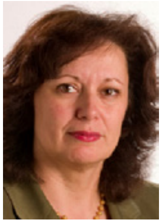
CO_2 zero schools

School building renovation towards emissions neutrality



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Vila Nova de Gaia, a 300 000 inhabitants' municipality in Portugal, has established the goal of transforming their schools into carbon emissions free buildings. The first pilot project shows a combination of cost effective energy efficiency measures with renewable energy harvesting allowing reducing nearly 90% final energy use and carbon emissions.

Keywords: School buildings renovation; Energy efficiency; Renewable energy; Nearly-zero emissions.

In Europe, the urban areas are responsible for 70% of the final energy consumption [1]. In an attempt to reduce these numbers, many initiatives have been developed, mainly within the scope of the Climate Change Package, where the main targets are the reduction of the carbon emissions, the increase of the production of energy based on renewable energy sources and increase the energy efficiency, with the well-known goal of 20% for each [2].

In Portugal, the energy efficiency goals include the renovation of public buildings, such as schools, in order to promote a more efficient management and better serve the local community, [3] while improving the comfort conditions and the energy performance and reducing the operation costs. The basic school buildings are owned and managed by the municipalities, which assume the responsibility for all the costs related to their use, maintenance and renovation.

Having joined the Covenant of Mayors initiative, a European movement involving local and regional authorities, voluntarily committing to increase energy efficiency and use of renewable energy sources in their territories, the municipality of Vila Nova de Gaia developed an Action Plan for Energy Sustainability aiming to exceed the European Union 20% CO_2 reduction objective by 2020.

Within this Plan, the municipality included an action, called School Buildings CO_2 Zero, where all school buildings under the municipality management, must present zero carbon emissions until 2020 [4].

Vila de Nova the Gaia municipality has 110 schools under their supervision, which, according to 2013 data, resulted in an energy consumption of 2.8 GWh and 1239 Ton of carbon emissions [5].

In Portugal, many school buildings were built between 1940 and 1970 and are still being used, with a significant number of these schools based on a model, known as P3, which was inspired in a Scandinavian design. These buildings present pathologies related to thermal discomfort, indoor air quality and signs of degradation.

The average indoor temperature varies between 15°C and 18°C during winter and 26°C and 29°C during summer and the CO_2 concentration is frequently above the regulation limit, overcoming 4000ppm several times during the day. These problems have been noticed in similar buildings placed in different locations, which mean that this is a common pathology in school buildings [5, 6, 7].

Figure 1 shows the general plan of a P3 school, with U shape. In the figure, number 6 refers to classrooms and number 5 is a multipurpose area.

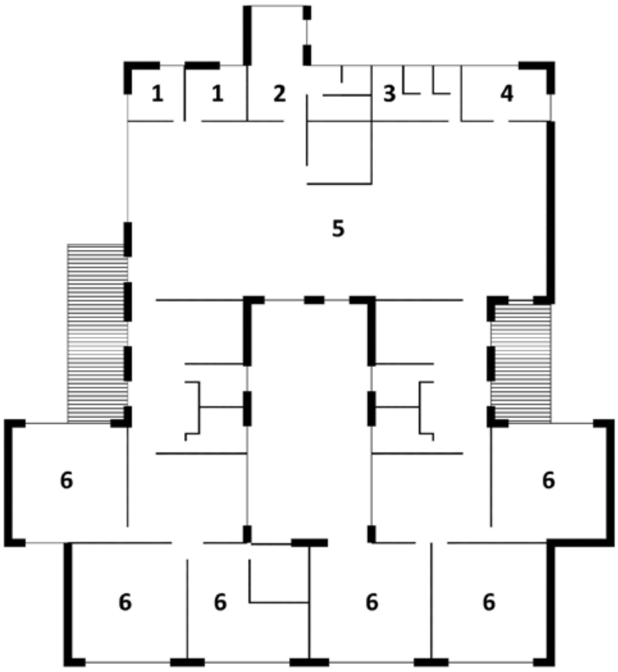

Figure 1. P3 School general plan of ground floor.

The renovation is currently in the project phase, where it has been important to analyse different solutions and choose the most cost effective way of reaching the goal of zero carbon emissions.

Objective

The main purpose, from the technical perspective of energy and emissions reduction, is to pave the way for the elimination of the CO_2 emissions and improve the overall energy performance of the building. This reduction will allow savings on the energy bills supported by the municipality and will cooperate in the implementation of the Action Plan for Energy Sustainability. Besides, it is intended to improve the comfort conditions and the indoor air quality to assure the users' health conditions and the optimization of the environmental conditions for the students.

For the present intervention, there is a constraint regarding the building integrated technical systems (BITS) for heating and cooling. As these systems have been recently replaced, they will be kept as they are in this first phase of the renovation process and their replacement by systems based on renewable energy sources will only occur in a later intervention, closer to the end of the systems lifetime.

Methods

The most cost effective way to reduce significantly the emissions, resulting from the use of buildings is very often improving the buildings envelope to a certain level and using efficient technical systems based on renewable energy sources [8].

The selection of the most cost effective package of measures has been done with a life cycle costs approach based on the cost optimal method, introduced by EC Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing Directive 2010/31/EU of the European Parliament and of Council on the Energy Performance of Buildings.

The method requires the calculation of the energy performance of the building with each one of the considered renovation packages. The energy calculations were based on the Portuguese thermal regulation that is based on ISO-13790. Then, the global costs were calculated using the net present value (including investment costs, energy costs, maintenance costs and replacement costs).

The comparison of the results can be made comparing the primary energy and the global cost of each renovation package. **Figure 2** shows a generic representation of a cost-energy curve where the cost optimal solution is identified.

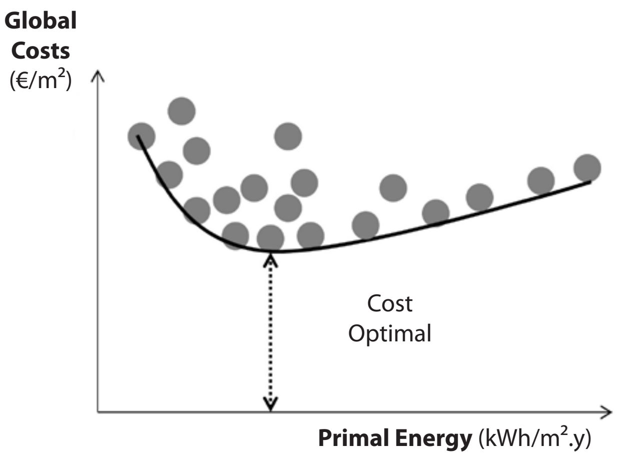

Figure 2. Generic results of the cost optimal calculations.

Building general characterization

The school was built in 1970 and it can be divided in two different zones, considering its occupation and energy use patterns: the classrooms zone and the multipurpose area, which is used as refectory and indoor playground.

The classrooms are distributed in two floors, with 6 classrooms in each floor, with a total acclimatized area of 733 m² and a floor to ceiling height of 2.7 m. The multipurpose area has only one floor with a floor to ceiling height of 5.2 m and an acclimatized floor area of 317 m². The total acclimatized area is 1 050 m².

Concerning construction solutions, the building has cavity walls without insulation, fibre cement tiles on the roof and simple glazing with aluminium frame windows. The glazing area corresponds to 41% of the vertical opaque area, which is very significant and with a great impact on the building thermal performance.

For heating the classrooms, electric storage heaters (with 2.4 kW/each and an efficiency of 1.0) that absorb energy during the night and release it during the day were recently installed, taking advantage of the reduced price of the electricity with the night tariff (when Portugal has a surplus of production). For DHW, in the toilets, there are electric heaters with 50 l storage tank (with nominal capacity of 1.5 kW).

In the multipurpose area there is an HVAC system for heating and cooling (COP=3.00/EER=3.50, nominal capacity of 6.50 kW) and in the kitchen, for DHW, there is a gas heater with 23.6 kW and an efficiency of 80%.

The classrooms do not have a cooling system or mechanical ventilation.

The internal lighting is mainly based on fluorescent lamps with an average capacity of 58 W each.

Energy renovation features

Data collected from energy monitoring before renovation allowed identifying the distribution of the energy use and the main physical pathologies. Regarding the energy use, main consumers are lighting, appliances and heating. Regarding the indoor air quality, the monitoring has shown that the concentration of CO_2 is above the adequate values most of the time.

In order to solve these problems in a cost effective way, several measures have been analysed individually, as well as several packages of those renovation measures, due to the trade-offs and synergies that can result from their combination.

In accordance with this methodology, the solution chosen for the renovation of this school resulted from the combination of each cost optimal measure that is associated to each building element.

Following, a description of the intervention on each of the main building elements is presented.

Exterior Walls

For the exterior walls, the solution includes placement of external insulation over the existing facades, consisting of EPS (expanded polystyrene) with 6cm of thickness, covered by Viroc® boards (compressed and dry mixture of pine wood particle and cement). This solution, besides significantly reducing the thermal losses and consequently the heating energy needs, improves the comfort conditions, solves the thermal bridges problems eliminating building pathologies and creates a façade with low maintenance costs.

Roof

For the roof, the chosen solution includes removing the existing tiles and the introduction of rock wool with 10cm, covered by new steel sheets. The inclusion of insulation reduces the heat losses optimizing the heating systems behaviour and preventing summer overheating.

Windows

As the glazing area is a very significant part of the building envelope in this building, the replacement of the existing windows is not only necessary, because of their state of degradation, but also an important measure due to its impact on the energy performance of the building. Therefore, new PVC windows with double-glazing (6 mm+16 mm+6 mm) will be installed. The cavity between the layers of glass is filled with argon. This solution leads to a U-value of 0.7 W/m²°C. Besides the thermal characteristics of the glass and frames, in the classrooms, shading devices will be placed outside above the windows, consisting on horizontal plats to control shading and to drive natural lighting into the interior ceiling.

Ventilation

To assure the interior air quality, a hybrid ventilation system has been designed and will be installed. The air intake is promoted by the adoption of ventilation grids under the windows and the air exhaust is done on the opposite side of the rooms, through the roof. Mechanical extraction in the exhaust area will allow the increase of the air renovation rate whenever the CO_2 sensors detect a concentration above the desired values.

In the multipurpose area, the air quality is already controlled due to the installed HVAC system.

Heating and cooling systems

The existing systems have been recently installed so, their replacement is not an option at the moment. Closer to the end of their lifetime, in a 2nd phase, it is planned that the heating systems can be replaced by systems fully based on renewable energy, namely a biomass boiler.

Lighting and appliances

LED lamps with 20 W each will replace the lighting. This solution allows reducing the energy consumption and producing less heat, reducing internal gains that are a problem during summer.

There are also appliances in the classrooms and in the kitchen that are not intended to be replaced within the current renovation process, but only when their replacement moment arrives. Appliances with the highest efficiency level should replace these.

These actions allow reducing very significantly the energy use, but the final energy values are yet far from the zero energy level. To fill this gap and get closer to the zero emissions goal, photovoltaic panels will be installed to produce electricity from renewable sources. These panels will produce energy for the school, mainly for lighting and appliances.

In brief, the adopted energy renovation features are the following:

- External insulation on the walls and roof;
- PVC framed double glass windows;
- Hybrid ventilation with natural crossed ventilation through ventilation grids and mechanical exhaustion controlled by CO_2 sensors;
- LED based lighting;
- Photovoltaic panels.

Table 1 presents the U-values for the elements of the building before and after the renovation. The ground floor solution is kept as it is, with a U-value of 1.89W/m²y.

Comparing the results achieved with the several renovation measures, the energy efficiency measure with the highest impact is the replacement of the windows (due to their large area and substantial reduction of the U-value), followed by the replacement of lighting. Besides these measures, only photovoltaic panels allow higher reductions of the non-renewable primary energy use as well as the future replacement of the heating system by a wood pellets based system.

Impact of renovation

The chosen renovation solution allows improving the comfort conditions, assuring the indoor air quality, saving energy and significantly reducing the carbon emissions. With the contribution of the photovoltaic panels, the electricity use is not far from zero but the high conversion factor for electricity in Portugal (2.5 kWh_{EP}/ kWh) still leads to a primary energy use of 39.73 kWh_{EP}/m^2y. **Table 2** presents the energy use, primary energy and carbon emissions before the renovation and the estimated use after the renovation (phase 1) and also after replacing the heating system (phase 2).

After the global renovation, 72% of the energy needs will be fulfilled based on renewable energy and the energy use for appliances and lighting will be reduced in 84%, when compared to the values before renovation. Concerning the primary energy

Table 1. Buildings thermal characterization before and after renovation.

Element	**U-Value** [W/m².y]	
	Before	**After**
Walls	1.19	0.40
Roof	1.40	0.38
Windows	5.20	0.70

Table 2. Summary of the renovation impact.

Energy use [kWh/m²y]	**Before**	**After** (Phase 1)	**After** (Phase 2)
Appliances (Electricity)	16.6	2.6	2.6
Lighting (Electricity)	20.2	3.2	3.2
Heating (Electricity)	47.6	4.8	0.0
Cooling (Electricity)	0.5	1.0	1.0
Ventilation (Electricity)	0.0	1.4	1.4
Cooking & DHW (Nat. Gas)	7.3	7.3	7.3
Primary energy [kWh/m²y]	219.4	39.7	27.7
Emissions [kgCO_2eq/y]	1 4127	3 260	2 535

and emissions, the reductions to be achieved are presented in **Table 3**.

Regarding costs, the chosen renovation solution has high investment costs but in a life cycle perspective, it has lower global costs than the base scenario (restoring the building functionality without improving the energy performance).

Figure 3 shows the costs for the thirty years' life cycle. Analysing the figure, it is noticed that the investment costs are clearly higher in the chosen renovation but the operating costs are lower.

Conclusions

It is expected that the users' comfort will improve significantly and the problems related to the quality of the air will disappear without the need of complex HVAC systems that have been widely used in this type of buildings during recent years.

The Portuguese thermal regulation has energy reference requirements for the buildings' envelope, thus the chosen renovation presents solutions for the walls, roof and windows that are in accordance with the reference U-values. It is noteworthy that the U-value of the windows is quite low when compared to the reference value.

According to the calculations, this intervention will also allow significantly reducing the energy consumptions and the carbon emissions in a cost effective way during the building's life cycle. The energy bills of public buildings under the municipality´s supervision are quite heavy, and the reduction of these numbers, through investment on energy efficiency improvement, is an added value for the municipality, that can use those savings for other purposes.

Further energy efficiency measures are possible, but reduced improvements are achieved with high investments costs and more photovoltaic panels will decrease the efficiency of the system due to the lack of synchronism between the electricity generation and its use.

Although the zero emissions level has not yet been achieved, the full planned renovation is considered a good compromise between this goal and the cost-effectiveness of the intervention. The renovation procedures analysed and presented in this paper do not constitute a single pilot project as the municipality intends to replicate these measures in the many similar schools in need of renovation in the country. ■

Table 3. Summary of total reduction of non-renewable primary energy and emissions.

	Reduction
Non-renewable primary energy	87%
CO_{2eq} emissions	88%

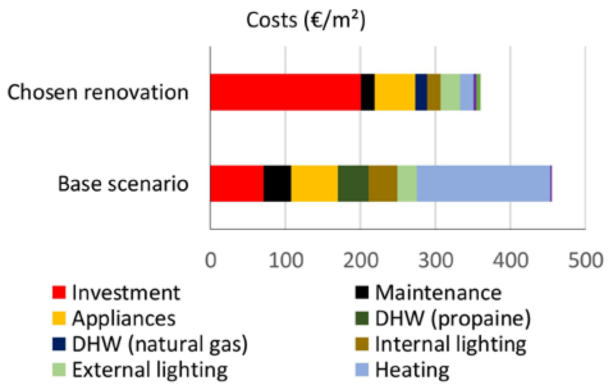

Figure 3. Distribution of the global costs during thirty years.

References

[1] European Investment Bank (IEB), 2012. ELENA – European Local Energy Assistance;

[2] Fundo Social Europeu, 2014 Metas de Portugal para 2020 e situação em 2013.

[3] Parque Escolar, 2014. Enquadramento estratégico.

[4] Energaia, 2011. Plano de Ação para a sustentabilidade energética de Vila Nova de Gaia.

[5] Gaiurb, 2014. Guião de apoio a ações de reabilitação energética do parque escolar do município de Vila Nova de Gaia – Relatório Preliminar.

[6] LNEC 2010. Net Zero Energy School – Reaching The Community, Escola Secundária de Vergílio Ferreira, condições ambientais no período de Inverno de 2010. Relatório 180/2010 – ES/LNEC.

[7] LNEC 2010. Net Zero Energy School – Reaching The Community, Escola Secundária de Vergílio Ferreira, condições ambientais no período de meia – estação de 2010. Relatório 269/2010 – ES/LNEC.

[8] IEA EBC, 2015. Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56).