CERAMICS AND ENERGY EFFICIENCY: PASSIVE AND ACTIVE CONDITIONING SYSTEMS

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ABSTRACT

In this work, a presentation is made of some solutions of passive and active building conditioning systems in which ceramic materials play a key role. Their durability and lack of maintenance make them ideal for introducing these environment-conditioning systems. The control of their porosity even allows them to contribute to lowering the interior temperature through evaporative cooling, and thus form part of possible summer cooling systems. The paper presents a system of extruded ceramic pieces with evaporative cooling, a cooling system for double-skin glass façades with ceramic pieces inside and water spraying, an embraceable heated ceramic, vertical parasols with a photovoltaic panel on one of their sides and domotic control, ceramic nozzles that open or close depending on the air pressure, and an air recirculation solution on a Trombe wall through glazed ceramic pieces.

1. INTRODUCTION

At the Chair of Ceramics of the University of Alicante, we are committed to searching for conditioning systems that lead to energy savings in the use of buildings. In our view, ceramic materials hold a privileged position in this challenge. As well as the rationality of their manufacturing process in energy terms, and their being a material that has been universally used since time immemorial, the economy of their production, durability and lack of need for maintenance make them ideal construction materials in passive and active building conditioning systems. The control of their porosity even allows them to contribute to lowering the temperature of the contained water through the passing of water vapour – evaporative cooling – and, this way, form part of possible summer cooling systems. Some of the lines of research developed are explained below.

2. GRES-BOT (BOT STONEWARE)

The cooling systems of spaces by radiant surfaces appear to be a more comfortable and convenient solution for people's health, with not inconsiderable energy savings. The conditioning operating temperature is mainly obtained through the semi-sum of two parameters: the air temperature and the average radiant temperature of the parameters that make up the space. The Gres-BOT (BOT Stoneware) project consists of a system of prism-shaped ceramic pieces manufactured by extrusion with a square cross-section. In their interior, water is supplied through a network of tubes. Due to evaporative cooling, the water turns into vapour through the pores of the ceramic material, with the consequent drop in temperature of the water and of the surface of the ceramic pieces. Since the increase in relative humidity is very unfavourable for proper conditioning, this system should have permanent and significant natural ventilation. For winter conditioning, the temperature of the water would rise through solar panels and a support boiler, with an increase in the temperature of the ceramic surface. Adjustment of the summer water circulation and/or stagnation is done through thermostatic valves and electrovalves.

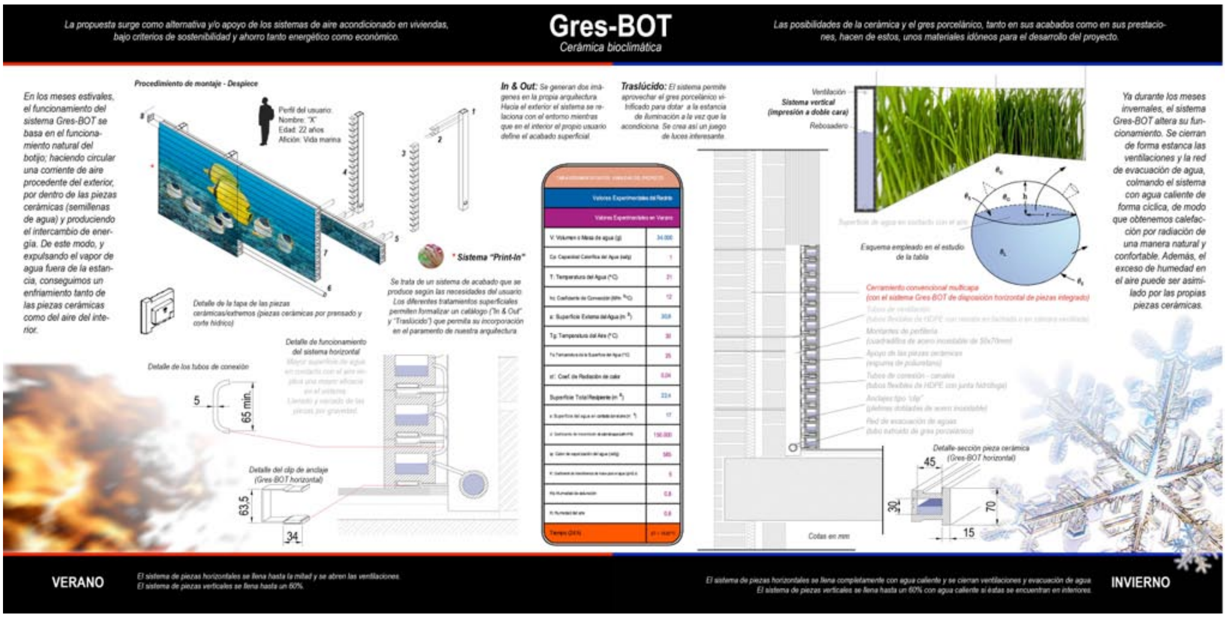

Figure 1.

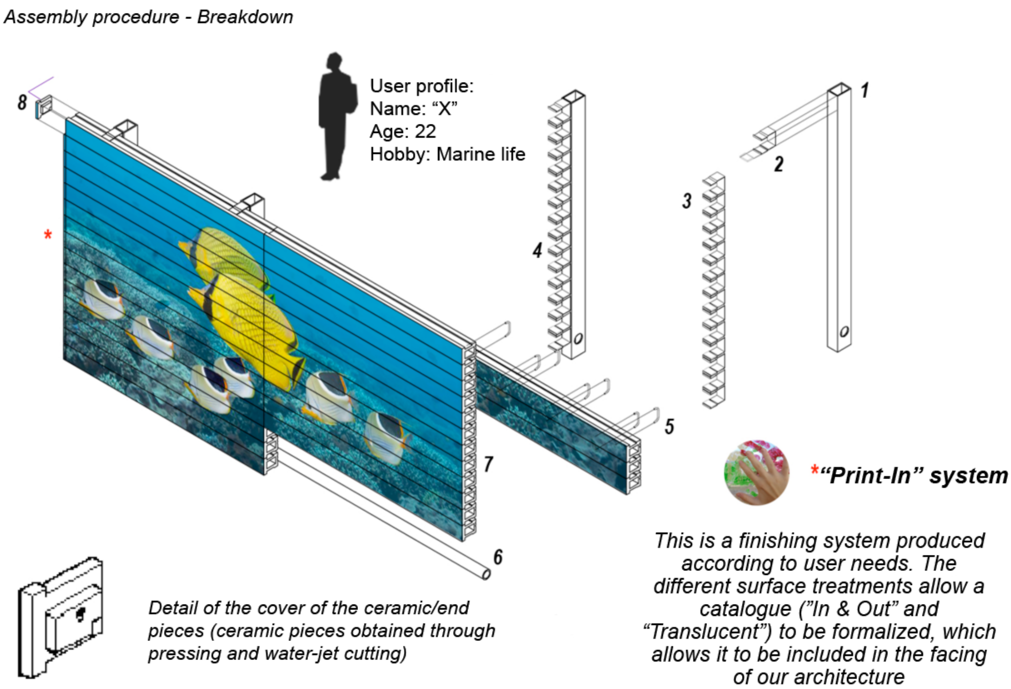

Figure 2.

The extruded piece also allows sand to lodge inside it. The water supply process would dampen the sand inside. The system would have more thermal inertia and soundproofing. The water evaporation process through the ceramic pores will lead to a drop in sand temperature and, therefore, in the ceramics. The quantification of the drop in temperature in the sand chamber can be estimated according to the model developed by M. Bah Abba [1], according to which decreases in interior and exterior temperatures of up to 14º C are obtained, picked up by sensors of 1 to 1023 measurement parts, as seen in the graph. While the outside temperature is 28 ºC, on the inside it is 15 ºC.

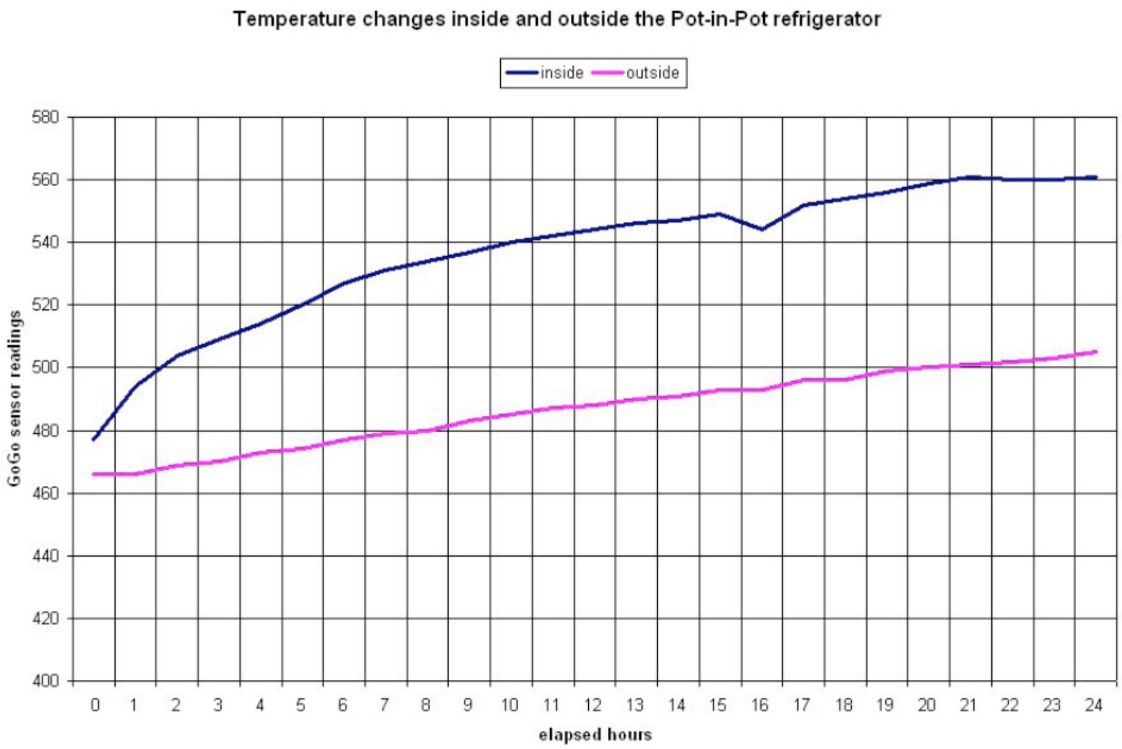

Figure 3.

Time after starting up the Evaporation-driven Refrigerator	Temperature inside the container (ºC)	Outside air temperarature (ºC)
15 minutes	23.7	23.8
20 minutes	23.6	24.0
30 minutes	23.2	23.8
40 minutes	21.7	24.7
1 hour	21.0	24.8
1 hora 15 minutes	20.4	25.0
1 hora 30 minutes	20.1	24.7
1 hora 40 minutes	19.9	24.7
2 horas 30 minutes	19.5	24.0
2 horas 40 minutes	19.4	24.4
13 hour	19.4	25.0

Table 1.

3. DISTILLATION TOWER

The object of the research arises from the need to obtain glass façades on which the supply of solar radiation is naturally controlled. Inspired by the effect produced in distillation towers, the developed construction system consists of a double skin of glass which stores a three-dimensional ceramic network in its interior. The ceramic pieces have been designed in a circular shape, as occurs in distillation towers, to obtain the maximum surface with the minimum material and, thus, achieve a greater energy exchange between the air mass that circulates through the chamber and the network of ceramic pieces. This maximizes the friction with the surface and the air takes longer to rise through the chamber, improving the comfort temperature in it and gaining stability throughout the height of the building.

This system is also combined with the presence of moisturizing decks, which vaporize water and evidently reduce the chamber temperature with evaporation. The final result is a ceramic latticework that controls solar radiation by air circulation through controlled openings, friction, and the humidity vaporization heat provided by the system on the deck fronts.

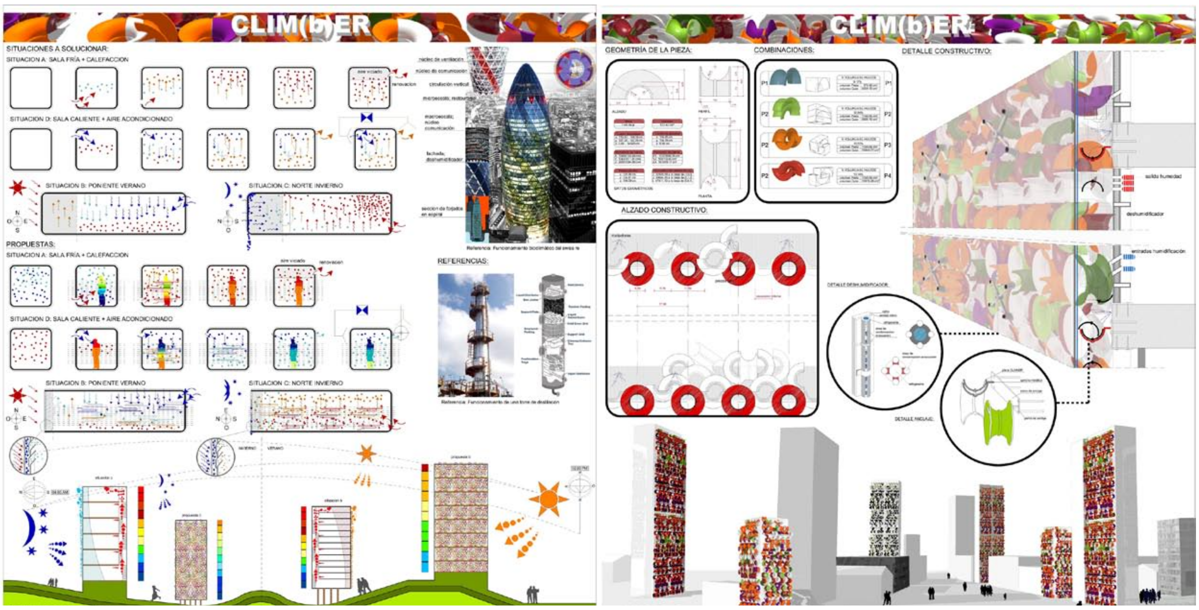

Figure 4.

3.1. Concept: the distillationn tower.

A distillation tower's function is to separate components in a liquid form found mixed: the mechanism is simple when these components have very different evaporation and condensation points to each other, but when these parameters are similar, obtaining the appropriate temperature becomes a complex process. The material incorporated as a system in its interior is considered a series of highly frictional parts when the airflows go through the tower; it does not block this flow, but it does delay the time it takes to rise or drop, thus producing heat exchange between the very cold descending and the very hot rising air masses, which makes those intermediate temperatures necessary for obtaining the distillation of the mixture.

The thermal segregations produced at heights in buildings due to the rise of hot air masses through the communication centres are usually significant [2], and the settling of air that is too hot and humid on the upper floors, and dry and cold air on the lower floors create polarizations inside the building height. This harmful effect tends to be corrected by increased energy use in the form of heating or air conditioning.

Therefore, the proposal consists of creating a device that handles the four critical situations arise, depending on the type of exposure the building is subjected to (northern façade in winter, or western façade in summer and warm area, etc.). This device is made up of three components: the moisturizing deck, the dehumidifying channels and the friction infill.

3.2. Friction infill.

This consists of a series of ceramic pieces with a design that attempts to optimize their thermal performance through elements that provide the maximum contact surface with air and humidity due to their geometry, while in turn having the maximum void volume in order to prevent unexpected condensation at undesirable points inside the façade chamber. These pieces tend to slow down the time that the hot air takes to rise, and the maximum possible mixture when necessary (west in summer) with the humidity introduced into the chamber. This improves the comfort temperature in the chamber, as well as temperature stability throughout the height of the building.

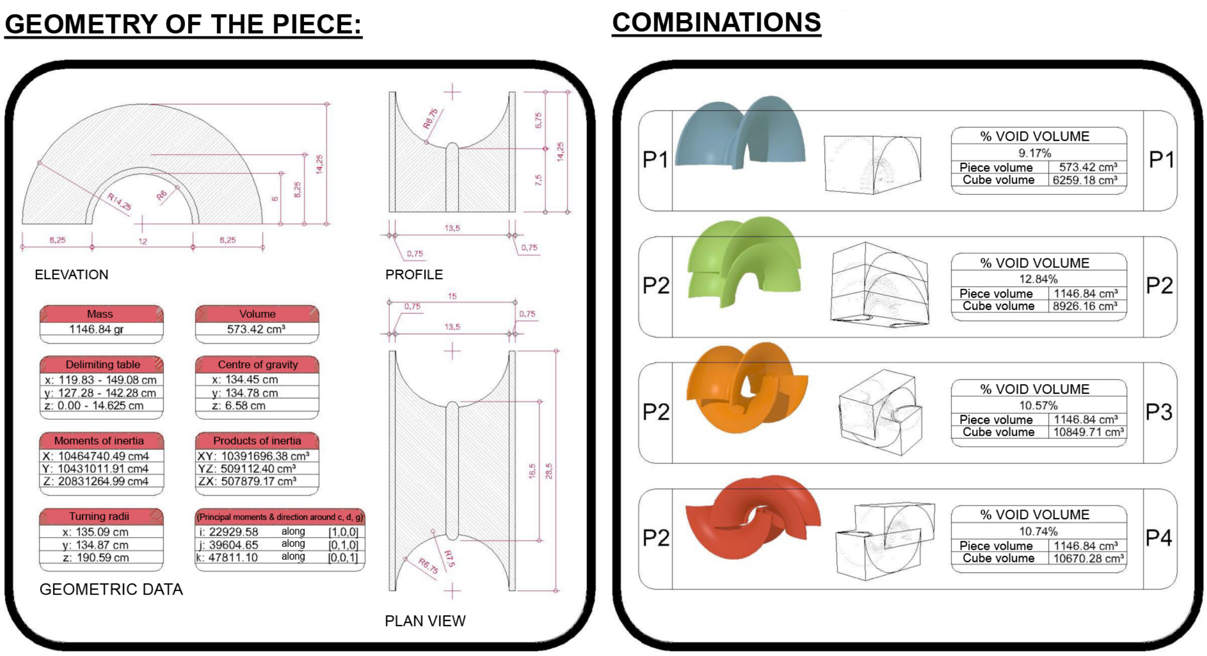

Figure 5.

3.3. Moisturizing decks.

The façade consists of a network of ceramic infill through which a water refrigeration system circulates with water that vaporizes on the deck fronts. For this, there is a water distribution system through polypropylene pipes that run through the deck fronts. Thus, through the effect of the exposure to the sun of the western façades, part of this cooling water evaporates with the resulting palliative effect of the heat excess from this exposure to the sun, with part of the heat being absorbed in the evaporation of the cooling liquid. This chamber, which looks plant-like thanks to the ceramic network, has a controlled ventilation system through openings in the top and bottom for evacuating the arising water vapour and for dissipating the hot air.

3.4. Image.

For its part, the architectural image obtained is that of a large, almost "plant-like" structure that can have a certain dialogue with ecology and the landscape, not only in the formal sense but also in its behaviour. One interesting feature is its capacity for being parameterizable with respect to colour criteria, it being known that a certain heat absorption corresponds to each colour.

4. AN EMBRACEABLE CERAMIC

The idea is inspired in traditional heating systems using ceramic bricks put in the fireplace of rural homes, later used for heating the bedrooms at night. The idea arises from the memory of a childhood in the north, of a traditional system that makes the home the unquestionable dwelling domain. The system consists of placing ceramic bricks or stones inside the fireplace halfway through the afternoon. The stones heat up during the afternoon so that they can be taken out at night and put into the bed to be able to sleep peacefully while the bricks emit the heat they have been receiving.

The system consists of a refractory ceramic piece glazed with high thermal inertia, with an ellipsoidal shape, made through casting, which include a printed circuit of conducting material inside. This piece contains an electric connection system for accumulating energy during the day. Its mass enables it to accumulate heat energy that can then be given off during the required interval of time. This removable part can be hung on the wall with a simple fastening system that provides direct connection to the electric circuit.

Figure 6.

Another variant of the system consists of using a hot water circuit for heating the piece. Through flexible pipes, it would be connected to the fastening device on the wall by a fast "click & cool" socket joint, used, for example, in KaRo hair wefts [3]. At the manufacturing stage, after the firing, polypropylene pipe coil would be introduced into the interior through the space that exists for pouring the paste. The inside space is filled with helium, an odourless, non-toxic heat conducting gas. The space would be closed with another glazed ceramic piece.

5. GIRAPLAX

The system consists of a solution of ceramic pieces for façades, and it is inspired by the shape of a traditional abacus calculator. The ceramic pieces fit into a vertical axis on which they can turn. They can adopt different sections – rectangular, polygonal, ovoid – and lengths, but work has mainly been done with triangular prisms. A photovoltaic plaque which produces electric energy is placed on one of its sides [4]. Since it can turn on its axis, the plaque can be directed throughout the day for a higher energy performance of the system through a solar tracker system. They also provide a changing image of the building throughout the day until night falls, when the piece would only show its ceramic part.

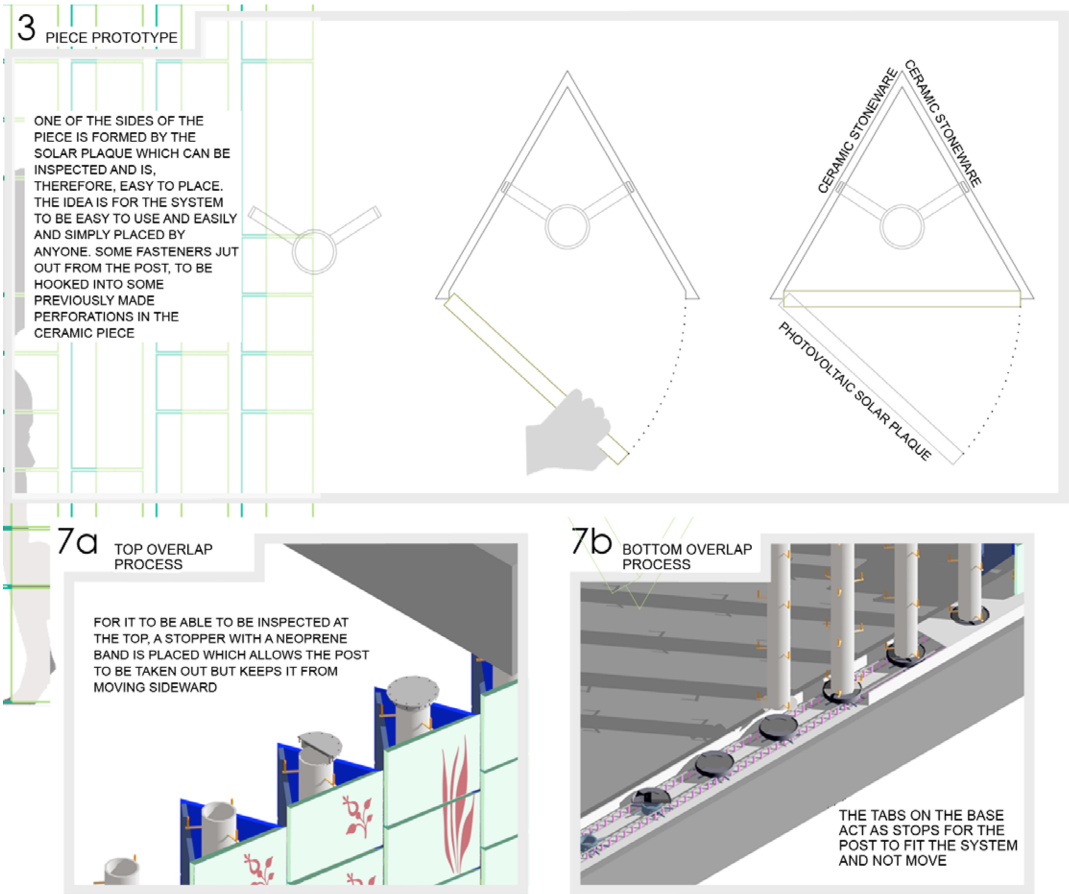

Figure 7.

The photovoltaic plaque has an average size of 20x20cm. We have chosen a model that has an energy production of 1000 W/m2 at 25°C, with 16% efficiency, so each piece can produce about 40 W power and each column of pieces about 560 W [5]. This means that a façade with this system can produce the necessary energy for the independent functioning of the general grid in the case of an apartment building, as well as cover the lighting in the building's common areas.

The ceramic pieces can be inspected. They can be opened on the side of the solar plaque for fitting a metal pipe onto the axis. They are held by gravity thanks to some fasteners included in the pipe. They are easy to move for maintenance or to change pieces. The electrical installations remain hidden inside the pipe. The metal pipe is fitted into the base by a system of tabs, which, when it turns, fits in and stops movement outside its axis. The turning of the pieces works through a motor which makes a chain turn that is hidden by a box on the base of the system. The chain makes all the pipes in a row turn simultaneously through a dented wheel located under the base of each pipe, like a bicycle wheel. All the rows are connected to a domotic system that allows the entire system to be simultaneously controlled according to the solar radiation perceived, or at the will of the user.

In the same way, the pieces can have a multitude of colours and textures, and can play with the movement of the system and the changing light throughout the day to obtain surprising results. The modern printing techniques in ceramics could even allow façades to be used for publicity by printing part of the desired design on each side of the piece to obtain changing designs. The final result of the system is that the user can adjust the entrance of sunlight and ventilation, while electric energy is captured with maximum performance, thanks to the solar trackers.

6. DIAPHRAGMS

A line that stirred our interest from the beginning was the possibility of using ceramics as materials capable of letting air through into spaces. The most universal materials for this are metallic, for obvious reasons. However, in our view some ceramics properties also make them ideal in this field.

Figure 8.

We chose the nozzle as a field of experimentation. When we thought of the design of a nozzle, we wanted to avoid the conventional funnel idea and shape, as a static and passive element in the air conditioning installation. Our piece was to play the leading role in the installation, itself expressing the system functioning. A triangular-shaped structure was designed, made up of six identical glazed pieces manufactured using moulding technology. They are all fitted by a type of tongued and grooved joint which allows one to slide on the other when the impulse air exerts a minimum pressure. As soon as the output pressure of the air conditioning stops, a spring returns the system to its resting position, with the hexagonal opening completely closed.

We thought of the nozzle as an organic, live being. This way, it expresses its functioning by opening like a diaphragm when the air flow passes and closing when the air stops. Air circulates through its veins. A live, throbbing being that moves through impulses, impulses caused by the pressure that the air creates on it.

7. TROMBE WALL

The Trombe wall is a passive system for indirectly collecting solar energy, which is used for heating the inside of homes at night using heat transfer from a wall with sufficient thermal inertia to the air inside a space. This wall works by absorbing solar radiation on the outside through the greenhouse effect, transferring this heat through the wall by conduction. The wall must have sufficient calorific power (Cp) and thickness to accumulate enough energy. The most usual materials are stone, ceramics, and concrete. The thicknesses vary between 20 and 45 cm (table 1). The surface of the wall depends on the surface of the interior space to be heated (table 2). In front of the wall there is a closed air chamber, between 20 and 50 cm thick, with glazing, as a solar thermal collector. The glass surface area must be between 7 and 12% of the area of the house. The system faces towards the incoming sunlight, between 5º and 15º from the true south, and the radiation energy is accumulated in the wall due to the greenhouse effect. This gradually heats up during the day. Wall thickness must be such that wall thermal conductivity (*k*), effusivity (*ε*), and diffusivity (*a*) prevent heat from entering the room during the day. During the night, in the months when the interior space requires heating, owing to the drop in outside temperature, vents at the top and bottom of the wall allow the room air to circulate through the chamber, introducing the heat accumulated in the wall due to the chimney effect. The energy accumulated by the wall needs to be sufficient to maintain an average temperature on the inside of 18°C to 20°C for 24 hours.

Material	Recommended thickness (cm)
Adobe	20 – 30
Brick	25 – 35
Concrete	30 - 45

Table 2.

$$\alpha = \frac{K}{\rho \cdot c_p} \qquad e = \sqrt{(\kappa \rho c_p)}$$

Equation 1.

Av. outside winter temperature	Wall surface area needed per unit useful surface
	Wall
Cold climates	
-10 ºC	0.72 > 1.0
-7 ºC	0.60 – 1.0
-4 ºC	0.51 – 0.93
-1 ºC	0.43 – 0.78
Warm climates	
+2 ºC	0.35 – 0.60
+5 ºC	0.28 – 0.46
+7 ºC	0.22 – 0.35

Table 3.

Our approach consists of using ceramics not only as elements for accumulating energy in the Trombe wall, but also as materials that serve to open and close the convection currents. We designed an assembly of ceramic pieces using a trumpet as a reference. These are set in openings in the wall, with the larger part trapped in the air chamber. The "trumpets" can be moved by hand according to the user's needs, such that, when stuck to the glass, they let no air through and when separated from the glass, they allow a flow of hot air during the night.

In order to define the size of the openings, experience dictates that their surface area must be sufficient to guarantee a uniform and constant flow, without causing any sudden movements of the circulating air. It is suggested that approximately 1dm^2 per m^2 wall should be taken as the total surface area of the openings in one row: i.e. 1% of the wall surface area. With this information and knowing that the maximum length of the façade needs to be 8 m for the interior space to be heated, we proposed 16 "trumpets" at the top and another 16 at the bottom, with a 10-cm diameter opening, so we managed to achieve an open surface area of approximately 1dm^2 for every m^2 wall surface area.

$$A_1 + A_2 + \dots + A_n = \frac{L \times H}{100}$$

Equation 2.

As well as the openings in a Trombe wall, there must be a distance of more than 1.5 m between the openings for them to work properly. Our proposal consists of pieces with different diameters, with separations in height of between 1.50 and 1.80 m.

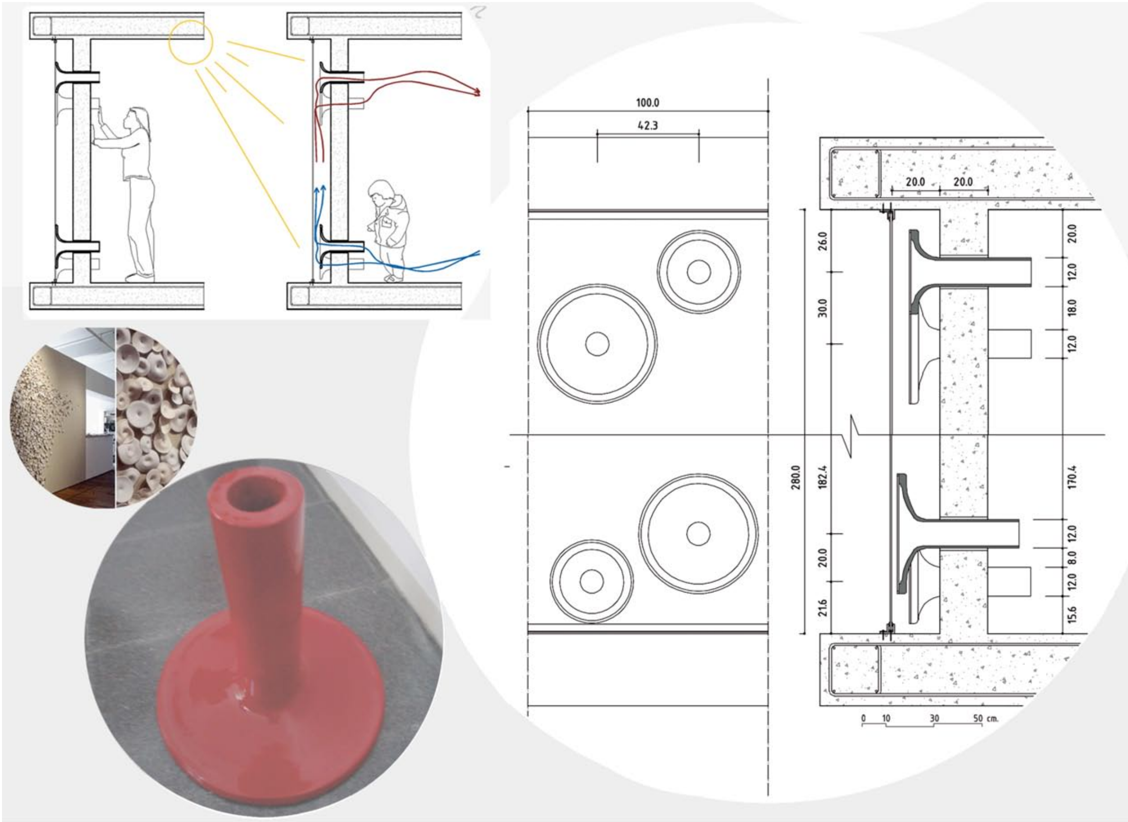

Figure 9.

8. CONCLUSIONS

Although the solutions presented have not yet been prototyped and, therefore, their functioning and the quantification of their energy efficiency have not yet been studied, we can conclude that ceramic materials can help efficiently to create sustainable and energy-efficient solutions [6][7] in architectural and urban conditioning [8] owing to their effusivity, variable porosity which allows an almost zero absorption or evaporative cooling, high thermal inertia, adaptation to the most varied forms and surfaces, durability and their lack of maintenance and manufacturing economy. Ceramic materials can be used in passive and active conditioning systems, in systems with high technological backing, and in other bioclimatic systems [9], and contribute to creating more sustainable architecture.

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