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Design and experimental study of an industrialized sunspace with solar heat storage

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ABSTRACT

This investigation deals with the thermal performance of two passive solar components. An attached sunspace with horizontal heat storage and another one with vertical thermal storage were designed in order to optimize the use of solar gain, its storage and distribution in an industrialized component.

These sunspaces have been tested under real conditions, comparing their thermal performance with two commonly used components in residential buildings in Spain: a window and a double window making up an attached sunspace. Different series of experimental measurements were made in two test-cells exposed to outdoor conditions in Pamplona (Northern Spain). As a result, nine scenarios during winter 2011 and six ones during summer 2012 have been carried out, comparing all the prototypes two by two with different use modes.

Resu**lts show that a sunspace with heat storage takes advantage of the solar energy and improves the indoor thermal performance of the adjacent room during winter in a better way than a window or a simple sunspace, and that it has also a better performance in summer. The best results in winter and summer were obtained when an appropriate use of the component is performed, in concordance with outdoor conditions; some thermal control actions for the good performance of these components are suggested.

1. Introduction

Directive 2010/31/EU on the energy performance of buildings (EPDB) lays down the requirement that in 2020 all new buildings must be "nearly zero-energy buildings" [1]. In order to achieve this goal, an important and classic strategy is to reduce the heating demand of the building taking advantage of free solar energy through passive and/or active elements integrated in the building's envelope. Comprehensive studies of these systems can be found in a review of passive solar heating and cooling technologies through facades and roofs [2], in a review of opaque solar facades [3] and in a review of transparent and translucent solar facades [4].

The simplest passive solar system is a window facing south (direct gain). However, to take great advantage of the solar gain as passive heating it is necessary to take into account the storage, distribution and conservation of the heat, that can make these passive systems more complex, like components such as a sunspace or a Trombe-wall (indirect gain). Several authors have studied the effect of thermal storage as a means of indirect gain. Kisilewicz compared a direct solar gain system (windows) with a large indirect system (collecting and accumulating wall). The useful solar gains from both components are similar; however, "the major advantage of the indirect system consists in significantly reduced overheating risk in winter and summer" [5]. Fernández-González studied the thermal performance of five different passive solar test-cells (Direct Gain, Trombe-Wall, Water-Wall, Sunspace, and Roofpond) and demonstrated "*the effectiveness of water as a thermal storage medium when compared to masonry and concrete*" [6]. For that reason an industrialized component, an attached sunspace, is proposed. It combines direct gains through glazing and indirect gains through its accumulation in an element with high thermal mass.

An attached sunspace is defined in the Spanish Building Code (CTE) as a "non-conditioned area formed by an exterior enclosure with a high percentage of glazed surface that is set adjacent to a building's facade. The facade element that acts as a separation between the sunspace and the building's indoor area may also include glass. A generally mechanically forced draught through this area can take place, either as a recirculation of the inside air or as a preheating of exterior air used for ventilation" [7].

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This component is very popular in residential buildings in Spain, although it does not always work as a passive solar system itself, principally because of an inadequate orientation for solar gains.

Two attached sunspaces with solar heat storage (SSHS) have been designed as part of the Research Project CONCLIMAT [8], funded by the local Government of Navarra in Spain. The main goal of the project was to develop a low cost industrialized energy efficient residential building. One of the measures proposed to reduce the energy demand of the building was the design of an industrialized component that takes advantage of solar radiation in winter, storing the heat in a component with high thermal storage capacity, in order to accumulate the solar gain and delay heat during the day and/or minimize thermal loss during the night, maintaining adequate indoor conditions in summer, by avoiding overheating.

Therefore, the aims of the design of these prefabricated sunspaces SSHS have been:

- To design an industrialized component suitable to be incorporated in any type of facade, being set in the supporting structure or on a wrought iron substructure. An industrialized component has the advantages of the optimization of cost, the decrease in execution times and the possibility of its re-utilization in the future.
- To optimize its operation as a passive heating element, incorporating in the industrialized sunspace the functions that permit a decrease in energy consumption and an increase in comfort due to minor temperature peaks and daily temperature fluctuations. These functions are: solar gain, accumulation of solar radiation in an element with high thermal mass, distribution of heat between the sunspace and the adjoining living area, and conservation of energy once there is no solar radiation (Fig. 1).
- To design the optimal sunspace for the climatic zone. The implementation of this kind of solution is challenging due to the complexity of the heating transfer processes involved and the dependence on the particular climatic conditions of each location. These conditions entail a proper operation of the component (ventilation time, use of the shading devices and low-emissive screen, etc.) in order to maximize the solar gain and reduce the thermal loss in winter, perform solar protection and proper ventilation during the summer.

As mentioned previously sunspaces are very popular components of Spanish residential architecture and have been used as a bioclimatic resource during the last centuries. However, the modifying of some of the component's characteristics, due to a lack of understanding of their real behaviour has not permitted the obtaining of optimal results. As an example the intermediate wall between the sunspace and the dwelling, originally built in masonry wall, is substituted for a light wall, or for a thermal insulation wall or for a full glazing, eliminating the sunspace's accumulation capacity.

Furthermore, these sunspaces are built traditionally. Although they may incorporate elements manufactured in factory, they are mounted piece by piece, even in the case of a window where the frame, the glass and the solar protection elements are executed in different stages. The sunspace-accumulators proposed in this paper (P1 and P4) are built in a unique component at the factory, transported to the site and hoarded for their later mounting in the building on the supporting structure or on a substructure anchored from slab to slab.

The incorporation in a unique component of the four functions of a sunspace permits not only a correct functioning but also orientates the project towards the main building objectives like the manufacturing of construction [9,10]. In this way sunspaces, as opposed to the ones executed on site, present some advantages in relation to the achievement of an homogeneous level of quality, an increase in security and health [11], and lower execution times,

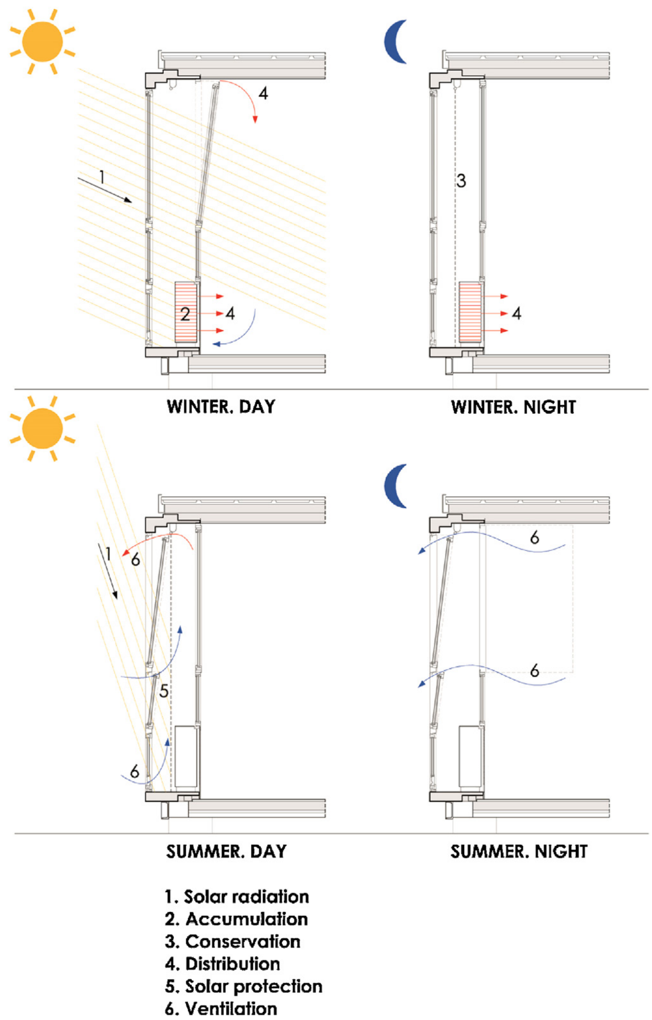

Fig. 1. Operational configuration of a sunspace with solar heat storage, according to the winter and summer conditions.

since the mounting on site is estimated at 3 h per sunspace. Benefits also come from the point of view of sustainability since industrial works can lower waste up to an 84.7%, as Vivian W.Y. Tam states in her article "Towards adoption of Prefabrication in Construction" [12].

No industrial component being commercialized with these characteristics has been found in the technical bibliography reviewed, therefore this proposal is considered a step ahead in knowledge.

The design of a non-conventional component for facades implies, firstly, a computer simulation in order to optimize the design and performance of the component. The methods for simulation programmes range from the SLR (Solar Load Ratio) method developed by Los Alamos National Laboratory and applied to e.g. attached sunspaces in Barcelona [13], to simulation programmes as Trnsys applied to e.g. sunspaces in European cities [14], Fluent applied to a gallery in Asturias, Spain [15], Derob LTH to sunspaces in Italian cities [16] or EnergyPlus to four houses with sunspaces in Oregon, US [17].

Secondly, it is necessary to build a prototype in order to perform an experimental study, under real conditions, comparing it with a window and its subsequent improvement. That is necessary because the complex heat transfer processes that take place in sunspaces are taking into account in a simplified way in computational software. In the case of sunspaces. The main source of error is the fact that this kind of software cannot consider in a proper way