INTRODUCTION OF CERAMICS IN PASSIVE HOUSE CLIMATE SYSTEMS

M. Bartolomé Álvaro, J. Corrales García, J. Mira Peidro, J. Ramón Albors

Instituto de Tecnología Cerámica (ITC)
Asociación de Investigación de las Industrias Cerámicas (AICE)
Universitat Jaume I. Castellón. Spain

ABSTRACT

This paper presents the results of a research project aimed at introducing ceramics in passive house climate systems in warm environments. The incorporation of ceramics into climate systems has been carried out keeping in mind the reduction in energy consumption and the contribution of aesthetic improvements, durability, etc. of the climate systems.

Taking as a starting point the climatic criteria and systems of the Passive House for cold climates, an adaptation of this type of house to a typically southern climate has been carried out, creating a house model on which a series of passive systems have been defined, using ceramic materials that act as collection, heating, and cooling systems.

Systems which have energy saving as their end goal have been justified in a first estimative assessment, using the LIDER and PHPP software to analyse and assess the systems under energy-saving criteria. Due to limitations in the software, several assumptions have been made in order to be able to introduce passive systems into the software.

1. INTRODUCTION

Bioclimatic architecture refers to applications in which solar energy is directly collected, stored, and then distributed, i.e. without the need for mechanical equipment. Constructive solutions are designed and provided that allow the building in question to reject or capture solar energy according to the time of the year, with the ultimate aim of controlling this energy according to heating or cooling needs. In these cases, the use of the radiation that reaches the building is based on the optimization of the orientation, and the definition of the volumes and openings of the building, the choice of appropriate materials and the use of specific and suitable design elements. In this context, any building located in cold environments, which require no type of additional system for heating and cooling of the internal inhabited space because they are heated or cooled in a purely passive way, using energy from the environment, are included in the passive house concept (the passive house heat demand does not exceed 15 $kWh/m^2 \cdot a$).

The passive house is a concept which first saw the light of day in northern Europe. Nowadays, the reference for the passive house concept is a group of houses built in Darmstadt-Kranichstein (Germany).

Passive house techniques are essentially based on good thermal insulation, passive use of solar energy thanks to so-called super-windows, high-efficiency recovery of exiting-air heat, and passive pre-heating of the incoming fresh air.

The passive house is a typical model for cold North European climates, which is why it is necessary to modify certain basic criteria of the original model in order to adapt it to warmer climates, in addition to seeking new solutions in the bioclimatic architecture tradition, using other heating systems and promoting cooling systems.

2. DESCRIPTION OF OBJECTIVES

To start with, the passive house concept for cold climates was adapted to typically southern climates, bearing in mind that there were fewer heating requirements, whereas there were more cooling needs. In order to achieve this objective, design concepts had to be changed, modifying the systems that were part of the passive house.

Ceramics were introduced into the adapted systems for warmer environments, parts of the systems being replaced with ceramic materials. To do so, the features of ceramics and the functions that they performed in the system were kept in mind. As a result, two groups of passive heating and cooling systems were obtained with ceramic materials, according to the contributions that ceramics provided. On the one hand, there were systems that provided energy saving thanks to the ceramics they contained, the systems being evaluated in an estimative fashion with the

LIDER and PHPP software and, on the other, there were systems that enhanced the aesthetic features and durability of the system.

The objective was to promote the use of ceramics in so called passive houses by incorporating ceramic materials into the passive systems used in the logical design of passive houses, since ceramic materials, thanks to their characteristics, should be able to play different parts in these types of systems.

The project's main contribution has been the introduction of ceramics into a new field or, at least, one in which ceramics have only participated to a limited extent, providing ceramics with a specific function, directly or indirectly linked to reducing energy consumption.

The study has established new possibilities for the use of ceramics as functional materials in a bioclimatic system, using industrially produced standard ceramic products in the majority of the passive systems.

3. DEVELOPMENT OF THE RESULTS

3.1. Passive house systems.

The key to passive houses is air tightness. A house only becomes cold when it loses heat to the exterior and it warms up in relation to the amount of heat it receives from outside. In a passive house, this heat loss is reduced in such a way that the inside heat (from people or devices in the home) and the energy from the sun are almost sufficient. Passive house energy consumption is one tenth of current overall energy consumption in a standard house.

Several strategies are used to obtain the necessary energy from the environment, which are more or less suitable, depending on the climate. Typical collection systems include the following:

<u>Direct collection systems</u>. The collection, accumulation and storage of energy occur in the living space itself, so that the living space itself acts as a collector. These systems vary, from windows with nocturnal thermal insulation, to complex mechanisms that use direct radiation, diffuse radiation, reflection or concentration features, etc.

<u>Collector-accumulator wall</u>. These walls are designed to control the thermal conditions of the living space. Normally this would call for materials of high thermal inertia. The collector zone is built on the outside of the wall and can be made from many different materials, provided they allow the passage of solar rays and are impermeable to infrared rays. There should be a 5-10 cm spacing between the elements, in order for the air chamber to function properly.

<u>Trombe wall</u>. This also uses the greenhouse effect that develops inside the air chamber between the glass and the internal wall, but it maximises its

effectiveness thanks to two sets of vents with flaps (one at the top and the other at the bottom) which, by combining the openings, enable the internal temperature to be controlled.

Parietodynamic walls. This is an envelope that uses solar energy to preheat the ventilation external air. It generally consists of an inner leaf of brickwork, an air chamber, and a glass or metal outer leaf that absorbs solar radiation. Air circulation can be natural (thermosiphon) or forced.

Airtight roofs. This system consists of considering the roof as a type of receiver-accumulator system, generally consisting of water stored in large plastic bags of 15–30 cm. It is important that the receiver-accumulator system should be able to protect itself from heat during summertime.

Independent collectors. Greenhouses and bay windows. These systems, just as the direct/indirect collection systems, are based on the greenhouse effect. They consist of two differentiated areas, the solar collection zone, (glass), and the storage zone (solid brick).

Passive cooling and natural ventilation systems. Due to the scant resources, or scant sources of natural cooling, it is particularly important to avoid overheating. Therefore, the first factor to be kept in mind is the need to minimise direct solar radiation on the building, using filters to screen or eliminate this.

Cooling systems by evaporation use the necessary energy consumption to change the state of water from a liquid to a gas. It is important that the environment should not present high relative humidity levels that add to the water vapour provided by evaporation.

3.2. Adaptation of the passive house to warmer environments.

As a result of the adaptation of the passive house to warmer environments, a type of bioclimatic house Model has been designed for warmer climates, with a useful surface area of 90 m^2. This model was used to introduce passive ceramic systems into the LIDER and PHPP software.

To define the house model adapted to warmer environments, certain design and sustainability criteria were established, which included the following:

- Cross-through or open-ended units. Bedrooms, respecting individual privacy. The internal doors are fitted with small grills that allow uninterrupted ventilation of the rooms without compromising privacy.
- Increased façade surface area, decreased party wall size.
- Predominant facing: north-south. Openings in the northern façade: 10%-20%, openings in the southern façade: 50%-60%.
- The façade as a passive heat-producing element, from solar energy and its transformation into heat.

- Chimney effect. The stairwell acts as a solar chimney, creating a continuous current of air.
- Crossed-through east-west ventilation, using air streams from the sea on summer nights.

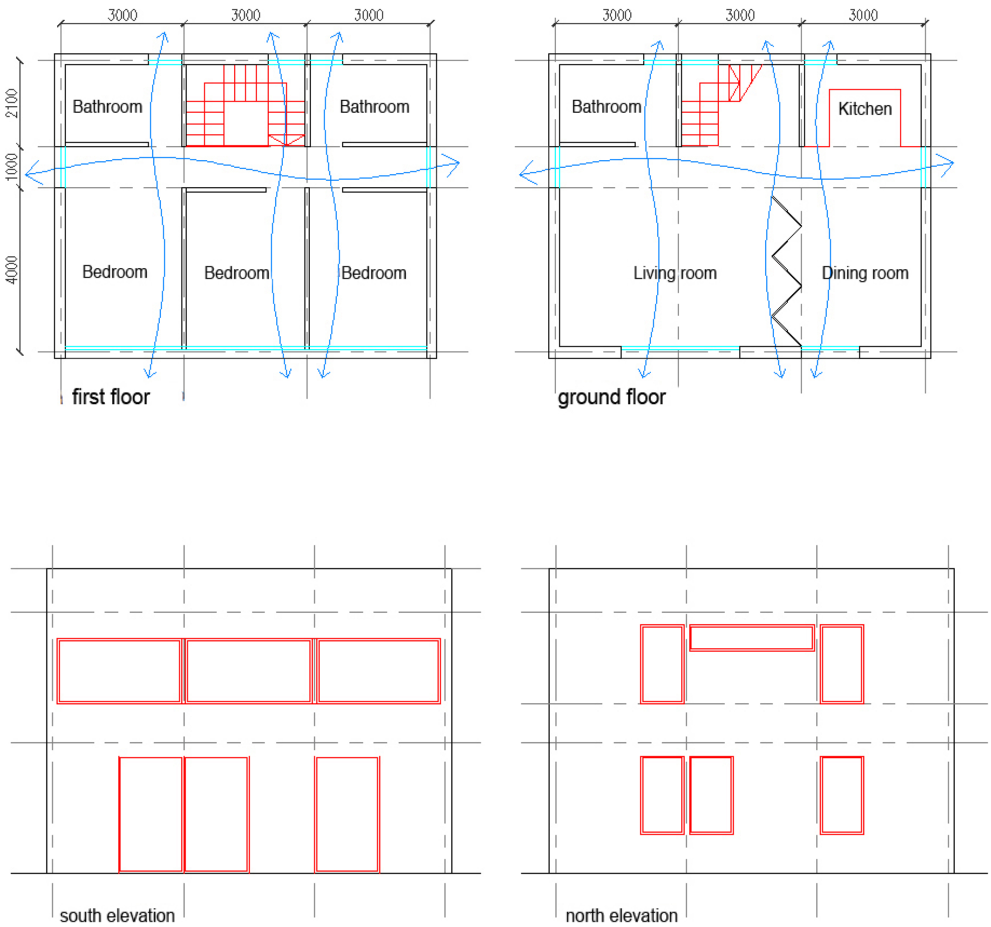

Figure 1. Proposed bioclimatic house model.

In addition to the design criteria, the following strategies were followed to control excess solar radiation in summertime:

- Thermal insulation: to obtain high external thermal insulation of all the closures, with high solar reflectance of sunlit roofs. To achieve high internal thermal inertia in order to maintain a constant fresh temperature in the resting areas (bedrooms and living room).
- Solar protection: to control the direct solar gain throughout the year by covering the openings in the southern façade with shelters, providing almost complete shade during the summer months.
- Ventilation: to prevent the infiltration of hot air and dust with high air tightness in the openings, while concurrently allowing direct ventilation at favourable times (early hours of the morning). To create a fresh and shady

microclimate in the living environment of the plot of land by means of vegetation and sheets of water on the ground.

- Renewal: to counteract overheating with energy renewal, with forced ventilation from 22.00 to 9.00 h (outside temperature<inside temperature) in the resting areas. With layered thermal storage in calyons.
- Environmental control: the bioclimatic conditioning of the building is a complicated issue, which is why it is advisable to use a demotic system that regulates passive thermal conditioning systems by means of sensors and timers.

3.3. Software tools for testing energy saving in buildings.

In order to validate passive ceramic systems with a enhanced energy efficiency, the "Passive House Planning Package, PHPP", software has been used, which consists of a spreadsheet format software tool for architects and designers of passive house projects, together with the LIDER software implementation of the general option for verification of the energy demand limitation requirement (HE1), laid down in the Basic Document on Habitability and Energy in the Technical Building Code (TBC).

In the PHPP software it is necessary to enter numerically all the data that define the project in different spreadsheets: the climate zone to which it belongs, number of occupants, characterisation and sizing of walls, ceilings, floors and windows, ventilation, winter shade, summer shade, internal temperature, definition of installations, etc. Using all these data, the PHPP software calculates the heating and cooling energy requirements for the building, taking into account the energy contributions made by solar insolation plus the internal heating loads produced by the daily use of household appliances, as well as the losses resulting from heat transmission through walls, ceilings, and windows. The software offers yearly and monthly results in easy-to-read tables and graphics.

Clicking the calculation button in the LIDER software activates the calculation engine for the building's energy demand, and for that of an identical reference building, in compliance with TBC restrictions. After doing the building calculations, the comparison is provided between the heating and cooling demand of the target building and that of the reference building, in terms of percentages and a bar chart. The relative importance of the heating and cooling is also displayed, such that the figures add up to one hundred.

Owing to the innovative nature of ceramic passive systems, the calculation software programs do not allow the particular features of these systems to be entered in the software. This required some working assumptions to be made in relation to the systems, which enabled us indirectly to introduce the beneficial effects of the systems in the virtual model and, thus, to analyse the climatic and energy improvements they provided in a first estimation. Each of the assumptions made are described below, together with corresponding systems.

3.4. Passive systems with ceramic materials. initial evaluation of the systems using lider and phpp software.

New passive systems with ceramic materials that provided energy improvements were defined in this first group, taking into account the bioclimate systems of the passive house and the functions that ceramics could serve according to their basic characteristics. At the same time, for the initial evaluation of these systems, the systems were incorporated into the passive house model adapted to the southern European area.

This new virtual model was used to carry out an initial assessment, using the LIDER and PHPP software, of the following systems: ventilated ceramic façade system, ceramic surface system with reflecting properties located opposite a collector window, and ceramic surface systems with reflecting properties on the jambs and sills of a collector window.

In all the analysed systems, a 6-cm-thick insulation was used which, though the thickness differs considerably from that used in passive houses, is much more in keeping with the thicknesses used in warmer climate zones. Two issues were thus solved: the construction reality was approached, and the results obtained could be displayed.

3.4.1. Ventilated ceramic façade.

Ventilated façades are considered to be climate conditioning systems because of the way they work. The heat generated behind the ceramic skin by the striking sun rays heats the air in the chamber, which decreases air density, causing the air to rise and leading to the chimney effect, so that heat is lost through the air chamber.

Ventilated façades cannot be directly entered into the LIDER software, so that certain assumptions were needed in order to be able to analyse ventilated ceramic façades with this software. The working of the ventilated façade presupposes the introduction of outside air into the cavity, which is why the temperature inside the cavity tends to resemble the outside temperature. This is the starting point for solar radiation on the outside screen, which warms up the air in the cavity and favours air convection, keeping part of the solar radiation from reaching the inner wall.

In order to introduce the effects of ventilated façade systems into the LIDER software, a simplification was made since the software did not allow them to be directly entered. Standard UNE 6946 indicates that, in an envelope with a ventilated air chamber, the external layers (the ceramic skin and the air chamber) can be disregarded, and it only considers the internal layers, assigning an external surface resistance of 0.13 m^2K/W, instead of the usual value of 0.04 m^2K/W for external surface resistance (the difference between both being considered to be 0.09 m^2K/W). Since in LIDER the external surface resistance cannot be changed, a "fictitious" layer was artificially created, such as an air chamber (new material), whose thermal resistance was the aforementioned difference, followed by the insulation layer and the brickwork in the conventional way.

This simplified solution for entering ventilated façades may be acceptable, but it does not reproduce the real workings of the ventilated façade.

When the house model with the ventilated façade system (fictitious air chamber with a thermal resistance of 0.09 m^2K/W, expanded polystyrene [0.037 W/[mK]] 0.060m), lightweight mortar aggregate (vermiculite perlite) 0.010 m, ½ foot hollow brick metric or Catalan 40mm< G < 50mm 0.115m, and plasterwork of 1000 < d < 1300 0.020m) was entered in the LIDER software, the following results were obtained: the percentage of the reference heating demand was 60.7%, and the reference cooling demand was 70.3%. On the other hand, when the house model with a traditional façade (1/2 foot hollow brick metric or Catalan 40mm< G < 50mm 0.115m, lightweight mortar aggregate [vermiculite perlite] 0.010m, EPS Expanded Polystyrene [0.037 W/[mK]] 0.060m, single hollow brick partition [40mm < thickness < 60] 0.040m and plasterwork of 1000 < d < 1300, 0.010m) was entered, the LIDER software provided the following results: the reference heating demand was 61.2% and the reference cooling demand was 72.5%.

The results show an improvement in the case of the ventilated façade, particularly in respect of the cooling, with a 2.2% improvement in performance. As regards heating, the reference values remain more or less constant in both cases, there being a minimal difference of about 0.5 %.

The PHPP software, just like the LIDER software, does not consider ventilated façades, thus making it necessary to enter the ventilated façade as an assumption, considering the semi-ventilated chamber concept in order to define the ventilated chamber.

The PHPP accepts a value (U) of thermal conductivity for a semi-ventilated chamber equal to twice the U value of a non-ventilated chamber. The ventilated façade was therefore entered as a system made up of the following layers: ceramics with λ 2.600 W/mk and thickness of 8mm, a semi-ventilated air chamber with λ 1.224 W/mk and thickness of 100mm, thermal insulation material with λ 0.038 W/mk and thickness of 60mm, aggregate mortar with λ 0.410W/mk and thickness of 10mm, ½ foot perforated brick with λ 0.667W/mk and thickness of 115mm and plasterwork with λ 0.570W/mk and thickness of 10mm.

To complete the ventilated façade assumption in the PHPP software, we considered that the heat loss through the chimney effect in the air chamber was equivalent to considering less insolation on the opaque elements of the ventilated façade. This concept was entered in the PHPP software with a value of 0.8 instead of 1 for the "shade factor" on the ventilated façade, which was equal to 20% reduction in solar insolation.

PHPP results for the ventilated façade		
Annual heating demand	4842 kWh	53.8 kWh/m^2
Annual cooling demand	10188 kWh	112.2 kWh/m^2

Table 1.

To determine the advantages of using a ventilated façade, we compared the foregoing results with those obtained using a traditional façade system made up of 1/2 foot perforated brick with λ 0.667W/mk and thickness of 115mm, lightweight mortar aggregate with λ 0.410W/mk and thickness of 10mm, EPS Expanded polystyrene with λ 0.038W/mk and thickness of 60mm, a double partition wall of hollow brick with λ 0.432W/mk and thickness of 70mm, and plasterwork with λ 0.570W/mk and thickness of 10mm.

The results obtained on calculating the traditional façade in the PHPP software provided an annual heating demand of 4743 kWh and an annual cooling demand of 10413 kWh.

PHPP results for the traditional façade		
Annual heating demand	4743 kWh	52.7 kWh/m^2
Annual cooling demand	10413 kWh	115.7 kWh/m^2

Table 2.

On comparing the house models with ventilated façades to those with traditional façades according to the PHPP results, an annual reduction in cooling demand of 225 kWh (2.5 kWh/m^2) was found for ventilated façades, which demonstrates the advantages of the ventilated façade in summer. In contrast, there was an increase in annual heating demand of 99 kWh, (1.1 kWh/m^2).

In both the LIDER and in PHPP software, there was an energy benefit with the ceramic ventilated façade assumption, especially if one takes the cooling demand into account.

3.4.2. Ceramic surfaces with reflecting properties located opposite the collector window.

The system seeks to take advantage of the reflections from the surfaces near the openings, generally floors, to increase the capture of sunlight through the windows in winter. This would allow the openings to be downsized, reducing overheating as a result of excess solar radiation.

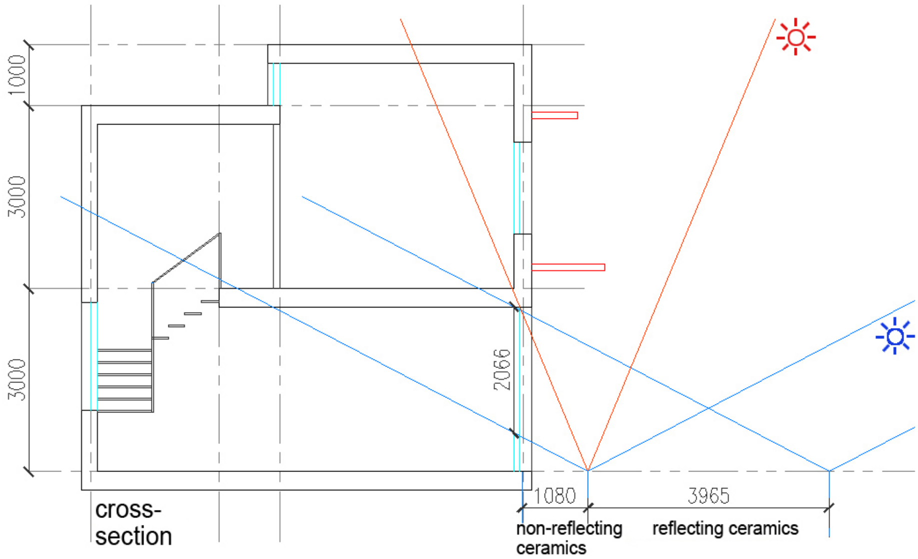

Figure 2.

In these systems it is necessary to study the degree of solar incidence meticulously throughout the year, in order to enhance system efficiency, bringing sunlight in during winter and keeping it out in summer.

Owing to the system's characteristics, it has not been possible to use the LIDER software, the PHPP software only being used in the initial assessment.

A "super-window" was then considered as a way of introducing the ceramic systems into the PHPP, which would guarantee the necessary contributions to satisfy heating needs solely by direct solar radiation. By using a reflecting floor, the surface area of the "super-window" could be reduced by a certain percentage, while keeping the necessary contributions, using the contributions provided by the downsized super-window in addition to the contributions of the light coming in through the window, reflected on the reflecting floor.

The reduction was directly related to the contribution produced thanks to the floor surface. It was estimated that a reduction could be attained of about 30% of the surface area needed to assure the contributions needed, this value being found by taking into account the reflection surface, the coefficient of reflection of the shiny ceramic surface, and a diminution coefficient.

If we start with the surface of the "super-window" and then downsize this by 30%, we obtain the reduced window surface area needed to keep the insolation required in winter, which we have termed "window+reflecting floor".

To obtain results relative to solar gains by means of the "window+reflecting floor", due to limitations of the calculation software, it has been assumed that the contributions for the winter months coincide with those for the "super-window", whereas for the summer months, the insolation decreases and corresponds to the reduced surface of the "window+reflecting floor".

Comparing the results obtained with both windows (the calculations were made taking into account the particular conditions of the window while keeping the other factors constant), the same contributions were obtained in winter, although one of them did it solely based on its surface area while the other was supported by the reflecting floor in order to achieve the same result. In the months of May, June, July, August and September, the "window+reflecting floor" displayed a cooling demand of 6047 kWh (67.2 kWh/m^2), and the super-window displayed a cooling demand of 6859 kWh (76.2 kWh/m^2). This meant a saving in cooling of 812 kWh (9.02 kWh/m^2) in the five hottest months of the year, throughout the entire house, just by downsizing the ground-floor windows in the southern façade.

3.4.3. Ceramic surface with reflecting properties on the jambs and sills of a collector window.

System function: the role of the jambs and the sills is that of increasing solar collection inside the building, thanks to their luminous qualities, so that the materials that these are made of should be light-coloured and reflecting.

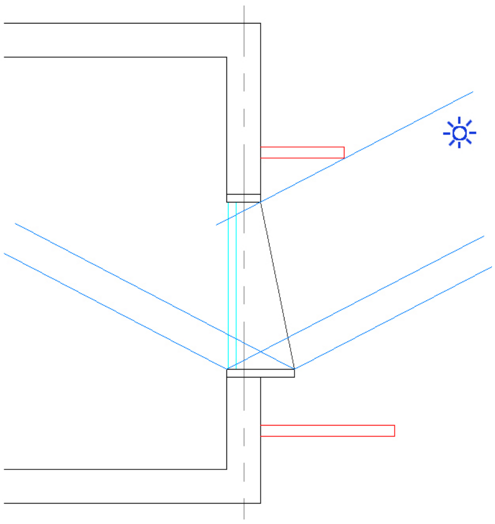

Figure 3.

This extra amount of luminous energy then allowed the opening to be downsized, lessening the energy losses from the dwelling without diminishing the heat gains during the cold winter months, when energy contributions are required. This system enhances its efficiency as the jamb and sill surface areas increase.

We considered a "super-window" again, which assured the required contributions to satisfy the heating demand using only solar radiation. By using reflecting jambs and sills, we reduced the surface area of a window without reducing the solar contributions during winter, since we took into account the contributions reflected in the jambs and sills. Taking into account the angle of the sun, surface reflection, coefficient of reflection of the shiny ceramics, and the diminution coefficient, it was thus estimated that a reduction could be achieved of about 10% of the surface area required to assure the necessary contributions.

Starting with the "super-window", we obtained a 10% smaller "window+reflecting jambs and sills". Since the winter contributions were considered to be the same, the cooling demand was then determined for each window in the summer months. In the months of May, June, July, August, and September, a cooling demand of 6539 kWh (72.65 kWh/m^2) was found for the "window+reflecting jambs and sills", a cooling demand being found for the super-window of 6859 kWh (76.21 kWh/m^2), entailing about 320 kWh (3.6 kWh/m^2) reduction in the cooling energy demand of the entire house by just reducing the first-floor windows in the southern façade.

3.5. Passive systems that improve functionally (durability) and aesthetically (shape) by incorporating ceramic materials.

3.5.1. Accumulator system with ceramic cladding beneath collector windows.

When there is a collector window, the flooring below it receives direct insolation, which causes colour changes in the flooring in a short time. In order to avoid this, we suggest the use of ceramic flooring, which undergoes no changes in surface colour on exposure to sunlight as a result of its inherent qualities.

The system has been defined as a structure consisting of ceramic flooring and a high-density substrate beneath a collector window in wintertime. The importance of using the substrate as a collector is due to the thinness of the ceramic tiles, since a material is basically required with high thermal inertia and a thickness of about 15cm. In order to achieve the desired effect, the concrete mass was located on top of the insulation, inside the living area, thus favouring the accumulation of energy in its mass during hours of insolation.

3.5.2. Raised floor for flat roofs.

The use of a raised roof deck provides a series of direct climatic advantages. Direct insolation on the actual building roof is avoided. Inside the chamber, the air is heated, reducing its density, causing it to tend to rise through the joints between trays, preventing a large quantity of heat from reaching the substrate and reducing the heat that penetrates inside. Since the raised deck does not need to ensure the system's impermeability, it can be installed with open joints to facilitate the release of hot air and the introduction of cold air into the chamber.

There is a reduction in solar gains through the roof throughout the year due to the shading that the ceramic skin produces on the building roof. However, a higher level of reduction is attained in summer because the angle of the sun rays in summer is almost perpendicular. Fresher environments are thus produced in summer, with the ensuing reduction in energy consumption for cooling interior environments.

Less solar energy is collected through the roof in winter, which has a negative effect on heating. However, these levels are not very high since the sun's rays fall onto the roof at an angle of 30 degrees during winter. This winter loss pales into insignificance compared with the benefits provided in summer, particularly in a Mediterranean climate.

4. CONCLUSIONS

An initial assessment of ceramic systems revealed a slight improvement in the results when these were compared with traditional systems, or with ones without ceramics. It must be kept in mind that the systems affect a part or elements of the house, while the results obtained relate to the entire house, which is why the positive effects are diluted and seem smaller than they really are. Ceramic passive systems exhibit great potential in this first assessment, making it very interesting to develop these further in future studies.

ACKNOWLEDGEMENTS

We acknowledge the support received from the European Union through the European Fund for Regional Development (EFRD) and from IMPIVA (Generalitat Valenciana).

REFERENCES

[1] FEIST, W. et al. Passive house planning package 2007: requirements for quality approved passive houses. Darmstadt: Passivhaus Institut, 2007.

[2] GARRIDO, L. de. Análisis de proyectos de arquitectura sostenible: naturalezas artificiales 2001-2008. Madrid: McGraw Hill, 2008.

[3] Lider v. 1.0: Manual de usuario [en línea]. [Madrid]: Ministerio de vivienda; IDAE, [2009]. http://www.codigotecnico.org/fileadmin/Ficheros_CTE/Documentos/ManualLIDER.pdf [Consulta: 2009-09-21].

[4] Proyecto Passive-On Project (programa europeo SAVE integrante de las actuaciones para Energía Inteligente-Europa) < http://www.passive-on.org/es/> [Consulta 21-09-2009].

[5] WIENKE, U. L'edificio passivo. Firenze: Alinea, 2002.