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On Venetian Campi Resilience to Climate Change

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Abstract. Venice is known for its history and beauty and its fragility and potential demise. The city is experiencing an increase in yearly average temperatures affecting outdoor - indoor comfort and average energy expenditure. Owing to existing literature demonstrating how local microclimate depends on urban density, shape, and orientation of buildings and materials, the work studies the influence of changing Venice temperatures by targeting such issues, focusing on an urban fabric typical form, known as Campi. Based on IPCC's future weather predictions for 2050 scenario A1B, the work highlights how the urban fabric configuration affects the local microclimate and outdoor conditions to define how buildings will mitigate and adapt to environmental transitions. The method couples microclimate and outdoor comfort users' perception of Physiological Equivalent Temperature (PET), via ENVI-met. Preliminary results show that the compactness of the urban fabric in Venetian Campi significantly reduces outdoor temperatures due to the increased density of shadow areas in the courtyard or in narrow Venice streets. The role of water is also simulated via ENVI-met, as buildings' materials and indoor energy consumption are assumed as invariant to evaluate the historic urban fabric climate resilience. The results constitute a first step towards understanding to what extent a particular urban fabric type is thermally resilient.

Keywords – Venice; Microclimate; Climate Change; Urban Form; Outdoor Liveability.

1. Introduction

In climate change, rapid urbanisation and densification processes are changing cities' microclimates. With the Paris Agreement (UN, 2015), the global average temperature should not rise above 2 °C when compared to pre-industrial levels [1], but global warming is likely to reach 1.5°C in 2030 [2], interplaying with the Urban Heat Island (UHI) [3]. Prolonged and intense heat waves affect cities' liveability and energy demand. One of the opportunities for reversing cities' climate change is to develop resilient design measures. These measures can minimise the localised changes of local microclimates. Whereas there is some work looking at parameterised ideal urban forms resilience [4], there is no work looking at how historical, dense cities such as Venice can respond to climate change issues. Venice between 2000 and 2018 had a 1.2° C increase in temperature related to the 20th-century average. Venice is built on islands and canals and has a close water connection. Recently as global warming pushes sea levels higher, many other climatic issues affect Venice's microclimate and outdoor liveability. Besides the effects of global warming are most evident in Piazza San Marco, the number of hot days (above 27° C over a 24-hour average) went from 0.3 days per year in the 20th century to 9.5 per year in the years since 2000 [5]. Despite this evidence, few scientific studies focus on climate change issues that affect the Venice mainland.

The typical trait of Venice is the irregularity of the urban fabric: Venice was built on a "void". Vernacular open areas called *Campi* exemplify the latter. Campo defines a square, recalling grassy or cultivated fields [6]; Campo is distinguished from public square as Piazza San Marco.

Given the lack of microclimatic studies in Venice, the research question is how the specific urban fabric of Campi is responding to climate change and what degrees of resiliency they offer.

The paper is based on software-based microclimatic analysis and the Physiological Equivalent Temperature (PET) [7] index evaluation of two areas of (240 m x 240 m) in contemporary and 2050 climatic scenario.

2. Background

2.1 Urban form and urban resilience in historical cities

Urban resilience has been debated over the past decades, moving from its origins in ecology, including modern city and urban planning. Most of the studies on urban resilience are focused on: i) densely populated cities that have suffered severe damages from Climate Change (i.e. Cape Town, New Orleans) [8]; ii) UHI and buildings' materials [9]; iii) urban heat resilience via urban parks [10]. A few studies are available for Italian cities like Bologna, Milan, Florence and Rome [11].

In addition, recent studies have been exploring the interrelations between urban form and annual energy performance, expanding urban environmental analysis from energy performance to new environmental quality-based considerations [12]. Nonetheless, historical cities' resilience has to be investigated thoroughly, as the link among microclimatic issues, urban form, land-use patterns and building materials is yet generally neglected. The relationship between urban fabric and microclimate has been studied. Urban fabric's effects on building energy consumption and daylight [13] are significant. As Givoni states: «The outdoor temperature, wind speed and solar radiation to which an individual building is exposed is not the regional synoptic climate, but the local microclimate as modified by the "structure" of the city, mainly of the neighbourhoods where the building is located» [14].

2.2 Urban Form in Venice and Campi

The urban form of Venice derives from historical sedimentations dated back centuries. Three urban configurations can be found in Venice: i) the quadrangular *Campo* (Byzantine period), located in the heart of self-sufficient islands; ii) the "comb structure" (Gothic age), with primary water and land routes, on parallel axes spaced from secondary structures: calli, communal courtyards, large individual houses; iii) the *Fondamenta* type (Modern age), a street parallel to a canal. They serve as a base/foundation, with houses aligned to foundations or transversal to courtyards and streets. Campi can vary in size: from small *Campielli,* to larger squares. Each Campo represents an essay of Venice urban life. According to Crowhurst Lennard's essay [15], their development is functional: «The campo is an open, irregularly shaped paved space surrounded by buildings. These buildings, which vary in height up to five stories, and also in importance and purpose, often contain small businesses and services on the ground floor and private dwellings above».

2.3 Urban Microclimatic modelling background

Microclimate simulations are widely used to compute air and surfaces temperatures, turbulence, radiation fluxes, humidity and evaporation fluxes. Many studies have employed ENVI-met, a three-dimensional prognostic model, to simulate the interaction between air, plants and surfaces within an urban environment [16]. ENVI-met can investigate the impact of the UHI phenomenon on the outdoor thermal comfort of different form patterns and evaluate the efficacy of heat mitigation strategies. Validation studies confirm its accuracy in modelling urban setting and sensitivity to form the built environment [17].

3. Aims and Objectives

The proposed research aims to investigate the thermal resilience of Venice's Campi forms. In order to fulfil the aim, the present and future weather scenario (2050) are analysed.

The paper responds to three main objectives: i) assess today thermal stress for Venice Campi (San Polo e SS. Giovanni e Paolo); ii) assess climate change thermal stresses in 2050 climatic scenario; iii) discuss resilience potentialities and constraints.

4. Methodology

The methodology assesses microclimate parameters for the hottest day in Venice to determine Venice's two key-selected areas' outdoor liveability levels. Venetian Campi thermal paths will be studied in the present and future weather scenario (2050). The work aims to assess patterns of influence of changing temperatures in Venice. These patterns could be later be used to outline climate mitigation strategies that will create a correct and well temperate local microclimate, leading to outdoor spaces liveability in the dense urban fabric. Operationally the work is subdivided into four parts: 1) identification of two representative urban patterns in Venice; 2) software-based microclimatic analysis of each area for the current and the projected 2050 scenario (the year 2050, modelled according to the IPCC scenarios); 3) calculation of the Physiological Equivalent Temperature PET index; 4) discuss and identify how urban form parameters (shape, orientation, density and canal location) influence outdoor comfort.

5. Methods

5.1. Campi Selection

The Venetian vernacular open areas, called Campi, are used as samples to investigate urban fabric typical configurations and resilience to climate change. Two different Venetian Campi are selected (figure 1a). Campo San Polo (figure 1c) is one of the typical "parish islands", built in Venice in the 10th-11th centuries, and it is the largest in Venice. It connects the Canale di Cannaregio and San Marco districts. Campo di S. Polo developed by one of the leading Venetian waterways (figure 1b). Buildings feature a double courtyard and present some variability in their heights (10-20 meters).

The second key-selected area is Campo SS. Giovanni e Paolo (figure 1e), between Cannaregio and Castello neighbourhoods. This Campo developed along with one of the Gothic city's fringe belts (XIV-XV century), where a greater space availability led to the construction of monastic and hospital buildings (figure 1d). Along the "land path" numerous Gothic buildings, with limited heights, form a homogeneous building front. On the other side, the Campo is open along the Canale della Misericordia. SS. Giovanni e Paolo Church is the most relevant building in the Campo.

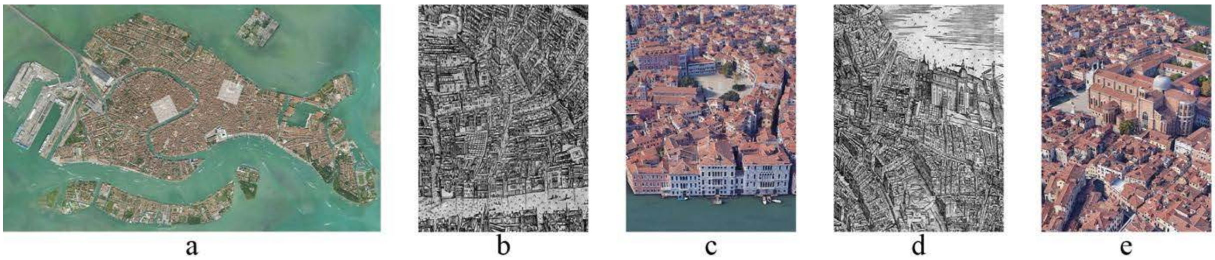

Figure 1. Aerial view of Venice (a); San Polo in de' Barbari illustration (1541) (b); view of San Polo (c); SS. Giovanni e Paolo in de' Barbari (1541) illustration (d); view of SS. Giovanni e Paolo (c).

5.2. Microclimatic studies

In order to perform an ENVI-met simulation, three groups of inputs are required: i) geometry and material information to build a digital spatial model, as in Figure 2 (Area Input File), ii) characteristics of the selected materials to define a material database (Database), iii) simulation settings and meteorological input data (Configuration File). Table 1 summarises materials information used to run the simulations for the Venice case studies.

In the Area Input Files, two domains are shaped using a grid cell unit of 2.0 m x 2.0 m x 3.0 m. Here the 3d models are built based on the data collected by survey and on spatial data retrieved by the open dataset Atlante della Laguna [18]. Materials and thermo-physical properties have been modelled according to literature sources. Thus, the material default Database was enriched by including the material thermal properties of the *Trachite Euganea* (a local quarried stone) for street pavements, exposed brick wall and plastered brick wall for building envelopes, and finally, shallow water for the canals (1.0 m deep), as in Table 1. It is worth noting that the material's properties have been deliberately simplified and kept as invariant in the simulation.

Configuration files are created to simulate an average hot day and the projected same day in 2050. The standard EPW file of Venice is used as a contemporary climatic reference. The global climatological database Meteonorm is used as meteorological input for 2050. The implemented IPCC scenario is A1B. The 19th of August is the simulation day. It is a typical summer clear sky day, according to the STAT file analysis. The simulation day in the current data marks an average temperature across the 24 hours of 23.7 °C, whereas the 2050 forecast is 30.5 °C. The average wind arises from 206 degrees.

The employed simple forcing method made use of climate boundary conditions described before. Finally, the four simulations are performed, and the results are studied for a selected number of hours.

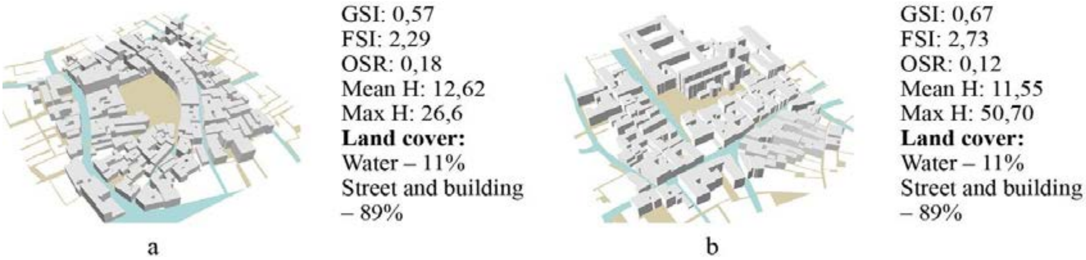

Figure 2. Axonometric view model for Campo San Polo (a), and for Campo SS. Giovanni e Paolo (b).

Table 1. Venice Material Database.

Exposed Brick Wall: brick-burned (10cm), masonry heavyweight (25 cm), plaster (2 cm)			
Plastered Brick Wall: plaster (2 cm), masonry heavyweight (40 cm), plaster (2 cm)			
	Plaster	Masonry-heavyweight	Brick-burned
Absorption	0.50	0.65	0.60
Transmission	0.00	0.00	0.00
Reflection	0.50	0.35	0.40
Emissivity	0.90	0.90	0.90
Specific Heat (J/kg·K)	850	840	650
Thermal Conductivity (W/m·K)	0.60	0.90	0.44
Density (kg/m^3)	1500	1850	1500
	Trachite Euganea		Canal Water
Roughness	0.01		0.01
Albedo	0.5		0.04
Emissivity	0.9		0.96
Profile 1: Trachite Euganea (6 cm), sand (2 cm), sandy loam (200cm)			
Profile 2: water (100 cm), loamy soil (50 cm), sand (50 cm)			

5.3. *Physiological Equivalent Temperature Index Microclimatic Studies*

In the next phase, the two areas' thermal comfort was assessed for the current and projected scenario. ENVI-met results are processed in the sub-module BIO-met to calculate the Physiological Equivalent Temperature (PET) comfort index. This index is based on a prognostic model of the human energy balance that computes the skin temperature and the body core temperature.

The assessment relies on obtained microclimatic values of Means Radiant Temperature (MRT), Potential Air Temperature (Pot), Wind Speed (WS) and Relative Humidity (RH) and the target person characteristics. For this study, the target person chosen is 35 years old and 1.75m tall.

In the last phase, the PET values, calculated for the two scenarios, are mapped in the two areas.

Finally, the predominant form and microclimate components that affect the thermal performance of the Campi are identified through a detailed comparative analysis of the thermal comfort variations.

6. Results

The comparison investigates the thermal comfort patterns for three selected hours of the day, 10.00,13.00 and 16.00, at the pedestrian level (1.5 m).

6.1. *Campo San Polo*

In scenario 2020, PET temperatures have a homogeneous distribution, moving from a prevalent temperature of 38-41 °C at 10 (Figure 3a) to 41-45 °C at 13 (Figure 3b) and 16 (Figure 3c).

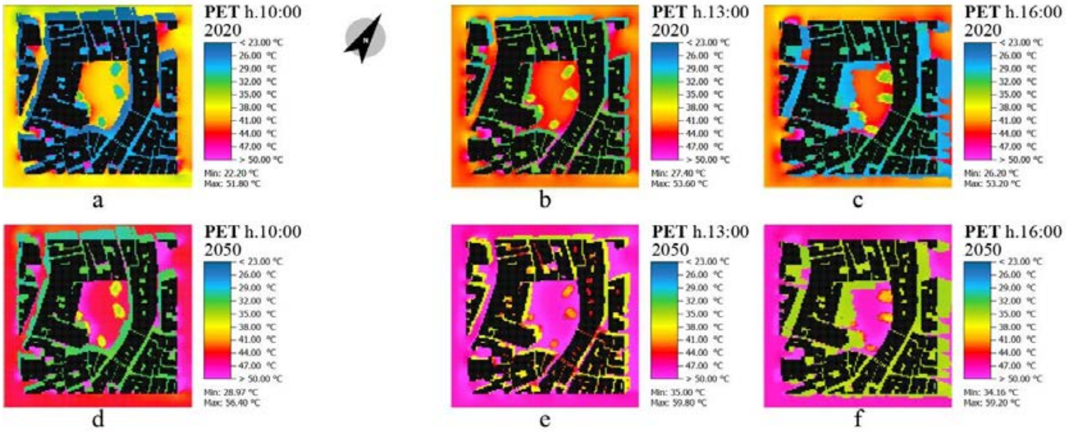

Figure 3. Campo San Polo PET values in 2020 and 2050.

During the three hours, despite the diurnal increase of PET values (Figure 3), vegetation and shadow decrease thermal discomfort in a range of 12-18 °C. In scenario 2050 (Figure 3d, 3e, 3f and Figure 5a) PET values maintain the same pattern distribution observed in scenario 2020. Perceived temperatures reach 50 °C already at 10 (Figure 3d), while ΔPET is around 3 °C.

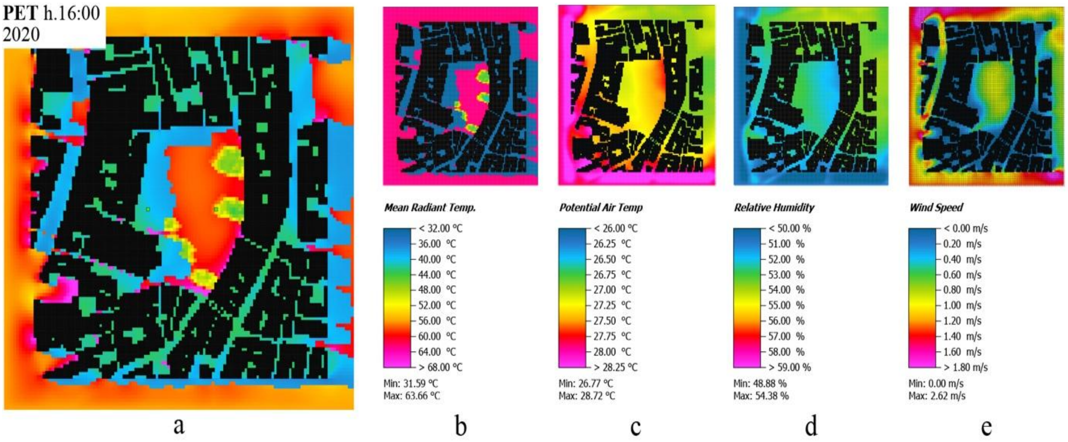

Figure 4. Campo San Polo thermal stress maps in 2020.

Wind speed (Figure 5e) and Potential Air Temperature (Pot) (Figure 5c) are homogeneous due to the similar buildings' height. In 2050 PET (Figure 5) values slightly increase compared to 2020 conditions (Figure 4) due to Mean Radiant Temperature (MRT) (Figure 5b) and lower Relative Humidity (RH) (Figure 5d).

However, shadow and vegetation's impact tend to increase, mitigating thermal distress in a range of 21-24 °C. Nonetheless, Campo San Polo seems to assure extreme heat stress since PET over 41 °C means extreme hot conditions for European cities.

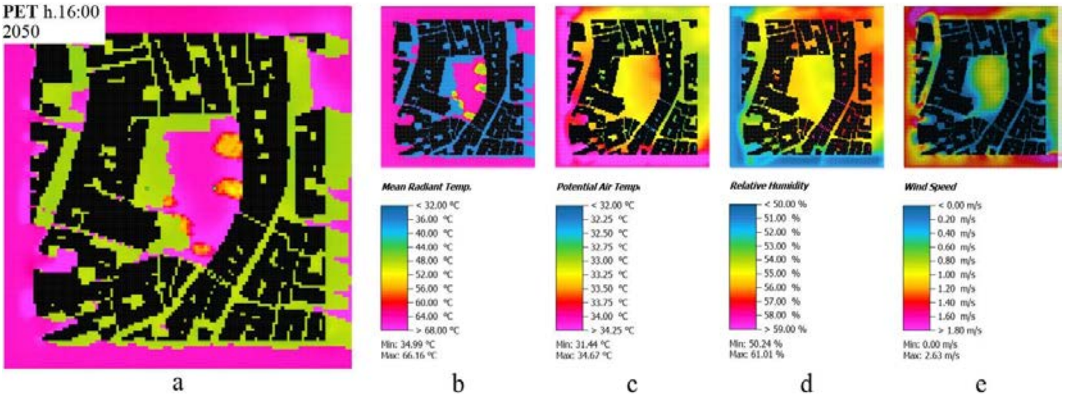

Figure 5. Campo San Polo thermal stress maps in 2050.

6.2. *Campo SS. Giovanni e Paolo*

Compared to San Polo, Campo SS. Giovanni e Paolo shows a more heterogeneous PET values distribution (Figure 6). Scenario 2020 (Figure 6a, 6b, 6c) shows that perceived temperatures tend to be lower in the northwest part of the square and increasingly grow towards the south-east side. In the latter, temperatures reach 50 °C since the early morning (Figure 6a) and persist till 16 (Figure 6c).

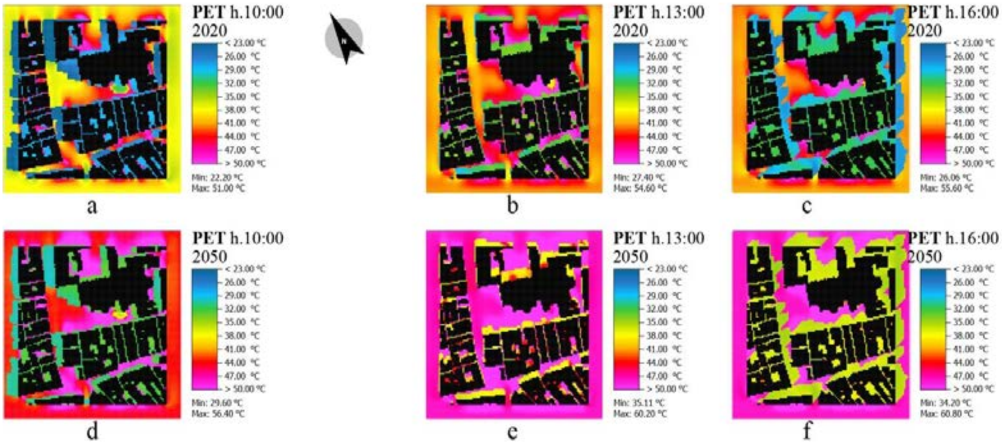

Figure 6. Campo SS. Giovanni e Paolo thermal stress maps in 2050.

Due to vegetation's scarce presence, only building shadow contributes to increasing the comfort level by lowering the perceived temperature (Figure 7b, 7d).

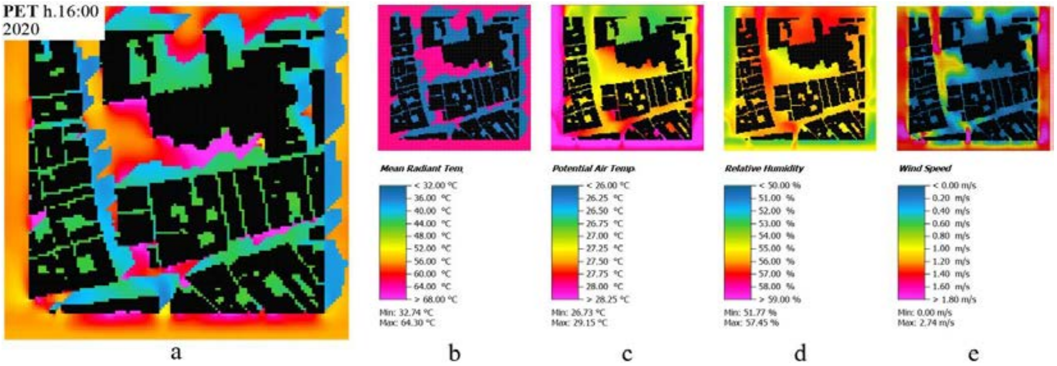

Figure 7. Campo SS. Giovanni e Paolo thermal stress maps in 2020.

The variation between max PET temperature and minimum temperature in shadow areas results equivalent to around 27 °C at 10 (Figure 6a), 19 °C at 13(Figure 6b), and 32 °C at 16 (Figure 7).

Similarly, in scenario 2050, a variation of comfort level was found between the northwest and south-east parts of the campo (Figure 8). PET temperatures reach a maximum of 60 °C (Figure 8a), while shadow patterns maintain their beneficial role in reducing thermal stress. A more detailed observation of the microclimate factors affecting PET values shows that shadow patterns play a crucial role. The canal canyon allows wind flow infiltration at a relatively high velocity of 1.8m/s (Figure 8e).

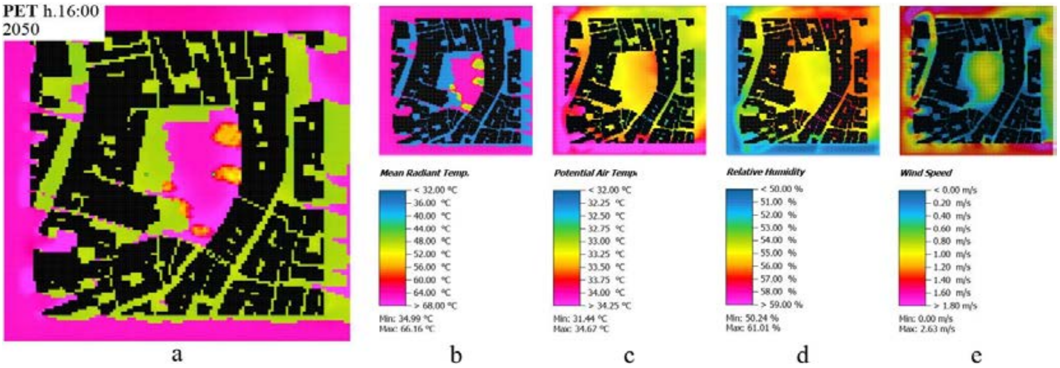

Figure 8. Campo SS. Giovanni e Paolo thermal stress maps in 2050.

7. Discussion

Urban Shape. In Campo SS. Giovanni e Paolo streets are oriented N-S, following the canal Rio dei Mendicanti, whereas the Campo is oriented E-W. The more regular shape of Campo San Polo is oriented N-S, and it is sided by two canals. These different patches also reverberate in MRT distribution: in SS. Giovanni e Paolo the shaded areas cast by the east side buildings and by the Church offer a reduction of the MRT for about a 1/3 of the campo open space. In San Polo, shaded areas are less extensive due to Campo's large width (70 m).

Built density. Venetian Campi show the prevalence of street and buildings (89%) compared to canals extension (11%). The average heights are similar in both Campi (mean height 11.55 m in SS. Giovanni e Paolo, 12.63 m in San Polo). The SS. Giovanni e Paolo façade (50.7 m) contributes to increasing the Campo shading. The compact and even building heights in San Polo cast more regular shadow path in Campo San Polo during the day. With the same square area (50922 m^2), SS. Giovanni e Paolo's total built area is larger than the total fabric floor area (FSI 2.73). Similarly, SS. Giovanni e Paolo's built space is larger than the total fabric area (Ground Space Index GSI 0.67). It reveals a more significant land consumption in SS. Giovanni e Paolo, than compared to San Polo (GSI 0.57).

MRT and Pot values. in SS. Giovanni e Paolo, the higher density and a homogenous building height (mean height 11.57 m) contribute to decreased MRT near the building front and close to the canal. Potential air temperature is lowered nearby the canal thanks to the shadow cast by the SS. Giovanni e Paolo Church and by the easter buildings' front. Similar results can be foreseen in the 2050 projection, but the urban form responds effectively to higher MRT and Pot values thanks to the high compactness. In San Polo, where building heights are homogeneous (max height 26.6 m and mean height 12.62 m), total built area compared to the total floor area of the fabric (FSI 2.29) is lower than SS. Giovanni e Paolo. Along with lower building coverage, shaded areas are less effective in reducing thermal discomfort, as they are more successful in reducing Pot values, nearby the eastern front. The distance of canal makes the infiltration of cool breezes less effective in lowering the Pot values in San Polo Campo, if compared to SS. Giovanni e Paolo.

PET values. Shaded areas allow for major thermal comfort in 2020 and 2050. The highest thermal stress occurs in the middle of the Campi, on unshaded paved surfaces. At large, nearby canals provide considerable thermal storage in San Polo and SS. Giovanni e Paolo. Heat stress increases in the 2050 scenario. It worth highlighting that the influence of the impact of urban form on the microclimate processes of ventilation and shadow patterns mitigates thermal stress. Due to the high compactness of the urban fabric, the Campi appear as the only open spaces that benefit from a higher velocity of wind flows. Such a phenomenon is reinforced when the water infrastructure of canals crosses or is tangent to these open spaces, such as SS. Giovanni e Paolo cases. This example suggests that the land cover and the canal canyons facilitate the infiltration of cool breezes contributing to lower PET. Future work will be carried out to address material' influence. Further investigations should include a wider variety of form patterns in the Venice context.

8. Conclusion

This study used the Venetian Campi case to evaluate how the fabric responds to climate change and what degree of resiliency is offered. The results suggest that compact urban fabric decreases PET values due to high shadow and lacks the wind's heat dissipation. Canals static water increases evaporative processes and, therefore, local relative humidity. Water plays a minor role in reducing MRT since canals have a limited depth of 1 m, and water is relatively still. A similar thermal distress trend can be foreseen in 2050. To conclude, Venetian Campi typical fabric is largely resilient by limiting overheating in future scenarios. Despite the lack of greenery and extensive waterproof surfaces, small and protected open spaces and uneven building heights offer extensive shadow. The historical fabric of Venice, built centuries ago, demonstrates that, despite impervious surfaces and the absence of greenery, the dense fabric is effective in mitigating thermal stress, both in 2020 and 2050 projections.

It can be assumed that historic Campi has evolved during ages in compactness, not only for functional purposes, but based on proven advantages in ensuring thermal comfort to their inhabitants. The Campi model and similar dense settlements in the Mediterranean area can be considered a reference of resiliency for modern climate-adaptive urban developments.

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