Urban pervious concrete for thermal conditioning in open spaces: an adaptation to the climate change and the urban heat island effect.

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Abstract. UIA CartujaQanat project is part of a new vision of the urban environment, in which the way of thinking about cities and their spaces is changed, as well as in the interaction of its inhabitants with them. In this new concept of urban space, possible solutions to current and future needs, both social and climatic, must be found, since these environments have the responsibility to contribute to improving the lives of their inhabitants by minimizing the consumption of resources used in it. These solutions are the result of the knowledge gained from experience and tradition together with innovation and research.

The project incorporates passive techniques and bioclimatic solutions adapted to the hot and dry climate of the city of Seville, which is where it is located, trying to create semi-confined open spaces that provide a comfortable environment. The solutions adopted introduced water as a heat transfer fluid that allows these spaces to be tempered. Apart from other solutions such as bioclimatic lattices, we worked on draining pavements that, thanks to their permeability, allow the flow of water and the evaporation of air through their surface.

In this work the study of the use of pervious concrete flooring solutions and their advantages over the use of other materials is developed. Analysing its behaviour in its combination in hybrid pavements with vegetal soils or with fines such as silica sand, as well as other solutions that allow a constructive solution that reduces the temperature of the pavement using the evaporative effect, with minimal maintenance and cost.

Keywords: Urban environment, adaptation to climate change, heat island effect, pavements, evaporative effect

1. Introduction

Rising temperatures in urban areas, due to the so-called heat island effect, affect the increase of energy consumption and human health. Initiatives such as the Cartuja Qanat project are important for the development of innovative solutions that allow the transformation of urban areas, their adaptation to climate change, creating spaces in which during periods of heat. Urban citizens can interact in a comfort zone. The solutions proposed in these spaces must respond directly to current concerns about sustainability, environmental protection, social development and economic growth, concepts that first appeared in the document "Our Common Future". [1].
In Spain, the number of events in which anomalies have been detected with an increase in the highest temperature levels has been increasing over the years [2] with cities in the Mediterranean basin being the most affected by climate change [3], even influencing the mortality rate during the highest temperature sessions, such as the cases studied in Seville and Madrid by F. Follos et al. [4].

The moment we replace existing vegetation with impervious surfaces (ISA), we are contributing to an increase in surface temperatures (LST), which is not only dependent on these factors, but has an important influence as studied by J. Li et al in a case study analyzed using satellite photographs in Shanghai [5]. This has sparked interest in assessing this impact in many research articles, which according to the systematic review by S. Capman et al [6] the absolute change in temperature as cities grow in some cases is high, with temperature increases of between 0.5 to 5 °C, with these temperature increases not only during the day, but also producing dangerous nights of heat stress compared to rural areas.

The Cartuja Qanat Project incorporates passive techniques and bioclimatic solutions adapted to the climate of the city of Seville, creating semi-confined open spaces with a comfortable atmosphere. The solutions worked with draining paving allow the flow of water and the evaporation of air through its surface. The study proposes its use together with other shading solutions, such as bioclimatic lattices.

2. Background

2.1. Evaporative cooling

A study by J. Wang et al. shows that porous materials may absorb more solar radiation than denser concrete materials under dry conditions. It also highlights the importance of the surface of the element because it is directly exposed to water and this influences the absorption and evaporation capacity of the element. [7]

There are two stages of evaporation mentioned by J. Wang et al. The first stage is rapid and triggered by atmospheric conditions driven by capillary conditions where water quickly reaches the surface. In the second stage the water by viscosity and because capillarity cannot overcome gravity, an internal evaporation surface is formed. [8].

An example of the use of evaporative cooling is used by María del Carmen Guerrero et al. as a sheet of water exposed at night to radiation cooling, it can be used as a natural water cooling technique and its use in buildings to improve thermal conditions. [9]

2.2. Greening

Another method of increasing the water retention capacity of materials is to create hybrid elements where vegetation also forms an important part of these constructive elements, there are studies where it has been shown that vegetation is an effective system, usually studied in green roofs and vegetation barriers for space conditioning.

M.J.M. Davis et al. using an experiment in which air was drawn through the vertical garden, where the air was to be cooled in a similar way to a traditional swamp cooler, demonstrated that, using the ambient temperature and relative humidity measurements from the research, a vertical garden 3m high and 0.9m wide could cool an empty office space 3m high, 5m wide and 9m long. In addition, there would be plenty of room to expand the vertical gardens incorporated into the architectural design to meet other internal cooling loads if necessary. [10]

2.3. Pervious concrete pavements

In the study by Y. Liu et al. [11] used different types of permeable pavements in comparison to a non-permeable pavement to measure their surface temperature behaviour, the temperatures of four different pavement surfaces were monitored continuously for approximately one week, when the day after precipitation was continuously sunny or cloudy.

For about a week, the temperatures of the four pavement surfaces were continuously monitored when the day following the precipitation was continuously sunny or cloudy. The results show that the PPI
capillary columns drastically enhance evaporation, resulting in a much lower surface temperature than conventional pavements, especially at midday on a summer day.

J. Chen et al. used an experimental and simulated model to demonstrate the effect of thermal properties and temperature variations of conventional concrete, pervious concrete and high conductivity pervious concrete. The heat output from the pavement surface to the air was used to indicate the impact of the pavement on the UHI effect in dry and wet conditions. Indoor measurements showed that, in dry conditions, permeable concrete slabs have a higher surface temperature than conventional concrete slabs. In wet conditions, pervious concrete slabs cooled down faster than conventional concrete slabs, and showed a similar or lower surface temperature than conventional concrete slabs. This is mainly because the pores can retain some moisture and heat is absorbed by the evaporation of water. [12]

3. Aims and objective
The purpose of this study is to present the results of the use of permeable porous floorings for the thermal conditioning of open spaces. In order to evaluate their thermal response under controlled conditions, an experimental room was designed under a radiant ceiling to control the temperature of the experimental area and expose the floorings to an excitation caused by the emitted radiation, with this controlled area and using the water retention properties that these floorings have, being permeable surfaces, we can monitor the thermal response of different types of floor geometries.

4. Methodology
In order to analyse the use of porous concretes for the thermal conditioning of open spaces, it is necessary to start from the permeability conditions of the PCP and its possible geometries according to the environment, the urban environment and the commercial solutions, we also determine the environmental factors.

4.1. Experimental design of porous pavements
For this study, samples of draining porous pavement were used, using an appropriate dosage following the design method of John T. Kevern et al [13] to obtain the following characteristics of a PCP:
- Porosity 20%.
- Density 1900 kg/m³
- Compression at 7 days 13 MP

4.2. Geometric factors
Three types of draining porous pavement samples were analysed, with a hole factor as shown in the Figure 1 and Figure 2.

![Figure 1. Experimental probes (a) PCP 20% Holes (b) PCP 40% Holes (c) PCP Solid](image-url)
4.3. Study of climatic conditions and factors
Solar shading is one of the main design features necessary to avoid overheating of materials, reducing efforts to condition spaces and thus generating comfort zones, in addition to the solar protection it provides to the user in the interaction of urban areas.
The barrier solutions are elements that have design flexibility to adapt to each of the orientations of the spaces, and allow integration with the urban characteristics of each project, adapting according to the needs. Different proposals have been studied for the Cartuja Qanat project.
Another of the determining factors in the design of these vertical elements is whether the area where they are to be installed is protected against the wind. In order to do this, the prevailing winds in the location area must be analysed.
The most common measurements collected by the different weather stations, along with temperature, include atmospheric pressure, wind speed and direction (as we have seen in the previous chapter), precipitation, hours of sunlight and relative humidity. Adequate relative humidity is essential for the final result to achieve adequate comfort for the user.

4.4. Thermal modelling by finite element analysis
For the simulation model, the Steady-State Thermal module of the Ansys program was used (Figure 3), with a mechanical mesh. The boundary conditions were a radiation emitted by the hot jacket, the convection temperature measured at the test site, and a water contact surface on the three submerged samples. One sample was left without contact temperature to simulate the reference sample, which helps us to calibrate the model with the experimental results.

4.5. Monitoring of experiments under irradiated conditions
The experiment consists of exposing the pavements to controlled hot roof conditions. To measure their thermal response when partially submerged in water, due to the water-holding capacity of porous
pavements and the evaporative effect, we measure the response of these pavements to the surface thermal response, compared to an unsubmerged porous pavement.

**Figure 4** shows the configuration of the experiment and the hot roof system (**Figure 5**).

**Figure 4.** Experimental configuration

**Figure 5.** Experimental configuration (heating surface)
5. Applications

The effectiveness of paving systems depends on the shading and vegetation factors working together to decrease excessive evaporation of the water used, as shown in Figure 6 and Figure 7 lattices can be integrated to increase shading and combined with vegetation.

Figure 6. Industrial production source ESCOFET S.A.

Figure 7. Example of using shading and greening in urban open spaces

Figure 8 shows the water distribution when a paving system is combined with vegetation elements and an integrated irrigation system. However, for the pavement to perform its evaporative function, it is not necessary for it to be saturated. But it does need to have some humidity.

Figure 8. Example of water distribution

6. Results

The study compares different geometric configurations of permeable porous pavements, and a hybrid system in which vegetation is incorporated within the PCP.
6.1. Thermal performance

During 16 hours of the experiment, with an average initial pavement temperature of 20 °C, the radiant ceiling was heated to a temperature of 47 °C for the entire duration of the test.

All other surfaces are insulated, both floor and walls, the ambient temperature was measured at three points at different heights from the floor, at 5, 100 and 200 cm, the final temperature at each point being 28, 28.5 and 31.8 °C respectively. As shown in Figure 9.

Final water temperature was:
- For PCP immersed in water it was 26.5 °C.
- For the PCP with square holes it was 27.5 °C.
- Finally, for vertical louvres PCP and PCP without gaps, the non-submerged reference had a final temperature of 30.9 °C.

**Figure 9.** Experimental probes

The hybrid system with vegetation was also experimented in the following case, the surface temperature of the vegetated area decreases compared to the no vegetated area, also increasing the water retention capacity as can be seen in Figure 10 and Figure 11.

**Figure 10.** Experimental probes
7. Discussion
The studies carried out on a theoretical and practical level with the different geometries make it possible to work on the incorporation of bioclimatic techniques in the design of the projects with confidence, since the values have been positive for the intended purpose.

Different aspects affecting the performance and efficiency of the system have been analysed, providing guidelines for the combination of building elements together with evaporative cooling methods.

The results obtained are promising, although achieving a level of comfort in open spaces requires a comprehensive treatment. Not only pavements, but also other measures, such as shading barriers, need to be evaluated.

In order to complete the analysis and check the real performance of the elements studied for the project, the temperature controlled islands will be installed in-situ and monitored for a reasonable period of time.

The data obtained will finally allow the results to be related to the calculations made at a theoretical level, providing an in-depth knowledge of their operation with which to calibrate design and simulation models in the future.

For these strategies to be valid, efficient water use and management is necessary. The water used for the different strategies is heated during the day and is therefore subjected to a cooling process at night. In this way, the system can work in daily cycles without the need for external energy input for its correct operation.

8. Conclusion
The use of porous materials seems to be a way to condition urban spaces to improve the comfort conditions of people and as a way to adapt to climate change, being necessary the study in real conditions, that is why the importance of projects like CartujaQanat where these pilot projects show that the adaptation and the new way to use innovative construction elements is possible using in a better way natural resources and renewable energies.

As for the technical study of the surfaces, we can conclude that the surface temperature of the PCP behaves better thermally retaining water inside, which using the slow evaporation stage is a good solution to limit and control water consumption.

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