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**Integration of Renewable Energy in the Built Environment (Electricity, Heating and Cooling)**

# Experimentation under real performing conditions of a highly integrable unglazed solar collector into a building façade

P. Elguezabal[a]*, R. Garay[a], K. Martin[b]

[a]*Tecnalia, Sustainable Construction Division, Parque Tecnológico de Bizkaia. Edificio 700, Derio 48160, Spain*
[b]*Department of Thermal Engineering – University of the Basque Country (UPV/EHU), Alameda Urquijo s/n, 48013 Bilbao, Spain*

## Abstract

In the current context of moving towards more sustainable construction, advanced façade systems that integrate solar collecting devices represent a commitment with future trends that combine renewable technologies with building skins. This paper describes a real experience when combining a novel unglazed solar collector based on sandwich panel technology, a heat pump and a controller that manages the different operation modes. Installed in the Kubik by Tecnalia testing building in northern Spain, the system has been monitored for several months in 2016, under an energy efficiency scope. The study will present measured values regarding the yield of the collector, performance of the heat pump and general efficiencies.

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## 1. Introduction and Context

Under global requirements to improve energy performance of buildings, several systems have been developed recently in order to provide solutions to reduce the high impact of the building sector into the environment and specifically to reduce their high dependence on fossil fuels and consequent carbon emissions. The Nearly Zero Energy

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* Corresponding author. Tel.: +34-946-430-850.
*E-mail address:* peru.elguezabal@tecnalia.com

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Building (NZEB) [1] is the way that the EU has adopted to meet that target, while the UNEP – SBCI states that already commercially available technologies have a high potential to improve the situation and reduce consumption in buildings [2].

A first traditional strategy adopted up to now has consisted in improving the thermal performance, focused on the envelope as main exchanger between the atmosphere and the indoor environment. Aspects such as thermal transmittance, mass inertia or thermal bridges have been assessed in order to increase the insulation behavior of the envelope.

On the other hand, solar energy has demonstrated its potential due to the high energy delivered and the reliability provided. Solar energy systems such as solar thermal and photovoltaic systems are being implemented in buildings, boosted by energy procurement policies and by the aim of owners to reduce the overall operation costs of buildings. A market report by BCC [3] estimates a promising progression for current and upcoming years for solar technologies with a Compound Annual Growth Rate (CAGR) of 23,5% for the 2014-2019 period.

As a conclusion, a trend aiming to activate façades is gaining interest, instead of working on their passive behavior. In such situation the envelope is transformed and becomes an element that does not only deal with insulation but also needs to participate and contribute to the energy production process.

Besides, there's a general understanding that the urgency does not rely on investigations for novel and sophisticated technologies still to be matured, but on developing the ones existing right now and improving their efficiency, reducing costs and in general making them more accessible.

## 2. Solar thermal collectors integrated in façade

The variety of solar collector products offers different alternatives in the residential sector, having the temperature delivered and the consequent application as main references. Solutions range from low temperature unglazed collectors, generally employed for pool heating and low-exergy systems, up to high temperatures above 100ºC achieved by vacuum collectors where solar cooling is obtained. In a middle range glazed flat plate collectors are typically used for DHW and heating purposes.

The efficiency of these systems is directly linked to the temperature of operation [4], getting a higher efficiency for the same solar input when the output temperature is reduced. However, in order to compensate for the temperature reduction, the collecting surface has to be increased to deliver the same amount of heat as a higher temperature collector. Also a remarkable benefit achieved thanks to the use of lower temperatures is the fact that security and maintenance measures are simplified with a direct impact in the cost.

In such situation unglazed collectors can provide an interesting solution for the integration in buildings and especially in their envelopes, looking for that required extra surface, while their low working temperature requires the use of heat pumps to ensure that the energy provided covers energy needs of buildings.

Once the integration is accepted, a common designing approach tries to place collectors in the surface with the best orientation and position in the roof and south oriented, in order to find the maximum incident irradiance, assuming that the highest efficiency is reached this way. However, if the design is not properly conceived balancing the annual production with the energy demand, an overproduction can occur in summer months resulting in a waste of energy [5] as well as potentially requiring some protection measures to avoid damages.

As a result, it seems possible to incorporate low temperature unglazed devices on less radiated surfaces but with higher areas, looking to provide a lower, more stable energy output during the whole year. The satisfactory performance of such devices will require specific and detailed design efforts looking for a successful integration.

There are some previous experiences in integrating such systems into façades. As the interest of the present study is linked to the metal and insulated sandwich panel product, two relevant systems are presented as reference. SOLABS [6], resulting from an FP5 project, developed an unglazed steel absorber with a hydraulic circuit inside a sandwich panel with a high level of integration into building façades. Austria based WAF Company [7] is the provider of the second façade solution, consisting in a hydronic system inserted into a polyurethane insulation in contact with the outer metallic cladding, offering variations to configure alternative textures for the external skin.

In summary, the envelope needs to evolve to a higher added value solution, getting active and participating as a component of the thermal equipment. This adaptation implies a change in the way envelopes and services are designed and implemented, increasing the complexity of these two elements separately, but aiming to converge into a combined solution that gets the best output of a synergic development.

## 3. Description of the system developed

Within the scope of the Building Active Steel Skin project (BASSE) [8] between 2013 and 2016, the objective was the development of a solar harvesting system, using steel sandwich panels combined with liquid to liquid heat pumps, for providing space heating and hot water within a range of building types.

One of the key aspects of the development was to look for a solution with a high potential to be integrated within building façades while the cost remains accessible. Sandwich systems suppose a solution for such boundaries as they are a well-known and proven technology manufactured under a highly industrialized process. Based on that approach, Figure 1 (a) represents the façade of a target block building located in Madrid where the system is applied for over-cladding the envelope as shown in Figure 1 (b). The disposition of panels is arranged in order to use longitudinal continuous elements as active panels (green) while the rest of the surface is covered with conventional sandwich panels (blue), dealing with openings and other singular elements obstructing the application of the integrated collector. As a result the solution allows to incorporate the collecting system as active panels while externally are not differentiated from conventional panels.

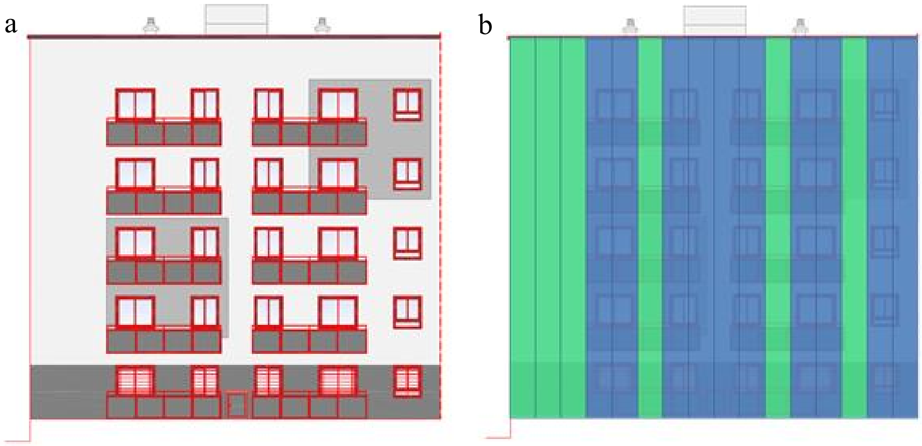

Fig. 1. (a) Target block building located in Madrid; (b) Disposition of panels in the façade.
Active panels (green). Conventional sandwich panels (blue).

The description of the active panel is provided in Figure 2 (a), consisting of a sandwich panel with an insulation core combined with two slotted steel skins (1). The plastic pipes (2) are installed into the slots of the external skin to be later completed with the final architectural cover (3). For interconnecting the pipes into a complete modular element, manifolds (4) are also arranged. Finally a hanging element (5) is also provided to install the panel into the support structure or envelope.

The cost of converting the panel into a collector has been estimated at 55.7€/m$^2$ starting from a plain sandwich panel with a cost of 37.0€/m$^2$. The resulting cost below 100€/m$^2$ is considered to be in an affordable range when façade construction or retrofitting are considered with the added value provided by the collecting function.

The complete system presented in Figure 2 (b) is designed to provide hot air and DHW by means of the heat pump that feeds these two loads, while it has the solar collector and a heat recovery system on its source side. The system is completed with the required storage tanks: one for the solar circuit and one for the DHW circuit. The liquid circulating through the heat pump and the solar circuit is a water-alcohol mixture to avoid freezing in cold season. The electric input is related to the heat pump as main consumer, the pump for circulating the fluid through the collector and for the air to liquid heat exchangers (air supply module and exhaust air recovery module).

Although not represented here as the interest relies on the heating production, the system has also the potential to be used for cooling as well through an externally reversible configuration switching load and source sides, as it was finally implemented in the Kubik case. In any case, this operation mode does not take benefit of the solar energy as the temperatures achieved in such application are insufficient for solar cooling production.

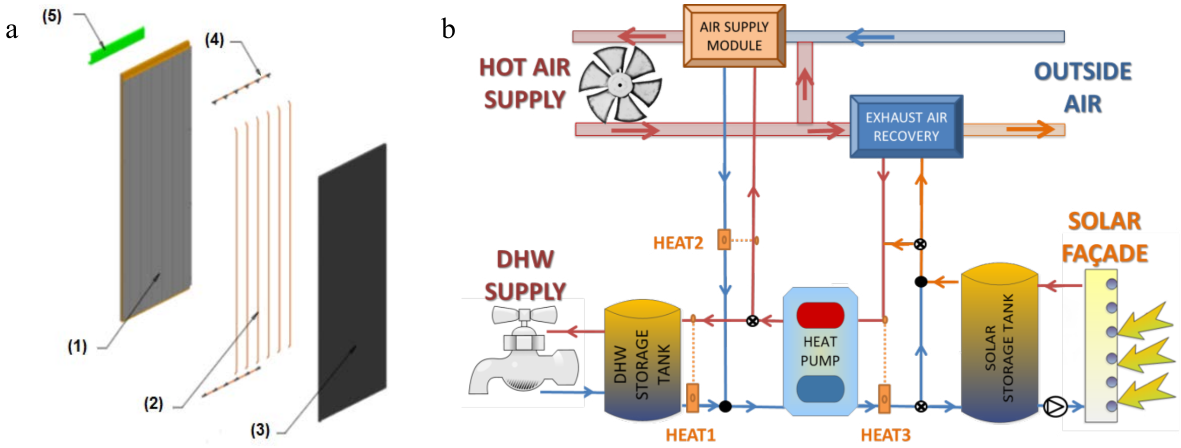

Fig. 2. (a) Complete system scheme with heat pump and solar façade as main elements; (b) Elements composing the Solar Façade

Globally, the main progresses of the project can be resumed in three elements. 1) Solar Façade: A new concept for a façade integrating a solar collector has been developed considering steel solutions and sandwich panels as main support of the element looking for an industrialized production. 2) Heat Pump: A new application for a heat pump originally designed for ground source uses, has been studied using in its source side the energy collected from the solar collector. 3) Control and Management System: A controller has been defined and constructed in order to properly govern the interrelation of the two above mentioned elements as well as their integration into the building, DHW and HVAC systems.

## 4. Installation into Kubik experimental building

Kubik by Tecnalia is an external building test facility oriented for R&D activities aimed at the development of new concepts, products and services to improve the energy efficiency of buildings. The possibility of configuring different realistic scenarios to analyze the energy efficiency of isolated or coupled constructive elements covering the envelope, floors and partitions and their interrelation with building's HVAC and lightning systems, gives Kubik a singularity to better understand the performance at room or at building level.

The building is located at Tecnalia's premises close to the northern coastline of Spain (43° 17′ N 2° 52' W), in a warm temperate climate representative of Central and Western Europe, corresponding to Cfb within the Köppen-Geiger classification [9]. The tests for solar dependent devices are completely determined by the geographical location of the building with an average yearly irradiation in a horizontal plane of 3.54kW/m$^2$.

When facing the incorporation of the solar façade into a real building, constructive issues arise for the effective implementation into the envelope as well as for the rest of the system components inside the building. This is of special interest when renovation works are developed. Besides the required available surface and space, interconnection between new and existing elements, effective pipework disposition and general needs have to be carefully considered for a successful integration of the system into the building.

For the case in Kubik as in a real retrofitting work, the available surface was also limited. The resulting disposition of the system is described in Figures 3 (a), (b) and (c). For the external solar façade 18 $m^2$ of south-oriented active panels were installed (21.29 $m^2$ if lateral trims are considered as marked in Figure 3 (b)). The support was the existing prefabricated concrete wall. For the internal space to be acclimatized a total surface of 67.9$m^2$ was arranged (Figure 3 (a)). Part of this total area, 12.4$m^2$, was required for the utility room, which is also directly connected to the conditioned space and contributes to the volume of air to be heated. Figure 3 (c) shows the final disposition of the utility room with the heat pump placed in the middle, the solar storage tank on the right side and the DHW storage tank on the left side, following the scheme represented in Figure 2 (b).

Fig. 3. (a) Floor plan of the Kubik building with the area for tests; (b) South façade of the Kubik building highlighting the solar façade; (c) Utility room with installed equipment.

## 5. Monitoring and Results

The procedure for measuring the efficiency of the system is based on energy balances between different elements composing the system and then for the overall system as a whole. Two main components are distinguished in this case; the solar circuit on one side and the heat pump on the other as main interest of the monitoring campaign. For the solar circuit, the energy output is recorded as a thermal increase into the storage tank, taking into consideration the incident radiation, external temperature and electric consumption of the circulating pump as main inputs. For the heat pump, three heat meters are installed on both sides as represented in Figure 2 (b). Heat 1 and Heat 2 in the load side record the energy provided for DHW and hot air respectively. Heat 3 measures the input to the source side that can be provided by the solar circuit, by the exhaust air recovery module or by the combination of both. The energy balance in the heat pump is completed with the electric consumption for the heat pump and the air supply and recovery module units.

Monitoring of the system under different working conditions was carried out between April and June in 2016. On one side, conventional energy requirements for covering the demand were measured for that mid-season period that has a stable and regular DHW demand but a medium-low demand for heating. On the other side, the system’s potential was preliminarily explored in order to look for the maximum achievable energy in some other periods.

The solar fraction achieved by the collector for conventional operation was 32.8% in average, providing 7.8kWh daily. For the heat pump, a Coefficient of Performance (COP) in a 4.8 – 5.5 range was achieved for DHW production and 3.2 – 4.4 for hot air production. These values are minored when the electric consumption of the circulating pump and air modules is accounted; however, the combined production supposes an average COP of 4.4.

## 6. Discussion

Results monitored during three months in year 2016 are the first preliminary results of a system that still needs further development. These values may be considered poor compared with a specific solar collecting system fully designed for comparable purposes. However, the system can’t be directly compared with a solar installation but as a combination of solar and heat pump application where in the end the COP of the heat pump has increased its performance over a baseline heat pump reference case.

Additionally the system has also potential to harvest energy when no irradiation is available. This occurs when the heat pump source side's temperature is below external ambient temperature, in a range of temperature difference of 10ºC. This behaviour has been demonstrated in the Kubik case in cool spring nights (9-13ºC minimum) for a source temperature requirement around 0ºC. However, the detailed assessment of these conditions has not been completely assessed and is highly interesting for future developments extending the working situation of the collector to a convective heat exchanger.

## 7. Conclusions

When incorporating renewable energy sources integrated into the building, the originally passive façade becomes an active element increasing its complexity as it has to be combined with the thermal equipment that was initially conceived as a separate system. However, there are synergies to combine them and, if properly designed, the system can contribute to reduce the overall energy performance of the building with a competitive solution.

The experience of implementing the system in a real working environment has helped to understand the implications of such solutions into buildings and the constraints imposed. The common understanding needed for each component and the requirement for making all them work as synchronized as possible has been highlighted as they do have an impact on the final performance of the overall system.

The use of a ground source heat pump combined with an unglazed solar collector integrated into a façade has offered reasonable results for a residential application. In addition, a higher potential than the one demonstrated has been identified once the system is optimized and future research is expected in such line.

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