Reducing cooling energy needs through an innovative daily storage based facade solution

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ABSTRACT

The framework of the research presented in the paper is a project oriented to promote the use of concrete solutions in buildings based on maximizing the benefits of its thermal inertia for cooling periods.

The constructive solution developed has one configuration for summer (cooling mode). This configuration is similar to a ventilated facade that is formed by a thermally insulated outer layer of concrete, an intermediate air layer and an inner layer of concrete. The inner layer is cooled at night by forced ventilation using an outdoor - outdoor scheme.

The aim of this paper is to show the preliminary results about the potential of special concrete walls as solutions to reduce energy demand in residential buildings by thermal offset in Spanish Mediterranean climates.

In summer, the concrete building facades are used as heat sinks. The aim is to cool the inner layer of concrete moving outdoor air through the air layer during night taking advantage of the low nigh-time air temperatures. The cool stored is released to the interior spaces when the maximum peak load of the space takes place.

With the aim of select a proper design of the innovative element, the influence of the thickness of the inner layer, the air velocity in the chamber and control lays to activate the ventilation are analysed. Simulations show that the use of this element is very promising for reducing energy demand in residential buildings in the Spanish climates.

Experiments are currently performing (summer 2014).

KEYWORDS

Cooling savings, Ventilated active facade, Cooling storage

1 INTRODUCTION

The framework in which this study takes place is the " Service Contract R + D + i Relating to Competence Scope of the Ministry of Public Works and Housing " with the research project entitled "Analysis of the energy performance of closures concrete based on maximizing the benefits derived from the thermal inertia".
Meeting the "20-20-20" targets (European Commission, 2012) for reduction of CO_2 emissions necessarily involves a drastic reduction of energy consumption in buildings.

For the climatic conditions of the south of Europe, as Andalusia region in Spain, cooling is required during the summer season, since there are high daylight temperatures an high levels of solar radiation.

To reduce energy consumption in cooling and therefore CO_2 emissions, it is previously necessary to reduce energy demand.

There are several techniques that can be applied to reduce the cooling demand (Santamouris, 2007), but some of the most obvious alternatives is to use the relatively low night outdoor temperature as a heat sink. In order to use this heat sink, energy (cold) storage is required since there is a gap between the cooling needs in the building and the time when the lowest temperatures are presented in the heat sink.

One option to storage the cold is to use the thermal inertia of the structure of the building. A simple definition of thermal inertia would say it's the ability to keep the mass of thermal energy received and gradually releasing it (Ruiz-Pardo 2008). Because of this ability, taking into account the thermal inertia of the walls of a building, can be decreased the need for air conditioning, with the consequent reduction of energy consumption and pollutant emissions.

The thermal inertia improves energy performance of buildings (Aste 2009) because it allows the damping of the temperature variation and the phase of the internal temperature relative to the outside.

For a situation with a high external temperature and solar radiation, the temperature outside the enclosure rises producing a heat transfer to the interior of the building. The evolution of the temperature of the outer face has a maximum (maximum amplitude) in a particular time of day depending on the location and orientation of the enclosure. This wave is damped outside temperature, in amplitude, crossing the enclosure, also emerging a time lag between the instants at which a peak temperature is produced. The effect of phase shift and damping allows the building to stay longer in the comfort zone without additional energy expenditure allowing free savings because they are inherent in the material (Ruiz-Pardo 2008).

The physical characteristics of the concrete gives it a high thermal inertia , which allows to predict optimum energy performance of the building in the event that this material forms the inner core (structure) and external (walls and roofs) thereof. The use of concrete as façade cladding and covered in the building:

- Reduce the energy consumption of heating.
- Softens variations in internal temperature.
- Delay maximum temperatures in offices and commercial buildings to the exit of the occupants.
- Reduces peak temperatures (maximum and minimum) and can make the air conditioning unnecessary.
- Maybe employed with nocturnal ventilation to eliminate the need for cooling during the day.
- Makes better use of sources of low temperature heating such as heat pumps for underfloor heating.

Overall the effect of thermal inertia in enclosures is a variable not usually considered in the design of the building.

In addition to its modelling difficult for designers and specifies, calculation tools were not sensitive to this parameter and the knowledge of its potential benefits have not been adequately considered by the technical and scientific community.

The main objective of the project is to parameterize the fundamental variables that characterize the thermal inertia of buildings overlooking substantially improve treatment procedures for calculating the thermal performance of buildings. This would be instrumental to value the role of concrete solutions as part of improving energy efficiency.

This setting will also allow designers can, easily, estimate the energy savings from the thermal inertia of buildings with contour and concrete structure.

2 MATERIALS AND METHODS

An experimental cell (Figure 1) was built in order to test a “thermally active wall” available to storage cold during the night and release it during the day.

The experimental cell is a reinforced concrete cubicle (3.0 x 3.0 x 3.0 m.) to which he included a special front face south to investigate several special construction solutions

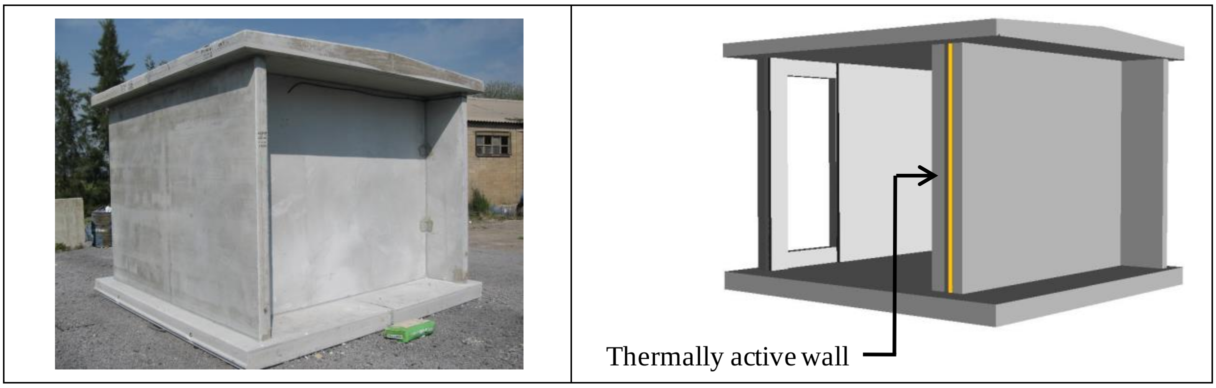


Figure 1. Experimental cell

The thermally active wall (Figure 2) is a facade composed of two solid layers speared by an air ventilated layer. The inner layer is a concrete wall with high thermal inertia. The outer layer is an insulated element having low thermal transmittance. During the night the air layer is ventilated using fans located in the upper zone of the facade. During the day, the ventilation is stopped.

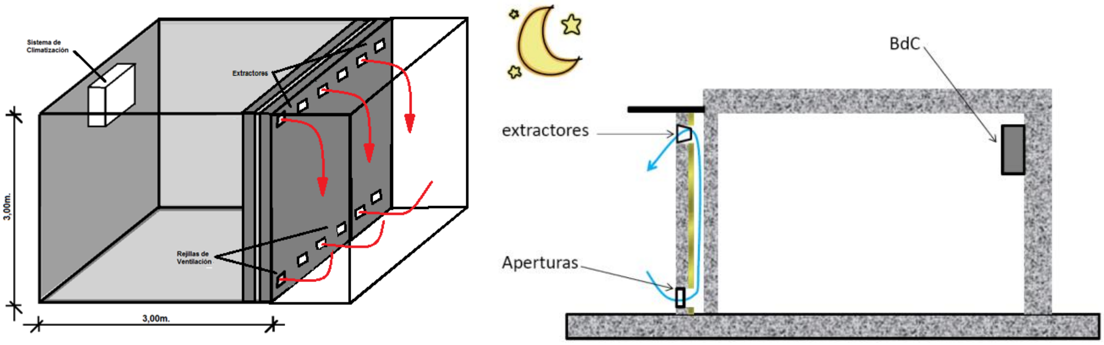


Figure 2. module test for the analysis of the influence of nocturnal cooling of the concrete wall through the chamber ventilated by forced ventilation.

A simulation model was performed with the following objectives: Dimensioning od the experimental setup, prediction of the thermal behaviour of the element under conditions different than those obtained experimentally, and to perform studies an analysis of the potential of the active facade. Thai model is based on the preiviously defined by Ruiz-Pardo (Ruiz-Pardo, 2010)

In simulation, previous to the construction of the experimental setup, the main variables affecting the thermal performance of the thermally active wall were studied: the inner layer of concrete (10-15-20 cm.), the thickness of the internal air chamber wall (2-5-10 cm.) and the air speed walking the chamber (0.5-1-2 m/s).

In the coming months the validations of the developed models will be performed using the results that currently we are obtaining.

3 RESULTS AND DISCUSSION

Previous to the campaign of experiments, some results were obtained with the aim to select a proper design and estimate the savings that can be obtained from the thermally active facade. They are shown below.

The experiments are currently in developing, so some partial results had been obtained and they are shown at the end of this section.

3.1 Simulation results

In order to select a proper design of the innovative element, several simulations were performed with different designs in two selected localities: Sevilla and Cádiz

The process performed was the following:

- Nine options were initially tested; this was the result of three air velocities in the air layer and three thicknesses of the inner wall. The results of these cases are shown in Table 1.
- From the results, the option with highest energy savings for summer was selected.
- For the selected option, some variations in the operational conditions were proved in order to maximize its behavior for winter season even though the design was optimized for summer.

For the two considered cities, it was found that the optimal design was the same. This result was not expected, since they are different climates. The only difference in the design is that for the case of Cadiz, the optimum temperature for allowing ventilation is 25°C and not 23 as in the case of Seville. The main descriptive parameters of the optimal design are shown in Table 1.

Table 1: Studied solutions to find a proper design of the innovative element in Seville

	Inner wall thickness	*Air layer velocity*	*air layer convective heat transfer coefficient (air in circulation)*
solution 5	*15cm*	*1 m/s*	*5 W/m^{2}K*

The overall behavior expected for the innovative element in these two cities is shown in Table 2. It can be seen that the innovative element performs cooling in summer and heating in winter.

Table 2. Gross heating gains for the innovative element in the three studied cities. Negative values means heating losses (desirable behaviour in cooling season) and positive values means heating gains (desirable behaviour in heating season). All values are in kWh/m^2

	Summer		
	month	*Monthly heat losses kWh/ m^2*	*Total heat losses kWh/ m^2*
Seville	*Jun*	*-7.57*	*-13.12*
	Jul	*-3.04*	
	Aug	*-2.51*	
Cadiz	*Jun*	*-19.81*	*-36.07*
	Jul	*-9.71*	
	Aug	*-6.54*	

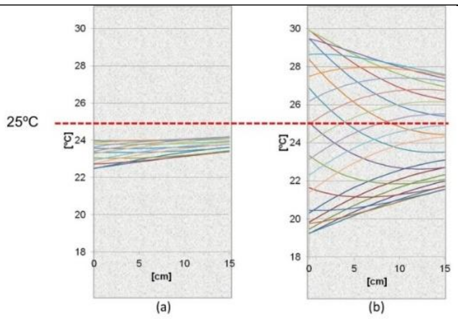
The results of Table 2 show that in the two studied localities, the innovative element removes heat and in addition when it is compared with a conventional wall, its benefit is increased since the conventional wall has the opposite behaviour of the innovative element, namely, it introduces heating during the summer season.

The expected savings for the innovative element are obtained from the comparison with a conventional wall. The results of this comparison are shown in Table 3.

Table 3. Heat gains comparison between the innovative element and a conventional Wall having the same U-value in the three tested localities

	Summer		
	Innovative element Heat gains	*conventional wall heat gains*	*difference (savings)*
	kWh/ m^2	*kWh/ m^2*	*kWh/ m^2*
Seville	*-13.1*	*12.6*	*-25.8*
Cadiz	*-36.1*	*4.2*	*-40.3*

To illustrate the behaviour of the innovative element in comparison with a conventional wall, in the Figure 3, the temperature profiles are shown for the interior layer of the innovative element and for a conventional wall. These profiles were calculated for one typical day of the cooling season and for a typical day of the heating season.



Cooling season

(a) Interior layer of the innovative element (b) Conventional wall

Figure 3. Temperature profile in: (a) the innovative element and (b) in a conventional wall

Figure 3 shows that the amplitude of the temperature oscillation obtained in the innovative element, is much lower than that obtained in the conventional wall. Additionally, it is seen how in the cooling season, the temperatures of the innovative solution are always lower than the indoor temperature (assumed as 25°C), while the conventional wall is oscillating around that temperature.

3.2 First experimental results

The first period of experiments were performed without night ventilation of the air layer. The objective was to observate the behavior of the experimental cell and compares it with the results obtained when the air layer is ventilated during the night.

In Figure 4 are shown the interior surface temperatures of the cell. The green lines are the average temperature of the conventional walls while the orange lines correspond to the surface temperatures of the active facade.

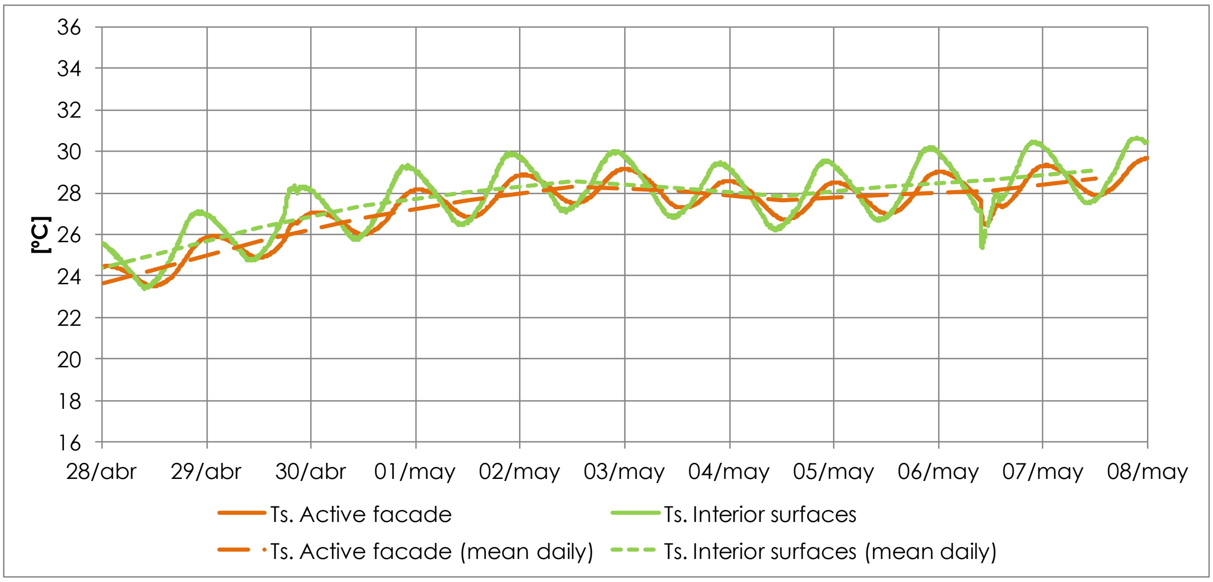


Figure 4. Temperatures of the interior surfaces of the experimental cell without night ventilation of the air layer

As it can be seen, the active façade shows les amplitude in the daily variation of temperature than the other interior surfaces. This behavior is obtained because the active facade has a greater thermal inertia. However, the mean daily temperature of the active facade is less than 0.5ºC inferior than de the mean of the other surfaces when the air layer is not ventilated during the night.

In Figure 5 are shown the same interior surface temperatures of Figure 4, but with night ventilation of the air layer. In this case the daily variation of temperature is closing similar for the active façade and for the other interior surfaces. This behavior is caused by the additional excitation suffered by the active facade when the ventilation is activated. But the most important result is that the daily mean temperature of the active façade is approximately 2ºC inferior than the corresponding temperature of the other walls. It is 1.5ºC colder than the values obtained when the air night ventilation is not operating.

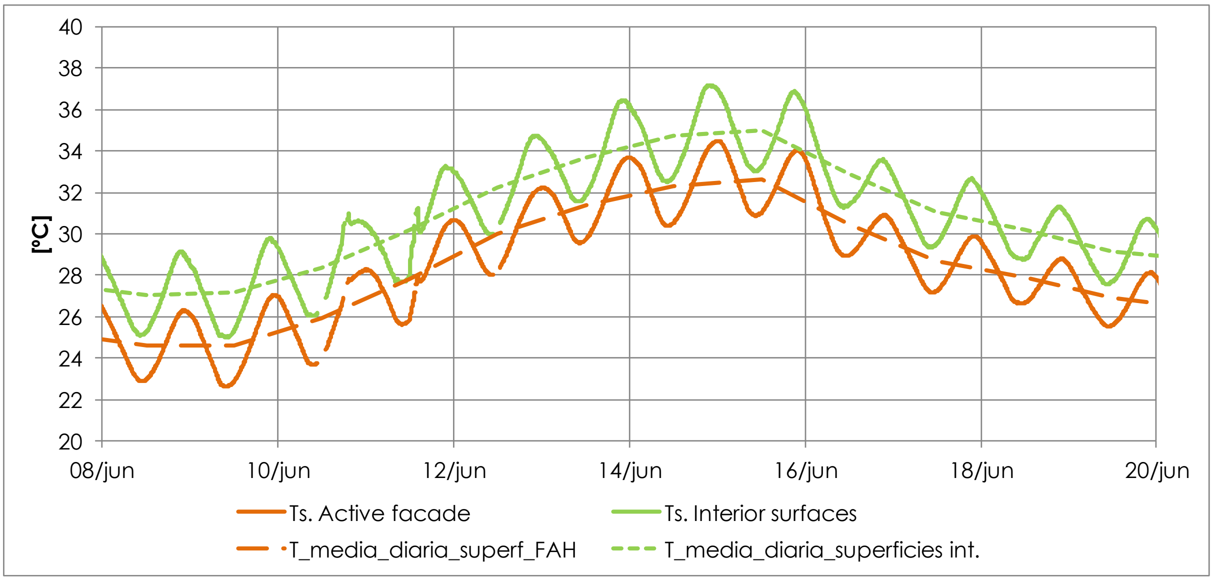


Figure 5 Temperatures of the interior surfaces of the experimental cell with night ventilation of the air layer

4 CONCLUSIONS

An innovative facade element has been designed with the objective of reduce energy cooling demand in buildings. This element is being evaluated by simulations and experiments.

Using the developed simulation model, a proper design was obtained for the cities of Seville and Cadiz. The obtained design was the same in both cases with only little differences in the adequate temperature to allow the air night ventilation.

The simulation results show that the active facade, using the selected design for the cities of Seville and Cadiz, has the potential to provide cooling in the summer season while a conventional wall provides heating. It means that the energy potential of this element shows a very interesting behaviour that has to be verified experimentally.

The very first experimental results shows a promising potential for the reduction of energy cooling consumption and seems verify the potential predicted in simulation. However, the experimental campaign is still carrying on, so definitive results and conclusions can not be taken yet.

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