Building Integration of Solar Thermal Systems- Upgrading Energy Efficiency of Existing Church Rectory

C. Cristofari[1], M.B. Carutasiu[2], J.L. Canaletti[1], R. Norvaišienė[3], F. Motte[1] and G. Notton[1]

1: UMR CNRS 6134 Scientific Centre Georges Peri, University of Corsica , Route des Sanguinaires, F20000 Ajaccio, France
2: University Politehnica of Bucharest, Power Engineering Faculty, Department of Energy Production and Use, Romania
3: Kaunas University of Applied Engineering Sciences, Tvirtovės al. 35, LT-50155 Kaunas, Lithuania

Abstract

The purpose of this article is to outline some of the potential challenges and rewards that come with the solar systems integration in the buildings.

We present in this article a project falls within the framework of a European project Maritimo with different Italians partners on the subject of refurbishment. The aim is the refurbishment of Mediterranean houses. This project is situated in a Corsican village near the centre of the island. In fact, the solar industry is relatively mature, the cost of these products is stabilized and it is likely to evolve quite slightly over the upcoming years: other than a scale effect resulting from rapid growth markets, only a technological breakthrough in the act of conception, could significantly change the economic level. The following barriers are identified (in order of importance): financial, technical and psychological (the psychological barriers are related with the aesthetics and the rigidity of the architectural codes. The problems, both technical and aesthetic, are the obvious obstacles to the development of this type of systems. For these reasons, in the frame of the present work, a new flat plate solar collector and a new solar air collector with high building integration and prototypes of these collectors were developed. First numerical results in a Church rectory situated in Bocognano, (Corsica, France) are presented in order to show viabilities of these solar technologies.

This project is built on the objectives of contributing at the European politic on the « Building Integration of Solar Thermal Systems » (BISTS) through the COST Action « European Cooperation in Science and Technology » - TU1205

1. Introduction

The importance of integrating renewable energy sources within buildings is highlighted and emphasized within the recast version of the EPBD (Energy Performances of Buildings Directive), which outlines the general framework for nZEB (nearly Zero Energy Buildings). The general definition stipulates that: "[nZEB is] *a building that has a very high energy performance. […] the amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable energy sources produced on-site or nearby*" (Directive of European Parliament, 2010/31/EU).

The European Union (EU27) possesses a residential building stock of 300 million housing units with some 25 thousand million square meters of buildings for a population of 512 million inhabitants, an area equivalent to about three times that of Corsica (8.6 km²). The mean annual growth of the residential construction sector in Europe is 1%. In area, the European building stock is 25% "non-residential" part (tertiary sector, hospitals, schools, administration, etc.) and 75% "residential" (dwellings). In the residential area, 64% is made up of individual housing, and 36% communal housing. In the residential buildings sector, 39% were built before 1960, 43% in the interval 1961–1990 and 17% in the interval 1991–2010. More than half of European dwellings are therefore not insulated. Buildings account for 40% of total energy consumption in the EU, and 36% of greenhouse gas emissions (European Commission, 2013). This sector, which consumes more energy than either industry or transport, is therefore of major importance for mitigating the EU’s energy dependency and carbon emissions.

The energy consumption of a typical household is divided between heating, domestic hot water, appliances and cooking. According to Enerdata statistics (Energy Efficiency Trends in Buildings, 2013), the typical house in EU is characterized by a yearly specific final energy consumption ranging from 200 kWh/m^2 (residential sector) to 300 kWh/m^2 (tertiary sector). The percentage of utilization is: 65% for HVAC systems functioning, 14% for domestic hot water preparation and only about 12% due to appliances, which tend to be more and more energy efficient. These facts imply a great potential of efficiency for new and retrofit buildings, obtained through implementation of clean energy systems which can provide a significant part of the energy requirements. These systems have to be evaluated for both their technical characteristics and their degree of integrability, as they should have a little impact over the aesthetics of buildings, even more in countries such as France with rigid guidelines regarding retrofitting actions. Nevertheless, the French Government acknowledges the importance of solar technologies in order to promote clean energy integration into buildings, but also highlights and promotes the importance of developing friendly aesthetics equipment (Ministry of Sustainable Development, 2012).

This paper analyses the energy and environmental performances of two patented solar thermal systems: solar water and solar air heating systems, design to correspond to the French legislation rigors. The proposed systems are characterized by very high building integration potential. The systems are integrated into a residential building in Bocognano, a commune located in the department of Corse-du-Sud, France. The systems were analyzed using the RETScreen analysis tool, widely used for simulating renewable energy sources implementation.

2. Equipment description

The two solar thermal systems are integrated into a Church Rectory located in Bocognano, Corsica, France, latitude N 42°04’50”, longitude E 09°03’44” and 651 m altitude. The residential building is subject to refurbishment process through a project aiming the renovation of Mediterranean houses. The experimental dwelling is composed of four apartments with different utilization: two are used for tourist accommodation, and its considered to be booked half the year, while the other two are permanently used, and serve as church rectory. The solar systems are integrated within the building’s framework and were designed to provide a significand part of energy required for space and water heating, without altering the building’s façade. The solar water collectors are integrated within the gutter and metal porch roof, while the solar air heaters are basically the windows shutters.

The area of the gutter solar collectors and a part of area of the solar metal porch roof are connected to one tank for two apartments (rural tourism houses–collector area 1.80 m²/43° tilted). The other part of area of the solar metal porch roof is connected to another tank for the others apartments (church rectory–collector area 2.02 m²/ 43° tilted). The hot water tanks have 100 l, considered suitable for 2 persons. Moreover, eleven solar air collectors are integrated in the shutters, increasing the efficiency of the building’s heating system and

allowing at the same time to maintain a healthy indoor air. The systems' integration within the analyzed building can be observed in Figure 1, and is detailed in the following sections.

Figure 1. The solar thermal systems integration
(a. vacuum collectors; b. flat collectors; c. air collectors).

2.1. Solar air heater – Volet'air®

Emerged from the facts that every building has windows, and that in the Mediterranean regions they are predominant equipped with shutters, we developed and patented a solar air shutter with high building integrability, named Volet'air® system (Figure 2). During heating period, it produces passive low temperature heat, increasing the efficiency of utilized heating system. Besides the frame, which can be composed of various materials (wood, aluminum or PVC), the solar air heater is composed of two transparent multi-wall polycarbonate panels conceived for outdoor applications. The panels encapsulate a black polypropylene panel, which serves as solar radiation absorber and generates the hot air (Figure 3).

Figure 2. Window shutter with wood frame and French-window shutter with aluminum frame

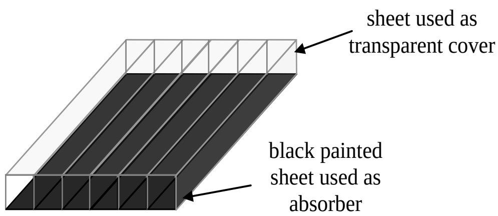

Fig. 3. Glazing panels in multi-wall polycarbonate

The polycarbonate material has almost the same optical proprieties as the glass, letting pass the solar radiation, but reflexing back the large infrared radiation emitted by the absorber, thus creating the greenhouse effect inside the shutter. The exterior cold air's inlet is facilitated by two openings placed at the inferior part of the shutter, under the frame, and dividing the air path. For increasing the overall heat exchange surface, and thus obtaining a better heat transfer, the air flows through two separate ways. Initially the inlet air has an ascendant flow through channels made between exterior polycarbonate panels and interior polypropylene panels. In the second part, the air has a descendent flow, and it circulates inside the channel, formed by the interior black polypropylene panels, as illustrated in Figure 4. After covering the entire path, the hot air exists the heater through a collector placed on the intern part of the frame, near the shutter's hinges. This solar collector does not use a thermal insulation as in a conventional one, which makes it thermally original.

The air circulation is assured by low-noise axial fans (2-4 W), designed according to the shutter's size, and powered by a-Si PV modules (12 V, 4-6W), integrated at the lower part of the heat converter (Figure 4). Besides the power generation, the PV modules also provides a part of the heat used by the solar shutter, increasing the overall efficiency of the process. The hot air collector is composed of two pieces which links the solar air heater with the interior of the house.

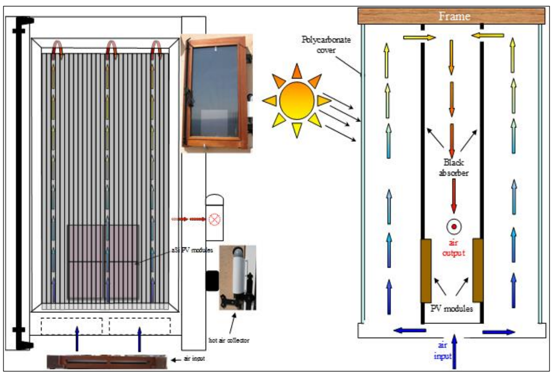

Figure 4. The solar shutter and air flow circulation

Given these facts, and taking into consideration that the shutter produces thermal energy opened, closed and in any intermediate positions (due to its symmetrical concept), the functionality of the Volet'air® system is extended and can be used for different cases (J.L. Canaletti, 2008). Its determined technical performances are: $\eta_0 = 0{,}76$; $a_1 = 8.12$ W/m^2/K; $a_2 = 0.0135$ W/m^2/K^2; $Q_{max} = 43$m^3/h

2.2. Solar water heater–Concept H2OSS®

In order to ensure a significant quantity of the hot water requirements, two solar water systems were integrated into the building's framework. The first system is composed of patented vacuum solar collectors and is not detectable from the ground level, due to its placement into the building's gutters (Figure 5). The H2OSS® Concept vacuum tube solar collectors consist of two concentric tubes, allowing the heat transfer fluid to enter from the exterior tube, and to exit from the interior one. For this case, the H2OSS® Concept integrate vacuum collectors with a length of 2 m in direct flow, the tube's diameter is 56 mm, while the thickness of the cladding tube is 1.8 mm.

Figure 5. H2OSS® Concept with Narva vacuum solar integration into the building's gutters

The vacuum tube glass cover is manufactured from raw materials containing very low iron content, presenting an increased transparency to light. Moreover, the glass was treated with nanoparticles of silicon dioxide (SiO), in order to increase its mechanical resistance and optical efficiency. This manufacturing procedure and chemical treatment increased the transparence of the glass at a maximum value of 96% and also prevents the deterioration of its surface, homogenizes its mechanical resistance, thus avoiding the microcracks. Moreover, this SiO treatment combined with the relatively high thickness of the tube's wall assures very high mechanical resistance, validated by tests conducted at TÜV Rhineland, according to the EN 12975-2 normative. Furthermore, compared with the usual types of borosilicate glasses used with other solar systems, the patented vacuum tube's glass has a lower hydrogen and helium permeability, allowing to maintain the high vacuum over more than 20 years. For this vacuum tube, its implementation induced a new and very robust glass-to-metal connection. The exposure to breakage of these connections through the most widespread technical solutions is avoided. The glass-metal connection resists without difficulty to the influence of high axial and radial forces. This solution has been the subject of a patent application: PCT/DE 2006/001244.

Besides the treated glass, the tube's absorber was chosen given the most modern copper absorbers available on the market, manufactured based on a coating of titanium oxide azide. The connection between the absorber and the heat transfer tube was realized using an ultrasonic welding process. The absorber layer shows no alteration of its physical proprieties, even considering a lifetime of 20 years. They are suitable for heating domestic hot water but also for applications requiring high water temperatures such as interior air heating, industrial thermal processes, drying process, laundries, etc. The technical data is provided in the following table:

Table 1. Vacuum-tube thermal module technical data

Single-sided absorber coating	Narva Vacuum tube Concept H2OSS			
Nominal length (mm)	800	1500	1775	2000
Tube's length (mm)	810	1510	1785	2010
Tube's diameter (mm)	56			

Length of junction tube (mm)	57			
Inlet area of the glass tube (m²)	0,0386	0,0750	0,090	0 ,1010
Nominal tube power for an exposure of 1000 W/m²	30	59	71	80
Conduction heat loss coefficient (W/m/K)	1,12			
Convection heat loss coefficient (W/m²/K)	0,004			
Yield (η_0)	0,781			

The second system is composed of flat collectors, mounted of a metal porch roof, also without altering the aesthetics of the building and its initial purpose. More details about this type of H2OSS solar collectors can be found in the following papers: (Notton, 2013; Motte, 2013a; Motte 2013b; Notton, 2014a; Notton, 2014b; Chr. Lamanatou, 2016).

3. Simulations and results

3.1. Solar water collectors

Firstly, we analyzed the two apartments used for residential purposed, supplied with the porch roof flat plate solar collectors, with a tilt angle of 43° and a total surface of 2.02 m^2. For this, we considered an occupancy rate of 100%, resulting an estimated daily hot water usage of 169 liters/day for each apartment. The system is supposedly used 100% of the time, each month of the year, as suggested by the domestic utilization.

Thus, the energy requirement for water heating is 2854 kWh/year. Using the glazed collector type, the performances parameters of the flat solar collectors (optical efficiency 0.906 and thermal losses 8.99 W/m^2/K), and a storage system of 100 liters with miscellaneous losses estimated at approximately 13%, the total heat delivered is 1292 kWh, meaning a solar fraction of 45%. The monthly thermal energy production is shown in Fig. 6.

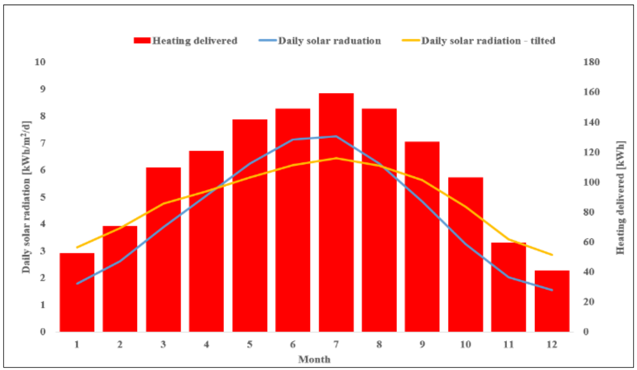

Figure 6. The simulation’s results for the flat solar collectors

The total annual horizontal solar radiation is estimated at 1.58 MWh/m^2, while the tilted annual solar radiation is greater, estimated at 1.77 MWh/m^2. Using this configuration, the thermal energy delivered ranged from 41 kWh in December, to a maximum value of 159 kWh in July, when the horizontal solar radiation reached the daily average peak value (7.26 kWh/m^2/day). The solar fraction of this configuration is 45%, while the total thermal energy saved is 1292 kWh. Moreover, if in the same conditions of occupancy, the second system is to be used (vacuum solar collectors with a total surface of 1.8 m^2, and performances parameters from Table 1), the total heat delivered will increase to 1615 kWh, while the solar fraction will increase to 57%, showing the improvement implied by the new patented solar collectors.

The second analyzed configuration is used to provide a significant part of the domestic hot water required by the other two apartments used as accommodation for tourists. Given the fact that the tourism season is about 7 or 8 months/year, we considered that the apartments will be fully used about 50% of the year. Consequently, the months with 0% hot water usage are January, February, March, November and December, while April and October are characterized by a system’s usage of 50%. Moreover, the considered daily hot water use is also 169 l/day, and at a supply temperature of 55 °C, results 1392 kWh energy usage.

By integrating the vacuum solar system at a 43° tilt (0° azimuth), a total collector's surface of 1.8 m^2, and the suitable functioning parameters, the total energy delivered is 960 kWh/year, and a solar fraction of 69%. This value is due to the fact that the apartments are used only in periods with high solar radiation and exterior temperature. The comparison between monthly energy available and produced can be analyzed in Fig. 7.

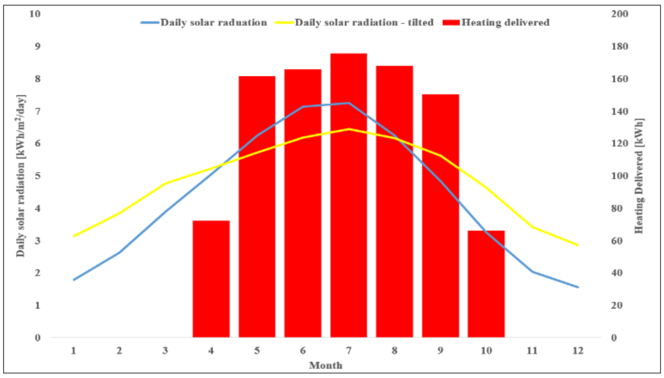

Figure 7. The simulation's results for the vacuum solar collectors

As observed in the previous Figure, even if the total area of the collector is smaller, the improved characteristics implies an increased heat delivered, comparing the same month. If the previous solar system provided maximum 159 kWh (2.02 m^2 surface), the vacuum solar system has a peak energy production of 176 kWh, for a 1.8 m^2 collector. Moreover, if the occupancy is considered to be 100%, as in the first study, the total energy production is 1608 kWh/m^2 and the total solar fraction decreases at 56%, due to the low energy production and high consumption during cold season.

4.2. Solar air shutters

In order to generate a quantity of the required heating energy, the dwelling is equipped with 11 solar shutters, dimensioned according to existing windows. Therefore, we analyzed each side of the building, taking into consideration the total surface of the installed solar shutters given by their number and individual sizes, as indicated through the next table.

Table 2. Number and dimensions of the solar air heaters

-	**West**	**South**	**East**
shutter 1 [mm^2]	910x1675	920x1670	660x1025
shutter 2 [mm^2]	920x1670	920x1670	600x1150
shutter 3 [mm^2]	915x1660	925x1665	660x1025
shutter 4 [mm^2]	925x1665	-	600x1150
TOTAL Surface [m^2]	**6.12**	**4.613**	**2.733**

Four solar shutters provide low temperature heat for two apartments at the ground level (40 m^2 each), one with the windows on the west side (the prayer room) and the other with them on the east side (a residential apartment). The other seven systems are used to provide heat for a 66 m^2 apartment, placed at the first floor of the building, having Est-West-South oriented windows. The individual dimensions for the considered shutters are given in Table 2. The analyzed building is not equipped with a mechanical ventilation system, so it is difficult to determine the airflow rate of the zone. Thus, considering that one apartment is habituated by 2 persons, and is composed by a kitchen/living-room, a bathroom and bedroom, the required air flow was estimated at 325 m^3/h/ according to ASHRAE normative (approx. 15 l/s per room), resulting a yearly heating energy requirement of 5731 kWh.

The heat is considered not to be needed in June, July and August, while in May and September the systems are used in only 50% of the time, resulting a total annual heating delivered of 644 kWh. This configuration led to 11.7% energy savings, while the seasonal solar air heater efficiency was estimated at approximatively 30%, with an average rise of the air temperature of 3.9 °C. The East orientation of the shutter is quantified by the azimuth angle, set at 90°. The same type on analysis was conducted for the West ground floor apartment, which is equipped with solar shutters with a total surface of approximatively 3 m^2 (915x1660 and 925x1665). The room is used as church or prayer room, thus we estimated only 110 m^3/h airflow for heating consumption. Moreover, the same utilization strategy was considered, resulting 1429 kWh heating energy delivered, a seasonal heater's efficiency of 30%, while the total energy savings for this configuration was estimated at 76.4%, over the entire year (Figure 8).

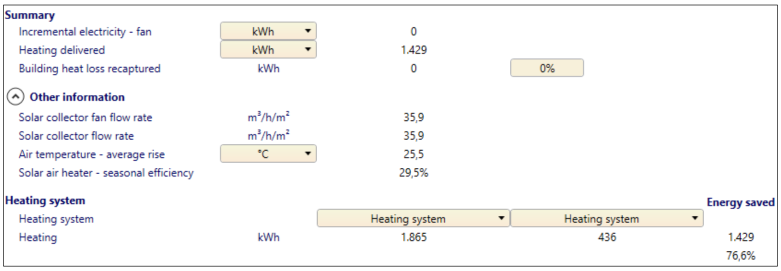

Figure 8. Final results for West orientated apartment

The building's first floor is intended for tourists, so the air flow is considered as in hotel rooms (3 l/s per m^2 floor area), indicating a treated airflow rate of approximatively 200 l/s, or 720 m^3/h. For this, the total heating requirement is estimated at 12735 kWh/year (12205 kWh/year considering the same utilization as the previous cases). For this apartment, the solar shutters are on each orientation, excepting North. These surfaces, along with the characteristics previously mentioned, were used to simulate and analyze the benefits provided by each of the solar heaters. The results are presented in the following Table and the total percentage of energy reduction was 47%.

Table 3. The main results of the first-floor air heaters simulations

Orientation	South	West	East
Surface [m^2]	4.61	3.06	1.37
Heating Delivered [kWh]	3479	1442	646
Seasonal efficiency [%]	47.7	29.8	29.8
Energy saved [%]	28.5	11.8	5.3
Air temperature average rise	5.3	3.9	1.8

5. Conclusions and discussion

This paper presents two new patented solar heating systems with very high building integrability. These solar systems were developed in order the respond to the aesthetic problems triggered by the need of using renewable energy in to decrease the energy intensity of a building and their utility was simulated with the RETScreen analysis tool.

The first simulations conducted for the flat solar collectors indicated an annual hot water production of 1292 kWh, meaning a solar fraction of 45% if the apartments are used all year. Moreover, if the vacuum system was used, the solar fraction increased at 57%. The second type of apartments, booked only half a year, are simulated in hotel/motel conditions, and the annual thermal energy delivered is 960 kWh and the solar fraction was estimated at 69. The solar air heaters were simulated based on their characteristics, surfaces and orientations. The building has two floors, each with solar systems integrated on Est, West, or South sides. Taking also into consideration a prior estimation of the required ventilation airflow, the apartments were analyzed based on their purpose (dwelling or accommodation). Thus, for the ground-level position, the annual energy savings was 12% for the East orientated apartment and 76% for the West apartment. The difference is more due to the utilization, the size of the shutters and less due to the orientation (324 m^3/h and 1.37 m^2 VS. 110 m^3/h and 3.01 m^2). The first-floor apartments were considered as hotel rooms, so more heating was required. The solar shutters mounted on East, West and South sides, provide a total 5567 kWh heat during a year, meaning up to 47% of the required energy, while the yield of the shutters ranged from 29.8% to 47.7% in the South side.

REFERENCES

Directive 2010/31/EU of The European Parliament and of the Council 19 May on the Energy Performances of Buildings (recast) 2010

Enerdata: Energy Efficiency Trends in Buildings in the EU, September 2012, page 15

Ministry of Ecology, Environment, Transport and Housing, Energy Policy - Ministry of Sustainable Development. 2012. [Online].
http//:www.developpement-durable.gouv.fr/Politique-energetique.html

J.L. Canaletti, G. Notton, A. Damian, I. Colda, C. Cristofari, New concept of solar air heater integrated in the building, 4th IASME/WSEAS International Conference on Energy, Environment, Ecosystems, and Sustainable Development (EEESD'08), Algarve, Portugal, June 11-13, 2008

G. Notton, F. Motte, C. Cristofari, J.L. Canaletti, New patented solar thermal concept for high building integration: test and modeling, Energy Procedia 42 (2013), 43–52.

F. Motte, G. Notton, C. Cristofari, J.L. Canaletti, A building integrated solar collector: Performances characterization and first stage of numerical calculation, Renewable Energy 49 (2013), 1–5.

G. Notton, F. Motte, C. Cristofari, J.L. Canaletti, Performances and numerical optimization of a novel thermal solar collector for residential building, Renewable and Sustainable Energy Reviews 33 (2014), 60–73.

Chr. Lamnatou, C. Cristofari, D. Chemisana, J.L. Canaletti, Building-integrated solar thermal systems based on vacuum-tube technology: Critical factors focusing on life-cycle environmental profile, Renewable and Sustainable Energy Reviews 65 (2016), 1199–1215.

F. Motte, G. Notton, C. Cristofari, J.L. Canaletti, Design and modelling of a new patented thermal solar collector with high building integration, Applied Energy 102 (2013), 631–639.