2018) (Li, Zhao, Zeng, Peng, & Wu, 2017), green roofs (Berardi, 2016), (Doulos, Santamouris, & Livada, 2004), (Salata, Golasi, Vollaro, & Vollaro, 2015) and urban canyons (Castaldo et al., 2017). Less attention is given on building envelopes (Alchapar, Correa, & Cantón, 2014) which are more investigated with relation to construction systems and material features for cladding purposes (Mauri et al., 2018) (Azarnejad & Mahdavi, 2015), (Alonso et al., 2017).
This topic is investigated by several authors (Coakley, 2002) (Du & Sharples, 2010) (Takebayashi et al., 2016) (Azarnejad & Mahdavi, 2015), providing direct references about the relationships between colour, reflectance and outdoor microclimate, on which this paper focuses.
The definition of reflectance is provided by some studies on the outdoor thermal comfort as "The ratio of the radiant flux reflected by a surface or a medium to the incident flux. Measured values of reflectance depend upon the angles of incidence and view and the spectral character of the incident flux: these factors should be specified." (Steinmant, 1987).
Within this framework, the potential influence of material's texture and colour on the surrounding microclimate appears a relevant correlation to be further evaluated, particularly with reference to the outdoor air temperature.

2 Aim

This research aims at assessing the effect of the building outer finishing reflectance on the outdoor surrounding microclimate. In particular, air temperature variations have been estimated for different reflectance values, corresponding to different façade cladding materials. The simulations have been performed for a case study located in the Northern Italy in the city of Parma.

3 Case of study

The territory of Parma municipality is entirely flat, with an average height of 57m above sea level and bordered by the Taro streams on the west side and Enza on the east one.
According to the Italian regulations (DPR 26/08/1993 n.412), the city is classified within the climatic zone E, with 2.502 Winter Degrees Day. The climate is typically continental, with hot and muggy summers and harsh winters. Kopper Classification of Parma (Italy) is Marine West Coast Climate, the subtype for this climate is "Cfb (Köppen & Geiger, 1936) (M. Kottek, J. Grieser, C. Beck, B. Rudolf, 2006).
The annual rainfall is around 780 mm, with peaks in autumn, while an average 35-40 cm of snow fall every winter. The predominant summer winds come from the North-East and have an average speed of 2 m/s (by ARPAER (ARPAER www.arpae.it, n.d.)). The fog is frequent, especially during autumn, more intense in the north of the Via Emilia and towards the Po river.

Figure 1. Location of Parma in the Italian territory.

Figure 2. Case-study building. Right: view of PEEP Sidoli area. Left: case study building south facade

The case-study is a multy-storey-building (Figure 1) dating back to 1983 included in the South-East expansion of the city and belonging to the "PEEP Sidoli" housing project (Figure 2). It covers a surface of 660 m^2 and is 31 meters tall, reaching a total volume of over 20.450 m^3.

Developed towards the east-west axis, the plan has a very regular shape with three stair bodies partially emerging from the north façade. This side faces a public square, while the south one faces a public park. East and West façades look on circulation spaces and parking lots. Social housing apartments are hosted in nine of the ten floors above ground, while the ground floor and the basement host garages, common areas and technical rooms. Prefabricated reinforced concrete pillars and beams provide the structural frame. The main envelope layer is made with brick block walls.

North and south main façades, including balcony and loggias parapets, are brick cladded till the fifth floor, while reinforced concrete prefab panels cover the upper floors. East and west facades are instead brick cladded for the ground floor only, while the concrete panels cover entirely the other nine floors.

4 Research methodology

The research carried out on the case study is divided into four steps:

1. collection of climate data and modelling of the physical-environmental conditions in the area surrounding the investigated building;
2. definition of a set of façade configurations ("scenarios") with different reflectance values of the external finishing;
3. modelling of the conditions that occur in each scenario;
4. comparison and interpretation of the outputs.

4.1 Envi-met outdoor microclimate modelling

The outdoor microclimate was modelled with Envi-met V.4.4 (*Envi-met www.envi-met.com*, n.d.) a modelling software, largely used in the scientific field (Battista et al., 2016) (Sharmin et al., 2017) (Mehaoued & Lartigue, 2019) (Noro & Lazzarin, 2015), which allows to create a three-dimensional model to simulate the interactions between the building and the surrounding external environment and therefore to evaluate the effects of architectural choices in the specific context.

The study considered an area of 180m x 120m (figure 3), including the investigated building and its immediate surroundings, with existing buildings and horizontal surfaces (both green and paved).

The model has been defined dividing the area into square cells of x=1.5 m, y= 1.5m, z=1.5, grid 120 x 80 x 30 in a regular grid, without nesting area. The three-dimensional model of the building was subsequently generated, thus determining the orientations and dimensions of all its contact surfaces with the outside air.

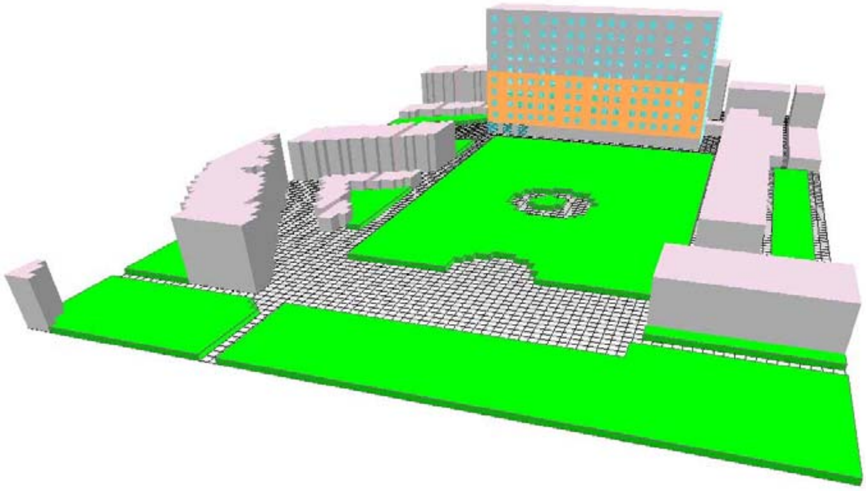


Figure 3. Envi-met 3D model

Since ENVI-met returns the individual variable calculated values for specific points, some "receptors" have been positioned within the building adjacent park, in order to obtain suitable information on the environment conditions. The initial positioning of the receptor set – as figure 4 shows – included four receptors AA, BB, CC, DD at different distances from the building in the green area. After setting the measurement protocol and testing the receptors, the gained data revealed that results from receptors BB, CC, DD didn't show significant variations and it was definitely decided to consider only the numerical outputs provided by the AA receptor (at a distance of 10.2 m from the façade) for the purposes of this study.

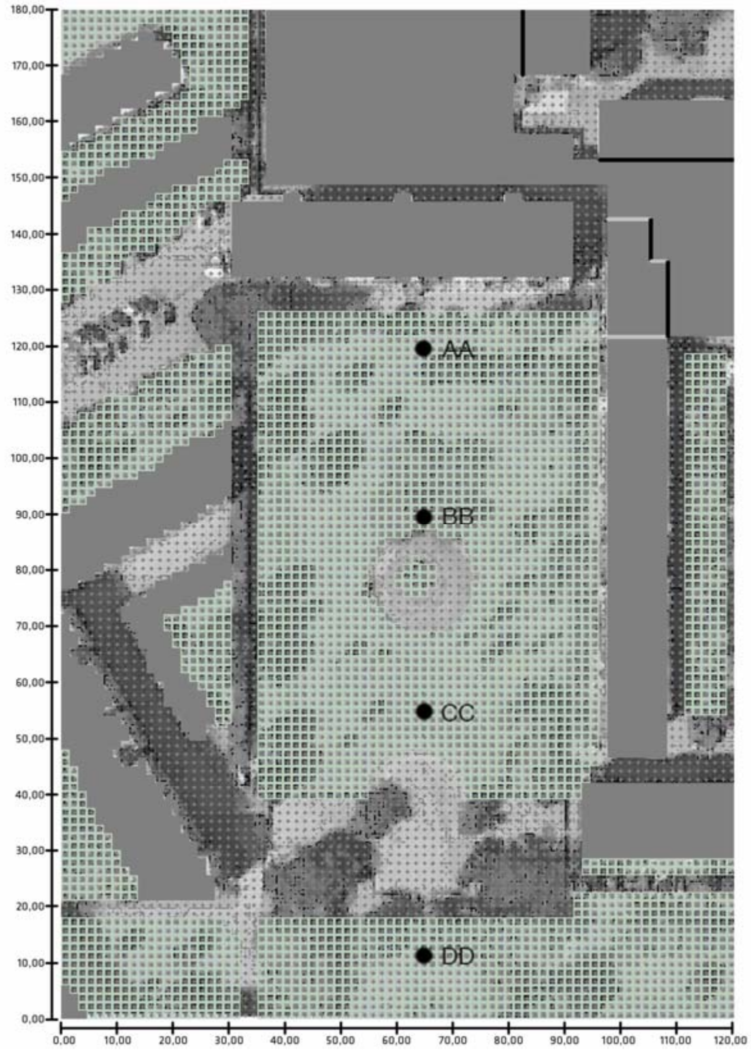


Figure 4. Positioning of the receptors.

Weather Data

The climatic data, such as temperature and relative humidity, were obtained from the ARPAE-ER 'Servizio IdroMeteoCLima-Simc', through the Dext3er application and refer to the station located in the city of Parma ("Parma urbano") (ARPAER www.arpae.it, n.d.). 6th August 2017 was chosen for simulations as it is the overheating peak day registered during the last heat wave in Parma.

The initial boundary conditions are:

- start date: 06.08.2017
- start time: 8:00
- total simulation time: 14 (h)
- wind speed measure in 10 m height (m/s): 2 m/s
- wind direction (deg): 90

Table 2 reports the outdoor air values. The first two columns report air temperature and relative humidity as initial meteorological condition (simple forcing).

4.2 Scenarios definition assuming different material options and related reflectance for cladding the façade.

The scope is to investigate how different reflectance values may impact on the outdoor temperature in the spaces narrowing the building. Two materials were chosen for this investigation: stoneware panels and High-Pressure Laminate [HPL] panels (Trespa) (*Trespa www.trespa.com*, n.d.) in several colours. The first is frequently used in façade cladding and the second one is a cheaper and quite recent material that is often used in retrofitting and renovation actions. It is a robust, homogeneous panel of raw wooden elements (till

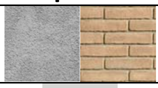
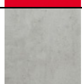
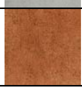
70% natural fibres are used) aggregated using thermosetting resins and coated with a High-Pressure Laminate (HPL) on both sides.
Both the panels reflectance (Touchaei, Akbari, & Tessum, 2016) (Coakley, 2002) was obtained by using App Albedo (Reflectance APP (http://misclab.umeoce.maine.edu/research/HydroColor.php), n.d.) (Nechad, Ruddick, & Park, 2010).
The app allows to get the albedo or reflectance value from most of material surfaces and to transfer it to Envi-met software improving the reliability of calculation outputs. The reflectance capture process requires to compare the material under investigation with a grey card to be used as baseline reference. A number of different materials have been explored and definitely the following options were assumed:

- Scenario 0: starting condition of the building façade
- Scenario 1: the building façade (starting condition) is covered using HPL panels light grey colour;
- Scenario 2: the building façade (starting condition) is covered using HPL panels intense red colour;
- Scenario 3: the building façade (starting condition) is covered panels light grey colour;
- Scenario 4: the building façade (starting condition) is covered using stoneware panels red colour.

4.3 Scenarios modelling

Each scenario was modelled changing only the outer finishing of the façade. The existing wall section includes a brick block layer (12 cm), a thermal-acoustic insulation layer (6 cm) and an inner lightweight brick block layer (8cm). These materials were modelled assuming an emissivity of 0.89 (having an opaque finishing), equal reflectance and albedo as set by the app “Reflectance App”
(Reflectance APP (http://misclab.umeoce.maine.edu/research/HydroColor.php), n.d.).
Table 1 provides the reflectance for the wall section of each scenario.

Table 1 Building Facade Reflectance values for each scenario

Scenario	Sample	Facade finishing		Reflectance	
0		Exposed brick finishing	Exposed concrete panels	0.29	0.43
1		HPL panels light grey colour		0.60	
2		HPL panels intense red colour		0.11	
3		stoneware panels light grey colour		0.57	
4		stoneware panels red colour		0.13	

4.4 Model calibration

Within the scope of the study, a calibrated model such as Oblivious would strengthen the results but it must be stressed that scientific literature does not provide a validated procedure to calibrate Envi-met results, as instead happens with software dealing with Building Energy Performance simulation following ASHRAE Guideline 14 (ANSI/ASHRAE, 2002). The calibration of Envi-met model can refer to:
a) weather simulation data from on-site point, as described in Fabbri et al. (K. Fabbri, Canuti, & Ugolini, 2017) Fabbri & Costanzo (K Fabbri & Costanzo, 2019) and Tsitoura et al, (Tsitoura, Michailidou, & Tsoutsos, 2016), where air temperature in a point is not influenced by local radiation (this ensure more reliable results than using data source in a distance larger than 10 km https://content.meteoblue.com/en/specifications/data-sources/weather-simulation-data);
b) on site measurement by probes as described in some research (Eckmann et al., 2018) (Forouzandeh, 2018) (Nasrollahi, Hatami, Khastar, & Taleghani, 2017) (Piselli, Pigliautile, Castaldo, Cotana, & Pisello, 2017) (Salata, Golasi, de Lieto Vollaro, & de Lieto Vollaro, 2016) (Sharmin et al., 2017) (Tseliou & Tsiros, 2016).
The first option is adopted in the present study and the calibration has been performed using weather data simulation by Meteoblue (*Meteoblue (www.meteoblue.com)*, n.d.) for comparing scenario 0 (starting conditions). Table 2 reports all air temperature data. Envi-met results for scenario 0 concern hours in a

range 10:00, 13:00 and 16:00 at 1.35 m. As Table 2 shows data gained by the weather-service Meteoblue (column D) are compared with those gained from receptor AA (column E) revealing that, in the most representative time interval during the day, the gap between the two is less than ± 5%. Figure 5 provides a graph considering air temperature trends by weather data, Meteoblue, Envi-met and linear regression R^2 equal to 0.909. Accordingly, the model can be assumed as calibrated.

Table 2. Air temperature (°C) outdoor average at 2 above sea level from ARPAER, Meteoblue and Envi-met

A	B	C	D	E
hours	*ARPAER Dexter (ARPAER www.arpae.it, n.d.)*	*ARPAER Dexter (relative humidity, %)*	*Weather simulation data (meteoblue)*	*Envi-met results Scenario 0 receptor AA as starting conditions*
08:00	31.70	46	17.60	
09:00	31.70	42	20.13	
10:00	31.50	42	22.10	22.86 [-3.44%]
11:00	33.20	44	24.36	
12:00	32.00	37	25.77	
13:00	32.00	43	26.94	26.27 [+2.49%]
14:00	30.30	44	27.29	
15:00	30.40	46	27.94	
16:00	30.80	45	28.16	29.39 [-4.37%]
17:00	29.80	44	28.14	
18:00	29.00	45	27.87	

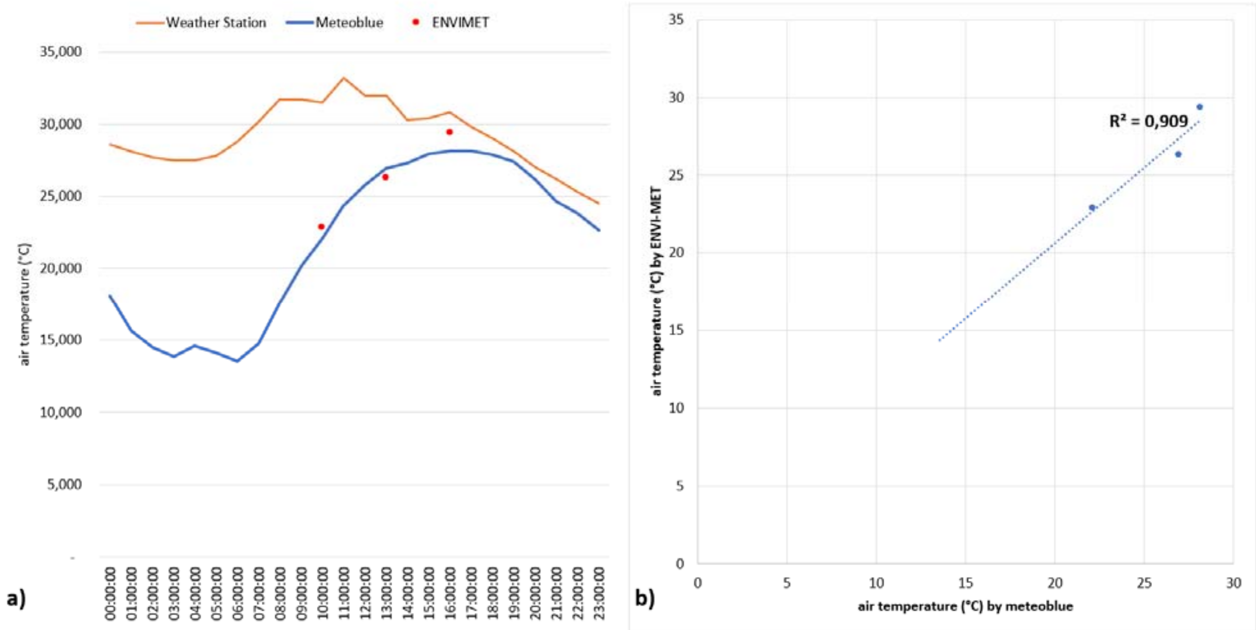


Figure 5. Outdoor air temperature measurement scale adopted in OMM.

5 *Results*

Simulation outcomes (Atmosphere files from Envi-met) were extracted and elaborated using Envi-met Leonardo. Outdoor air distribution map was set as closest as possible to ground level (1 m). Simulation outcomes deal with: a) Outdoor Microclimate Map (OMM) representing the air temperature isolines distribution from Leonardo; b) specific temperature values with relation to receptor AA.

a) *Outdoor Microclimate Map*

Simulations provided Outdoor Microclimate Maps concerning air temperature variations of the five investigated scenarios. The considered time range is between 8:00 and 20:00 and results are reported at 10:00, 13:00, 16:00. For each scenario the following outcomes are included in this study:

1) Outdoor air temperature Maps at 10:00, 13:00, 16:00 for all the analysed scenarios (figures 7 to 11);
2) Outdoor air temperature Maps at 10:00, 13:00, 16:00 comparing the starting condition with the scenarios in which reflectance value is minimum and maximum.

There were not observed relevant differences occurring in terms of relative humidity, mean radiant temperature, wind speed, surface temperature in the investigated scenarios. All the reported maps adopt the same scale as figure 6 shows.

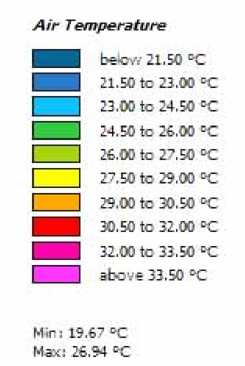


Figure 6. Outdoor air temperature measurement scale adopted in OMM.

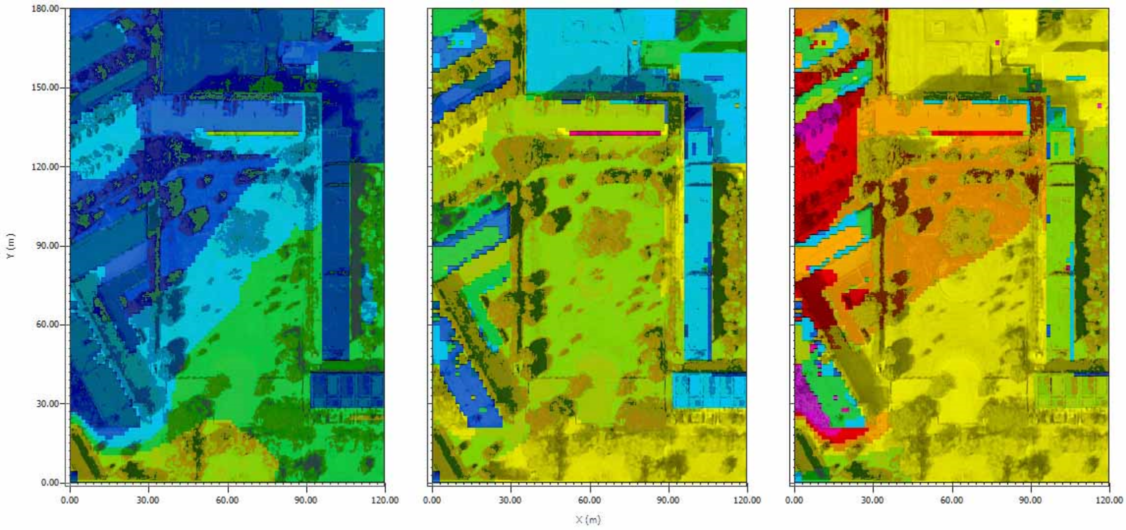


Figure 7. OMM outdoor air temperature. Scenario 0: building façade - starting condition. (right: results at 10:00, center results at 13:00, left: results at 16:00)

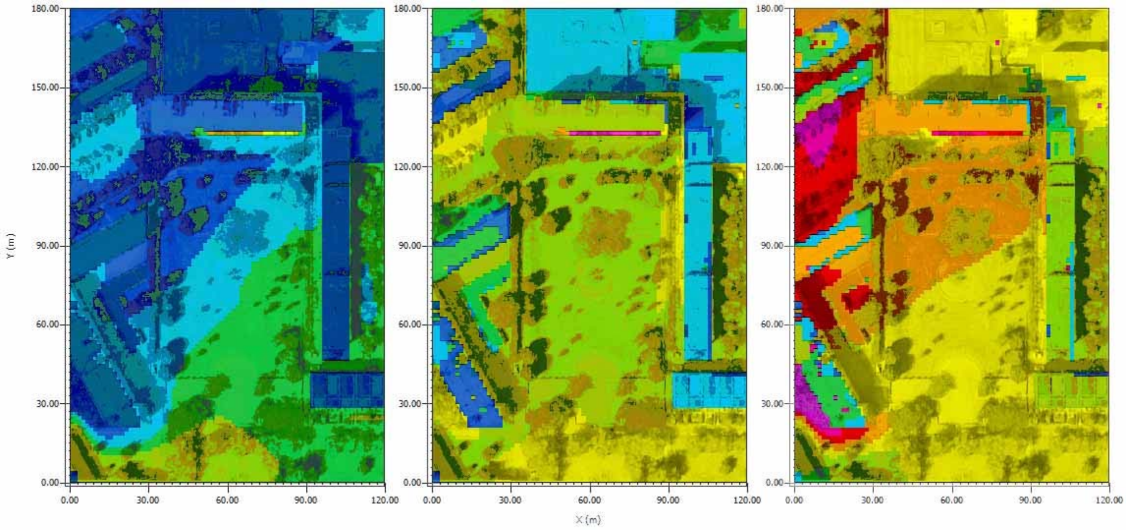


Figure 8. OMM outdoor air temperature. Scenario 1: building façade - HPL panels light grey colour. (right: results at 10:00, center results at 13:00, left: results at 16:00)

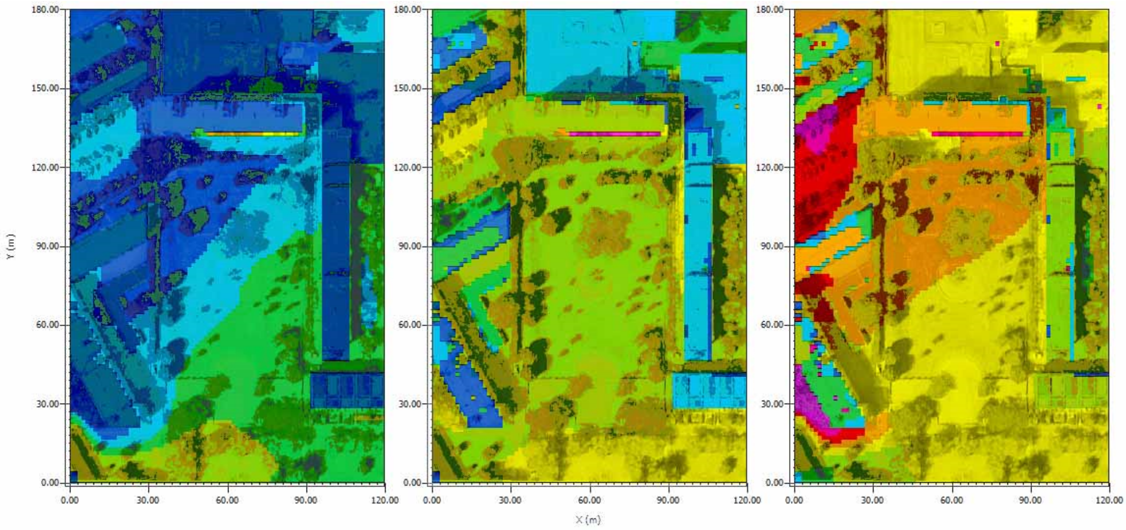


Figure 9. OMM outdoor air temperature. Scenario: 2 building façade - HPL panels intense red colour. (right: results at 10:00, center results at 13:00, left: results at 16:00)

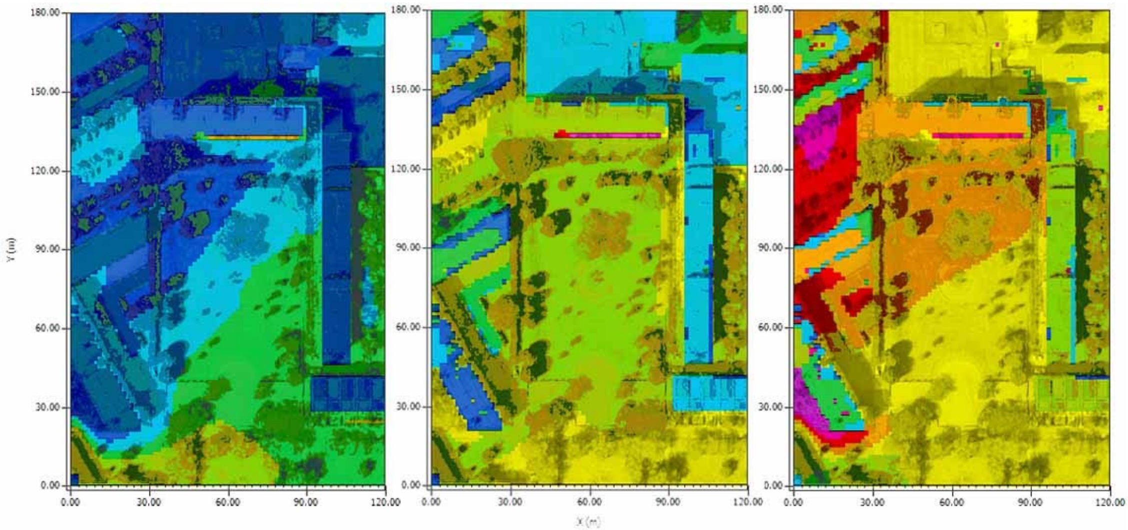


Figure 10. OMM outdoor air temperature. Scenario 3: building façade - stoneware panels light grey colour. (right: results at 10:00, center results at 13:00, left: results at 16:00)

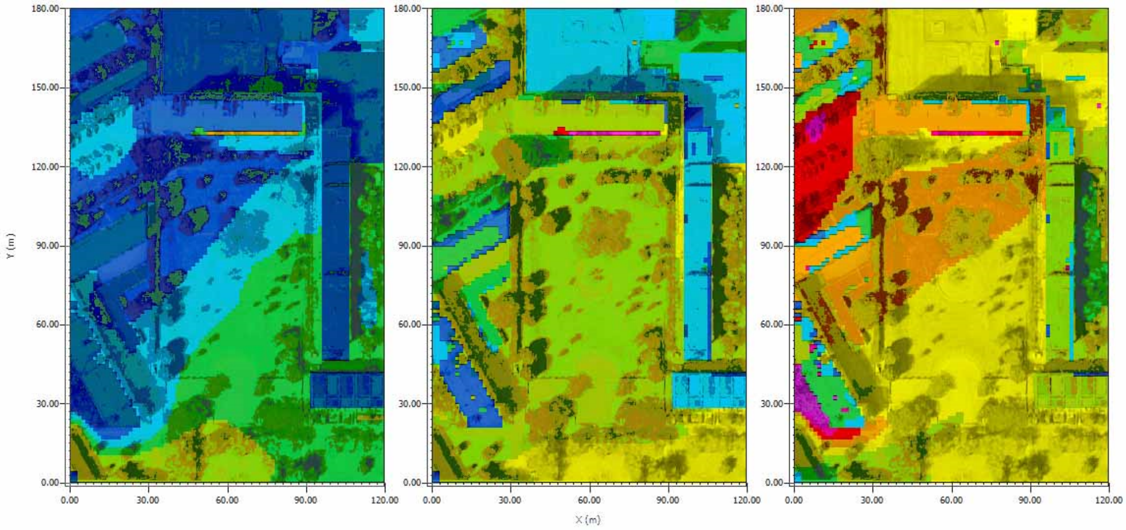


Figure 11. OMM outdoor air temperature. Scenario 4: building façade - stoneware panels red colour. (right: results at 10:00, center results at 13:00, left: results at 16:00)

Reading each figure (7 to 11) from left (h 10.00) to right (h 16.00) side it can be noted that, in all the simulations for the outdoor space of the investigated building, an increase of temperature can be registered following its own shade and the ones of the neighbouring buildings. However, no relevant variations can be detected. Reading the figures from top to bottom, that means scenarios are compared in the three specific time hours, it can be noted that OMM are really very similar and there are significant impacts in terms of temperature variations with relation to material and colour options for the façade cladding.
In order to discuss this observation, comparative OMM between the starting condition (scenario 0) and the other scenarios (1,2,3,4) have been produced with reference to outdoor air temperature (°C). All the reported OMMs adopt the same measurement scale [K] (figure 12).

Figure 12. outdoor air temperature measurement scale.

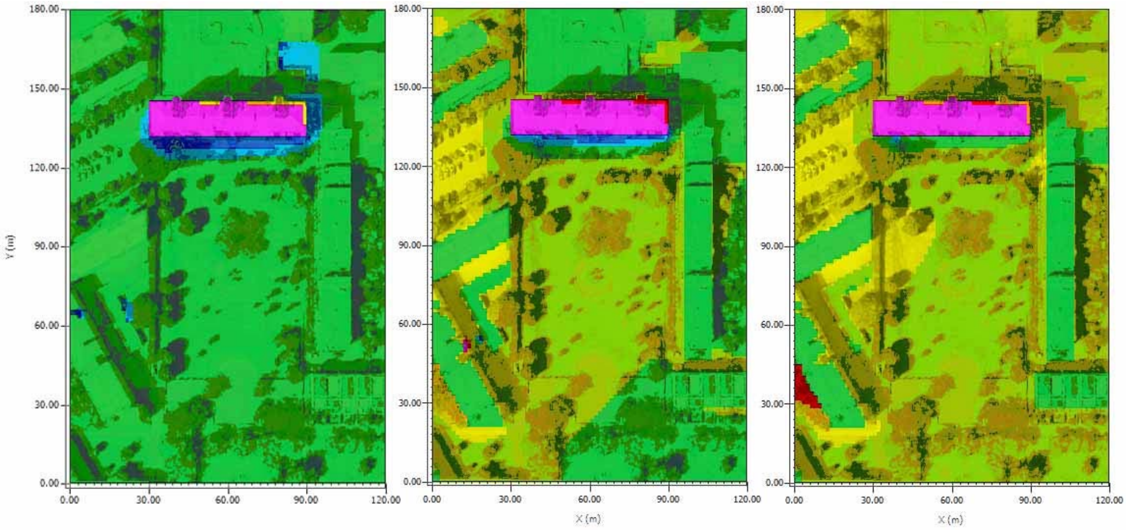


Figure 13. OMM comparing outdoor air temperature between Scenario 01 and Scenario 1. (right: results at 10:00, center results at 13:00, left: results at 16:00)

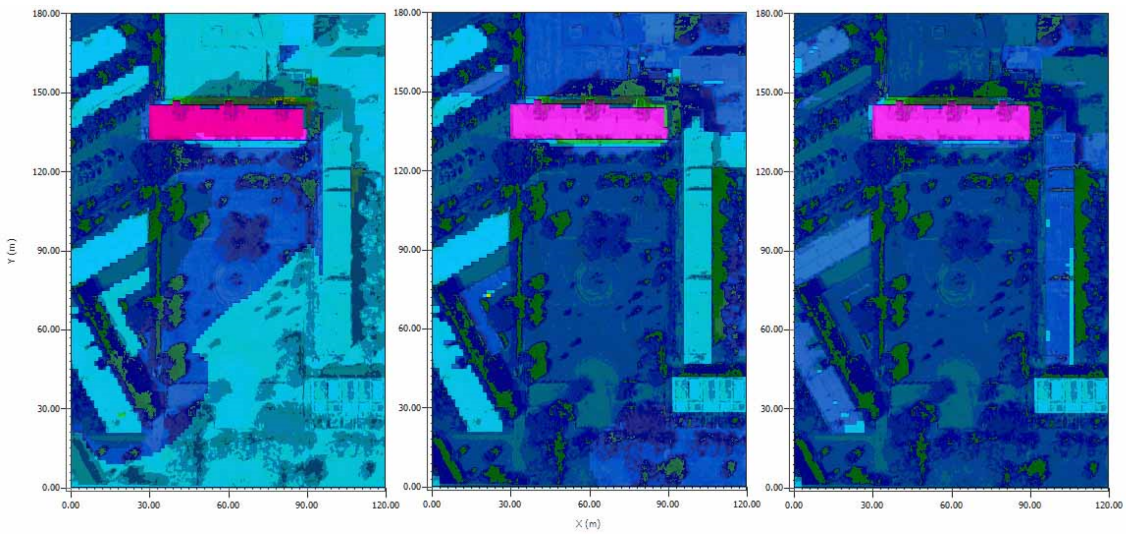


Figure 14. OMM comparing outdoor air temperature between Scenario 0 and Scenario 2. (right: results at 10:00, center results at 13:00, left: results at 16:00)

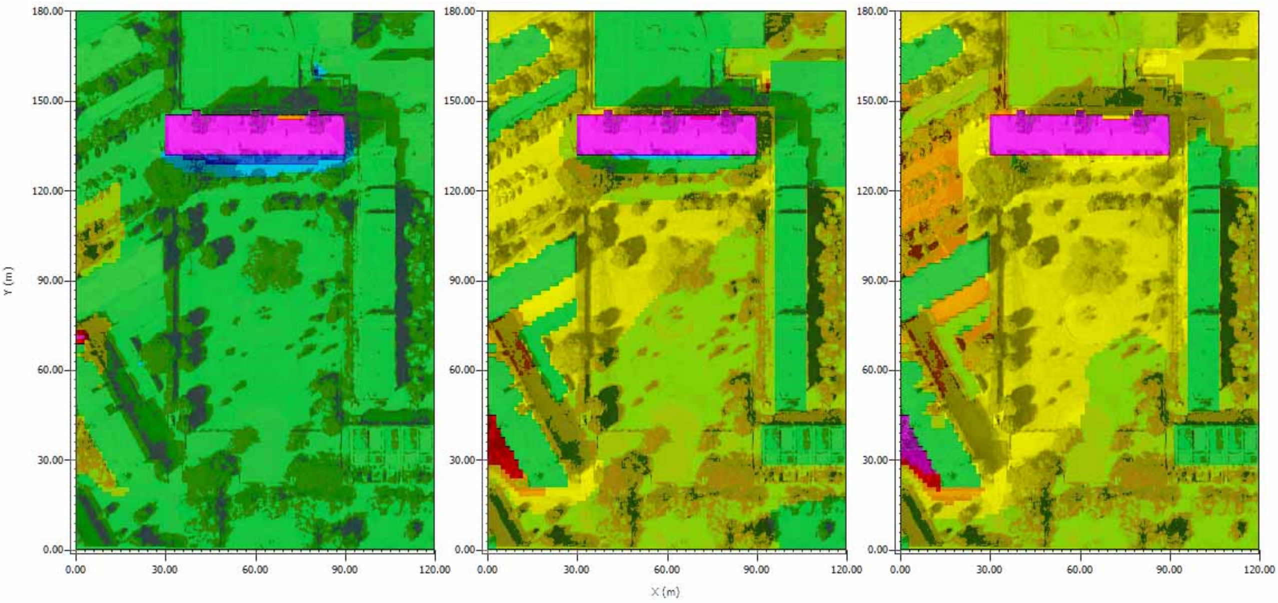


Figure 15. OMM comparing outdoor air temperature between Scenario 0 and Scenario 3. (right: results at 10:00, center results at 13:00, left: results at 16:00)

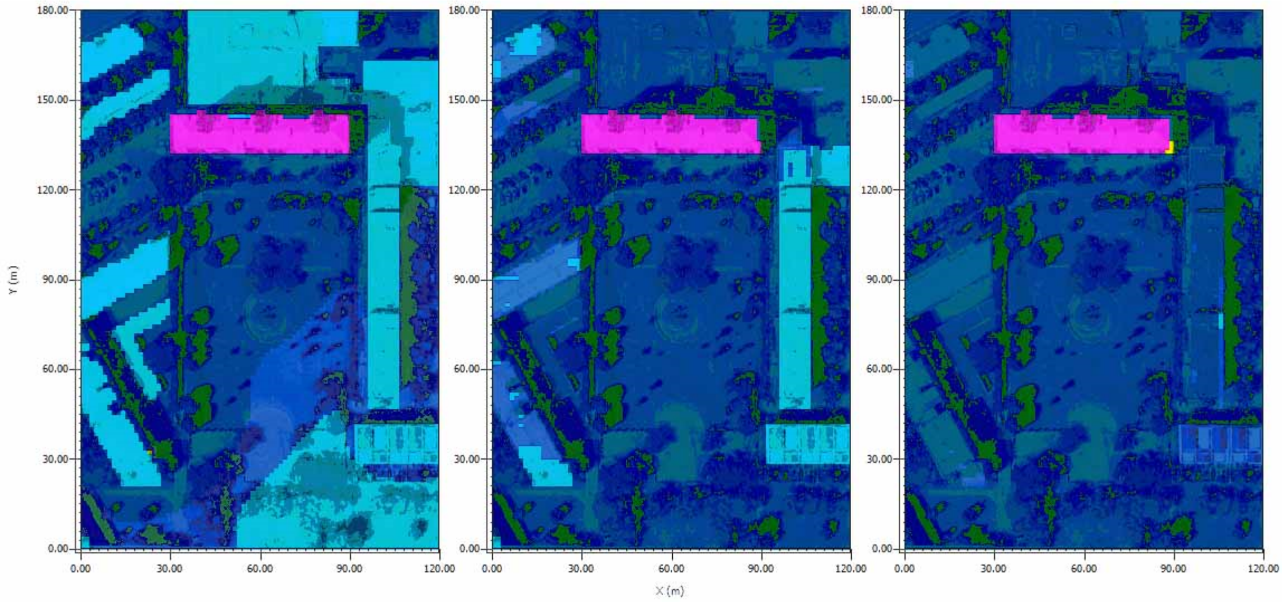


Figure 16. OMM comparing outdoor air temperature between Scenario 0 and Scenario 4. (right: results at 10:00, center results at 13:00, left: results at 16:00)

Looking at each figure (13 to 16) from left (h 10.00) to right (h 16.00) side it can be noted that very similar effects derive from the use of different materials having very similar colours for the façade cladding. Particularly the red ones produce a slight decrease of air temperature. This results more evident during the afternoon. Using a light grey colour there is instead a slight increase of temperature during the afternoon.

b) *temperature values in the receptor AA in the green area facing the investigated building*
OMMs do not allow to detect significant variations of outdoor air temperature. Therefore, data referred to air temperature of each scenarios were extracted in receptor AA (figure 4) that is 10.2 far from the building envelope. Comparing reflectance and air temperature value referred to receptors placed in the green area facing the building, a small variation within a range of 0.19 °C can be detected.
Table 3 reports reflectance values referred to each scenario, the related outdoor temperature of receptor AA, the temperature difference with relation to scenario 0 at 10.00 and 16.00.
With the increase of reflectance, a very small outdoor temperature variation can be registered.

Table 3. Temperature variations elaboration.

Material	**Exposed brick and concrete**	**HPL panels light grey colour**	Gap respect sc.0	**HPL panels intense red colour**	Gap respect sc.0	**stoneware panels light grey colour**	Gap respect sc.0	**stoneware panels red colour**	Gap respect sc.0
Reflectance	**0.36**	**0.60**		**0.11**		**0.57**		**0.13**	
h. 10:00 (°C)	**22.19**	**22.19**	0	**22.16**	-0.03	**22.19**	0	**22.13**	-0.06
h. 13:00 (*C)	**24.80**	**24.82**	+0.02	**24.75**	-0.05	**24.83**	+0.03	**24.66**	-0,14
h. 16:00 (°C)	**27.10**	**27.13**	+0.03	**27.04**	-0.06	**27.14**	+0.04	**26.91**	-0.19

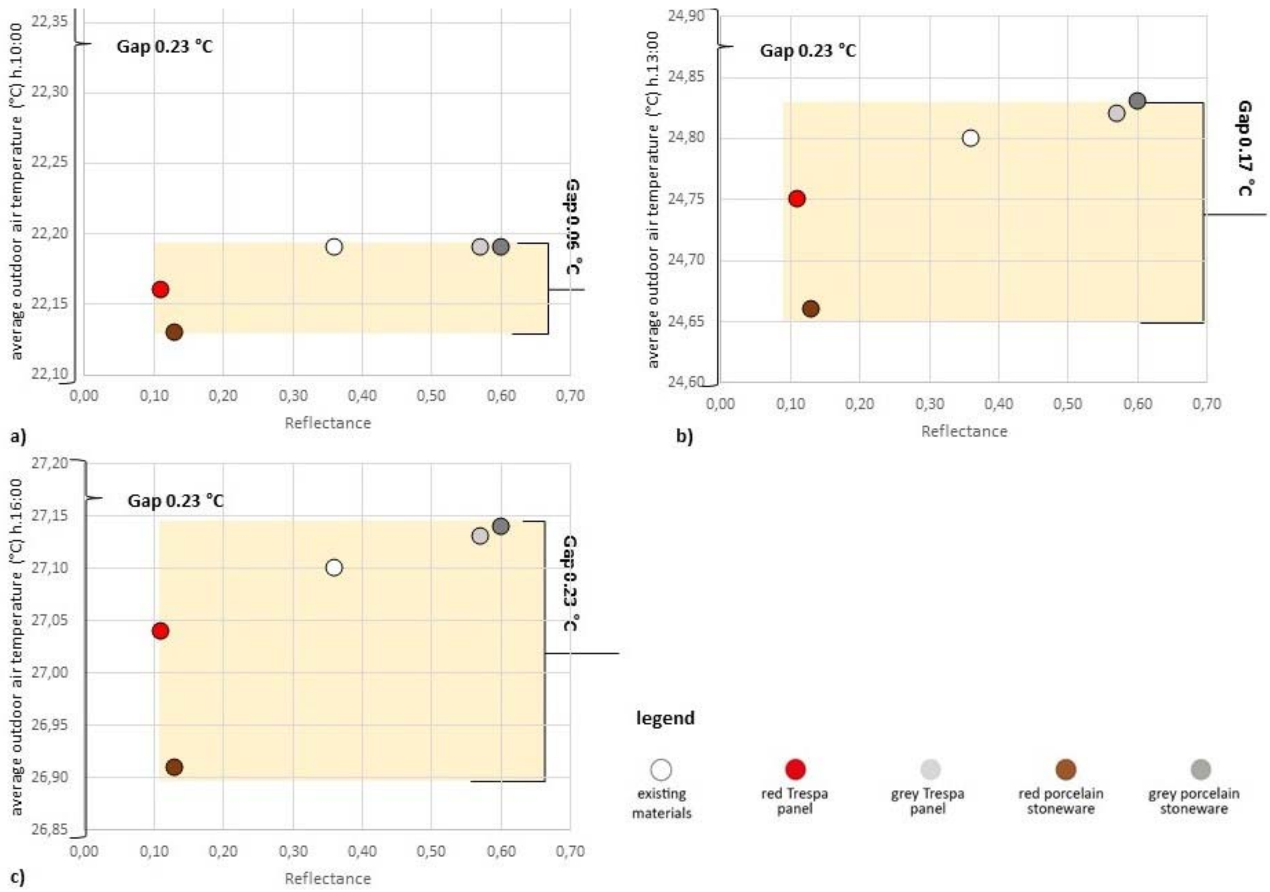


Figure 17. Comparison between reflectance and average outdoor air temperature with reference to receptor AA. Graphs show on the y axe the ΔT gap of 0.23°C while on the right side ΔT gaps for each time hour are reported: ΔT at 10.00 is 0.06°C; ΔT at 13.00 is 0.17°C; ΔT at 16.00 is 0.23°C. Despite the very limited variations it can be noted that with the increase of radiation and air temperature the gap between colours having a reflectance less than 0.3 or more than 0.6 increases.

Figure 17, obtained by table 3, displays the correlation between reflectance and air temperature with relation to each time.

Graph a) reports the temperature variation with relation to receptor AA of each scenario compared to the state of art scenario (scenario 0). It can be noted that the variation between scenarios 1 (HPL panels light grey colour) and 2 (stoneware panels light grey colour) is limited to 0.06 °C compared to scenarios 3 (HPL panels intense red colour) and 4 (stoneware panels red colour). Thus it can be argued that reflectance has no influence. Graph b) reports a similar observation at 13.00 with a registered gap of 0.17 °C while in Graph c) at 16.00 is 0.23. Comparing the graphs, the gap depends on the simulation hour. The variation is still very limited and included in a range ± 0.3°C that produces no significant impact on outdoor comfort and microclimate. A further interesting observation is that there is no linear correlation between reflectance and air temperature.

6 Discussion

The outcomes of OMM, tables and graphs show a relation between the façade reflectance and outdoor temperature, but this is so limited (±0.02°C and ±0.19°C) that it is not able to influence the outdoor microclimate. Accordingly, it can be said that the façade choices do not affect the outdoor space.

Despite this, the correlation between reflectance and outdoor air temperature is less or more evident with relation to the investigated time range of the day.

7 Conclusions

The research investigated the relation between the colour of some building façade options and the potential effect on the outdoor microclimate using Envi-met simulations. The adopted methodology allows to evaluate the variations for each scenario. Results are discussed using OMM and data extracted from the receptor to analyse the reflectance influence. The methodology can be easily replicated elsewhere both in case of real case studies and simulations.

The scientific literature provides some studies about the impacts of material and colour choices for cladding building façades on outdoor microclimate with relation to urban canyon, while this study is aimed at investigating the potential effects on open spaces. The proposed study considers one input variable (façade reflectance) and one output variable (air temperature) without exploring the effects that may derive from modifying paved or green surfaces or coming from other potential elements of interaction (i.e. wind). This is due to the major impacts that these could produce on air temperature, consequently reducing the chance to observe the investigated phenomenon.

The results confirm that the façade reflectance is not able to significantly influence open spaces microclimate, despite the correlation between the two variables was demonstrated.

Thus, it can be concluded that in case of open outdoor spaces, the role of paved or green horizontal surfaces has a much more relevant influence on comfort compared to the very minor contribution offered by the properties of façade materials of the facing buildings. This evidences a great difference with relation to other urban forms such as courtyards or street canyon.

In outdoor spaces solar radiation plays a main role in influencing the microclimate and so happens with simulation software where solar radiation reflection depends on reflectance surface and Sky View Factor (SVF) by buildings and trees. When SVF is near to 1 – like in the case study – reflectance does not influence the microclimate of the open space. On the contrary, being SVF value less than 1 and sometimes of 0.5, reflectance can contribute to solar trapping as happens with urban canyons and especially dense urban fabric.

Further studies in this sector may investigate other urban forms (adopting the same methodological approach), compare simulation outcomes with in-situ captured data and analyse indoor microclimate with relation to the variation of the building façade reflectance.

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References

Alchapar, N. L., & Correa, E. N. (2016). The use of reflective materials as a strategy for urban cooling in an arid “OASIS” city. *Sustainable Cities and Society*, *27*, 1–14. https://doi.org/10.1016/j.scs.2016.08.015

Alchapar, N. L., Correa, E. N., & Cantón, M. A. (2014). Classification of building materials used in the urban envelopes according to their capacity for mitigation of the urban heat island in semiarid zones. *Energy and Buildings*, *69*, 22–32. https://doi.org/10.1016/j.enbuild.2013.10.012

Almhafdy, A., Ibrahim, N., Ahmad, S. S., & Yahya, J. (2013). Courtyard Design Variants and Microclimate Performance. *Procedia - Social and Behavioral Sciences*, *101*, 170–180. https://doi.org/10.1016/j.sbspro.2013.07.190

Alonso, C., Martín-Consuegra, F., Oteiza, I., Asensio, E., Pérez, G., Martínez, I., & Frutos, B. (2017). Effect of façade surface finish on building energy rehabilitation. *Solar Energy*, *146*, 470–483. https://doi.org/10.1016/j.solener.2017.03.009

ANSI/ASHRAE. (2002). ASHRAE Guideline 14-2002 Measurement of Energy and Demand Savings. *Ashrae*, *8400*, 170.

ARPAER www.arpae.it. (n.d.). *Dati climatici, Parma urbana*.

Azarnejad, A., & Mahdavi, A. (2015). Building façades’ visual reflectance and surface temperatures: A field study. *Energy Procedia*, *78*, 1720–1725. https://doi.org/10.1016/j.egypro.2015.11.277

Battista, G., Carnielo, E., & De Lieto Vollaro, R. (2016). Thermal impact of a redeveloped area on localized urban microclimate: A case study in Rome. *Energy and Buildings*, *133*, 446–454.

https://doi.org/10.1016/j.enbuild.2016.10.004
Berardi, U. (2016). The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. *Energy and Buildings*, *121*, 217–229. https://doi.org/10.1016/j.enbuild.2016.03.021
Castaldo, V. L., Rosso, F., Golasi, I., Piselli, C., Salata, F., Pisello, A. L., … De Lieto Vollaro, A. (2017). Thermal comfort in the historical urban canyon: The effect of innovative materials. *Energy Procedia*, *134*, 151–160. https://doi.org/10.1016/j.egypro.2017.09.553
Coakley, J. A. (2002). *Reflectance and albedo, surface*. 1914–1923. https://doi.org/10.1016/B0-12-227090-8/00069-5
Doulos, L., Santamouris, M., & Livada, I. (2004). Passive cooling of outdoor urban spaces. The role of materials. *Solar Energy*, *77*(2), 231–249. https://doi.org/10.1016/j.solener.2004.04.005
Du, J., & Sharples, S. (2010). Analysing the impact of reflectance distributions and well geometries on vertical surface daylight levels in atria for overcast skies. *Building and Environment*, *45*(7), 1733–1745. https://doi.org/10.1016/j.buildenv.2010.01.026
Eckmann, T., Morach, A., Hamilton, M., Walker, J., Simpson, L., Lower, S., … Kessi, A. (2018). Measuring and modeling microclimate impacts of Sequoiadendron giganteum. *Sustainable Cities and Society*, *38*(November 2017), 509–525. https://doi.org/10.1016/j.scs.2017.12.028
Envi-met www.envi-met.com. (n.d.).
European Commission. (2017). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK - Clean energy for all Europeans* (Vol. 14, p. 3). Vol. 14, p. 3.
Fabbri, K., Canuti, G., & Ugolini, A. (2017). A methodology to evaluate outdoor microclimate of the archaeological site and vegetation role: A case study of the Roman Villa in Russi (Italy). *Sustainable Cities and Society*, *35*. https://doi.org/10.1016/j.scs.2017.07.020
Fabbri, K., Di Nunzio, A., Gaspari, J., Antonini, E., & Boeri, A. (2017). Outdoor Comfort: The ENVI-BUG tool to Evaluate PMV Values Output Comfort Point by Point. *Energy Procedia*, *111*. https://doi.org/10.1016/j.egypro.2017.03.213
Fabbri, K, & Costanzo, V. (2019). Drone-assisted infrared thermography for calibration of outdoor microclimate simulation models. *Sustainable Cities and Society*, *in press*, 101855. https://doi.org/10.1016/j.scs.2019.101855
Fabbri, Kristian, Di Nunzio, A., Gaspari, J., Antonini, E., & Boeri, A. (2017). Outdoor Comfort: The ENVI-BUG tool to Evaluate PMV Values Output Comfort Point by Point. *Energy Procedia*, *111*(September 2016), 510–519. https://doi.org/10.1016/j.egypro.2017.03.213
Fong, C. S., Aghamohammadi, N., Ramakreshnan, L., Sulaiman, N. M., & Mohammadi, P. (2019). Holistic recommendations for future outdoor thermal comfort assessment in tropical Southeast Asia: A critical appraisal. *Sustainable Cities and Society*, *46*(September 2018), 101428. https://doi.org/10.1016/j.scs.2019.101428
Forouzandeh, A. (2018). Numerical modeling validation for the microclimate thermal condition of semi-closed courtyard spaces between buildings. *Sustainable Cities and Society*, *36*(August 2017), 327–345. https://doi.org/10.1016/j.scs.2017.07.025
Gaspari, J., & Fabbri, K. (2017). A Study on the Use of Outdoor Microclimate Map to Address Design Solutions for Urban Regeneration. *Energy Procedia*, *111*. https://doi.org/10.1016/j.egypro.2017.03.212
Gaspari, Jacopo, Fabbri, K., & Lucchi, M. (2018). The use of outdoor microclimate analysis to support decision making process: Case study of Bufalini square in Cesena. *Sustainable Cities and Society*, *42*(July), 206–215. https://doi.org/10.1016/j.scs.2018.07.015
IPCC. (2018). *Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming*.
Köppen, W., & Geiger, R. (1936). Das Geographische System der Klimate. *Handbuch Der Klimatologie*, (c), 7–30. https://doi.org/10.3354/cr01204
Krüger, E. L., Minella, F. O., & Rasia, F. (2011). Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. *Building and Environment*, *46*(3), 621–634. https://doi.org/10.1016/j.buildenv.2010.09.006

Kyriakodis, G. E., & Santamouris, M. (2018). Using reflective pavements to mitigate urban heat island in warm climates - Results from a large scale urban mitigation project. *Urban Climate*, *24*, 326–339. https://doi.org/10.1016/j.uclim.2017.02.002

Lai, D., Liu, W., Gan, T., Liu, K., & Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of the Total Environment*, *661*, 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062

Li, Z., Zhao, M., Zeng, J., Peng, C., & Wu, J. (2017). High-solar-reflectance building ceramic tiles based on titanite ($CaTiSiO_5$) glaze. *Solar Energy*, *153*, 623–627. https://doi.org/10.1016/j.solener.2017.04.033

M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. R. (2006). World map of the Koppen- Geiger climate classification updated. *Meteorol. Z.*, *15*(3), 259-263ù.

Mauri, L., Battista, G., de Lieto Vollaro, E., & de Lieto Vollaro, R. (2018). Retroreflective materials for building's façades: Experimental characterization and numerical simulations. *Solar Energy*, *171*(May), 150–156. https://doi.org/10.1016/j.solener.2018.06.073

Mehaoued, K., & Lartigue, B. (2019). Influence of a reflective glass façade on surrounding microclimate and building cooling load: Case of an office building in Algiers. *Sustainable Cities and Society*, *46*(May 2018). https://doi.org/10.1016/j.scs.2019.101443

Meteoblue (www.meteoblue.com). (n.d.). 3171457.

Morini, E., Castellani, B., De Ciantis, S., Anderini, E., & Rossi, F. (2018). Planning for cooler urban canyons: Comparative analysis of the influence of façades reflective properties on urban canyon thermal behavior. *Solar Energy*, *162*(October 2017), 14–27. https://doi.org/10.1016/j.solener.2017.12.064

Nasrollahi, N., Hatami, M., Khastar, S. R., & Taleghani, M. (2017). Numerical evaluation of thermal comfort in traditional courtyards to develop new microclimate design in a hot and dry climate. *Sustainable Cities and Society*, *35*(June), 449–467. https://doi.org/10.1016/j.scs.2017.08.017

Nechad, B., Ruddick, K. G., & Park, Y. (2010). Calibration and validation of a generic multisensor algorithm for mapping of total suspended matter in turbid waters. *Remote Sensing of Environment*, *114*(4), 854–866. https://doi.org/10.1016/j.rse.2009.11.022

Noro, M., & Lazzarin, R. (2015). Urban heat island in Padua, Italy: Simulation analysis and mitigation strategies. *Urban Climate*, *14*, 187–196. https://doi.org/10.1016/j.uclim.2015.04.004

Piselli, C., Pigliautile, I., Castaldo, V. L., Cotana, F., & Pisello, A. L. (2017). Microclimate and air quality investigation in historic hilly urban areas: Experimental and numerical investigation in central Italy. *Sustainable Cities and Society*, *33*(September 2016), 27–44. https://doi.org/10.1016/j.scs.2017.05.017

Reflectance APP (http://misclab.umeoce.maine.edu/research/HydroColor.php). (n.d.). *Reflectance App*.

Salata, F., Golasi, I., de Lieto Vollaro, R., & de Lieto Vollaro, A. (2016). Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. *Sustainable Cities and Society*, *26*, 318–343. https://doi.org/10.1016/j.scs.2016.07.005

Salata, F., Golasi, I., Vollaro, A. D. L., & Vollaro, R. D. L. (2015). How high albedo and traditional buildings' materials and vegetation affect the quality of urban microclimate. A case study. *Energy and Buildings*, *99*, 32–49. https://doi.org/10.1016/j.enbuild.2015.04.010

Santamouris, M., & Kolokotsa, D. (2015). On the impact of urban overheating and extreme climatic conditions on housing, energy, comfort and environmental quality of vulnerable population in Europe. *Energy and Buildings*, *98*, 125–133. https://doi.org/10.1016/j.enbuild.2014.08.050

Schabbach, L. M., Marinoski, D. L., Güths, S., Bernardin, A. M., & Fredel, M. C. (2018). Pigmented glazed ceramic roof tiles in Brazil: Thermal and optical properties related to solar reflectance index. *Solar Energy*, *159*, 113–124. https://doi.org/10.1016/J.SOLENER.2017.10.076

Sharmin, T., Steemers, K., & Matzarakis, A. (2017). Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment. *Sustainable Cities and Society*, *34*(July), 293–308. https://doi.org/10.1016/j.scs.2017.07.006

Sözen, İ., & Koçlar Oral, G. (2019). Outdoor thermal comfort in urban canyon and courtyard in hot arid climate: A parametric study based on the vernacular settlement of Mardin. *Sustainable Cities and Society*, (December 2018), 1–15. https://doi.org/10.1016/j.scs.2018.12.026

Steinmant, R. M. (1987). Glossary of terms for thermal physiology. *European Journal of Physiology*, (410), 567–587.

Sun, S., Xu, X., Lao, Z., Liu, W., Li, Z., Higueras García, E., … Zhu, J. (2017). Evaluating the impact of urban green space and landscape design parameters on thermal comfort in hot summer by numerical simulation. *Building and Environment*, *123*, 277–288. https://doi.org/10.1016/j.buildenv.2017.07.010

Takebayashi, H., Miki, K., Sakai, K., Murata, Y., Matsumoto, T., Wada, S., & Aoyama, T. (2016). Experimental examination of solar reflectance of high-reflectance paint in Japan with natural and accelerated aging. *Energy and Buildings*, *114*, 173–179. https://doi.org/10.1016/j.enbuild.2015.06.019

Touchaei, A. G., Akbari, H., & Tessum, C. W. (2016). Effect of increasing urban albedo on meteorology and air quality of Montreal (Canada) - Episodic simulation of heat wave in 2005. *Atmospheric Environment*, *132*(x), 188–206. https://doi.org/10.1016/j.atmosenv.2016.02.033

Trespa www.trespa.com. (n.d.).

Tseliou, A., & Tsiros, I. X. (2016). Modeling urban microclimate to ameliorate thermal sensation conditions in outdoor areas in Athens (Greece). *Building Simulation*, *9*(3), 251–267. https://doi.org/10.1007/s12273-016-0270-y

Tsitoura, M., Michailidou, M., & Tsoutsos, T. (2016). Achieving sustainability through the management of microclimate parameters in Mediterranean urban environments during summer. *Sustainable Cities and Society*, *26*, 48–64. https://doi.org/10.1016/j.scs.2016.05.006

Vuckovic, M., Maleki, A., Kiesel, K., & Mahdavi, A. (2015). Simulat ion-based assessment of uhi mitigation measures in central european cities. *14th International Conference of IBPSA - Building Simulation 2015, BS 2015, Conference Proceedings*, (December).

Ward, K., Lauf, S., Kleinschmit, B., & Endlicher, W. (2016). Heat waves and urban heat islands in Europe: A review of relevant drivers. *Science of the Total Environment*, *569–570*, 527–539. https://doi.org/10.1016/j.scitotenv.2016.06.119

Yang, X., Zhao, L., Bruse, M., & Meng, Q. (2013). Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces. *Building and Environment*, *60*, 93–104. https://doi.org/10.1016/j.buildenv.2012.11.008