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Novel Architectural Strategies to Support an nZEB Mediterranean School

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Abstract. The Educational Department of Catalan Government has designed a new public school located at the center of Catalonia, in the town of Solsona. For this new construction model, they have set a main goal to minimize the energy demands, which are a key factor in reducing carbon dioxide emissions over the whole life of the building. Specifically, the objective is to increase the envelope performance, permitting to reduce, as much as possible, the implementation and use of active heating and cooling systems. The most representative strategy to do so is the use of brick curtain wall, designed in analogy with glass curtain walls as a facade. It allows the use of thermal mass to cool the building passively during the night in summer time and it helps to ensure airtightness in the envelope to minimize air leaks. This facade is complemented with an architectonical element that produces electricity based on photovoltaic panels. Based on the energy simulation results and waiting for the actual building's construction, some relevant conclusions can be made. The role of the architecture has been crucial to ensure an optimal result, especially contributing on the reduction of the overheating hours, resulting to the minimization of the cooling energy demand. The building does not require any installation of mechanical cooling systems, even being located in the Mediterranean climate. In south orientations, the use of doubled glazing seems to be efficient enough to achieve a low energy demand, while it optimizes at the same time the total economic construction cost. Photovoltaic production in schools must be combined with some other actions. The energy exportation to the grid, as well as the use of the energy for the electric vehicle charging, are feasible options for the future.

1. Introduction

The Energy Performance of Buildings Directive (EPBD) is the European Union's main legislative framework aiming to promote the improvement of the energy performance of buildings within the European Community [1], [2].

In this framework, this article presents the experience of new strategies that could be used in future designs of educational buildings in Catalonia, extender also to the Mediterranean region, in order to achieve a behaviour of nearly zero energy buildings (nZEB). Specifically, this work presents a design proposal for educational buildings, focusing on three main objectives: The reduction in full measure of the heating and cooling demands, the use of high-energy efficiency systems, and the local generation of renewable energy sources for self-consumption. The following sections present a newly proposed construction model, applied on a studied building, as well as the resulted energy performance values.

2. Materials and systems

2.1. The brick curtain wall

Traditionally, curtain walls are made of glass and steel, representing perfectly the conditions of lightness and transparency, which are the central core of modern architecture. Nevertheless, other designs can be result, using the most representative material in Catalan tradition, such as faced bricks. A potential design can be formed by a thin faced brickwork supported by its own steel structure and behind it, another layer made of mineral wool panels, which can be also continuous over the structure and the internal wall of the facade. This design has as a result the minimization of the energy losses of the thermal bridges, tending to zero. According to another study that was made over eight existing high schools in Catalonia, it was concluded that thermal bridges represents about 20% of the energy loses though the facade.

This novel thin faced brickwork design permits to achieve 'the pencil's principle', which consists in possibility to draw a continuous line wrapping the external building's envelope. In order to achieve a real continuity in this insulation layer, window frames were located in the middle of the façade, in the same layer of thermal insulation. Other benefits of this novel constructive system is the thermal inertia behaviour, when temperatures are fluctuating throughout the day, a thermal mass can serve to flatten out the daily temperature fluctuations, also by the outside and inside temperatures. In Solsona, the location of the new school, in summer time temperatures can fluctuate between 15º C during the night and 34º C in the middle of the day. The educational use has high thermal loads. The brick façade and the concrete building's structure made a massive building which works as a battery, charging heating energy during the day (or hotter hours) and discharging it at night (or cooler hours).

2.2. Air tightness

The effectiveness of the building thermal behaviour relies on the lack of air current. On the other hand, the air leaks can have collateral effects, due to the condensations on the thermal insulation and its reduction of the insulation effectiveness performance, with the risk of being an origin of numerous pathologies.

The proposed façade in this work has an external faced brickwork layer, a 3 cm. thick cavity and the internal concrete blockwork layer to which the insulation panels are attached. The solution consists in rendering the blockwork with plaster that is a validated airtight material, as well as in applying an air thigh band in the joints with the window frames, which can be finished with timber boards.

2.3. Effective mechanical ventilation

The mechanical ventilation system is useful to provide the users with a good indoor air quality, as well as to ensure an extremely low energy demand and a high level of efficiency in the systems operating in the building. Nevertheless, this can be only achieved by implementing energy recovery systems.
The Mechanical ventilation system is composed of four air treatment units: two air treatment units located in the roof space for all classrooms, offices and general services in the school, and two additional units for the gym and changing rooms.

2.4. Circular economy of the Catalonian woodlands

Catalonia includes plenty of forest areas, covering approximately 64% of its surface. Taking advantage of its resources, the Catalan government established a roadmap on forest management that was focused on their cleaning and brushes removal, and their posterior use as fuel for biomass systems [3]-[5]. The biomass system is considered as a fuel with zero CO_2 emissions. In order to consider the building as an environmental friendly facility, which can use the biomass technology, a criterion of close distance to forests has to be met for two main reasons: i) the CO_2 emissions of the combustion could be quickly absorbed by the trees and ii) the CO_2 emissions, related to the transportation phase should be minimised.

In the presented work, a biomass boiler has been used as heating production system, to provide with energy the underfloor heating circuit of the building that works at a temperature between 40º and 45ºC degrees. This system works with thermal inertia in analogy with the mass constructive system, according to the thermal demand of the build, as a result of its use and weather. On the other hand, another criterion for the selection of the boiler's model has been the CO2 and nitrogen oxide emissions.

2.5. Photovoltaic porch

An important challenge for the architects and designers is the integration of the facilities and services in the building design in general, but particularly, to achieve an architectonical design considering solar panels. There is an installation guide established by Catalan Education Department, indicating that a porch is a key element in any new school in front of classrooms and the gym. In one hand, it allows the children from 3 to 5 years old to have class outdoors, while on the other hand it provides the students with a sheltered playground area for rainy days.

In the presented study, this porch has been used for the integration of a renewable energy system, which will later be used as a showroom for the students, promoting the environmental benefits of the green technologies.

3. Building's performance

For the design phase of the building, the Design Builder simulation program has been used to evaluate the energy behaviour of several architectural strategies, permitting to determine the optimal one, based on the established (economic and energetic) criteria. Because of this dynamic evaluation, it was possible to decrease the heating and cooling demand at 5.23 kWh/m²y ensuring a cost effectiveness. Below some conclusions and results of this part of the study are presented.

As mentioned previously, an evaluation of the different passive design strategies was made to analyse the impact of including triple o double pan glazing in windows in natural lighting and solar gains. A summary of the transmittance values of the envelope elements (U-values) are presented in Table 1, considering that the triple pan glazing has a transmittance value of U=0.60 W/m²K and a solar factor of g=0.51, while the doubled pan glazing has a U=1.10 W/m²K and a g=0.65.

Table 1. Transmittance values of envelope elements

Envelop element	*U Value*
Façade	0.13
Basement slab	0.17
Window frames	2.0
Roof slab	0.14
Roof metal panels	0.46
Interior partitioning	0.34

For the evaluation of the active design strategies, only a heating system was considered, discarding the need of cooling generation. The heating system consist of a biomass boiler with a power of 188 kW, which supplies the floor circuit. The seasonal coefficient performance (SCOP) of the boiler is 83%.

The lighting implemented system is based on a LED system with a high level of performance, 123lm/W of luminous efficacy, with the support of a management and control system in order to adjust the medium level of lighting in accordance to lighting external conditions.

For the design of the photovoltaic porch, the energy consumption of the building has been taken into account, in order to size optimally the installation, focused on self-consumption (without the use of electrical storage systems). The final performance values of the installation include a total power per panel of 270 Wp, a total annual production of 40.062 kW and inclination angle for the panels of 4 degrees. It has to be mentioned that the inclination value is not the optimal one, but was used to achieve the best architectonical integration, resulting to an energy production reduction of 12%. The different outdoor temperatures considered in the simulations are presented in Figure 1.

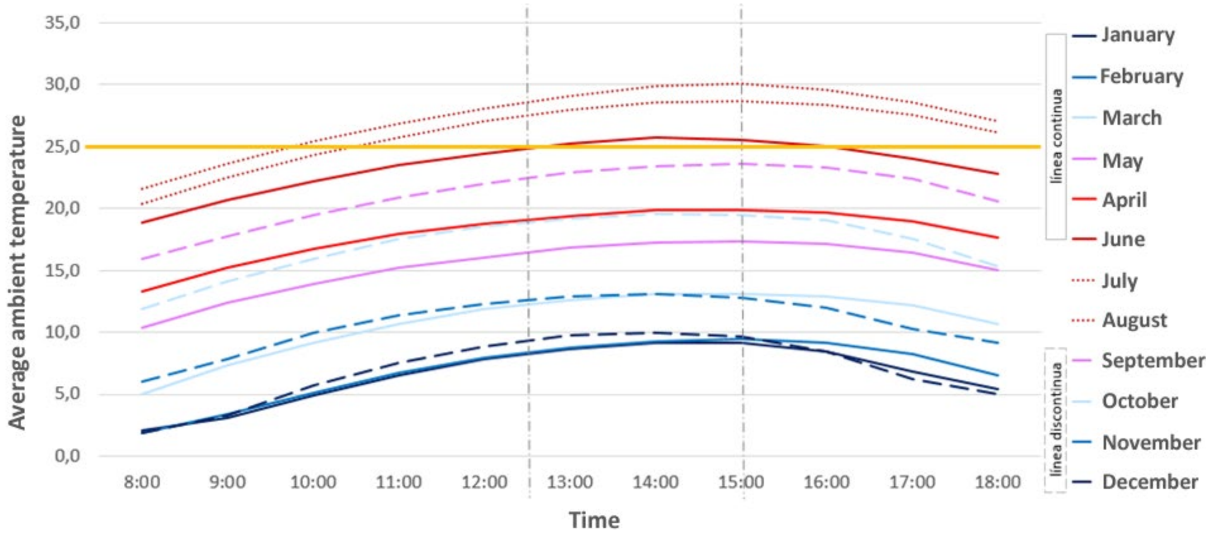

Figure 1. Average temperatures of every month and time zone.

From the analysis, it can be concluded that the higher temperatures occur between 12:30 to 3:00 pm, which corresponds to lunchtime in schools.

4. Energy performance simulation

The following subsections present a brief description of the main results of the application of the energy analysis methodology and summarizes the main optimized parameters.

4.1. Case studies. Energy performance values

As mentioned previously, several case studies have been analyzed to determine the energy performance values of the building, with objective to achieve a final cost optimality [6], [7].

- Case 1 (BASE): The original design of the building with no modifications.
- Case 2 (*CTE*): The building's design, including modifications related to the reduction of U-values of the external envelope elements to the minimum required by Spanish regulations [8].
- Case 3 (*RITE RC55*): The building's design, including a heat recovery system with a 55% of performance, as established as minimum by the Spanish regulation.
- Case 4 (*Vidre 2V*): The original building's design, changing the triple pan glazing to double pan for the case of south façade, with the intention to maximize the solar gains. The new obtained solar factor increases from 51% to 65%. However, double pan glazing U-value is 1.1 W/m²K., instead 0.6 W/m²K of the initial one.

- Case 5 (*RC85*): The building's design, including a heat recovery system major to 75% of performance.
- Case 6 (*optimitzat 2V+RC85+PV*): The building's design, including several modification of cases 4, 5 and reducing the photovoltaic panels surface from 178 m² to 132 m², considering the fact that the maximum level of production is in summer time when the consumption is highly low.

The following table presents the obtained results, related to the cooling and heating demands, the final and primary energy consumptions and the CO_2 emissions of the different cases.

Table 2. Results of simulation cases

values regarding the surface of air conditioned space	*E. Demand (kWh/m²y)*				*Final Energy (kWh/m²y)*				*Primary Energy (kWh/m²y)*				*CO_2 emissions (kgCO_2/m²y)*		
	Cool.	*Heat.*	*Bio*.*	*Bio*.*	*Elect.*	*Elect.*	*Elect.*	*TOTAL*	*Bio*.*	*Elect.*	*TOTAL*	*TOTAL*	*Bio*.*	*Elect.*	*TOTAL*
			Heat 1.	*HSW 2*	*Total*	*Light 3*	*PV*	*∑ 1+2+3*				*Non renewable*			
BASE	0.075	5.23	6.30	5.45	0.39	2.59	2.2	14.34	12.188	6.133	18.321	13.111	0.212	0.129	0.341
CTE	0.006	18.08	21.79	5.45	0.40	2.60	2.2	29.84	28.251	6.157	34.408	29.198	0.490	0.132	0.623
RITE RC55	0.081	14.87	11.22	5.45	0.39	2.59	2.2	19.26	17.290	6.133	23.423	18.213	0.300	0.129	0.429
Vidre 2V	0.071	5.56	6.70	5.45	0.38	2.58	2.2	14.73	12.603	6.109	18.712	13.503	0.219	0.126	0.345
RC85	0.072	4.32	5.2	5.45	0.39	2.59	2.2	13.24	11.047	6.133	17.180	11.971	0.192	0.129	0.321
Optimized	0.068	4.23	5.18	5.45	0.39	2.59	2.2	13.21	11.026	6.109	17.136	11.950	0.191	0.129	0.320

*Bio = biomass fuel.

It can be observed that cooling demand values are insignificant in every case, however, as far as heating demand is concerned, there is a considerable reduction when applying additional measures compared with the minimum ones established in Spanish regulations. In the case of having the thermal transfer coefficients established by law and no heating recovery in ventilation system, heating demand is about 15 kWh/m²y, over the value established in Passive house standard.

This value can be reached installing a heating recovery with the minimum level of performance established in Spanish regulations, which is 55%. Increasing the level of performance up to 85%, heating demand can be reduced one third. Increasing the heat recovery efficiency from 75% to 85%, the reduction in heating demand is 17% and the results of the economic cost increases by only 0,36% in relation to the total cost of construction. Table 3 presents the improvement percentages compared to case 1; the building's original design without any modification.

Table 3. Performance changes of different strategies compared to the original one

Impro-vement respected the base (%)	*E. Demand (kWh/m²y)*				*Final Energy (kWh/m²y)*				*Primary Energy (kWh/m²y)*				*CO_2 emissions (kgCO_2/m²y)*		
	Cool.	*Heat.*	*Bio*.*	*Bio*.*	*Elect.*	*Elect.*	*Elect.*	*TOTAL*	*Bio*.*	*Elect.*	*TOTAL*	*TOTAL*	*Bio*.*	*Elect.*	*TOTAL*
			Heat 1.	*HSW 2*	*Total*	*Light 3*	*PV*	*∑ 1+2+3*				*Non renewable*			
CTE	-92%	71%	246%	0%	2.6%	0.4%	0%	108%	132%	0.4%	87,8%	123%	132%	2.6%	83%
RITE RC55	8%	65%	78%	0%	0%	0%	0%	34%	42%	0%	27.8%	39%	42%	0%	26%
Vidre 2V	-5%	6%	6%	0%	-2.6%	-0.4%	0%	3%	3%	-0.4%	2.10%	3%	3%	-2,6%	1%
RC85	-4%	-17%	-17%	0%	0%	0%	0%	-8%	-9%	0%	-6,20	-9%	-9%	0%	-6%
Optimized	-9%	-19%	-18%	0%	0%	-0.4%	0.5%	-8%	-10%	-0.4%	-6,50	-9%	-10%	0%	-6%

*Bio = biomass fuel.

From the obtained results, it can be observed that the use of double pan glazing on the south facade provides solar gains though windows of 25,5% higher than using triple pan glazing. Nevertheless, the heating demand increases to 6% with a reduction of 5% in cooling demand, which is an important aspect, taking into account that there is not cooling system installed in the building.

During winter time, the fact of having a glazing with the conductivity level doubled, does not imply a proportional increase in heating demand. This occurs because it is located on the south façade, in a location with plenty of hours of solar radiation and actually, there is a balance between the losses caused by the high level of conductivity and the heating gains as a result of a better glazing solar factor. Additionally, it should be mentioned the economic saving in choosing double pan glazing compared with triple pan and the advantages in manipulating these products.

4.2. Case studies. Energy loads values

Figure 2, presents an analysis of the heating thermal loads for each case study, with and without the use of heating recovery system (on right and left side, respectively), described in Wh/m²y.

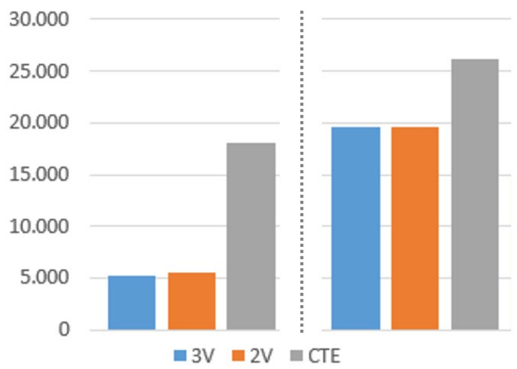

Figure 2. Annual thermic loads due to transmissions per each case study

Despite the fact that there are no cooling systems installed in the building, good indoor conditions were achieved for the whole year. Analyzing the software results, it can be observed that the indoor average temperature in the building is above the comfort temperature (25º C) for only three teaching days, from 3:00 pm to 4:00 pm, where it reaches a value of 25.20º C.

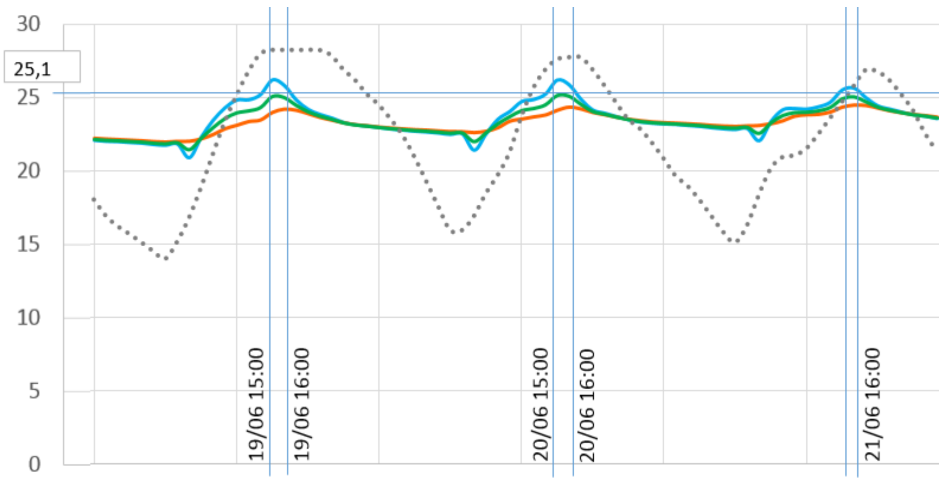

Figure 3. Average overheating days in the whole building

Figure 3 presents the average temperature of the building, where the air temperature is depicted in blue, the operational temperature is depicted in green and the radiant temperature is depicted in orange. Finally, the dotted line represents the outdoors temperature.

During the analysis, months of July and August were discarded, due to the fact that schools and high schools in Catalonia do not operate during these months.

4.3. Case studies. Renewable energy values

Finally, related to the photovoltaic installation, a reduction of the total installed power was decided (from 48kWp to 37kWp), to achieve a cost optimality. Figure 4 present a comparison between the electricity consumption of the building and the electricity production by the photovoltaic installation. It can be observed that the photovoltaic power is enough to cover the energy requirements of the building of more than the 50% of its yearly operation (Figure 5).

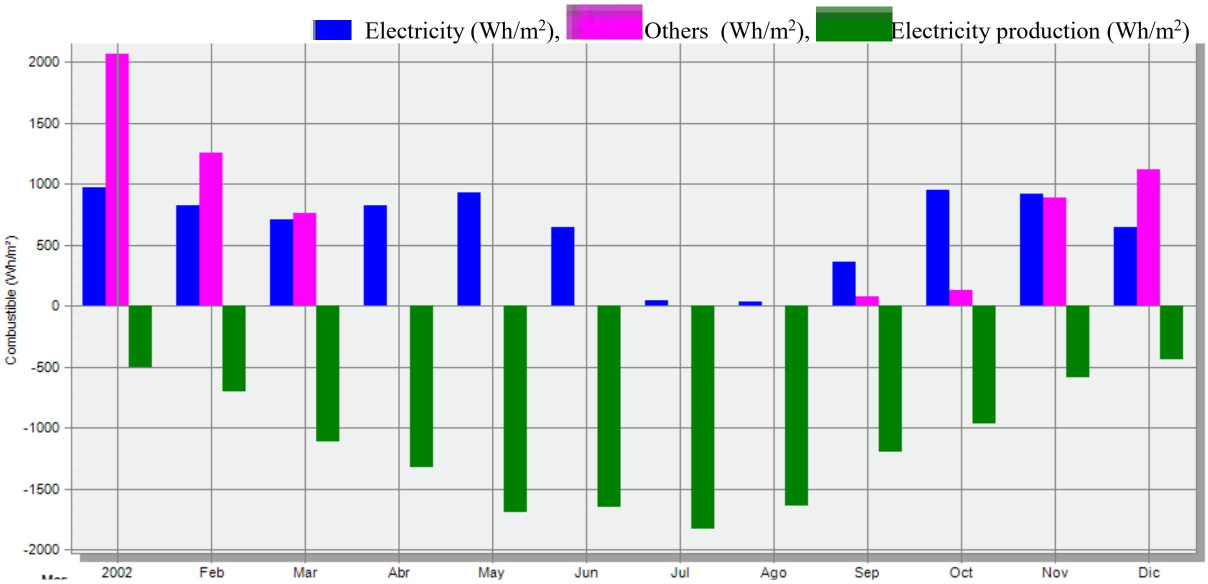

Figure 4. Photovoltaic production and energy consumption. Panel surface: 178 m^2

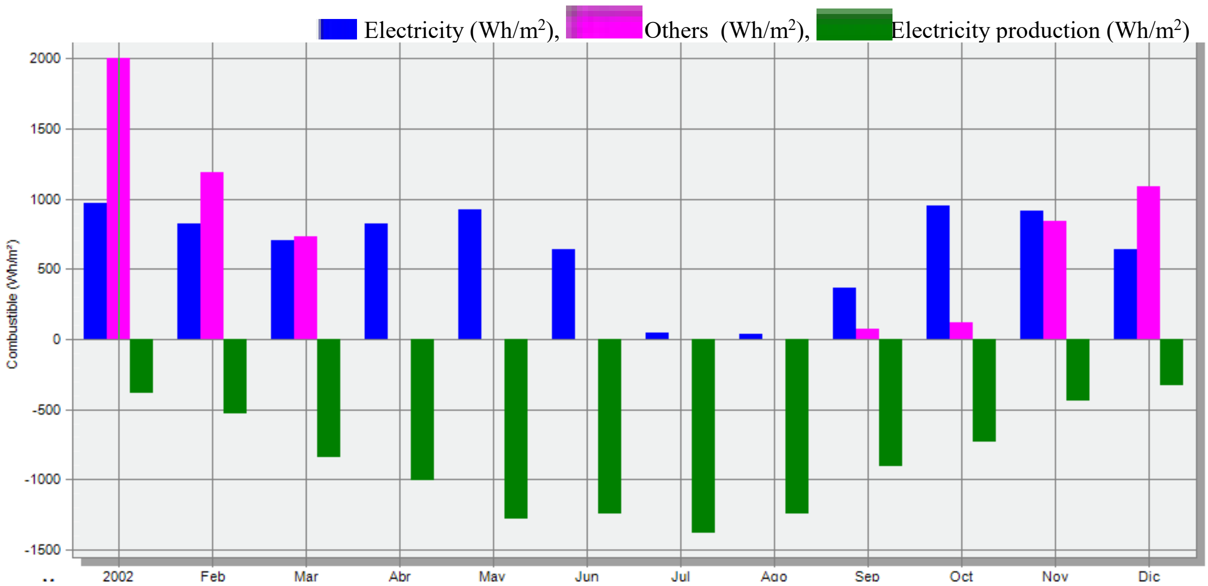

Figure 5. Photovoltaic production and energy consumption. Panel surface: 135 m^2

5. Conclusions

The role of the architecture has been crucial to ensure an optimal result, especially contributing to the reduction of the overheating hours, resulting to the minimization of the cooling energy demand. The building does not require any installation of mechanical cooling systems, even being located in the Mediterranean climate. In south orientations, the use of doubled glazing seems to be efficient enough to achieve a low energy demand, while it optimizes at the same time the total economic construction cost. Photovoltaic production in schools must be combined with some other actions. The energy exportation to the grid, as well as the use of the energy for the electric vehicle charging, are feasible options for the future.

From the presented study and the obtained results, the following global conclusions can be made.

Initially, by implementing several design strategies, it is able to decrease the heating demand of the building by 11%, as well as the non-renewable primary energy by 6%. Additionally, a decrease of 4.1% of the total primary energy can be achieved, resulting to a reduction of 4% of the CO2 emissions. The following table summarizes the impacts of the different proposed actions.

Table 4. Transmittance values of envelope elements

Actions	*Savings (+)* *Costs (-)*
South windows: from triple pan glazing to double.	4,697€
Heating recovery system: from 78% to 85% of performance	-13,490€
Photovoltaic porch: from 104 panels to 80	8,900€
Economic saving (€)	107.44€
Reduction of energy demand (kWh/m^{2}y)	0.59
Reduction of non-renewable primary energy (kWh/m^{2}y)	0.73
Reduction of CO_2 emissions (kg CO2/m^{2}y)	0.328

Related to the above information, some specific conclusions can be made.

In terms of user comfort, by implementing the proposed actions, it was able to minimize the overheating hours in summer period but also in spring and autumn.

In terms of passive design strategies, the proposed solution results to a really low heating demand, only 5,23 kWh/m^2 y. Taking into account that compared with a building that strictly meets Spanish regulations in the energy demand level, (18,08 kWh/m^{2}y) our building has a reduction of 71% in this aspect. The building is located in a Mediterranean climate area in a soft climate. Passive house standard was initially conceived for rough climates, countries with continental weather because of this one of the case studies consist in replacing triple pan glazing in south façade, with double pan ones. With doubled pan glazing in south façade, heating demand raises an insignificant value of 6%, but solar gains though windows with double glass are 25,5 % higher.

Related to the ventilation strategies, it was concluded that a natural crossed ventilation during daylight combined with free cooling during night-time is enough to ensure comfort conditions inside the building without mechanical cooling system. The reduction of energy demand was estimated to 26% in warm periods, spring, summer and autumn.

It is also necessary to point out the importance of heat recoveries efficiency to have a low level of energy demand. Increasing the heat recoveries efficiency from 75% to 85%, a reduction of 17% in heating demand can be achieved.

Finally, photovoltaic production in schools and high schools must be combined with some other actions in the medium term, considering its exportation to the grid or use for electrical vehicle charging.

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