ENVI_MET

Courtyards for climate change

Emanuele Naboni | Barbara Gherri | Rossella Siani
Eleftheria Touloupaki | Marcello Turrini
Francesco De Luca

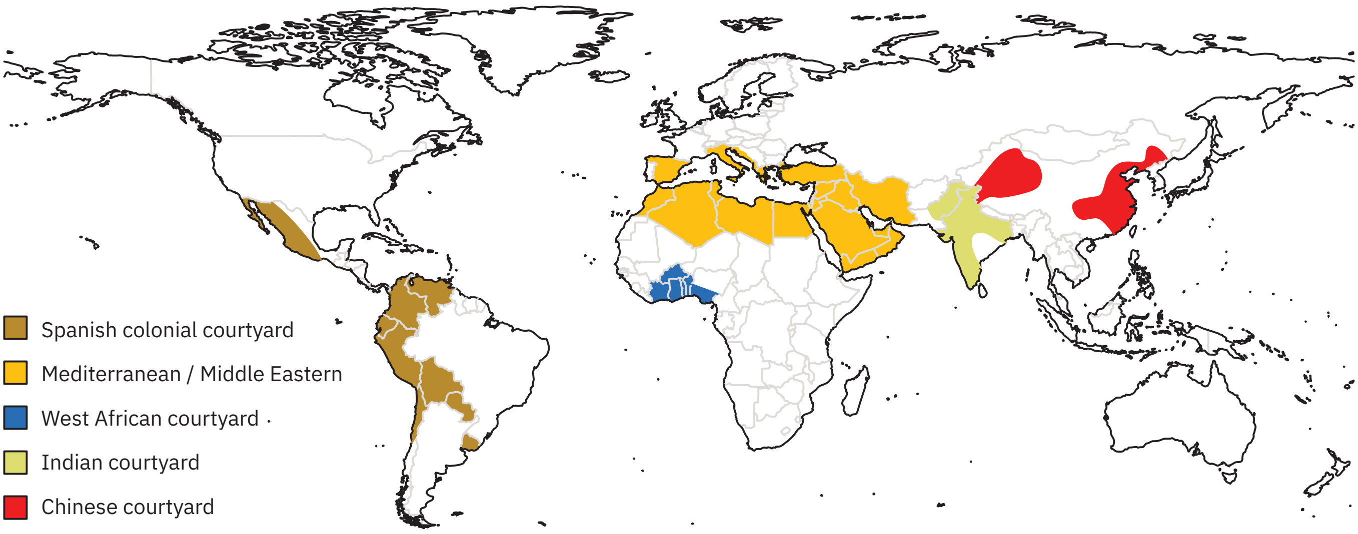
Introduction

Biomimicry courtyards

Courtyards are common in temperate climates. Climate change is threathening their function. Can simple solutions create thermal resilience?

With more than half of the world population living in cities and climate change intensifying during the last decades, the need to address increasing average temperatures and frequent heatwaves in urban environments is even more. The challenge is greater for historical cities, where architectural mitigation and adaptation measures need to be foreseen in accordance with the conservation of cultural heritage.
This computational study, based on the ENVI-met software tool, attempts to understanding the thermal resilience of a courtyard located in Parma in 2080 and to test approaches for the mitigation of climate related challenges. These are solutions applicable to other courtyards in similar climatic settings. Mimicourt is the process of this study, a word born from the crasis of biomimicry and courtyard.

Courtyard distribution



As the maps above shows, courtyards are present in many areas of the world. The courtyards differ in type, construction system and their specific function. Also specific charactaristics have developed over the centuries, according their location, terroir and climate.

Emanuele Naboni | Barbara Gherri | Rossella Siani | Eleftheria Touloupaki | Marcello Turrini | Francesco De Luca
THE UNIVERSITY OF PARMA | TALLINN UNIVERSITY OF TECHNOLOGY

Definitions

Courtyards are designed to be thermally pleasant, with the use of vegetation and albedo materials. Urban heat island and climate change are making most of them underused

Courtyard

Courtyards were typical in Roman times (peristyle), and in the East they continued to be of central importance: in the Islamic context, the creation of fortresses and palaces was often enlivened by fountains and water features. Courtyards without arcades are found in the public buildings in Europe. In the Renaissance, courtyards with arcades were rediscovered as part of the recovery of elements of the classical civilization.

Cloister

Among the large variety of courtyard buildings, the research focuses on cloisters. Cloisters are widespread in the Mediterranean basin. The term "cloister" has two definitions, both derived from the Latin claustrum (pl. Claustra), which means enclosure, closed place.

The grammar of courtyards

Some architectural components characterize the courtyards and cloisters. There is always a 'fence', created by the surrounding buildings, that closes the inner courtyard on the sides but leaves it open to the sky (fig.1).

The portico (fig. 2, 3, 4, 5, 7, 11, 12) is typical of the religious cloisters and courtyards of Mediterranean and European areas.

In some cases there are loggias (fig. 5, 7, 11) on the upper floor of the portico. The courtyard flooring can be paved (fig. 2, 5, 6, 7, 8) or turf (fig. 11, 12). Vegetation such as lawns (fig. 12), circumscribed trees (fig. 7, 8) or as gardens (fig. 11) are present.

The water element can be found in the form of a fountain (fig. 7, 8, 10) or as a basin (fig. 6, 9, 10), mainly used in Arabic courts (fig. 9).

Courtyards of Saint Petersburg.
Florstein. 2015

Patio del Palacio de Diego de
Bracamonte, Ávila

Cloisters at Iona Abbey. Roger Vander Steen. 2012

Cloister of Priory Saint-Michel of Grandmont, France.
Krzysztof Golik. 2019

Courtyard, Palazzo Ducale, Modena, Italy. Kgbo. 2019

Kanazawa 21st Century Museum of Contemporary Art.
Lukas. 2008

Claustro del Convento del Carmen Calzado, Córdoba. Jl
FilpoC. 2017

Italian Court courtyard in Kutná Hora, Czech Republic.
Czeva. 2009

Patio de los Arrayanes (Myrtle Courtyard), Alhambra,
Granada, Spain. Jebulon. 2012

Courtyard of Museo Nacional de Antropología, Mexico
City. Lars Plougmann. 2015

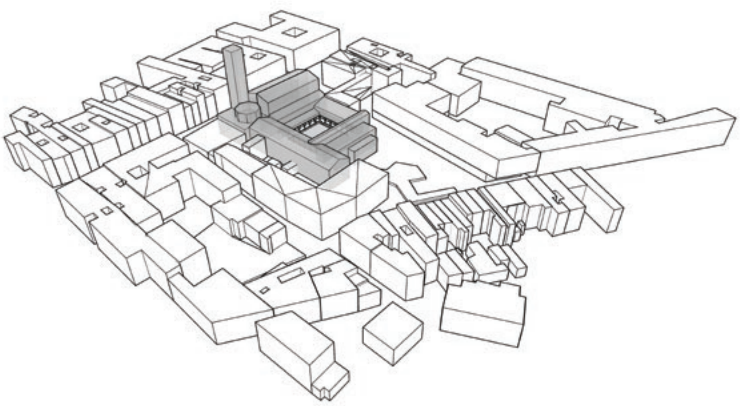
Claustro del Convento de Nuestra Señora de la Consol-
ación, Salamanca

Klaustroa-Orreagako kolegiatan. Makeip. 2020

ENVI
_MET

San Sepolcro in Parma

The cloister of San Sepolcro, built in Parma in 1100 is attached to a church.



Overview in the urban context.

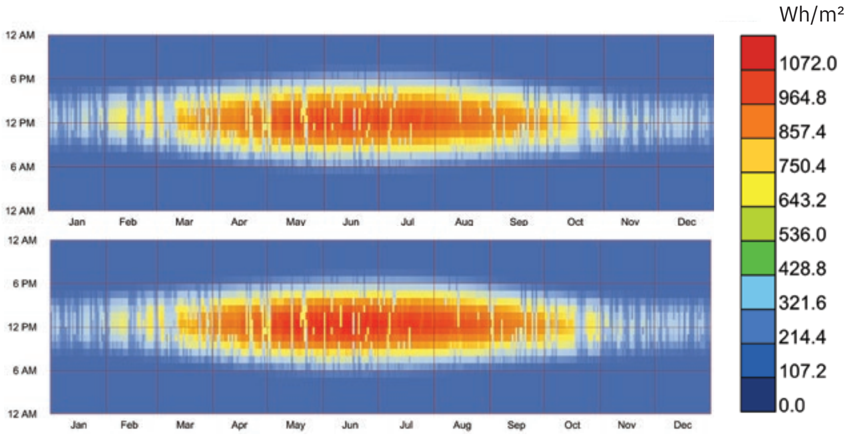
The cloister dates back to 1493-95. The Renaissance architecture features a single-storey square plan, without any loggia on the upper storey. It has three porticoed sides and the north side was buffered in the XIX century. Each side has six round arches in sand-stone, overlooking the green space, where several trees such as figs and pomegranates. Today a small box hedge and a decentralized well remain.

Climate change

Global horizzontal radiation

18a

18b



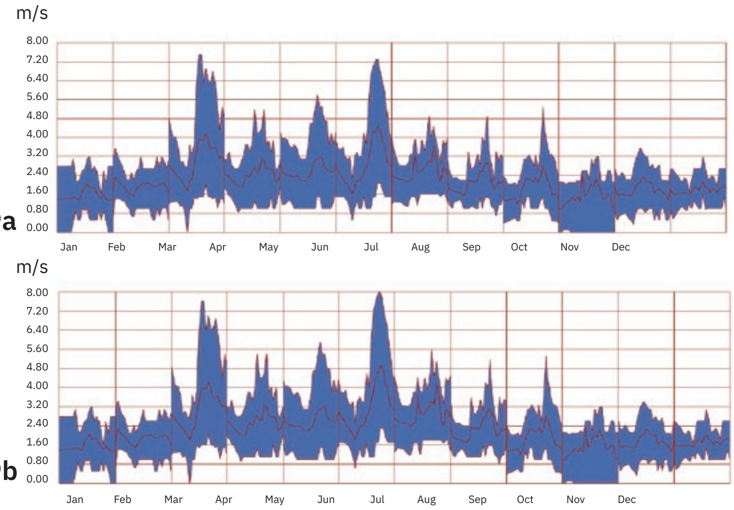
Global horizontal radiation in 2022 (fig 18a) and in 2080 (fig 18b).

Considering the climate data for 2080, global horizontal radiation to is expected to increase 8% during summer and decrease by 4% during the cold season.

Wind speed

19a

19b



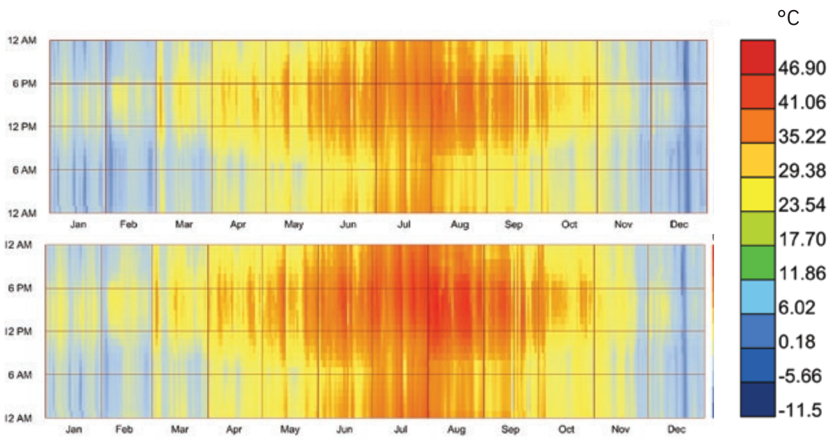
Wind speed in 2022 (fig 19a) and in 2080 (fig 19b)

Average wind speed is mainly below 3m/s, with some peaks from March to September. In 2080 there will be an increase of the peaks, but a light decrease of the average speed.

Temperature

20a

20b

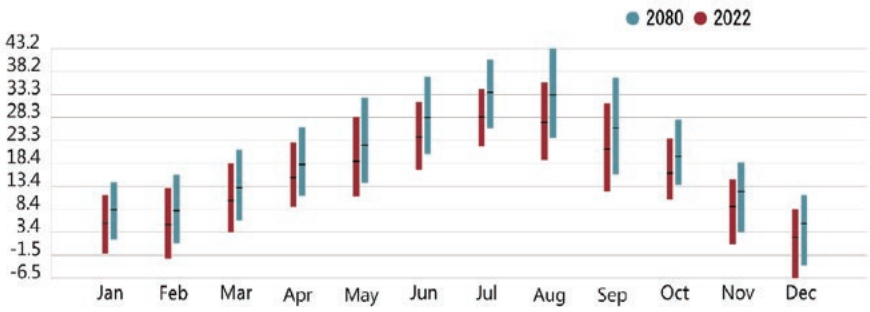


The statistical dry-bulb temperature in 2022 (fig. 20a) and in 2080 (fig. 20a).

The actual air temperature ranges from a minimum of -11,5°C in December to a maximum of 39°C in August. The minimum temperature will be -8.7°C and the maximum temperature will be 46.8°C.

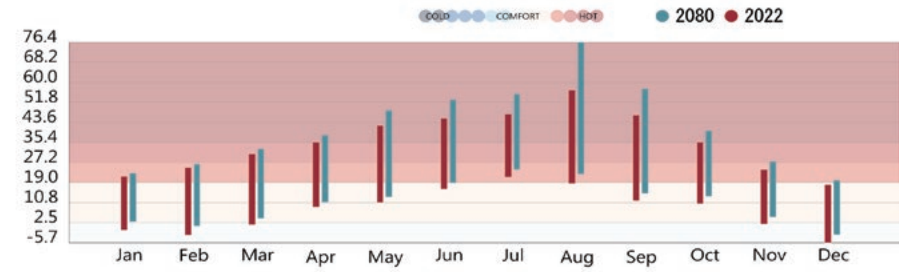
Climate change in 2080

The projected climate data for 2022, according to the IPCC scenario SSP5 - 8.5, show several criticalities



21 Dry Bulb Temperature annual variation.

Dry bulb temperatures rises with higher deltas during the hot season. The difference in average Dry bulb temperature reaches 6°C in August, between now and 2080 and values up to 8°C on the hottest day (5th of August).



22 UTCI annual variation.

In terms of comfort, UTCI [2] will reach in 2080 the category of "Extreme Heat Stress" (UTCI > 46°C) from May to September, while in the actual period it is extremely hot only in August. A significant peak in heat stress of more than 76°C will be recorded in August.

---

[2] The Universal Thermal Climate Index (UTCI) is an equivalent temperature, therefore, it is a comparison between the actual condition and a reference one. The reference environment has the 50% relative humidity not exceeding 20 hPa vapor pressure, radiant temperature equaling air temperature and still air.

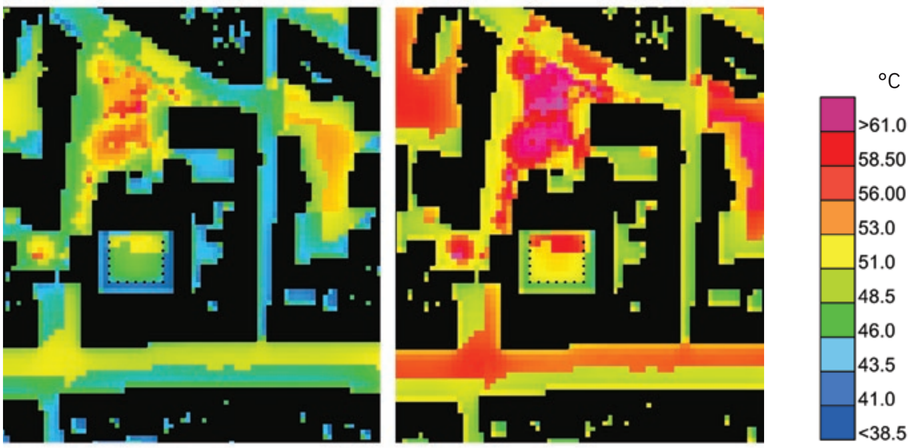
The UTCI, equivalent temperature for a given combined effect of air temperature, humidity, wind speed and radiation, is defined as the reference air temperature at the above mentioned conditions that would produce the same dynamic physiological response of the actual one. UTCI gives the measure of perceived comfort.

Case study analysis

The comparative microclimate analysis of the courtyard and its surrounding areas between 2020 and 2080 reveals three climate-related criticalities.

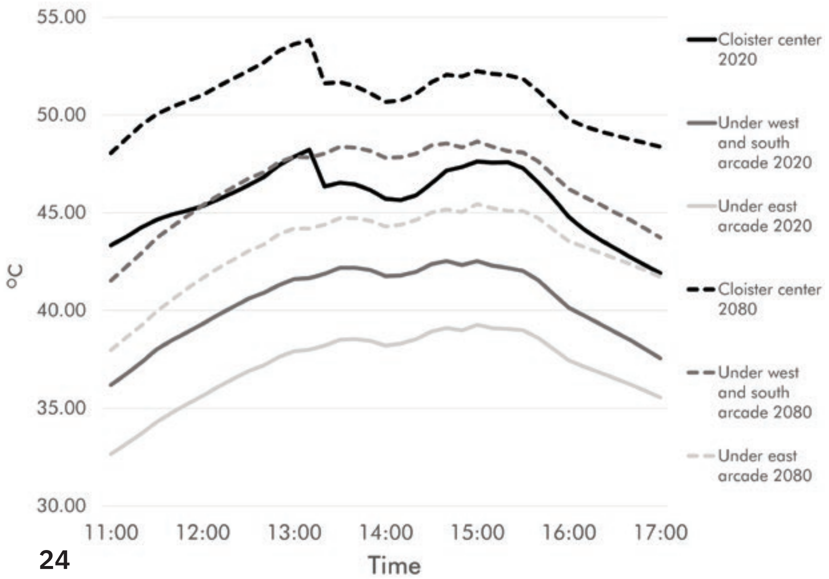
High mean radiant temprature

Mean radiant temperature in the cloister center will reach 54°C in 2080 (Fig. 23, 24).



23

Mean radiant temperature in 1.15 m height from the ground in 2020 and 2080 for the hottest time of the year (5th of August-15:00).



24

Cycle of the mean radiant temperature inside the San Sepolcro cloister at 1.15 m height from the ground between 2020 and 2080 on the hottest time of the year (5th of August - 15:00).

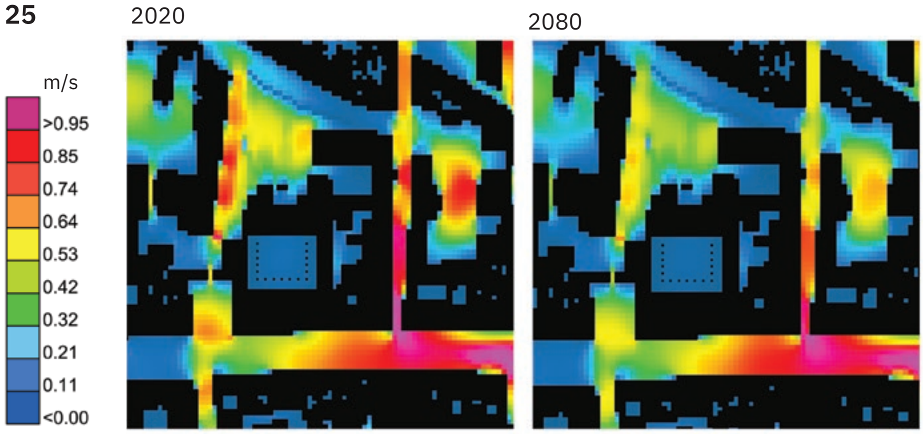
ENVI_MET

Low wind velocity

Wind speed analysis shows that the cloister presents very low flow values (about 0.20 m/s at 15:00) because there are no air passages to move in and through. In surrounding street canyons and open areas, the wind can reach higher values of around 0.80 m/s for 15:00 and over 3 m/s for other times of the day (fig. 25, 26).

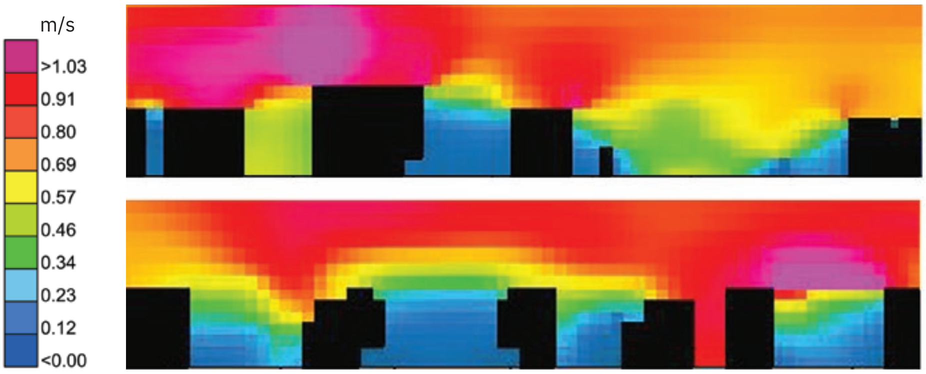
These values are not expected to change much since the different profiles of temperature and radiation predicted in 2080 are locally not significant enough to achieve different barometric pressures. Therefore, lack of ventilation inside the courtyard is identified as the second important criticality.

25



Wind speed in 1.15 m height from the ground in 2020 and 2080 for the hottest time of the year (5th of August-15:00).

26

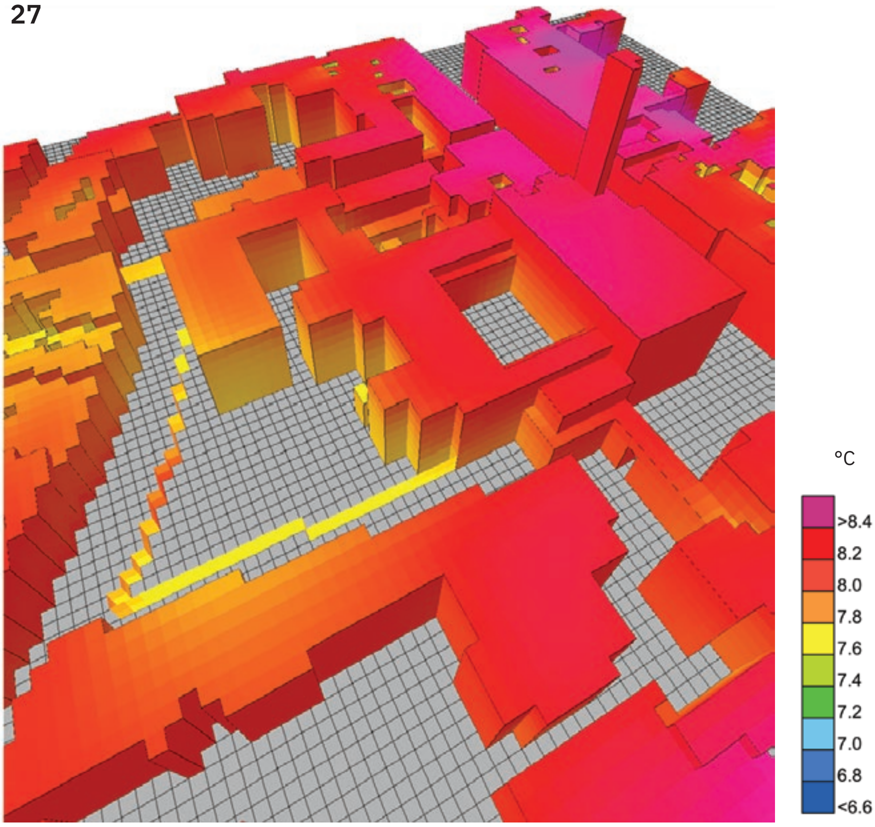


Wind speed sections in 2080 for the hottest time of the year (5th of August-15:00).

Increase of temperature on top floors

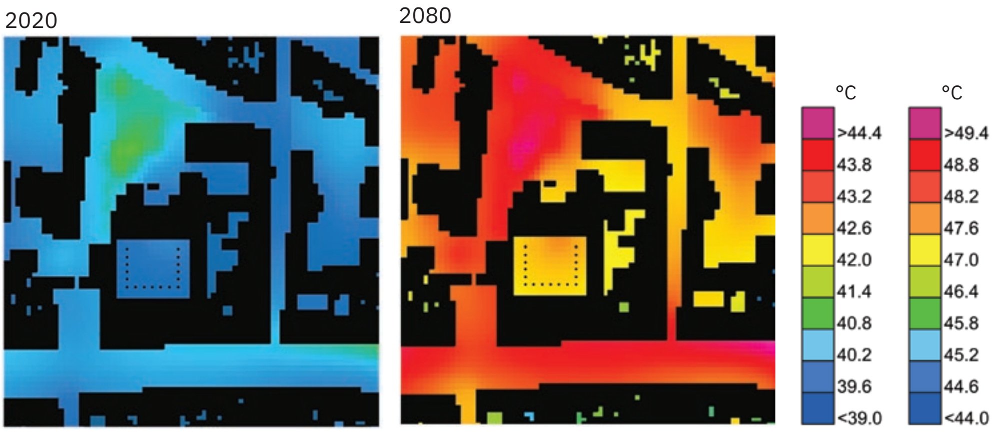
Air temperature is expected to increase by 8°C, with overheating of higher building floors (fig. 27). Inside the cloister (in the center), potential air temperature during the hottest time of the year is going to change from 40°C in 2020 to 47.6°C in 2080 (Fig. 28). The three covered sides provide better conditions compared to the surroundings, but still the situation is critical. (Fig. 29-30)

27



Change in air temperature in front of facades between the years 2020 and 2080 during the hottest time of the year (5th of August-15:00).

28



Potential air temperature at 1.15 m from the ground in 2020 and 2080 during the hottest time of the year (5th of August-15:00).

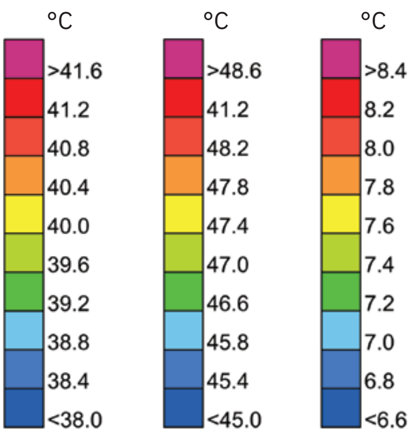
ENVI_MET

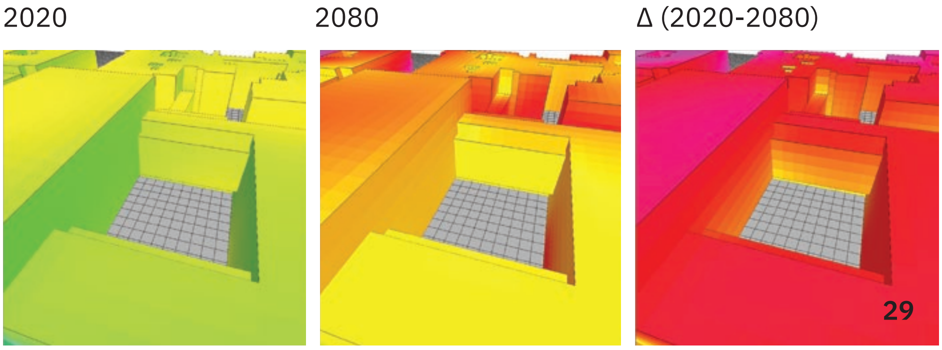
Universal thermal climate index

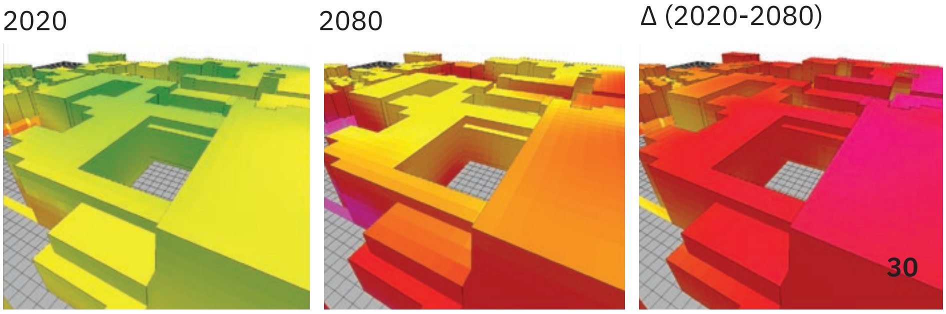
Comfort is already, and will be further compromised by increased direct solar radiation, lack of ventilation and higher air temperature.

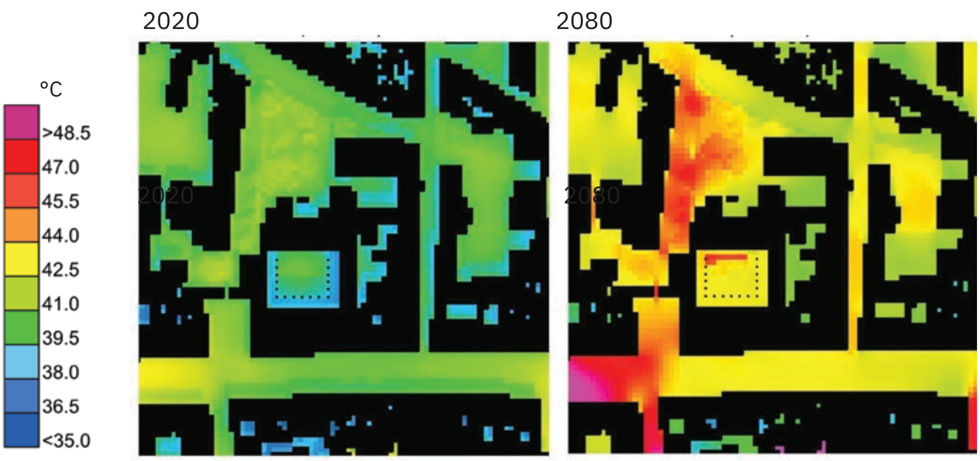
In 2020 the value under the arcades ranges from 35 to 38°C (strong heat stress-SHS according to UTCI classification), whereas values at the exposed part of the cloister reach 42°C (very strong heat stress according to UTCI classification). In 2080 this effect is not visible, with all cloister parts (both exposed and covered) presenting a value around 43°C (VSHS).
Lack of thermal comfort is an evident climate-related issue to be addressed. The comparative analysis reveals that the most resilient parts of the area are those with high LAD (Leaf Angle Distribution) vegetation, suggesting that the role of evapotranspiration is crucial to the mitigation of overheating in the urban context.

Air temperature in front of facades inside the cloister for 2020, 2080 and as a difference.









UTCI at 1.15 m height from the ground in 2020 and 2080 during the hottest time of the year (5th of August-15:00).

31

ENVI_MET

Issues

The ENVI-met analysis highlighted some critical issues. The thermal discomfort occurs due to three causes:

1. Excessive radiation
2. Lack of cross-ventilation
3. High-temperature

The focus is on simple solutions, addressing one cause at a time.

Solutions lead to partial improvements in comfort-showing their relative potential.

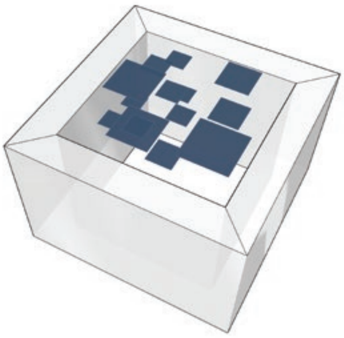
Mitigation of the excessive radiation affecting the upper part of the facades and the courtyard floor is a shading system. Lack of ventilation can be addressed by cross ventilation.

High temperature can be mitigated use of water and vegetation.

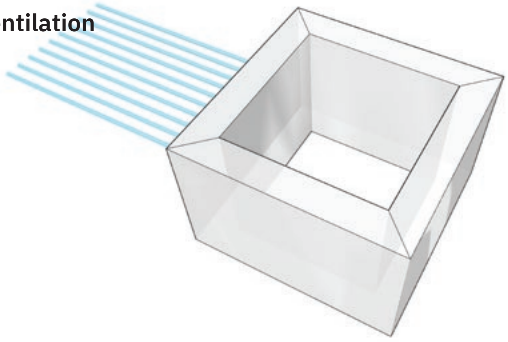
Excessive radiation

→

Shading

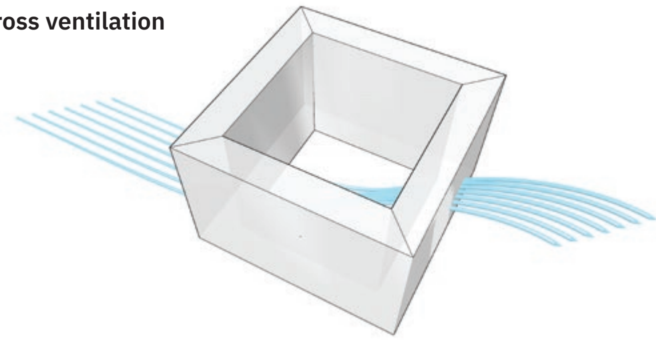


Lack of ventilation

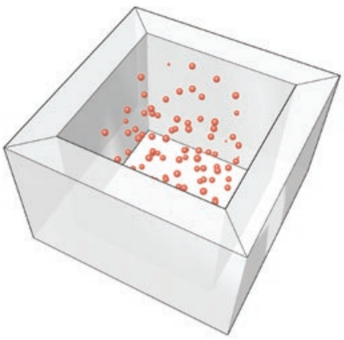


→

Cross ventilation

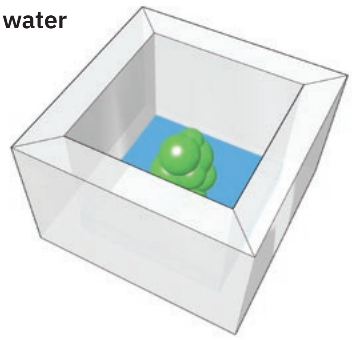


High temperature



→

Vegetation and water



ENVI
_MET

Inspiration from vegetation

32

33

34

Biomimcry “consciously emulates the genius of life” [3] and develops design solutions based on strategies found in nature. It leads to imitating the form and the strategy, or the process, or the ecosystem. This study examines three solutions based on their thermodynamic principles as an inspiration for the courtyard climatic adaption.

Shading – Cacti
The peaks-and-troughs pattern that encircles the thick stems or branches of cacti work in ways to protect them from getting too hot and dry. The peaks provide shade for the troughs, reducing the amount of solar heat that gets into them. (fig. 32)

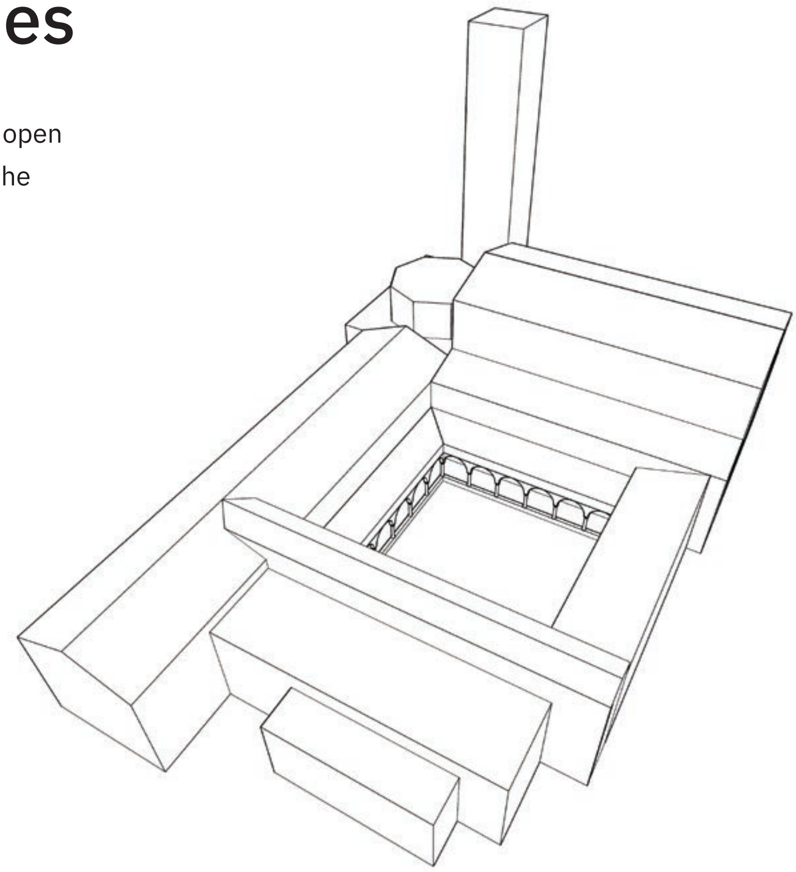
Ventilation – Monstera
In warm and humid areas plant leaves are large to provide shelter from the sun while still containing many nutrients, and thin ro facilitate thermal dispersion. Monsteria is an example of a tropical plant with large leaves with holes to support ventilation. (fig. 33)

Evapotranspiration – Sweating plants
Sweating in plants is activated by transpiration, which is the movement of water through the plant to the leaves. Plant sweat or guttation is the secretion of water droplets from the pores of the leaves and is used as a cooling mechanism. When the water evaporates from the leaves, heat is removed providing a cooling effect. (fig.34)

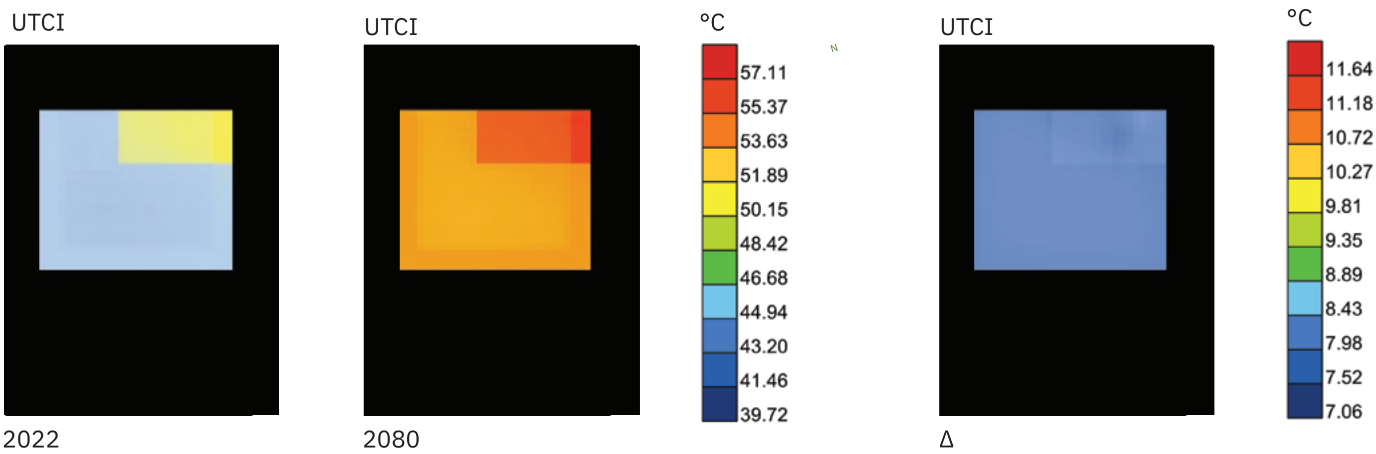
ENVI_MET

Microclimatic studies

The cloister simulation results show a criticality in open spaces of the cloister, with an increase of UTCI in the north-eastern part (fig. 36).



35 Ante Operam.



36 UTCI Simulation Results of UTCI of the Cloister in its current conformation.

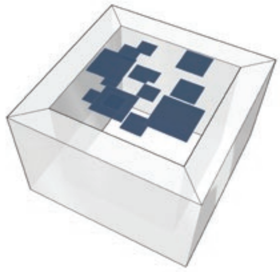
ENVI_MET

Strategies

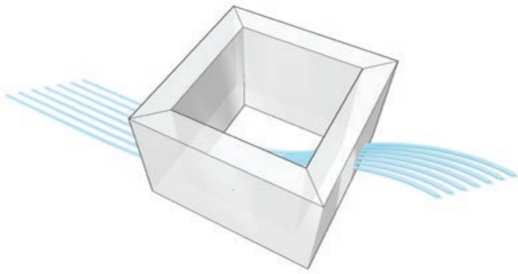
Three proposals

The study leads to the development of solutions for the three main criticalities identified earlier.

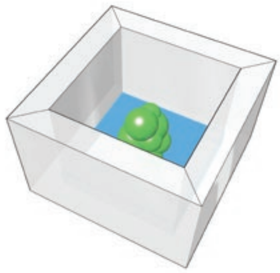
Shading
The shading of the upper part of the addresses the solar radiation. The analysis shows the internal facades of the cloister are very exposed to sunlight in summer, especially in the upper parts. The shading imitates the morphology of cacti (fig. 32) through vertical structures create shading without hindering the vertical radiation exchange.



Cross Ventilation
The closed conformation prevents ventilation.The cloister is protected from winter winds, but, in the summer period, this lack of ventilation causes thermal discomfort. The second design proposal works by subtracting volumes and creating an opening in one of the walls surrounding the cloister. The proposal imitates some tropical leaves that have holes on their large surface (fig. 33)



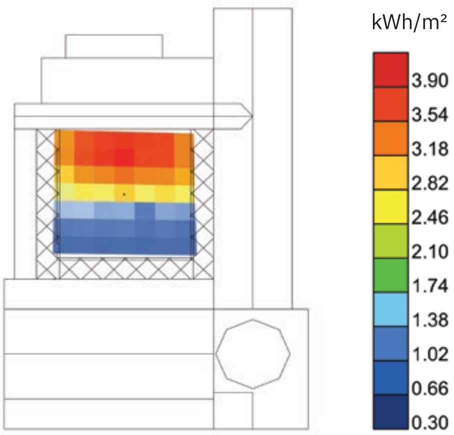
Water and Vegetation
The third project works to add a large pool of water and dense vegetation. The presence of water and vegetation create evatranspiration.



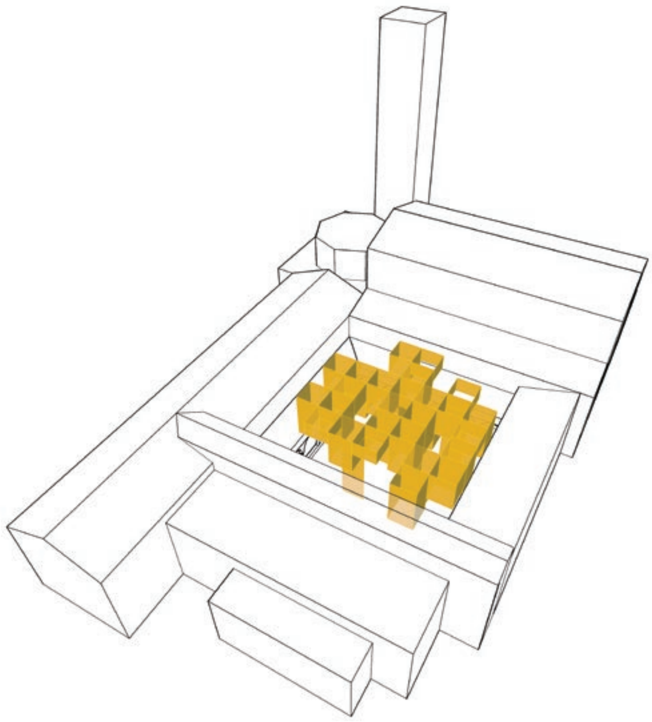
Shading

The shading structure, generated through a parametric and generative workflow, proposes vertical hollow elements descending from the roof. The algorithm subdivides the cloister area in a square grid (3,00 x 3,00 m) , and uses the downward extrusions with increments of 1 m as variable of the optimization process. The objective is the minimization of solar radiation at ground level, equalling that received by the side of the cloister shaded by the church.

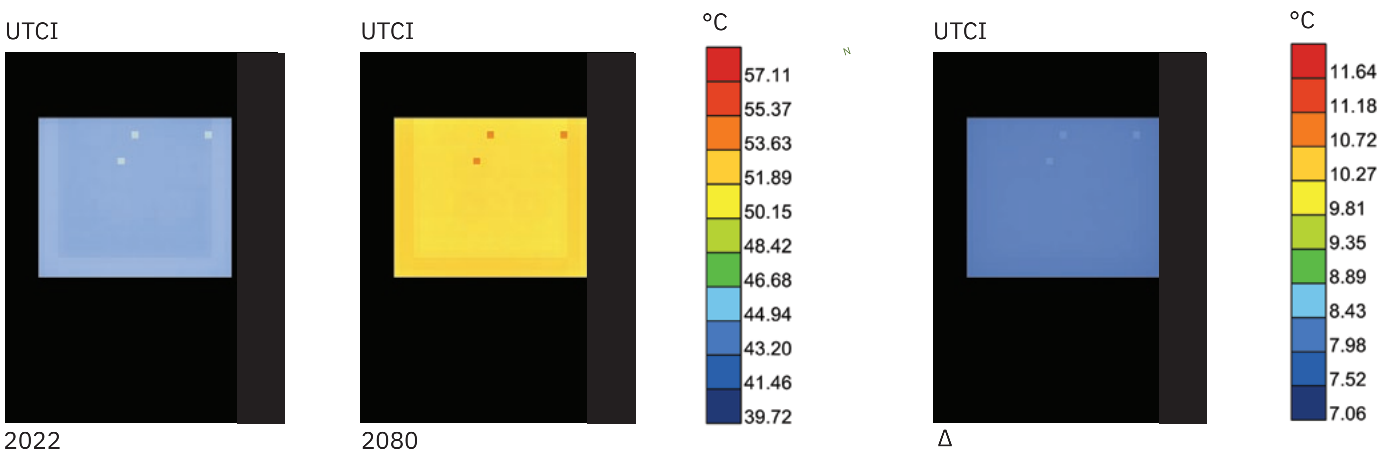
At 3pm the entire courtyard is sheltered from the direct radiation. A higher UTCI is recognizable under the arcades (sides east, south and west) due to the different materials on the floor(grass in the open area and granite under the porch).



37 Radiation Analisys ante operam



38 Shading project



39 UTCI simulation results in the shading project

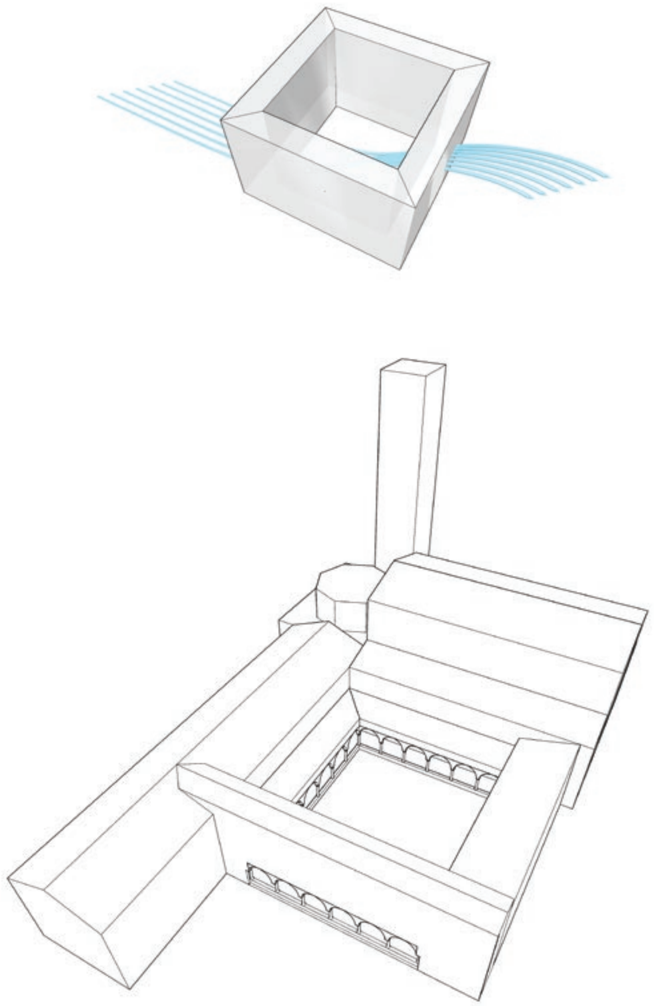
Cross Ventilation

The design solution proposes an opening on the north side of the cloister to favor horizontal ventilation. The northern, buffered side is restored to its initial form as an arcade.

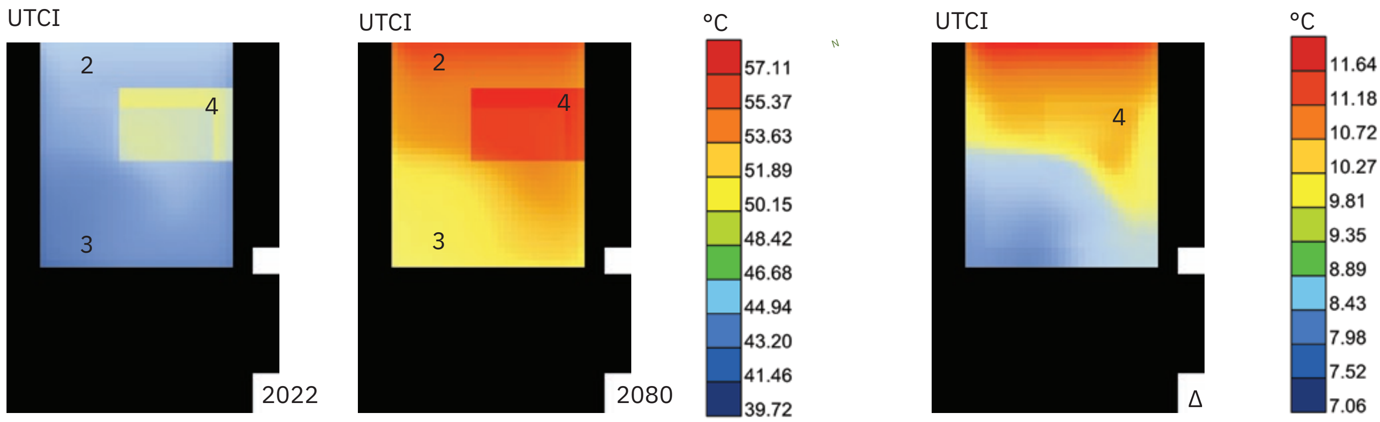
The direct effect of the big opening in the north façade of the courtyard is that air is brought inside the court via natural ventilation.

But this air is very hot when it enters, as we can see in point 2, and it gets cooled down by the effect of the permeable soil and the grass on the floor, at is is shown in point 3. In point 4 is visible the different re-action of different materials under direct radiation: the air over the granite pavement becomes hotter than the one over the grass in terms of UTCI.

However, in terms of Delta, which means resilience to climate change, the UTCI over the granite pavement increases less than that over the grass between 2022 and 2080.



42 Cross ventilation project



43 UTCI Simulation Results of the Cloister of San Sepolcro in cross ventilation project

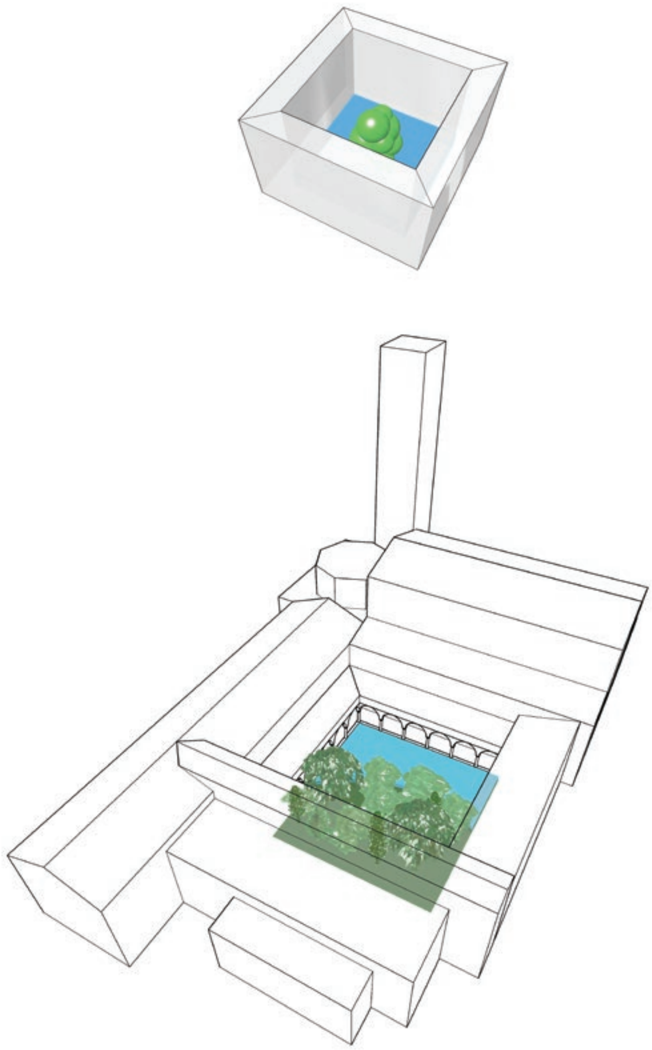
ENVI_MET

Water and vegetation

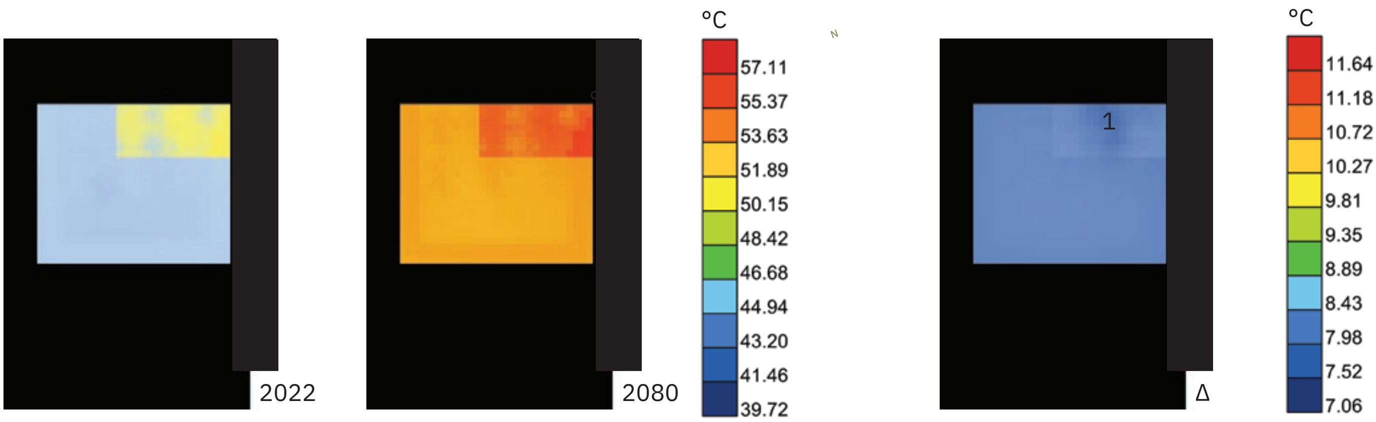
The project involves planting of dense vegetation and the construction of a large basin, covering about a third of the area.

No relevant difference in UTCI is recognizable between the water (Southside) and grass and trees.

There is a a reduction in UTCI (point 1) in areas shaded by trees, this accounts for a worse result in terms of delta 2022-2080.



46 Water and vegatation project



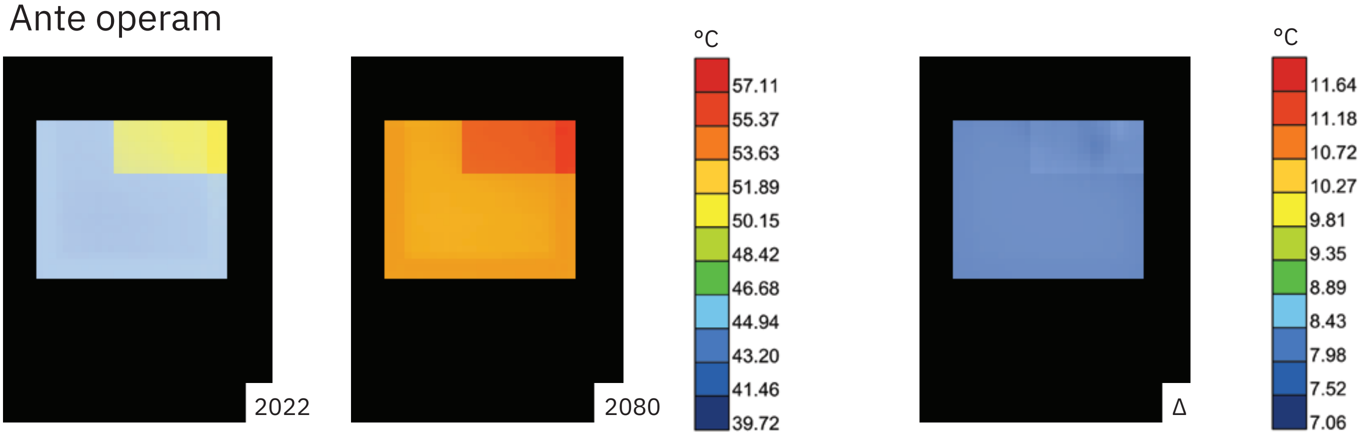
47 Simulation Results of the Cloister of San Sepolcro in water and ventilazion project

ENVI
_MET

ENVI
_MET

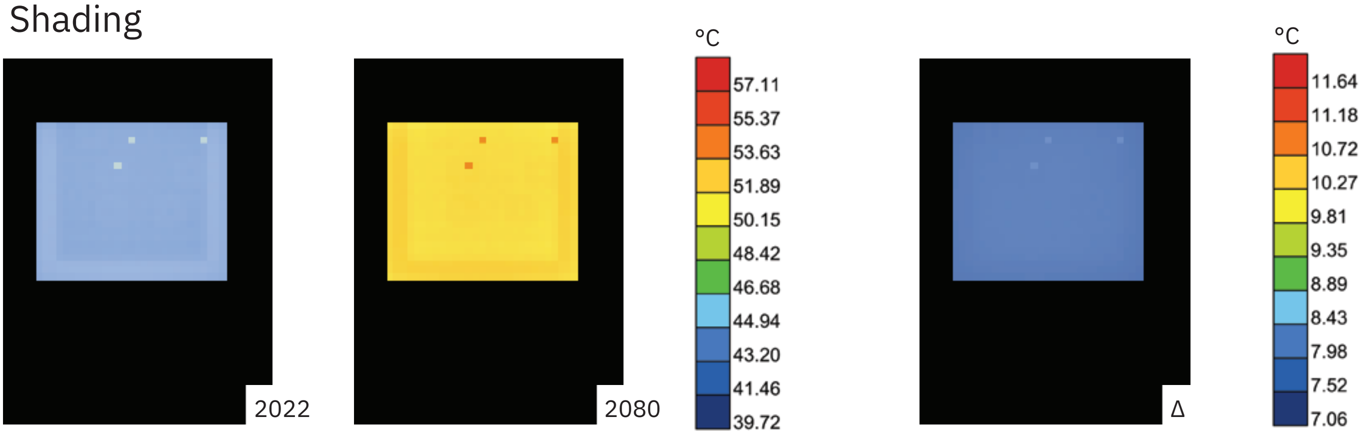
UTCI

Ante operam



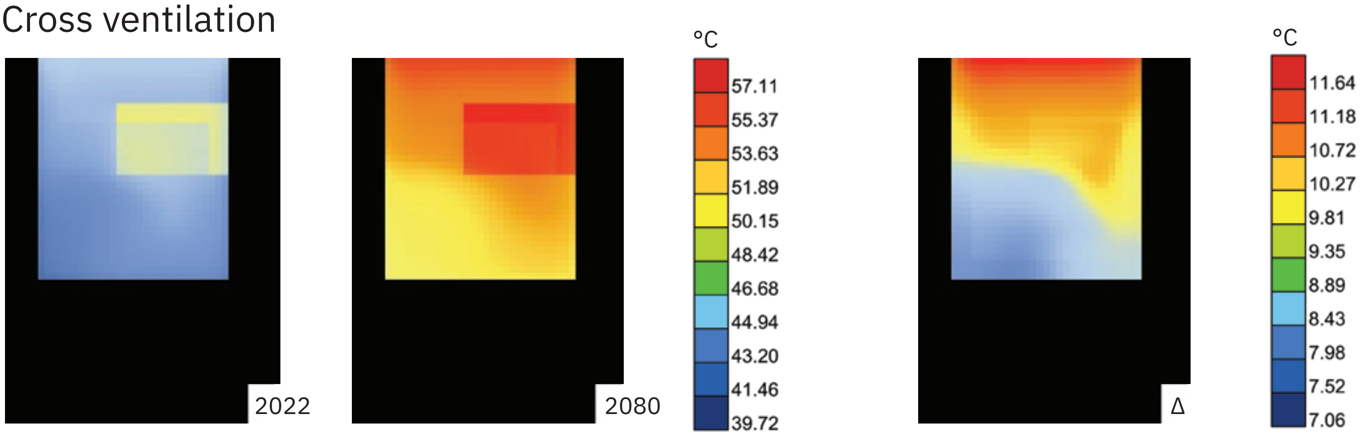
50

Shading



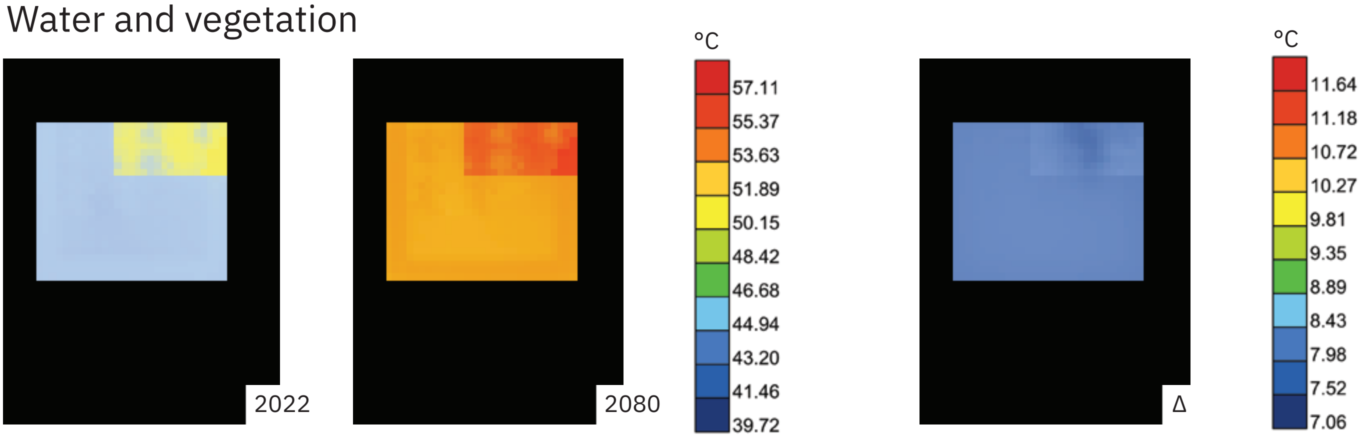
51

Cross ventilation



52

Water and vegetation



53

Conclusion

Results show that light interventions can counteract local climate change

The structure is meant to offer a pleasant climate despite urban heat islands and global warming. The design encompasses strategies derived from the study of overshading in cacti and ventilation from Monstera plants. The porous system is able to account for ecology, decarbonization, and health from now to 2080. The system moderates radiation and temperature, and by promoting ventilation, allows the creation of a pleasant habitat.

According to the study, climate change will affect mainly top floors. By proving a selective shelter to buildings in the upper parts the system allows to reduce building cooling loads without impairing views from windows and modulating daylighting. In terms of human health, the system provides an increase in pedestrian comfort and prevents.