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A new design of roof-integrated water solar collector for domestic heating and cooling

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Abstract

A new design of roof-integrated water solar collector is presented. It takes advantage of new synergies found between collector and roof. Its main concept is based on the use of water redistribution for changing the roof configuration. This design provides a low-cost system for household heating and cooling that could be even cheaper than conventional roofs with similar thermal qualities, by using fully its configurable property. In this sense, this design could help us to modify the deeply-rooted paradigm of the classic roof.

Keywords: Roof solar collector; Passive solar heating; Passive cooling

1. Introduction

Many feasible designs of roof-integrated solar collectors have been developed in the last 50 years. It is possible that the oil price increase will prompt their applications in the future, but at present, high costs have delayed their massive application (Belusko et al., 2004). In recent years, many roof-integrated collectors have been proposed, such as hybrid systems with photovoltaic (Vokas et al., 2003) or thermoelectric (Maneewan et al., 2005) panels, intended to overcome this limitation. These integrated designs have obtained modest cost reductions, but they contributed to improved collector performance. For example, the photovoltaic-panel efficiency is improved by lowering its operating temperature using water cooling. But in spite of their success, they did not change the actual roof paradigm. There are few designs proposing substantial changes to the basic roof concept, leading to further cost reductions.

Solar collectors use water or air. Water systems are more expensive but have better performance than those with air due to their higher energy density (Khedari et al., 1996). It is common knowledge that a small solar collector (*i.e.* 4 m^2), can satisfy the domestic hot water demand in many places worldwide. Hence, we can expect that extending the collector onto the whole roof could provide the household with heating as well. As Hassan and Beliveau (2007) have demonstrated, this can still apply close to 40° latitude. However, at present, large solar collectors are rarely used due to the high costs.

The use of water ponds on roofs for house cooling in arid regions is well known (Nahar et al., 1999; Jiang et al., 2001; Jain, 2006). The water is cooled during the night by evaporation and radiation heat losses, and is protected against solar irradiation by a scrollable cover. Contradicting prior observations of Nahar et al. (1999), Jain (2006) states that a shallow water depth of 5 cm is enough. Jain also suggests that the inverse procedure could be used for household heating in winter.

In the pioneer work of Harold Hay (1977) and his patented Skytherm system, water bags are mounted over a simple metallic roof that is protected by a folding cover

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with good thermal insulation. This system provides the household with heating by infrared radiation in winter, and cooling by free convection in summer. As Hay showed in his own house in California in the 1970s, this system can provide a comfortable temperature all year even in arid climates (Hay and Yellott, 1969).

Hay's design works under four configurations, combining the summer–winter and day–night options. By just moving the insulator cover it collects or stores solar energy during the day or night respectively in winter, and does the opposite in summer. Although Hay could be considered a pioneer in this field, he did not see one potential of his innovative idea, and neither did his followers, like Hammon (Alves and Milligan, 1978), who were more interested in improving details in Hay's design, such as the folding cover. One of the main drawbacks of the Skytherm was the extremely high cost of its movable cover and thick insulation layer mounted over a very bulky mechanical system. According to the actual climate where it is applied and its low graduation ability, other disadvantages of Skytherm that can arise are: the uncomfortable effects causes by the infrared heating overhead in winter, and by vapor condensation on the cold ceiling in summer. This point will be further discussed in Section 6.

Medved et al. (2003) predicted the possibility of heating a swimming pool of 600 m^3 by using a 600 m^2 collector for a monthly insolation of 165 kWh/m^2 over an unglazed roof-integrated solar collector. In addition his work shows efforts in designing water-coil collectors integrated to the undulatory roof, as we shall propose here.

In this work an innovative design for a solar roof is presented. It is based on the original combination of many concepts of the previous designs. This design is expected to satisfy the demand of household heating and cooling in many low and medium-latitude locations, with lower costs than standard roofs with similar thermal quality. This last condition is achieved by using common building elements, so that this type of roof can be massively applied. In addition, it could serve as an inspiration for other researchers to develop new environmentally friendly buildings. This design was recently patented (Juanicó, 2006).

2. Analyses of different roof techniques

2.1. The classic roof concept

Consider the evolution of conventional roof designs along with developments of new materials and building techniques. At present, a metallic roof is assembled by using sheets of customized lengths to avoid overlapping of short sheets common in previous methods. Instead of the old flat plates, undulatory or trapezoidal profiles are now used to increase mechanical resistance. These changes have produced significant improvements in construction techniques, including costs and time. Among these are:

- Roof surface is reduced by using gentler slopes (20° against 45° required by previous designs to prevent rain filtrating between overlapped plates).
- Construction time on site is reduced because fewer unions, seals and supports are needed for assembly.
- New finishes now make sheets more resistant to corrosion.
- Since metal sheets can become a self-supporting roof, a wider space can be left between braces or these can even be left out completely.
- In some trapezoidal systems, contiguous metal sheets are joined to adjacent sheets by means of welded joints. This system provides an excellent water-tight roof and an upper step several centimeters higher useful for our objective.

This technological evolution in roof systems opens an opportunity window for new designs. In contrast, the classic concept of roof has prevailed without changes for a very long time. Classic roofs are designed following two main goals:

- To prevent rain or snow infiltration.
- To provide good thermal insulation.

The traditional way to fulfill these objectives in high quality roofs has been to overlap several internal layers of different materials (low thermal conductivity, high reflectivity, etc.) between air gaps or chambers, under the waterproof exterior layer. This whole system constitutes a good-quality roof; but at high costs in relation to materials and labor. On the other hand, low quality roofs (with fewer intermediate insulating layers) usually have lower costs but are "warm in summer and cool in winter", as they do not reach the "almost adiabatic" category of the previous ones.

Summarizing, the traditional roof concept can be described as a fixed roof in which the greatest adiabatic degree is intended, and in which the investment made is directly proportional to the objective achieved. This fits the current architectural trend to design low-energy buildings, but with the drawback of having to pay high costs in order to achieve this adiabatic goal (Wall, 2006; Smeds and Wall, 2007). We, on the other hand, are proposing to maximize the degree of adaptability of the building to the environment.

Note that new piping technologies (continuous lines, fittings without elbows, etc.) can be used to minimize leakage problems. Therefore, at present, the application of multi-pipe systems within the construction of new buildings does not imply excessive costs in materials and labor. In addition, new developments in low-conductivity windows (triple glazing filled with low-conductivity gases, low-emissivity coating, new low-conductivity transparent materials, etc.) provides a way to obtain very good insulation by using multiple-glass windows. There are in the market triple-glazing windows with global conductivity coefficient U of 0.6 $W/m^2\,K$, (www.efficientwindows.org) and new