Cost-effective options for nearly zero energy renovation of municipal buildings

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Abstract

The European Energy Efficiency Directive demands strict energy efficiency measures for the public sector. Many of the municipal buildings in Southern Europe require deep renovations to become nearly Zero Energy Buildings (nZEB), but the compliance with the directive is difficult for the public sector due to the required investments. CERtuS is a project involving Municipalities, energy service companies and financing entities from all economically stricken Southern European countries. The objective of CERtuS is to stimulate the growth of the energy services sector and to help stakeholders gain confidence in investments on the public section, by developing representative deep renovation projects and innovative financing schemes that can act as models for replication.

In Portugal, three nZEB renovation projects were prepared for the Municipality of Coimbra, being the selected buildings the Town Hall (building listed and protected by UNESCO), the Municipal Library and an Elementary School. The renovation designs were mainly focused on the retrofit of lighting and HVAC and on the integration of photovoltaic generation. With such renovation, it will be possible to achieve savings on the final net energy consumption of 80 %, 97 % and 98 % and simultaneously, 70 %, 95 % and 96 % of the consumed energy will be ensured by renewable energy sources, for the Town Hall, Library and School, respectively. Energy service models and suitable financing schemes were adapted for each renovation scheme. For these three buildings, the 'Shared Savings' type of ESCO contract can be feasible with 5 % annual yield for the Municipality, being the suggested financing plan a mix of ESCO equity, senior debt and VAT facility.

Introduction

Energy efficiency in buildings is one of the most relevant and strategic issues that are debated in recent years in European and global level, since buildings are responsible for more than 40% of world global energy use and as much as 30 % of global greenhouse gas emissions (UNEP SBCI, 2009). The European Union has been promoting programs, guidelines and Directives, such as the 2002/91/EC (EC, 2003) and 2010/31/EU on the energy performance of buildings (EC, 2010), 2006/32/EC on energy end-use efficiency and energy services (EC, 2006) and, 2012/27/EU on energy efficiency (EC, 2012), in order to put in place instruments, criteria and harmonized and shared solutions on the specific issue of the increase of energy efficiency of buildings.

Since 2010, the recast of Energy Performance of Buildings Directive (EPBD) introduced the concept of nZEB at European level: 'nearly zero-energy building' means a building that has a very high energy performance. The nearly zero or very low amount of required energy should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. According to the recast of the EU Directive on EPBD by the end of 2020 all new buildings should be nearly Zero Energy and the deadline is even sooner (by the end of 2018) for the new buildings occupied or owned by public authorities.

New buildings have limited impact on the overall energy reduction as they just represent a small part of the building stock.

Simultaneously, existing buildings can often be improved at far lower cost than would be required to demolish and erect new buildings (Crawford et al., 2014). If energy consumption is high in the existing buildings, the potential for energy savings is proportional and this constitutes a great opportunity for energy efficiency improvements. It is equally true that it is more difficult to apply the concept of nZEB in existing buildings with respect to the new buildings, since there are limitations and obstacles caused by the existing infrastructure. More difficulties arise when the renovation options interfere with preservation requirements of historic buildings.

According to the more recent report of national applications of the nZEB definition (Erhorn and Erhorn-Kluttig, 2015) there is not a common and homogeneous national progress within the Members States. Furthermore, the progress in developing and setting the national application of the nZEB definition in most countries, as Southern European countries, has been a slow process. As claimed by the report, about 40 % of the Member States did not have, at that date, a detailed definition of the nZEB, while 60 % of them had laid out their detailed nZEB description, although in different levels of definition. The report shows also that the Central and Northern Member States are more advanced in implementing the articles within the Directive.

It is requested by the EPBD recast that "public sector in each Member State should lead the way in the field of energy performance of buildings" and "buildings occupied by public authorities and buildings frequently visited by the public should set an example". Energy efficient renovations of public buildings for high energy performance show that energy innovation through deep refurbishment of envelope and energy systems, as well as a large contribution of Renewable Energy Sources (RES) is possible and public buildings can be forerunners and "shining examples" in it. The impact of the innovative technologies and systems can be visualized by every day users and visitors of public buildings and the implemented measures can also be repeated in the private sector. The energy renovation of the public building stock opens the way for ambitious large-scale renovation of the entire existing building stock, since its role can be symbolic, and it can generate a spillover effect.

The investments on the existing buildings tend to focus on measures with short and medium payback period (less than 10 years) which usually generate less than 30 % energy savings. However, ambitious energy and climate policies require saving up to 80 % energy in buildings, which are only possible with large scale interventions with deep changes in the used technologies (Bullier and Milin, 2013). These deep renovations are likely to have a payback time between fifteen and forty years in the EU, at current energy prices.

Southern European countries undergo a severe economic crisis, with a profound negative effect on energy savings, since investments on energy efficiency in the public sector have been delayed. More specifically, the crisis hinders the compliance to the latest Energy Efficiency Directive, demanding strict energy efficiency measures for the public sector. Investments required to renovate public buildings and achieve nearly zero energy consumption have long payback times. Moreover, banks have limited resources and Energy Services Companies (ESCOs) and third parties hesitate to be involved in financing in the public sector because of disincentives such as the complex administrative procedures and current budget management of public buildings which need reform (Szomolányiová et al., 2015).

CERtuS (CERtuS, 2016) is a project aiming to produce representative deep renovation projects that can act as models for replication. The objective of the project is to help stakeholders gain confidence in such investments and initiate the growth of this energy service sector. Municipalities, energy service companies and financing entities in Italy, Greece, Spain and Portugal are involved in this project. Twelve buildings in four municipalities in each country were selected and existing energy service models and procedures were adapted to ensure suitable financing schemes e. In Portugal, three nZEB renovation projects were prepared for the Municipality of Coimbra, being the selected buildings the Town Hall (building listed and protected by UNESCO), the Municipal Library and an Elementary School. This paper presents these three nZEB renovation projects, presenting details of the technical design and assessment of options, as well as the considered energy service models and financing schemes. The remainder of the paper is structured as follows. Section 2 presents the current conditions of each building. Section 3 presents the proposed renovation schemes and Section 4 assesses its impacts. The considered energy service models and financing schemes are presented in Section 5. Finally, Section 6 summarizes the paper, emphasizing its main conclusions.

Current Building Conditions

Coimbra is the largest city in Centro Region of Portugal, with about 101,000 inhabitants in the urban area and 150,000 inhabitants in the area of the municipality. As the largest urban centre of a region of over 2 million inhabitants, Coimbra functions as regional capital. As a historic city, Coimbra holds an important cultural and architectural heritage, which added to the fact that the city is being crossed by the River Mondego, gives to Coimbra a distinctive character and make her attractive for tourists. Part of the historic city centre, older University buildings and other urban structures are since June, 22nd 2013 inscribed on the World Heritage List of UNESCO. The Property is composed of a set of buildings whose history has been associated to the academic institution, either through participation in the process of knowledge production and dissemination, or through contribution to the creation of unique cultural and identarian traditions.

The selected buildings for CERtuS are the Town Hall, the Municipal House of Culture and the Elementary School of Solum.

ELEMENTARY SCHOOL OF SOLUM

The Elementary School of Solum (Figure 1) is located in the East side of the city, near to the Stadium and a commercial area. The school was built in the 1950s, but until the 1970s it was an annex school to the teacher training colleges, dedicated to pedagogical training. In the 1990s it was converted into an Elementary School. The construction of refectory and a partial renovation of the building was done 10 years ago. The school has about 300 students with daily activities (Monday to Friday) between 7h30 and 19h00.

The building is divided in 3 main areas: 2 blocks of classrooms and the refectory. It has a total area of about 1,650 m^2

Figure 1. Elementary School of Solum.

Figure 2. Municipal House of Culture.

and a volume of 6,270 m³. The roof is of ceramic tile and has a surface of 900 m². All the window frames are aluminium and the windows are double glazed.

The lighting system is mainly constituted by fluorescent linear T8 lamps with electromagnetic ballast. The 2 main blocks have old wall radiators with circulation of hot water. However, the system is no longer operational and therefore these buildings do not have any source of central heating. To ensure the heating during the coldest days the classrooms have one oil-filled radiator. The building has an electricity consumption of about 23 MWh/year (13.6 kWh/m²) and a consumption of natural gas of about 17 MWh/year (10.1 kWh/m²), during the winter, used in the heating of the refectory.

MUNICIPAL HOUSE OF CULTURE

The Municipal House of Culture (Figure 2) was built in 1991–1993 and opened on October, 26th 1993. It is located near the city centre and near to the University. It has several cultural equipment, such as library, auditorium and art gallery, as well as several offices used by Municipality. The building has 80 employees and is visited by 17,500 users/year and has activities (Monday to Saturdays) between 9h00 and 19h00.

The building has 8 floors with a total area of about 13,200 m², with a total used surface of about 9,900 m² and a volume of 39,900 m³. The roof is flat without tiles and has a surface of 2,600 m². The building external walls are made of breeze blocks and bricks and have a thickness of 20 to 55 cm. The windows are of single glazing with aluminium frames. Almost all windows have interior shutters. The exception is the front floor where darkened windows are used.

The lighting is usually ensured by fluorescent lamps. Most of the rooms have a false roof in wood with small square holes, being the luminaries installed above the false roof. The lighting fixtures are open luminaires with double reflector and have 2 or 3 lamps. Almost all working rooms, as well as all the rooms receiving public have acclimatization., being the total acclimatized area is about 6,900 m². The building does not have a centralized Heating, Ventilation and Air Conditioning (HVAC) system, being the HVAC ensured by several mono-split units (single indoor unit connected to a single outdoor unit), which were gradually installed. The exception to it, are the silos and the storage areas which have systems of temperature and humidity control, with pipelines, to protect the publications. The building has an electricity consumption of about 488 MWh/year (49.4 kWh/m²).

COIMBRA TOWN HALL

The Coimbra Town Hall (Figure 3) was built after the demolition of part of the old Monastery of Santa Cruz. The demolitions work and construction was carried out mainly between 1876 and 1879, but some construction works were developed gradually until the beginning of century XX. The building is used as the Town Hall of the Municipality of Coimbra, being mainly constituted by offices and storage areas. The building has 220 employees and is visited by more than 25,000 users/year.

The building has 3 floors and 2 intermediate floors with a total area of about 5,900 m² with a total used surface of about 3,700 m² and a volume of 40,600 m³. The roof is made of ceramic tile and has a surface of 2,000 m². The external walls are made of stone masonry and have a thickness of 90 to 145 cm. All the windows and balcony doors are of single glazing with wood frames.

The existing lighting is ensured by several different types of lamps and luminaires, including fluorescent linear T8 and T5 lamps, several types of compact fluorescent lamps, incandescent lamps, halogen spots and projectors and metal halide lamps. The HVAC is ensured with several heat pumps, which

Figure 3. Coimbra Town Hall.

were being installed gradually. Therefore, there are several equipment with different characteristics and performance. In total, there are 8 multi-split units and 21 mono-split units. Almost all the areas of permanent use have HVAC systems, being the control of the HVAC systems locally ensured with units of individual control. The building has an electricity consumption of about 305 MWh/year (51.9 kWh/m^2).

Renovation Scheme

Each renovation scheme was proposed according to the specific characteristics and conditions of the buildings and different scenarios were simulated in order to reach the optimum renovation design. The selected renovation options are concentrated in three main areas: lighting, HVAC and photovoltaic (PV) generation.

ELEMENTARY SCHOOL OF SOLUM

The actual lighting system is mainly constituted by fluorescent linear T8 lamps with electromagnetic ballast. The planned action is to replace all 175 lamps by LEDs, ensuring a decrease on the total installed power of about 4 kW (Table 1). The energy consumption was simulated with EnergyPlus (EnergyPlus, 2016) considering the actual usage profile for each lamp type and room of the building and taking into account the effect on increased heating energy and reduced cooling energy, resulting in 5,730 kWh/year (57.9 %) of savings.

The main opportunity of renovation in the HVAC is the replacement of the gas boiler, used in the central heating of the refectory. It is possible to replace this boiler directly by a heat pump without the need of a total refurbishment of the system. It was considered that the actual boiler is replaced by a heat pump of 11 kW with a seasonal Coefficient of Performance (COP) of 3.57. The energy consumption was simulated considering the actual usage profile and the change of COP, leading to about 11.9 MWh/year (70.8 %) of energy savings.

The building already has a small PV system (18 panels with a total power of 4.23 kW) and a 200-litre solar thermal system. In the renovation plan, it was considered the installation of PV panels oriented to south, but keeping the orientation of the building (azimuth of -15 º) in order to minimize the visual impact of the PV panels. It was considered the installation of 72 PV panels, ensuring an installed power of 16.92 kWp (kilowatt peak – output power achieved under full solar radiation under set standard test conditions). Such scenario was simulated with PVSyst (PVSyst, 2016) resulting in a total generation of about 23 MWh/year (Figure 4).

MUNICIPAL HOUSE OF CULTURE

The actual lighting system is mainly constituted by fluorescent linear T8 lamps with electromagnetic ballast. The planned action is to replace all 1,266 lamps by LEDs, ensuring a decrease on the total installed power of 42 kW (Table 2). The energy consumption was simulated with EnergyPlus resulting in about 101 MWh/year (60.6 %) of savings.

The systems of temperature and humidity control are constituted by 9 systems with a Seasonal Energy Efficiency Ratio (EER) of 2.43, COP of 2.97 and a total power of 301 kW. In the renovation plan the replacement of such system by new systems with higher efficiency was considered, being selected a system with EER of 5.2 and COP of 5.74. The HVAC in most of the building is ensured by mono-split systems with heat pumps installed at the wall and on the roof with a total power of 239 kW. The replacement of the several mono-split systems by multi-split systems was not considered, since despite the potential lower purchase cost of multi-split systems the costs of installation would be higher and mainly the impact of the installation process on the building operation would be much higher. Therefore, it was considered the replacement by other mono-split systems with higher efficiency, keeping the same total power (Table 3). The energy consumption was simulated considering the actual usage profile and the change of COP/EER, leading to about 118 MWh/year (61.3 %) of energy savings.

It was considered the installation of PV panels oriented to south, but keeping the orientation of the building (azimuth of 20º) in order to minimize the visual impact of the PV panels. Therefore, it was considered the installation of 770 PV pan-

Table 1. Types and Quantity of Lamps Considered in the Lighting Renovation – School.

Actual			*Renovation*		
Lamp	*Quantity*	*Power (W)*	*Lamp*	*Quantity*	*Power (W)*
Fluorescent Linear T8 F150	4	270	LED Linear F150	4	95
Fluorescent Linear T8 F120	127	5,940	LED Linear F120	127	2,540
Fluorescent Linear T8 F60	12	280	LED Linear F60	12	120
Compact Fluorescent	28	500	LED Bulb	28	265
Emergency	4	50	LED Emergency	4	5
Total	**175**	**7,040**	**Total**	**175**	**3,025**

Number of PV modules	In series 18 modules In parallel 4 strings
Unit Nominal Power	235 Wp
Total Power	4.23 kWp
Total area	Module 117 m² Cell 43.2 m²
Generated Energy	23.32 MWh/year
Specific Generation	1,378 kWh/kWp/year

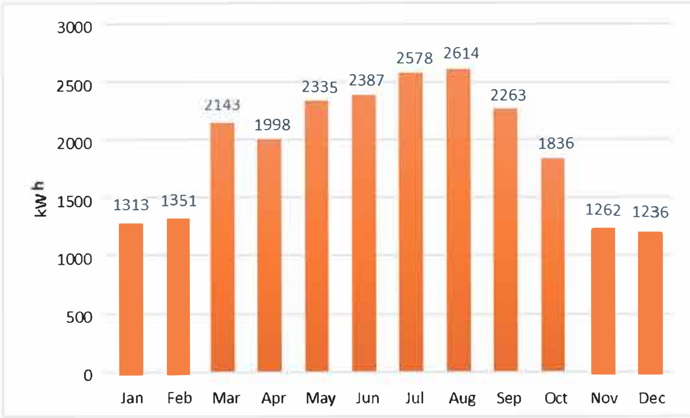

Figure 4. PV Generation – School.

Table 2. Types and Quantity of Lamps Considered in the Lighting Renovation – Library.

Actual			*Renovation*		
Lamp	***Quantity***	***Power (W)***	***Lamp***	***Quantity***	***Power (W)***
Fluorescent Linear T8 F150	312	21,090	LED Linear F150	312	7,490
Fluorescent Linear T8 F120	803	37,580	LED Linear F120	803	16,060
Fluorescent Linear T8 F60	9	210	LED Linear F60	17	170
Fluorescent Linear T5 F60	8	140			
Halogen Projector	24	7,200	LED Projector	24	2,400
Halogen Spot	5	250			
LED Spot	12	70	LED Spot	17	95
Incandescent	23	1,380			
Compact Fluorescent	70	1,260	LED Bulb	93	885
Total	**1,266**	**69,180**	**Total**	**1,266**	**27,100**

els, ensuring an installed power of 181 kWp. Such scenario was simulated with PVSYST resulting in a total generation of 254.2 MWh/year (Figure 5).

COIMBRA TOWN HALL

The actual lighting system is constituted by several different types of lamps and luminaires, including fluorescent linear T8 and T5 lamps, several types of compact fluorescent lamps, incandescent lamps, halogen spots and projectors and metal halide lamps. The planned action is to replace all 1,266 lamps by LEDs, ensuring a decrease on the total installed power of 34 kW (Table 4). The energy consumption was simulated with EnergyPlus resulting in about 49 MWh/year (57 %) of savings.

The HVAC system is constituted by 8 multi-split units and 21 mono-split units with a total cooling power of 273 kW. Most of the systems are old and have low levels of efficiency. It was considered the replacement by systems of the same type, but with higher efficiency, keeping the same total power (Table 5). The energy consumption was simulated considering the actual usage profile and the change of COP/EER, leading to about 57 MWh/year (62.6 %) of energy savings.

Since the building is part of the property "University of Coimbra – Alta and Sofia" inscribed on the World Heritage List of UNESCO, due to the protection rules, the use of traditional PV panels was not considered due to its high visual impact. Therefore,

Table 3. Technical Data of the New Mono-Split Systems Renovation – Library.

P_{ind} (kW)	EER	COP	Quant.	P_{total} (kW)
2.5	9.1	5.2	5	12.5
3.5	8.9	5.1	10	35.0
5.2	6.1	3.8	16	83.2
6.8	6.1	3.8	16	108.8
Total	**6.7**	**4.1**	**47**	**239.5**

it was decided to use solar tiles, to replace the actual roof. The installation was designed with 2,102 m² (with the different directions of the roof) of thin film PV panels, ensuring an installed power of 126.1 kWp. Such scenario was simulated with PVSYST resulting in a total generation of 143,3 MWh/year (Figure 6).

Impact Assessment

The impact of each renovation scheme was assessed in terms of energy savings, net energy consumption (difference between the energy consumption and generation) and contribution of renewable generation, as well as regarding specific energy, primary energy and CO_2 emissions.

Number of PV modules	In series 22 modules In parallel 35 strings
Nominal Power	235 Wp
Total Power	181 kWp
Total area	Module 1248 m² Cell 462 m²
Generated Energy	254.2 MWh/year
Specific Generation	1,405 kWh/kWp/year

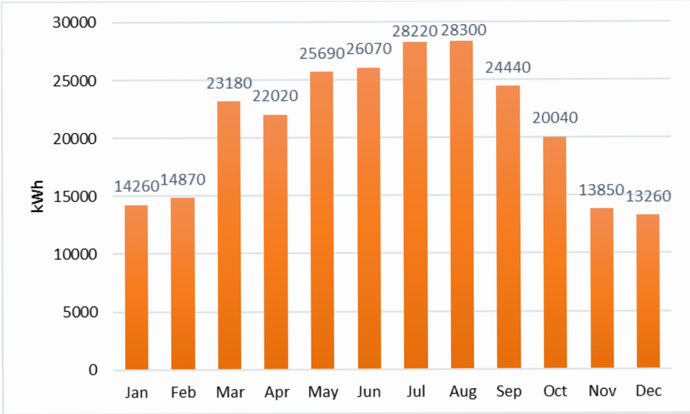

Figure 5. PV Generation – Library.

Table 4. Types and Quantity of Lamps Considered in the Lighting Renovation – Town Hall.

Actual			*Renovation*		
Lamp	***Quantity***	***Power (W)***	***Lamp***	***Quantity***	***Power (W)***
Compact Fluorescent E27	139	2,500	LED E27	173	1,640
Incandescent	34	2,040			
Compact Fluorescent E14	156	1,400	LED E14	156	470
Compact Fluorescent 2G11	182	4,910	LED 2G11	182	3,280
Fluorescent Linear T8 F30	6	70	LED Linear F30	6	40
Fluorescent Linear T8 F60	69	1,620	LED Linear F60	69	690
Fluorescent Linear T8 F120	242	11,330	LED Linear F120	262	5,240
Fluorescent Linear T5 F120	20	600			
Fluorescent Linear T8 F150	195	13,200	LED Linear F150	251	6,020
Fluorescent Linear T5 F150	56	3,130			
Halogen Spot	4	200	LED Spot	4	20
Halogen Projector	22	5,500	LED Projector	22	2,200
Halogen Projector	18	9,000	LED Projector	18	3,600
Metal Halide	10	2,500	LED Projector	10	800
Total	**1,153**	**58,000**	**Total**	**1,153**	**24,000**

Table 5. Technical Data of the New Mono and Multi-Split Systems Renovation – Town Hall.

	P_{ind} (kW)	EER	COP	Quant.	P_{total} (kW)
Mono	1.3	9.1	5.2	3	3.9
	2.5	9.1	5.2	12	30
	3.5	8.9	5.1	2	7
	5.2	6.1	3.8	4	20.8
	Total	**8.1**	**4.7**	**21**	**61.7**
Multi	28	5.20	5.74	7	196.0
	14.6	4.68	4.92	1	14.6
	Total	**5.16**	**5.68**	**8**	**210.6**

ELEMENTARY SCHOOL OF SOLUM

Table 6 presents the achievable yearly savings, generation and net energy consumption in each scenario. The presented scenarios are: before the renovation, renovation of lighting, renovation of HVAC, installation of PV, and total renovation considering renovation of lighting, renovation HVAC and installation of PV. Such scenarios were simulated with EnergyPlus (consumption) and PVSyst (generation), as explained in section 3. As can be seen, with the total renovation about 18 MWh/year (42.1 %) of energy savings are achieved, decreasing the total energy consumption to about 24 MWh/year. The installed renewable generation is able to ensure about 23 MWh/year of generation (96.2 % of the consumption after renovation), decreasing the net energy consumption to only 930 kWh/year (2.2 % of consumption before renovation).

The results were also assessed in terms of final energy, specific energy, primary energy and CO_2 emissions, considering the following conversion factors: electricity to primary energy – 2.5; natural gas to primary energy –1.0; electricity to CO_2 emissions – 139.89 g/kWh; natural gas to CO_2 emissions – 202 g/

kWh. As can be seen in Table 7, the renovation plan can ensure 97.4 % savings in final energy, 96.4 % savings in primary energy and 97.8 % savings in CO_2 emissions, decreasing the specific energy of the building to only 0.56 kWh/m².

MUNICIPAL HOUSE OF CULTURE

Table 8 presents the achievable yearly savings, generation and net energy consumption in each scenario. As can be seen, with the total renovation about 220 MWh/year (45.1 %) of energy savings are achieved, decreasing the total energy consumption to about 267 MWh/year. The installed renewable generation is able to ensure about 254 MWh/year of generation (95 % of the consumption after renovation), decreasing the net energy consumption to only 13.5 MWh/year (2.8 % of consumption before renovation).

As can be seen in Table 9, the renovation plan can ensure 97.2 % savings in final energy, primary energy and CO_2 emissions, decreasing the specific energy of the building to only 1.4 kWh/m².

Total Power	126.1 kWp
Total area	2,102 m²
Generated Energy	143.3 MWh/year
Specific Generation	1,336 kWh/kWp/year

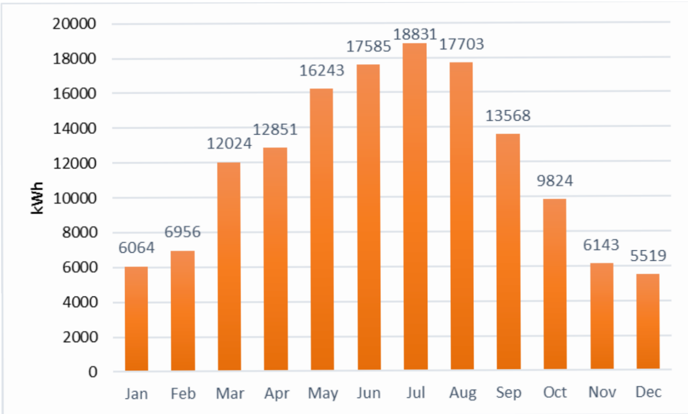

Figure 6. PV Generation – Town Hall.

Table 6. Consumption, Generation and Net Consumption – School.

Scenario	*Consumption (kWh/Year)*	*Savings (kWh/Year)*	*Generation (kWh/Year)*	*Net-Cons. (kWh/Year)*
Before Renovation	41,850	–	6,100	35,750
Lighting Renovation	36,120	5,730	6,100	30,020
HVAC Renovation	29,975	11,875	6,100	23,875
PV Installation	–	–	23,315	18,535
Total Renovation	**24,245**	**17,605**	**23,315**	**930**

Table 7. Final energy, primary energy and CO_2 emissions savings – School.

Scenario	*Final Energy (kWh/Year)*	*Specific Ener. (kWh/m²Year)*	*Primary Energy (kWh/Year)*	*CO_2 Emissions (kg CO_2 /Year)*
Electricity – Before	18,975	11.47	47,440	2,655
Gas – Before	16,775	10.14	16,775	3,390
Total – Before.	35,750	21.61	64,215	6,045
Electricity – After	930	0.56	2,320	130
Gas – After	0	0	0	0
Total – After	930	0.56	2,320	130
Savings	**34,820**	**21.05**	**61,895**	**5,915**

Table 8. Consumption, Generation and Net Consumption – Library.

Scenario	*Consumption (kWh/Year)*	*Savings (kWh/Year)*	*Generation (kWh/Year)*	*Net-Cons. (kWh/Year)*
Before Renovation	487,230	–	–	487,230
Lighting Renovation	386,070	101,160	–	386,070
HVAC Renovation	368,840	118,390	–	368,840
PV Installation	–	–	254,200	233,030
Total Renovation	**267,680**	**219,550**	**254,200**	**13,480**

Table 9. Final energy, primary energy and CO_2 emissions savings – Library.

Scenario	*Final Energy (kWh/Year)*	*Specific Ener. (kWh/m²Year)*	*Primary Energy (kWh/Year)*	*CO_2 Emissions (kg CO_2 /Year)*
Before	487,230	49.4	1,218,070	68,160
Renovation	13,480	1.4	33,700	1,890
Savings	**473,750**	**48.0**	**1,184,370**	**66,270**

Table 10. Consumption, Generation and Net Consumption – Town Hall.

Scenario	*Consumption (kWh/Year)*	*Savings (kWh/Year)*	*Generation (kWh/Year)*	*Net-Cons. (kWh/Year)*
Before Renovation	305,100	–	–	305,100
Lighting Renovation	256,190	48,910	–	256,190
HVAC Renovation	247,730	57,370	–	247,730
PV Installation	–	–	143,310	161,790
Total Renovation	**198,820**	**106,280**	**143,310**	**55,510**

Table 11. Final energy, primary energy and CO_2 emissions savings – Town Hall.

Scenario	*Final Energy (kWh/Year)*	*Specific Ener. (kWh/m²Year)*	*Primary Energy (kWh/Year)*	*CO_2 Emissions (kg CO_2 /Year)*
Before	305,100	51.9	762,770	42,680
Renovation	55,510	9.4	138,770	7,765
Savings	**249,590**	**42,4**	**624,000**	**34,915**

COIMBRA TOWN HALL

Table 10 presents the achievable yearly savings, generation and net energy consumption in each scenario. As can be seen, with the total renovation about 106 MWh/year (34.2 %) of energy savings are achieved, decreasing the total energy consumption to about 199 MWh/year and the installed renewable generation is able to ensure 143 MWh/year of generation (72.1 % of the consumption after renovation), decreasing the net energy consumption to only 55.5 MWh/year (18.2 % of consumption before renovation).

As can be seen in Table 11, the renovation plan can ensure 81.8 % savings in final energy, primary energy and CO_2 emissions, decreasing the specific energy of the building to only 9.4 kWh/m².

Financing Schemes

The proposed project sustainability evaluation methodology was based on the following seven working stages:

- Ex-ante sharing of the main project variables;
- Analysis of the project's main risks and identification of the mitigation instruments;
- Elaboration and analysis of the project data;
- Identification of an Energy Performance Contract (EPC) contract for each project;
- Identification of the optimal financial resources based on the identified technological solutions and the results of the risk analysis;
- Development and finalization of the model with output evidence;
- Presentation, for each project, of the key indicators and of the optimal financial structure;

The analysis of the project for each building was carried out in three steps:

- Market test: this analysis concerns the sustainability of the project by itself, in terms of ability to pay back the investment cost with annual savings. In addition, it investigated the sustainability of the project assuming a standard ESCO involvement with third party finance and the implementation of an EPC contract as described above.
- Single renovation option convenience tests: in this simulation, the impact on the project sustainability of the removal of some interventions/layers was analysed. In particular, the removal from the renovation schemes of those single interventions/layers showing a very high cost/savings ratio was assumed. Those interventions/layers are represented by those technological solutions that are too expensive on the market and that may lengthen the payback period of the investment without improving energy savings significantly.
- Financial structure optimization: in this simulation, the financial structure of the project was changed in order to make it profitable for an ESCO. In order to do so, according to the level of sustainability of the project itself in the base case, some hypothesis of the previous model analysis was changed (i.e. the equity/debt ratio, the duration of the contract, the availability of subsided funds and public grants, etc.).

The results were mainly assessed considering the Internal Rate of Return (IRR), equity payback period and equity Net Present Value (NPV). NPV is the difference between the present value of cash inflows and the present value of cash outflows; IRR is the interest rate that will bring a series of cash flows to a NPV of zero; and payback period is the length of time required to recover the cost of an investment.

In the Elementary School of Solum the total investment cost of the designed renovation is €31,470, which represents an investment cost per square meter of €19.12/m². The renovation is expected to ensure an energy expenditure saving of €5,080/year, therefore leading to a project payback period of 6.19 years. In the Municipal House of Culture the total investment cost of the designed renovation is €338,000, which represents an investment cost per square meter of €26.6/m². The renovation is expected to ensure an energy expenditure saving of 53,100 €/year, therefore leading to a project payback period of 6 years. In the Coimbra Town Hall, the total investment cost of the designed renovation is €632,000, which represents an investment cost per square meter of €107.5/m². The renovation is expected to ensure an energy expenditure saving of €34,900/year, therefore leading to a project payback period close to 17 years.

To the financial scheme, an Energy Performance Contract of "shared savings" was chosen, since it is considered to be the most widespread among the four CERtuS countries. The ESCO is supposed to invest through a Special Purpose Vehicle, which is a subsidiary company with an asset/liability structure and legal status that makes its obligations secure even if the parent company goes bankrupt. The EPC has a duration of 15 years for the Elementary School of Solum and the Municipal House of Culture and 25 years for the Coimbra Town Hall.

Given the selected renovation schemes and the characteristic of the projects, an ESCO involvement is possible at current market conditions, but it needs a mix of source of finance, in particular the use of subsides funds, considering the share of financial sources presented in Table 12. Equity is the value of an asset less the value of all liabilities on that asset (in this case, the equity is financed by the ESCO). Senior debt is the borrowed money that a company must repay first if it goes out of business. Subsided funds are benefits given by the government or European funds in the form of a cash payment or a tax reduction. VAT facilities are used to finance the VAT deficit incurred during the construction period of the project.

With the financial structure for the Elementary School of Solum project, an ESCO intervention is possible and the remuneration of the invested capital, in terms of IRR, should be considered adequate for this kind of projects. The same occurs for the Municipal House of Culture project, being the ESCO intervention possible and the remuneration considered adequate. However, for the Coimbra Town Hall project, the project generates enough cash flows to pay the debt, but it is not able to remunerate sufficiently the capital invested by the ESCO. As a consequence, an ESCO intervention at market conditions should be considered sustainable but with a lower profit. The main indicators for the ESCO investment are presented in Table 13.

The implementation of this EPC contract in the Elementary School of Solum project leads to a reduction of expenditure for the Municipality of about €38/year, resulting from the 5 % shared energy savings of €201 less the increase in maintenance costs of €162. In the Municipal House of Culture project, the reduction is about €2.339/year, resulting from the 5 % shared energy savings of €2.664 less the increase in maintenance costs of €325. In the Coimbra Town Hall project, the reduction is about €1.130/year, resulting from the 5 % shared energy savings of €1,738 less the increase in maintenance costs of €609. While the immediate savings for the Municipality in the three projects is not relevant, because the 5 % shared savings from the interventions is offset by the higher costs of maintenance, at the end of the contract, the Municipality will benefit from the whole energy savings generated by the renovation.

Conclusions

Project CERtuS developed representative deep renovation projects of twelve buildings in four municipalities in Italy, Greece, Spain and Portugal and existing energy service models and procedures were adapted to ensure financing schemes suitable for the projects. This paper presents the three nZEB renovation projects prepared for the Municipality of Coimbra, Portugal, being the selected buildings the Elementary School of Solum. Municipal House of Culture and Coimbra Town Hall.

First, the current conditions of the buildings were described. Then, each renovation scheme was proposed according to the specific characteristics and conditions of the buildings. Different scenarios have been simulated in order to reach the optimum renovation design, being the selected options:

Table 12. Considered Financial Sources.

Source	*School*	*Library*	*Town Hall*
Equity	33 %	25.6 %	9.9 %
Senior Debt	22 %	59.8 %	37.2 %
Subsided Funds	31.3 %		49.4 %
VAT Facilities	**13.6 %**	**14.5 %**	**3.4 %**

Table 13. Main Indicators for the ESCO investment.

Indicator	*School*	*Library*	*Town Hall*
Equity Payback Period (Years)	13.5	12.5	18
ESCO IRR (%)	8.0	9.06	7.5
Equity NPV (€)	1,050	23,950	5,800

- Elementary School of Solum: Installation of 16.92 kWp of PV panels; replacement of all T8 lamps with electromagnetic ballast by LEDs; replacement of the gas boiler by a heat pump.
- Municipal House of Culture: Installation of 181 kWp of PV panels; replacement of all lamps by LEDs; replacement of the systems of temperature and humidity control and mono-split systems by systems with higher COP/EER.
- Coimbra Town Hall: Installation of 126 kWp of PV tiles; replacement of all lamps by LEDs; replacement of the multi and mono-split systems by systems with higher COP/EER.

These options were selected with the main objectives to maximize the use of renewable energy generation and to achieve a short payback time. All buildings have good areas to the installation of PV panels and therefore one priority was to take advantage of these conditions to achieve a high share of renewable generation. The options for the reduction of the demand were concentrated in the two systems with higher impact on the energy consumption: lighting and HVAC. The objective was to achieve a high impact with the use of a small group of technologies (to achieve gains of scale) with high cost-effectiveness.

The renovation of the building envelope is not part of the selected options. The envelope of 2 buildings (Elementary School of Solum and Municipal House of Culture) was recently partially renovated and a new major renovation is not cost-effective. The Coimbra Town Hall building is protected by UNESCO and due to the protection rules, it is not possible to implement any change in the building envelope that causes a visual impact. Therefore, it is not possible to use standard solutions and the use of specifically designed solutions is not cost-effective. Additionally, the Municipality has decided to avoid renovation options requiring major construction works, incompatible with the normal use of the buildings. This is not an insurmountable barrier, but since other solutions able to achieve the same impact were available, such solutions were preferred. Therefore, since the other solutions (efficiency of the energy systems and renewable energy resources) present enough potential to achieve the objectives and ensure higher cost-effectiveness, the renovation of the envelope was not selected to the renovation plan.

The overall improvement of energy efficiency, as well as use of renewable energy sources was calculated with respect to the current buildings conditions. The achieved results were:

- Elementary School of Solum: 96.2 % of the consumed energy is ensured by renewable energy sources; 97.4 % savings in final energy, 96.4 % savings in primary energy and 97.8 % savings in CO_2 emissions.
- Municipal House of Culture: 95.0 % of the consumed energy is ensured by renewable energy sources; 97.2 % savings in final energy, 97.2 % savings in primary energy and 97.2 % savings in CO_2 emissions.
- Coimbra Town Hall: 72.1 % of the consumed energy is ensured by renewable energy sources; 81.8 % savings in final energy, 81.8 % savings in primary energy and 81.8 % savings in CO_2 emissions.

Energy service models and financing schemes were then assessed with different options of annual remuneration and the 'Shared Savings' type of ESCO contract can be feasible with 5% annual remuneration for the Municipality. The suggested financing plan is a mix of ESCO equity, senior debt and VAT facility. Subsidized funds are also included in the school Town Hall's financing structures. The main indicators for the ESCO investment in each project are:

- Elementary School of Solum: Equity Payback period of 13.5 years, ESCO IRR of 8.0 %, Equity NPV of €1,050.
- Municipal House of Culture: Equity Payback period of 12.5 years, ESCO IRR of 9.06 %, Equity NPV of €23,950.
- Coimbra Town Hall: Equity Payback period of 18 years, ESCO IRR of 7.5 %, Equity NPV of €5.800.

With the proposed financial structure, an ESCO intervention is possible and the remuneration of the invested capital is adequate for the two first buildings. For the Town Hall, an ESCO intervention at market conditions is sustainable, but with a lower profit.

Therefore, such results prove that it is possible ESCO interventions at market conditions in nearly zero energy renovations of public buildings. Most Portuguese Municipalities have buildings with the same characteristics. For instance, the elementary schools in different Municipalities have similar architecture and it is also normal to have a large building with library and other cultural facilities, as well as a listed building used as Town Hall. Therefore, the renovation projects can be easily used as examples and adapted for other Municipalities. The proposed financial structure can also act as model for replication, since the financial conditions in different Municipalities are identical. Therefore, the project has developed assessment tools that can receive as input economic data from other projects and Municipalities in order to easily generate an optimized financial scheme.

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