2018 ICAE
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VIII INTERNATIONAL CONGRESS
ON ARCHITECTURAL ENVELOPES

Low Temperature Solar Thermal System for Building Envelope Integration

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Key words: Solar collector, Façade integration, Construction, Solar systems, Ventilated façade. Solar collector, Façade integration, Construction, Solar systems, Ventilated façade.

Abstract

In this article it is presented an innovative façade system with a solar thermal system. The developed solar system can be classified as modular unglazed collector, designed for low temperature energy capture. It is compatible with a solar combined system that integrates a solar heat pump. The external appearance of the building remains untouched thanks to this innovative system. Experimental works at façade collector level are presented. The integration of the unglazed collector in a heat pump based combined solar system, its performance levels and economic figures are presented.

1 Introduction

The solar energy potential is considerably higher in comparison to fossil energy sources, being this factor the main reason to develop and promote those solutions that include solar energy systems in buildings. The solar energy has an important role in the energy balance of the considered building.
The Spanish Technical Building Code (CTE) determinates the minimum solar contribution of domestic hot water (DHW) in its basic document DB HE Energy Saving [1]. This is represented by a solar fraction or percentage of the annual DHW demand that needs to be provided by solar energy. This contribution can be replaced with an alternative system (based on other renewable energies, heat

recovery or cogeneration process), if it is justified an equivalent reduction in the primary energy consumption and the carbon dioxide emissions.
One of the main reasons why the solar thermal technologies are not widely adopted is the economic aspect [2] as well as the lack of suitable products for its integration in the construction [3]. The solar modules should be designed as integrated components of the building that fulfil with constructive, functional and formal requirements of the replaced elements.
The installation of solar thermal collectors as façade elements offers notable advantages, such as better space availability and higher reception during winter. However, its use is quite limited.
The integration of solar collector in façades is a complex issue that can be simplified according to the following architectural considerations:

- The position and size of the collector must be coherent with the building composition.
- The size and proportion of the module needs to articulate with the compositional mesh and the other façade's elements.
- The material, texture and colour of the collector have to be compatible with the rest of the materials.
- Joints with the adjacent materials should be implemented in a consistent way with the architectural language of the façade.

There are many researches in this field and in this context is where the BATISOL [4] project has been developed. It is based on an unglazed, low cost technology designed for non-intrusive integration into the wall backfilling of metal cladding elements. This combined system will allow supplying thermic energy for space heating (SH) and DHW with a high efficiency technology.
BATISOL's main advantages are zero architectural impact and modular integration with flexible joints providing a higher acceptance between the customers.

2 Architectural conceptualization

Nowadays, in the market of integrated solar collectors there are several solutions such as collectors integrated in unglazed elements, vacuum tube collectors and elements integrated into curtainwall modules, among other solutions.
BATISOL seeks for an integration of solar technologies in common buildings using modular technologies in size and dry joints, that can be integrated in conventional construction systems.
Due to its multiple architectural, thermal, hygrothermic and aesthetic benefits there is a tendency in using ventilated façade systems. This system is characterized for using a metallic substructure and for allowing the use of several finishing materials. Among all the alternatives, the plastic-aluminium composites, with a metallic external enveloping, presents the highest opportunities for solar collector integration.
It has been developed a system with a metallic finish for ventilated façade compatible with composite-aluminium architectural systems. These systems are based on a metallic substructure commonly made of aluminium which has a double effect: firstly, support the outer layer of the façade and secondly support an insulation layer that reduces the heat transmission between the building and the surroundings.
The studied collector (Figure 1) consists of a metallic collecting surface (a), a body (b) over which it is mechanised the hydraulic circuit (d) and input/output hydraulic connectors (c). The hydraulic circuit consist of rectangular section channels whose connection can be in parallel or in series, depending on each case.

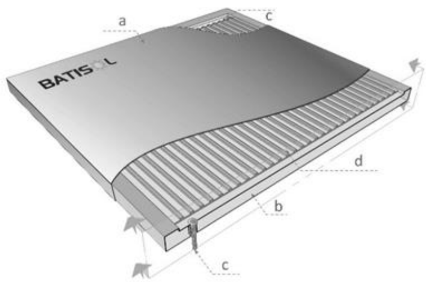

Fig 1.Parts of the collector

The use of ventilated façades has increased recently due to all the advantages, such as a good energy performance while protecting against overheating and humidity. It is characterized for having an air chamber next to the exterior cladding, mechanically fixed to a substructure which transfers the loads to the external wall or to the forged. Usually these solutions include a thermic insulation layer which is fixed to the external surface of the wall. For solar collector integration, metallic finishes are used due to its high capacitance of absorbing solar radiation as well as its high lightness comparing with other materials (for example, ceramic). Normally it is used either steel or aluminium, that are the ones that allow multiple finishing treatments.

Solar combi systems are a group of elements that incorporate solar technologies with thermic and external sources storage systems, such as boilers and several heat pumps, to satisfy the demand of space heating, hot domestic water and cooling of buildings. The most common configuration of these systems is the integration of several sources of generation, in which the solar collectors are the main heat source with additional contributions coming from a boiler. This is only use in those situations in which the desired temperature is not reached with the main source. Specific information can be found in [5].

The system that is being described in this article is characterized by using the external surface as the heat source. Not having external unglazed elements leads to an optimal solar absorption, but high heat losses.

In general, the efficiency of unglazed elements presents a high sensibility to the thermal gradient between the collector and the surroundings, meaning operational temperatures must be low in order to get proper efficiencies. BATISOL system can reasonably operate between 10 and 15 degrees above the ambient temperature for incident radiation of 500W/m2, getting performances around 50-60 % which are clearly not enough to cover all the demand. Therefore, another heat source is needed, and that is why for this system a water-water heat pump is going to be used.

3 Numerical modelling

Several numerical thermal models of solar collector have been constructed [6]. The ultimate conclusion of their comparison showed that a two-dimensional model provided sufficient resolution to properly define the solar collector.

Models have been constructed in COMSOL [7], getting collector performance efficiencies for different geometries. This efficiency is defined with the following equation (1):

$$\eta = c_0 + c_1 \cdot \frac{T_{sup} - T_{ext}}{I_{sol}} \quad (1)$$

To reduce the calculation time, the area has been reduced to the lowest value possible and the mesh has been optimised by increasing its density in those areas with the highest heat flux.

A parametric study of the thermal performance of the solar collector has been performed. For this purpose, a reference configuration has been established, upon which changes have been set. Table 1 shows the reference values and the range of variation studied for each of the parameters and the necessary input variables for this modeling. In total, more than 220 variations have been assessed.

Table 1.*Parameters and variation ranges evaluated in two-dimensional study*

Parameter	Unit	Reference value	Assessed values
I_{sol}	W/m²	400	400
T_{ext}	°C	0	
T_a	°C	5	
h_{ext}	W/(m²·K)	15	5, 15
e_{col}	mm	30	0, 10, 20, 30, 40, 50
e_{sup}	mm	1	0.1, 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.4
d_{can}	mm	35	5, 10, 15, 20, 25, 30, 35, 40, 45, 50
a_{can}	mm	15	2, 3, 5, 6, 9, 10, 12, 15, 18, 20, 21, 24, 27, 30
p_{can}	mm	2	1, 2, 3, 4

In conclusion, after analysing the results, the reference parameters are the optimum ones. The efficiency is established on the ratio between temperature and radiation difference ΔT/I = (Ta - Text) / Isol. The finishes are galvanized steel (α = 0,6 ε = 0,2) or matte black paint (α = 0,95 ε = 0,95), while convective conditions correspond with significant (h = 15 W/m²K) or reduced (h = 5 W/m²K) wind speed.

Table 2 shows performance curves calculated using the pseudo-tridimensional model for a 1000 × 350 mm collector with 10 channels in series, which corresponds to a total length of channel 10 m.

Table 2.*Parameters of the performance curves of the collector*

α	**ε**	**h**	**η, f(ΔT/I)**
			2D
0,6	0,2	5	0,576 - 7,44·ΔT/I
0,6	0,2	15	0,549 - 16,2·ΔT/I
0,95	0,95	5	0,899 - 10,9·ΔT/I
0,95	0,95	15	0,855 - 19,3·ΔT/I

The results show that the variation between correlations for 2D and pseudo-3D correlations is always in the second significant digit of each parameter. It is also observed that the constant coefficient is around 90% of the surface absorptivity. The results justify the use of simplified models getting an optimal design for the collector.

4 Experimental study

There is an excellent correlation between the parametric and the experimental results. In this article there is not going to be a detailed explanation of the experimental study as there are already several articles about it. Further information about the experimental study is available in [8].

5 Integration in combined ST system based on heat pumps

The combined system consists of the solar collector directly connected to the heat pump, with a series connexion. In the Figure 2 it can be seen a schematic solution for this system, obtained from [9].

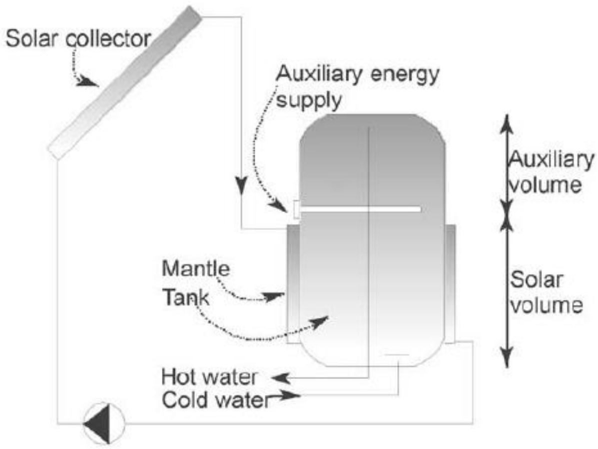

Fig 2. Combined ST system from the SERC

Sizing of the system:

- There has to be a relation between the surface of the collector and the accumulation volume which is set on 30 l/m2. This relation depends on the demand of the building. Normally the solar collector's area is around 5-7% of the total area of the building, with common values for a single-family house of 15 m2. Analyzing similar systems, it can be obtained a relation of kWh/m2 of around 25.
- In order to get more knowledge in this field, more information on combined ST system based on heat pumps can be found in [10]. In this book it can be found several cases of study from which the previous relation can be obtained.

6 Economic evaluation

In order to evaluate the advantages of a system it is necessary to compare the studied system with alternative ones, so a performance comparative can be made. A study of these characteristic include several factors to be analysed such as the investment costs and the pay back.

For the economic evaluation five technologies have been compared:

- BATISOL
- Air-source heat pump
- Ground source heat pump

- Natural gas boiler (condensing)
- Joule heating

Energy costs have been obtained from the simulation report for the selected climate, considering the following information:

- Load: Residential building (student dormitory) in Strasbourg with (1759 MWh/ year heat load for space heating and DHW).
- Performance levels (COP): BATISOL (5.6), Air-source heat pump (3.5), Ground-source heat pump (5), Natural gas (90%) and Joule heating (100%).
- Cost of primary energy: Electricity (0.14 €/kWh), Natural gas (0.056€/kWh).
- Financial data: Discount rate (5%) and service life (20 years).

Investment costs have been calculated considering cost of equipment .Each alternative has been constructed based on the following cost statements:

- 143/178kW Reversible geothermal heat pump + auxiliary systems.
- 74kW Air-source heat pump + auxiliary systems.
- 244kW condensing boiler.
- 5000l heat storage tank.
- Solar thermal loop for 7-15 solar collectors
- Solar thermal panels for installation for roof installation
- Geothermal field with 200m borehole length

Considering these elements for each technology the investment cost are shown below:

- BATISOL (442€/kW)
- Air-source heat pump (358€/kW)
- Ground-source heat pump (1293€/kW)
- Natural gas (91€/kW)
- Joule heating (5€/kW)

In the following figures, Investment and operational costs of each of the heat production technologies are presented. Economic metrics of the suitability of each of the technologies are also presented. Three main metrics are used:

- Payback period
- Discounted payback period
- Net Present Value, NPV

Figure 4 (left) shows the payback period, which refers to the period of time required to recoup the funds expended in an investment, but it is considered a method of analysis with serious limitations as it doesn't take into account the time value of money, risk, financing or opportunity cost. When net annual cash inflow is even, the payback period of the project can be computed by applying the simple equation (2) given below:

$$Payback\ period = \frac{Investment\ required}{Net\ annual\ cash\ inflow} \quad (2)$$

Finally the last figure (Figure 4, right) represents the Net Present Value (NPV) that is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. Normally an investment with a positive NPV will be a profitable one. For calculating the NPV the following equation (3) needs to be used:

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^t} - C_0 \quad (3)$$

Where Ct is the net cash inflow during the period t, C_0

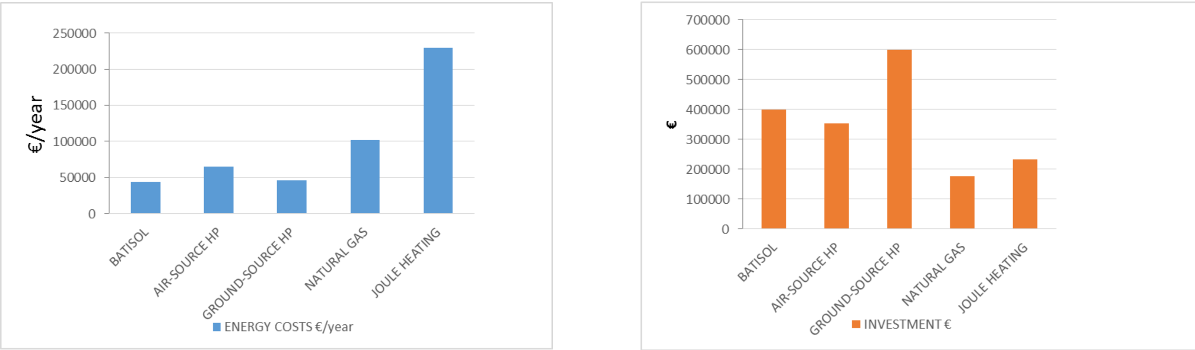

Fig 3.Energy costs (left). Investment (right)

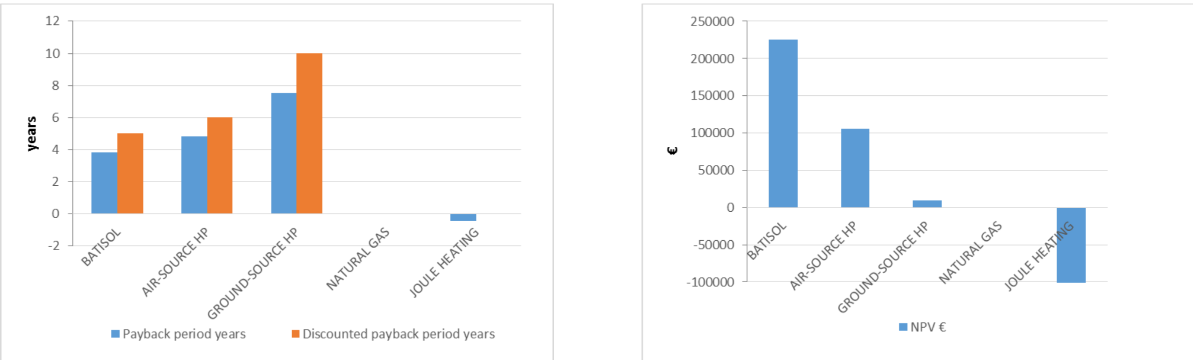

Fig 4.Payback period/Discounted payback period (left). NPV (right)

Energy costs of BATISOL are in the COP range of geothermal systems, with substantially lower investment needs. Energy costs of BATISOL are ~30% lower than for Air-source heat pumps.
When energy costs are confronted to investment needs, BATISOL pays back in 4-5 years. 1 year before air-source heat pumps and 4 years earlier than ground-source heat pumps. In these calculations, natural-gas is taken as the baseline technology for the calculation of differential investment needs and energy cost reduction.
When considering the net present value, BATISOL doubles Air-source heat pumps and it is 4 times larger than ground-source heat pumps. As in previous cases, the baseline energy carrier is natural gas.
In the case of net present costs, BATISOL is the technology presenting the lowest cost, at least 20% below all other technologies, and 30% below natural gas. For the considered case, net present cost savings of 30-50 000 € can be achieved with BATISOL in comparison with competing technologies over a 20 year service life.

7 Conclusions

This paper presents a system based on a low-cost unglazed solar technology designed to be integrated into a ventilated façade. Its main advantages lies in its neutral aesthetic impact (façade design and construction processes remain untouched) and its modular integration with dry unions. It has been estimated that the use of this solar collector combined with a heat pump leads to an increment of the overall performance of the system (COP) of 1.5-2 units.

Numerical models have been developed and compared with experimental ones in a satisfactory way. Thus, these models can be used for the parameterization of design variants. The sensibility study has shown that the thickness of the metal sheet has less influence in the collector's performance than the geometry and dimensions of the channels, as well as the surface properties of the collector.
In general, and considering data of literature such as [11], collector's design is satisfactory, expecting performance levels around 50-60 %, operating at 10-15 ºC above the ambient temperature.
Finally, as it can be seen in the economic evaluation, this system presents several advantages compared to the other technologies such as a lower investment and a shorter payback period. Combining all the advantages will lead to higher savings while keeping an optimal performance.

8 Acknowledgements

This project has been financed by INEF4, Institut pour la Transition Energétique, founded in 2013 thanks to the funds of the Commissariat Général à L'Investissement CGI/ANR and the Regional Council of Aquitaine.

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