Patiño Cambeiro, F., Armesto, J., Bastos, G., Prieto López, J. I. & Patiño Barbeito, F. (2019). Economic appraisal of energy efficiency renovations in tertiary buildings. *Sustainable Cities and Society, 47*. https://doi.org/10.1016/j.scs.2019.101503

Link to published version: https://doi.org/10.1016/j.scs.2019.101503

Economic appraisal of energy efficiency renovations in tertiary buildings

Abstract: The EU, through its energy policy, has established a renovation rate of 3% for public buildings. This activity has a key role in achieving European targets regarding reducing energy consumption and greenhouse gas emissions. Moreover, the promotion of building renovations would reduce energy dependence and unemployment in the EU. The present work is aligned with the recently updated EPBD in the energy policy through an economic evaluation of energy renovations of eleven tertiary buildings. These buildings belong to three Spanish university campuses, and most of these buildings were built under the previous Spanish building code, which was enforced between 1979 and 2006. While revisions to the envelope are typically cost prohibitive, active measures can achieve a significant reduction in energy consumption and energy costs. The investment is recouped in 1.1–6.7 years for a new lighting installation and 0.7–7.7 years for a natural gas or biomass boiler. For the optimal combinations, typical reductions in primary energy consumption range between 12% and 48%. In the current scenario of limited economic resources, the data provided in this work can be used to prioritize expenditures in energy renovations from environmental or economic approaches.

Keywords: energy efficiency, public buildings, renovation, economic assessment, interventions prioritization

1. Introduction

Over the last few decades, an international discussion about mitigating climate change by reducing energy consumption has emerged. In 2012, the European Union (EU) adopted through its Energy Efficiency Directive (EED) (European Parliament, 2012b) a 2020 target of reducing energy consumption and greenhouse gas (GHG) emissions by 20% relative to the 1990 values. Further effort is needed to achieve this objective because data from 2017 (European Environment Agency, 2017; Filippidou, Nieboer, & Visscher, 2017) indicated that it will not be met, and the targets for 2030 were tightened to 27% and 40% for energy consumption and GHG emissions, respectively (European Commission, 2018a).

Among final energy consumers in the EU, buildings account for 38.9% of the total consumption, higher than transportation (33.1%) and industry (23.3%) (Eurostat, 2016b, 2017b). Energy generation is by far the most important GHG emitter in Europe, with a share of 75.2% (Eurostat - European Environment Agency, 2016; Eurostat, 2012). To reduce this energy consumption, upgrading existing European buildings is the key path due to the low efficiency of the existing building stock. In addition to the environmental impact, the evolution towards energy efficiency in buildings would also entail positive effects on national economies. First, the stimulation of building renovations would mean the reactivation of an industry that mobilizes huge economic resources and workforces. These effects support the complementary goals of 2020 regarding the employment of 75% of 20- to 64-year-olds (Delmas, 2015). Second, the correlation in developed countries between economic growth, CO_2 emissions and energy consumption has been studied extensively (Chen, Chen, Hsu, & Chen, 2016; Huang, Hwang, & Yang, 2008), and an increase in energy efficiency is essential to make the economic growth rate less dependent on energy consumption. Third, geopolitical factors are behind the increasing need to avoid energy dependence, which has stagnated at approximately 54% in Europe for a decade (Eurostat, 2016a). Additionally, from the international point of view, the energy renovation of buildings is aligned with the UN’s Sustainable Development Goals (SDGs), which will drive the policy and funding of the United Nations Development Programme until 2030. These goals include the reduction in the adverse *per capita* environmental impact of cities (United Nations Development Programme, 2018).

Measures oriented to improve the energy efficiency of buildings have proved to be effective in the past. The most significant improvement in the energy efficiency of European buildings was observed after 1990 due to tighter building regulations introduced in several member states (MSs) in the mid-1990s. As a result, residential buildings built in 2002 consume 24% less energy than those built in 1990 (Balaras et al., 2007). However, the estimations of annual building renovation rates across Europe is between only 0.5% and 2.5% of the building stock (Builidings Performance Institute Europe (BPIE), 2011; D'Agostino, Zangheri, & Castellazzi, 2017).

In 2011, Eichhammer et al. (Eichhammer et al., 2009) reported that there is still a potential for reduction in the tertiary sector, specifically ranging between 22% and 29% for 2030, and up to 37% under a technical scenario that considers advanced and expensive technologies. Tertiary buildings in Europe account for 25% of the built stock, and their final energy consumption is at least 40% higher than that for residential buildings (Mazzarella, 2015). As a result, tertiary buildings are responsible for 32% of the energy consumption, increasing 2.5% yearly since 2000 (European Union, 2015). In this frame, the systematic renovation of tertiary buildings should be accomplished to meet energy efficiency targets in the EU.

In the renovation field, the EED includes a binding target: from 2014, 3% of the total floor area of buildings of national governments should be renovated each year, which means that the public sector would become a frontrunner in the promotion of the renovation market. This action would constitute a beginning for the deployment of the national renovation strategies that the EED requires (The Coalition for Energy Savings, 2018). In 2016, the European Parliament proposed to extend the “3% target” to all public buildings given that it is the sector with the highest potential for energy savings, in addition to comfort improvement (European Parliament, 2016).

The 3% target is not being accomplished by all MSs through the direct renovation of buildings. Eighteen MSs adopted indirect approaches over the period of 2014–2015, i.e., measures that create incentives for occupants to change their behavior (European Commission, 2017). The European Commission preliminarily concluded that all MSs achieved the 3% target in that period. However, some uncertainties arose regarding the reports from MSs that adopted the indirect approach. Because of the lack of monitoring, no data exist to assess if the 3% target has been reached (European Commission, 2018b). The report by the Buildings Performance Institute Europe (BPIE) on 9 MSs (Buildings Performance Institute Europe (BPIE), 2017) confirmed this lack of information, and the heterogeneity of policy responses continued in 2016 (Rosenow & Fawcett, 2016).

When tertiary buildings are studied, the case study typically involves a single building. For instance, Irulegi et al. (Irulegi, Ruiz-Pardo, Serra, Salmerón, & Vega, 2017) assessed the highly energy-efficient renovation of an educational building based on student comfort. Salihbegović et al. (Salihbegović, Čaušević, Rustempašić, Avdić, & Smajlović, 2017) described the vulnerability of the Austro-Hungarian architectural heritage under energy-efficient renovation. Ferrari et al. (Ferrari & Beccali, 2017) assessed the economic issues of highly energy-efficient renovation of a representative building of the Italian public tertiary stock. Although they reported substantial energy savings, they also noted that defining a procedure for choosing the cost-optimal package of measures is not easy because each tertiary building has its own peculiarities. These difficulties were addressed by Zangheri et al. (Zangheri, Armani, Pietrobon, & Pagliano, 2018), who carried out a thorough review of the results obtained by the cost-optimal approach in residential and nonresidential buildings of the 1960s–

1970s under a wide variety of climates. To take advantage of available financial incentives, they pointed out the convenience of defining energy-cost clouds instead of a single energy-cost curve, which is what the cost-optimality of the Energy Performance of Buildings Directive (EPBD) (European Parliament, 2010, 2012a; The European Parliament and The Council, 2018) consists of. Medrano et al. (Medrano et al., 2018) defined a methodology for assessing the historical energy consumption and renewable generation of buildings, which was tested on 20 university buildings on the East Coast of Spain. Most of these buildings were built in the 1990s and 2000s, and the results serve to evaluate the gap between the energy performance of tertiary buildings and the energy-efficiency levels recommended by the European Commission (Comission, 2016).

To contribute to addressing the renovation of public service buildings, the present work provides a criterion to select the package of measures that achieves a balance between cost optimization and energy savings. This procedure is conducted on 11 tertiary buildings located in the Atlantic area of Spain; these buildings have different geometries, living areas and types of use, but they were built under the same building code preceding the current one. In the next section, the characteristics of the studied buildings and their locations are presented. The current energy performance of the buildings is shown in Section 3. The passive and active measures selected for the analysis on the buildings are described in Section 4. Section 5 collects the results of the proposed renovations in terms of the economic assessment and energy performance. These results are discussed in Section 6. Finally, the conclusions are presented in Section 7.

2. Case studies

In this work, eleven university buildings located in Galicia, in northwest Spain, were examined. A first criterion in the selection of the buildings was the period of construction: the last decades in which the previous building code was in force. Buildings constructed in this period lack of insulation, and their original installations are close to end of their service life. They have a great energy renovation potential. Secondly, the selected buildings are representative in terms of different climate areas, geometries, and types of use. Finally, the accomplishment of this kind of studies requires on-site access to analyze the buildings and to gather data. Since the authors are University staff, the selection under these criteria was made among the whole buildings under University of Vigo administration. Moreover, the EED promulgated the aim that public bodies should increase the efficiency of buildings by addressing the renovation of public buildings. This exemplary role is emphasized in the case of the university. The public system has a crucial role in the growth and diffusion of humanistic and technical knowledge and contributes to the social welfare through research and development activities.

The Spanish renovation sector constitutes a notable case study because it offers promising prospects for development. The Spanish energy dependence stands at 73.3% (Eurostat, 2016a), far greater than the aforementioned European mean value. Since the 1970s, the construction industry has had a substantial impact on the Spanish economy (Banyuls & Recio, 2012; Febrero & Uxó, 2011; Kapelko, Oude Lansink, & Stefanou, 2014). Furthermore, the communications campaign Renovate Europe, developed by the European Alliance of Companies for Energy Efficiency in Buildings (EuroACE), claims that the construction sector accounted for more than 10% of the Spanish GDP in 2014, employing 991,202 workers (Renovate Europe, 2018). After the stagnation in the construction industry in 2007, the construction workforce in renovation activities grew from 13% in 2007 to 31% in 2014. The promotion of energy renovation would further promote employment in this sector. Moreover, the result of the intensive construction since the 1970s is an extended build stock that is poorly insulated and equipped. The peak of the last construction boom took place in 2006, but the energy performance of even those buildings offers room for improvement in the light of modern requirements. In Spain, although approximately only 4% of buildings are service buildings, such buildings accounted for 12.1% of the total final energy consumption in 2012 (Kontonasiou, 2016; Ministry of Industry, Energy and Tourism, 2014). Educational buildings constitute 17% of Spanish tertiary buildings (Macarulla, Casals, Gangolells, & Forcada, 2014).

According to the Spanish building code ("Spanish Standard. Código Técnico de la Edificación. Documento Básico. Ahorro de Energía (CTE-DB-HE)," 2016), the climate zone, and thus the weather conditions, of a given location are assigned based on the altitude and the distance from the capital of the province of the location. Consequently, the group of buildings considered in this study are distributed among three climate zones corresponding to the coast of Vigo and Pontevedra, to inland Vigo and to Ourense. To obtain an overview of the energy needs of the buildings due to climatic conditions, the precise location and real weather characteristics from recent years for the three climatic zones are collected in **Figure 1**. The morphology of each building is shown in Figure 2.

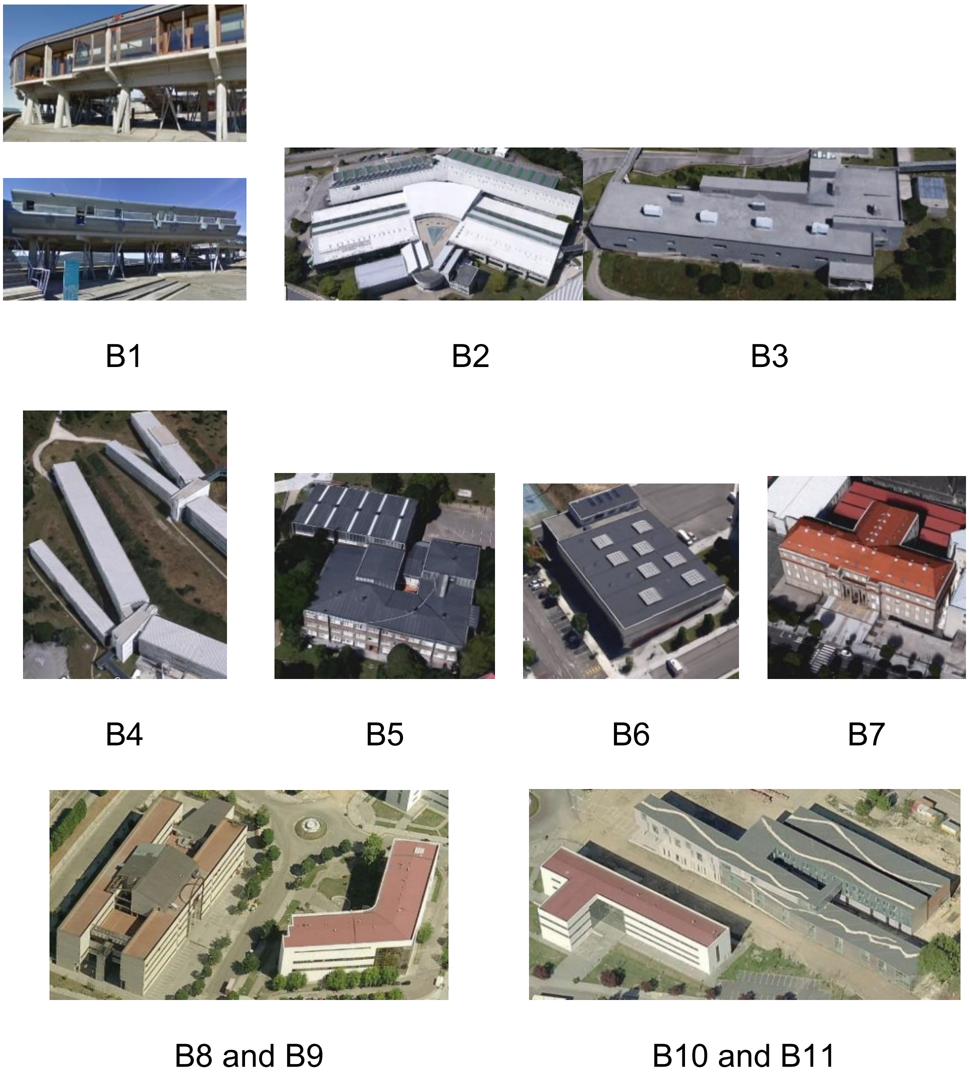
(**a**)

	Coast locations	Inland Vigo	Ourense
Altitude (m)	10	426	140
Average temperature (°C)	15.3	13.6	14.4
Yearly averaged maximum temperature (°C)	35.3	33.2	40.6
Yearly averaged minimum temperature (°C)	4.2	0.4	-4.3
Average annual precipitation (mm)	1265	1584	830

(**b**)

Figure 1. (a) Location of the university campuses (source: www.gifex.com); (b) Meteorological data from the three locations from the last 6, 11, and 7 years for the

coast locations, inland Vigo and Ourense, respectively (source: www.meteogalicia.gal).


B1 B2 B3

B4 B5 B6 B7

B8 and B9

B10 and B11

Figure 2. Overview of the buildings analyzed: (B1) Miralles Building; (B2) EEI (Engineering School – main campus); (B3) Central Library; (B4) EIME (Mining Engineering School); (B5) Fundición Building; (B6) Sports Center; (B7) EEI (urban campus); (B8) FCSC (Faculty of Social and Communication Sciences) (left) and (B9) EIF (Forestry Engineering School) (right); (B10) Physiotherapy School (left) and (B11) FCED (Faculty of Education Sciences and Sports) (right). Sources: maps.google.com (B1–B7), www.bing.com/maps (B8–B11).

All but one of the eleven buildings were built according to the same building code. This condition allows us to compare the energy performance of the tertiary buildings with different geometrical morphologies, uses, configurations of interior partitions, and different solutions adopted on envelopes. **Table 1** shows the characteristics of the buildings.

Table 1. General data of the buildings studied

		Year of construction	Number of floors	Living area (m^2)	Climatic zone [1]	Occupancy profile [1]
B1	Miralles Building	2000	1	2,169	D1	High – 8 h
B2	EEI (main campus)	1980	2	10,174		Medium – 16 h
B3	Central Library	1997	5	11,184		Medium – 12 h
B4	EIME	2005	2 – 4	15,597		Medium – 8 h
B5	Fundición Building	1980	3	3,471		Low – 12 h
B6	Sports Center	2003	3	3,033	D2	Medium – 16 h
B7	EEI	1930	7	7,630	C1	Low – 12 h
B8	FCSC	2002	4	13,833		Medium – 12 h
B9	EIF	1994	4	8,505		Low – 12 h
B10	Physiotherapy School	1998	3	2,749		Medium – 12 h
B11	FCED	2003	3	6,249		Low – 12 h

[1] Data from the current Spanish building code ("Spanish Standard. Código Técnico de la Edificación. Documento Básico. Ahorro de Energía (CTE-DB-HE)," 2016).

3. Evaluation of the as-built energy performance

The recast EPBD (European Parliament, 2010) and its amendment approved in 2018 (The European Parliament and The Council, 2018) are the foundations of the energy policy for buildings in the EU. Nevertheless, the EPBD does not set precise binding targets on the renovation of the building stock; instead, it calls on MSs to meet at least the "minimum energy performance requirements" that must be established using the cost-optimal methodology (European Commission, 2012; European Parliament, 2012a). This approach leaves MSs to define the requirements for energy performance after renovating the buildings. The EPBD even allows MSs to choose between two generic definitions for "major renovation", either in terms of a percentage of the surface of the building envelope that undergoes renovation or in terms of the ratio between the cost of the renovation and the value of the building. The EPBD also encourages the development of national schemes of energy performance certifications, which were further treated in the EED. The EPBD was revised in 2018 (The European Parliament and The Council, 2018). With this amendment, building renovations are to be fostered, and MSs shall bring into force the law necessary to comply with the new guidelines by March 2020.

These directives were transposed to the legal Spanish framework (Ministerio de la Presidencia, 2007) (Ministerio de la Presidencia de España, 2013). Currently, several types of software can be used to certify existing tertiary buildings. CE3X prevails for the certification of existing buildings since it was used in 98% of all energy certifications in Spain (ECOEFYS, 2018). This tool was also selected in this study for the energy performance evaluation. The results of the calculations are collected in **Table 2**. The letter associated with each value of the energy performance parameters represents the efficiency level that would be included in the efficiency label of the building. It can be appreciated that the transition values between efficiency levels are not constant, but they depend on the climate zone of the building, its physical characteristics and its occupancy profile (IDAE (Instituto para la Diversificación y Ahorro de la Energía), 2012). An overview of these bondary values through an energy-efficiency mapping of the Spanish building stock was provided by (Gangolells, Casals, Forcada, Macarulla, & Cuerva, 2016). The efficiency regarding the primary energy consumption is taken as the global efficiency in the label.

Table 2. Energy performance of the buildings studied as stated in their energy certificate

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
Primary energy consumption (kWh/m^2 year)	401.4 – D	222.4 – D	90.3 – C	155.9 – C	262.2 – E	592.5 – D	192.1 – D	171.2 – C	204.5 – C	205.5 – D	271.1 – C
Heating demand (kWh/m^2 year)	193.9 – D	54.3 – F	78.8 – G	47.8 – D	69.0 – E	68.8 – D	76.4 – F	36.2 – E	58.3 – E	55.9 – E	76.6 – F
Cooling demand (kWh/m^2 year)	5.8 – F	23.3 – F	102.4 – G	17.4 – F	5.3 – G	238.8 – D	0.4 – B	17.8 – E	8.7 – E	18.5 – F	15.9 – E
Global CO_2 emissions (kg CO_2/m^2 year)	87.9 – D	56.7 – D	22.5 – C	39.8 – C	67.0 – E	149.5 – D	43.3 – C	42.0 – C	52.1 – D	63.2 – E	69.7 – C

The high energy consumption of the Miralles Building (B1) is caused by the solar irradiation impinging on the south-oriented façade, in which the windows occupy between 47% and 57% of the façade area. The high energy consumption of the Sports Center (B6) has two causes. One is the high power consumption of the lighting, as it consists primarily of 32 discharge lamps of 400 W in the main sport area, 12 discharge lamps of 250 W in the squash area, and 128 fluorescent lights of 58 W. The other one is the warm microclimate of Orense, which entails a high energy consumption by cooling systems in warm seasons. In contrast, the Central Library (B3) has a low energy consumption because of its geothermal plant for both heating and cooling functions.

4. Retrofit measures

The proposed renovation measures include passive measures that would reduce the energy needs and active measures related to the energy installations of the buildings. The measures have been selected considering Spanish building codes and previous experience regarding building renovations (Patiño-Cambeiro, Armesto, Patiño-Barbeito, & Bastos, 2016). Although the Spanish framework does not consider active measures as refurbishment, such measures are known to be essential in the achievement of cost-optimal solutions.

4.1. Passive measures

Two passive measures were considered: the replacement of windows and the improvement of the building envelope. Each of these measures was adapted to the characteristics of each building. The thermal insulation was the most needed feature, but infiltrations of air and moisture are also weaknesses of certain buildings. **Table 3** shows the packages of passive measures for four buildings. As presented in the next section, renovations integrated only by passive measures have low profitability. Only the buildings with the most profitable possibilities were included, along with another building with the average payback period of nonprofitable renovation packages. On the basis of the characteristics and conditions of the other buildings, their actual energy performance and, above all, the high costs involved in refurbishing their façades, roofs and in replacing the windows, the authors concluded that improved economic profitability would not be obtained in those buildings. Even despite the estimated service life of new elements on the envelope was considered to be 30 years.

Table 3. Package of measures consisting of passive measures.

Building	**New windows**	**Actions on the envelope's insulation**
B3	Solar factor: 0.70 Thermal transmittance: U: 2.1 W/m^2 K	Improvement of roof insulation by inserting a 100 mm thick layer of XPS (thermal conductivity: 0.034 W/m K)
B5		ETICS on façades (thermal transmittance: 0.505 W/m^2 K)
B10	Solar factor: 0.58 Thermal transmittance: U: 1.7 W/m^2 K	Improvement of roof insulation by adding an 80 mm thick layer of glass wool (thermal conductivity: 0.04 W/m K). Improvement of insulation of the false ceiling of nonliving spaces by adding a 90 mm thick layer of rock wool (thermal conductivity: 0.038 W/m K)

B11	Improvement of façade insulation by adding a 40 mm thick interior layer of cellular polycarbonate (thermal conductivity: 0.2 W/m K), 40 mm of rock wool (thermal conductivity: 0.037 W/m K), and 20 mm of gypsum plaster (thermal conductivity: 0.25 W/m K)

4.2. Active measures

Two types of energy systems were studied: heating and lighting. When viable, the more efficient single-boiler configuration was considered. As shown in **Table 4**, several buildings are fed by two oil boilers, and natural gas infrastructure is currently available for all the buildings analyzed. A high share of energy consumption in educational buildings, as in most of tertiary buildings, is accounted for by the lighting system. Most of these buildings contain fluorescent lamps; replacing these lamps with LED lamps would allow a significant reduction in energy use. The estimated life span was considered to be 9 years for new lighting elements, 25 years for new boilers and burners, and 20 years for the solar thermal installation.

Table 4. Active measures considered.

	Original systems [1]	**New systems**
B1	Fluorescent lighting: 5.2 kW	• LED lighting: 2.3 kW • Manual potentiometer for 23 lamps over the corridor
B1	Low-temperature gas boiler: 255.2 kW, 90.3%	Condensation gas boiler: 254.5 kW, 97.9%

B2	Fluorescent lighting: 15.8 kW	• 9.1 kW of LED lighting • Automated lighting control in public areas: human presence detection and sunlight detection
B2	Oil boiler: 752 kW, 75% Oil boiler: 531 kW, 85%	Two condensation gas boilers: 640 kW, 110%
B3	Fluorescent lighting: 58.8 kW	LED lighting: 21.5 kW
B4	Fluorescent lighting: 159.3 kW	LEDs: 135.4 kW
B4	Oil/gas boilers (working with oil): 600 kW, 93% Oil boiler: 24 kW, 85%	Biomass boiler: 1000 W, 95%
		Replacing the oil burners by gas burners: 103% efficiency
B5	Fluorescent lighting: 45.7 kW Discharge lamps: 3 kW	• Replacement of electromagnetic ballast + igniters by electronic ballasts of the 68% of fluorescent lamps and of all the discharge lamps. • Replacement of the other lamps (10.9 kW) by LEDs (3.1 kW).
B5	Heating: 290.3 kW oil boiler, 85% Heat pumps: • Cooling: 3.50 kW, 315% • Cooling: 14 kW , 258% Heating: 16 kW, 352%	Two options: A. Condensation natural gas boiler: 333 kW, 103%.

	- Cooling: 22 kW, 322% Heating: 27 kW, 361% - 2 units. For each unit: Cooling: 8.2 kW, 248% Heating: 9.3 kW, 273% - 2 units. For each unit: Cooling: 1.8 kW, 265% Heating: 1.8 kW, 327% - 2 units. For each unit: Cooling: 3.5 kW, 239% Heating: 2.6 kW, 320%	B. Biomass boiler: 300 kW, 92.0%.
B6	Fluorescent: 7.5 kW	LEDs: 2.4 kW
B7	Fluorescent: 73.3 kW	LEDs: 41.9 kW
B7	Heating: low-temperature gas boiler: 310 kW, 92%	Biomass boiler: 250 kW, 90.6%
B8	Fluorescent: 127.7 kW	LEDs: 79.7 kW
B8	Two oil boilers: 697.8 kW, 90.5%	Biomass boiler: 1250 kW, 95.0%.
B9	Fluorescent: 74.2 kW	LEDs: 41.2 kW
B9	Two oil boilers: 290.7 kW, 90.9%	Two condensation natural gas boilers: 292 kW, 95%.
B10	Two oil boilers: 290 kW, 85% / 58.1 kW, 85%	Condensation natural gas boiler: 376.2 kW, 97.6%.
B11	Fluorescent: 57.2 kW	LEDs: 29.7 kW

B11	Two oil boilers: 500 kW, 90%	Natural gas burners: 94% efficiency

[1] The data provided for boilers represent the nominal heat output and efficiency.

5. Economic evaluation of energy renovation packages

An economic assessment was performed for each package of renovation measures through their payback period and their net present value (NPV). In accordance with cost-optimal methodology (European Commission, 2012; European Parliament, 2012a; Patiño-Cambeiro, et al., 2016), the period of calculation for public buildings is 30 years, and the NPV was based on the following expression for each measure package j:

$$C_j + \sum_j \left[\sum_i \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right]$$

Where:

- C_j means initial investment costs,
- $C_{a,i}(j)$ are the net anual costs,
- R_d is the discount factor for year i based on the discount rate r: $R_d(i) = \left(\frac{1}{1+\frac{r}{100}} \right)^i$,
- $V_{f,\tau}(j)$ means the residual value of the set of measures j at the end of the calculation period.

The net annual costs $C_{a,i}(j)$ include maintenance savings (when applicable) and energy savings that the renovation package j would generate. The starting values of energy cost and their yearly increments used are collected in **Table 5**. The yearly increment of maintenance cost was 3%, and the economic evaluations were carried out for two different discount rates r: 3% and 6%.

Table 5. Values of economic parameters used

	Electricity	Natural gas	Heating oil	Pellets
Energy cost (€/kWh)	0.1595	0.04360	0.0473	0.04454
Increment of energy cost (% yearly)	2018 – 2020: 1.5 2021 – 2030: -0.3 2031 – 2047: -0.2	Low scenario: 2018 – 2020: 5.6 2021 – 2030: 3.0 2031 – 2047: 0.8 High scenario: 2018 – 2025: 5.9 2026 – 2047: 1.7	Low / high scenarios: 1.3 / 1.8	0.5

The starting price of electricity was extracted from “Eurostat – Electricity prices for nonhousehold consumers - biannual data (from 2007 onward) (nrg_pc_205)” (Eurostat, 2017a), while the “EU Reference Scenario 2016” (European Commission, 2016) document provided its annual growth. The sources for the starting price of natural gas and its annual growth were extracted from “Eurostat – Gas prices for nonhousehold consumers - biannual data (from 2007 onward)” (nrg_pc_203) (Eurostat, 2017c) and from “Outlook for natural gas” (International Energy Agency

(IEA), 2018), respectively. With regard to heating oil, the source of the starting price was “IDAE – Informe de precios energéticos: combustibles y carburantes” (IDAE, 2018). For its annual growth, the two considered scenarios correspond to a deviation of ±20% with respect to the projection from the U.S. Energy Information Administration (EIA) for the price of the barrel of Brent for 2047 (NASDAQ, 2018; The Balance, 2018; U.S. Energy Information Administration (EIA), 2018). Finally, the source for the pellets cost was “AVEBIOM – Índice de precios del pellet doméstico en España” (AVEBIOM, 2018).

Table 6 **presents the economic assessment of the passive measures considered (Table 3). The results when only active measures are considered are collected in** [1] Interest rate.

[2] Low-price scenario (LPS) and high-price scenario (HPS) for fossil fuels.

Table **7**, and an optimal package of measures was determined for each building, all of them presented in Table **8**. These packages include invasive and noninvasive passive elements, the replacement of lighting, the installation of an automated lighting control, the replacement of the heating source and, in the case of the Physiotherapy Faculty, the installation of a solar thermal plant. The primary energy savings are equivalent to the reduction in CO_2 emissions. The optimal packages were ordered by their effectiveness, this is, the relation between the reduction in the primary energy consumption achieved and the investment.

Table 6. Economic assessment of major renovations on the envelope.

Building	Reduction in annual primary energy consumption (%)	Investment (€1000s)	NPV (€1000s)			
			r [1] = 3%		r = 6%	
			LPS [2]	HPS [2]	LPS	HPS
B3	8.7	203	-161		-177	
B5	5.0	128	-103	-100	-110	-109
B10	9.0	319	-230	-224	-258	-255
B11	1.4	59	-36	-32	-44	-42

[1] Interest rate.

[2] Low-price scenario (LPS) and high-price scenario (HPS) for fossil fuels.

Table 7. Economic assessment of the most effective active measures on all of the buildings.

Building	New energy/lighting system [1]	Reduction in annual primary energy	Investment (€1000s)	Payback period (years)				NPV (€1000s)			
				r [2] = 3%		r = 6%		r = 3%		r = 6%	
				LPS [3]	HPS [3]	LPS	HPS	LPS	HPS	LPS	HPS

		consumption (%)									
B1	LEDs + lighting control	1.8	8.3	—		—		-11	-12	-10	-10
B1	NG	10.4	13.7	—	—	—	—	-23	-49	-15	-32
B3	LEDs	15.2	48.2	4.3		4.7		115		71	
B5	Lighting system	15.0	16.7	4.1	4.1	4.4	4.4	96	94	60	59
B5	NG	11.7	23.4	—	—	—	—	-87	-109	-68	-82
B5	Biomass boiler	8.4	103.7	—	—	—	—	-62	-41	-72	-60
B6	LEDs	3.7	3.7	1.1	1.1	1.2	1.2	46	45	32	32
B7	LEDs	15.7	36.1	5.5	5.6	6.2	6.3	31	22	16	11
B7	Biomass boiler	5.9	46.3	6.9	6.2	7.7	6.8	182	247	105	144
B9	LEDs	16.1	189.4	5.9	5.9	6.6	6.7	200	192	101	97
B9	NG	4.8	57.4	2.6	2.6	2.8	2.8	353	346	231	224

B10	NG + lighting control + solar thermal installation	17.4	43.1	2.6	2.6	2.8	2.8	304	322	199	208
B11	LEDs	14.0	98.0	3.1	3.1	3.3	3.3	404	398	265	261
B11	NG	5.6	13.4	0.7	0.7	0.7	0.7	287	261	200	182

[1] LEDs: replacement of existing lamps by LED lamps. NG: replacement of existing boiler by a natural gas boiler.

[2] Interest rate.

[3] Low-price scenario (LPS) and high-price scenario (HPS) for fossil fuels.

Table 8. Economic assessment of the most effective packages of measures on all of the buildings.

Building	**Optimal package** [1]	**Reduction in annual primary energy consumption (%)**	**Investment (€1000s)**	**Effectivity (kWh/m^2 of PEC savings / €1000s invested)**	**Payback period (years)**				**NPV (€1000s)**			
					r [2] = 3%		**r = 6%**		**r = 3%**		**r = 6%**	
					LPS [3]	**HPS** [3]	**LPS**	**HPS**	**LPS**	**HPS**	**LPS**	**HPS**
B6	LEDs	3.7	3.7	5.92	1.1	1.1	1.2	1.2	46	45	32	32

B5	LEDs + electronic ballasts	15.0	16.7	2.35	4.1	4.1	4.4	4.4	96	94	60	59
B1	NG + LEDs + lighting control	12.3	21.1	2.34	3.8	3.8	4.1	4.1	113	128	71	80
B10	Improvement in the roof insulation + lighting control + NG + solar thermal installation	19.2	53.9	0.73	3.2	3.2	3.4	3.4	310	313	198	199
B11	LEDs + NG	19.6	111.4	0.48	2.1	2.1	2.2	2.2	652	619	453	430
B3	LEDs	15.2	48.2	0.28	4.3		4.7		115		71	
B4	Ground insulation + Solar control films + LEDs + NG	13.2	111.3	0.18	5.6	5.6	6.3	6.3	290	295	192	175
B9	LEDs + NG	21.4	246.8	0.18	4.5	4.5	4.9	4.9	593	578	360	349

B2	Improvement of the insulation of façades, replacement of windows, installation of louvers and lattices, NG, LEDs, lighting control	48.4	661.4	0.16	5.5	5.4	6.4	6.0	1751	1832	1048	1092
B8	Installation of louvers + LEDs + biomass boiler	23.7	341.8	0.12	4.6	4.6	5.0	6.0	1064	1132	652	692
B7	LEDs + biomass boiler	17.7	82.5	0.10	5.4	5.2	6.0	5.7	249	331	148	197

---

[1] LEDs: replacement of existing lamps by LED lamps. NG: replacement of existing boiler by a natural gas boiler.

[2] Interest rate.

[3] Low-price scenario (LPS) and high-price scenario (HPS) for fossil fuels.

6. Discussion of the results

Although the most adequate passive measures depend strongly on the characteristics of the specific building, Table **6** clearly shows that for the four buildings, the passive measures alone are not economically viable. The service life of passive elements (30 years) would not be enough to recoup the investments. The reason typically lies in the high investment needed but also in the low energy savings obtained, as is the case for the Central Library (B3). Although B3 would reach an appreciable reduction in energy consumption (8.7%), the correspondent financial energy savings would be low because this building is the one with the lowest current energy consumption.

A deeper analysis of passive and active measures was performed by García Kerdan et al. (García Kerdan, Raslan, Ruyssevelt, & Morillón Gálvez, 2016). They conclude that passive measures provide lower improvement in the thermodynamic performance of buildings, despite in typical practice it is believed that buildings with better performance are those who tend to have a good passive design and a tighter envelope. Moreover, Belusko et al. (Belusko, Bruno, & Saman, 2011) explained that with increasing of insulation levels in buildings it is more likely the gap between expected and assumed thermal resistance will increase. In fact, they found the actual level of roofing insulation systems to perform half that expected (Karimpour, Belusko, Xing, & Bruno, 2014).

Table **7** presents varying results for the active measures. Replacing current oil boilers by more efficient boilers would reduce the primary energy consumption between 4.8% and 11.7%, with a payback period ranging from 0.7 to 7.7 years. However, the long-term evolution of energy costs dramatically affects economic assessments. In Spain, the current price of natural gas is slightly lower than the price of heating oil, but according to the sources used, the price of natural gas is expected to grow faster than that of oil. Consequently, replacing oil boilers by natural gas boilers would become economically feasible in the cases when the heating system lacks efficiency, resulting in a high consumption of heating oil. In any case, the characteristics of the buildings constitute another key variable for the feasibility of active measures since replacing boilers could require work on the partitions of the building. This is the main reason for the difference in investments between the installation of a biomass boiler in buildings B5 and B7.

Replacing obsolete lighting systems by LEDs, with or without an automated control system, would entail for the buildings analyzed a reduction in the primary energy consumption of approximately 14–16%, reaching complete return of investment between the 1st and the 5th years. In most cases, replacing fluorescent lamps by LEDs would become profitable under the EU's projection for Spanish electricity cost. The most recent changes in this cost suggest that the electricity cost could grow faster than expected, and thus switching to LEDs would become more attractive. However, LEDs have lower heat losses than fluorescent or halogen lamps, and thus the installation of an LED lighting system entails additional expense in heating. Heating costs also affect the profitability of updating lighting systems since the higher efficiency of LEDs entails a lower heat generation, which must be countered by the heating source. This phenomenon can be observed in the case of B7.

Finally, when the optimal package of measures is pursued (see Table **8**), the profitability of active measures is typically the factor that allows the inclusion of passive measures. The overall analysis reveals varying results. Considering the reduction in the primary energy consumption, the intervention of building B2 should be prioritized over that of the others. The payback period for this energy renovation would be close to 6 years in the four different economic scenarios, which could be considered reasonable by energy service companies (ESCOs) and managers. However, this step requires the highest investment among all the buildings, and the effectivity of the high investment required is one of the lowest (0.16 kWh/m^2 of primary energy saved per 1000 € invested). In the opposite case, the proposed solution for building B6 reduces the primary energy consumption by only 3.7%; the investment is the lowest among the whole set of buildings under analysis, the effectivity of this investment is the highest, and the payback period is less than 1 year. In the rest of the cases, the achieved energy savings are typically not proportional to the required investment. The obtained variability in the economic performance of the renovations might be due to the varying characteristics of each building.

In view of the strong influence that heating systems have on the benefits of the suggested renovations, installing a centralized facility emerges as a logical alternative. The use of district heating in buildings remains below 10% around the world and in the EU (Werner, 2017). Waste heat from industrial processes or power plants can be supplied to local buildings, or ad hoc facilities can be installed in the neighborhood of a group of buildings or for entire urban areas (Lund, Möller, Mathiesen, & Dyrelund, 2010). This approach would address the heterogeneity present in the energy sources of tertiary buildings.

7. Conclusions

The improvement of energy efficiency in buildings constitutes a key task in EU policy for environmental, economic and geopolitical reasons. The EPBD establishes the foundations for criteria on the energy renovation of individual buildings based on optimal cost. In the current scenario of limited economic resources, when a single stakeholder considers a set of buildings for energy renovation, interventions should be accomplished considering the individual analysis of every building and the analysis of the set of buildings as a whole. This collective analysis would list the buildings by priority order following different criteria, in particular the environmental and the economic targets. The present work accomplishes this task for 11 public buildings under the purview of university administration.

Passive renovation measures on building envelopes are necessary to significantly decrease energy needs, both in cold and in warm seasons. However, passive measures alone are not economically feasible: they need high investments that are recouped only at the end of the estimated life of the installed elements, if at all. Active measures are currently the optimal strategy for energy renovation of tertiary buildings. Their high profitability would allow, in some cases, the inclusion of passive measures. The optimal packages of measures would achieve a reduction in energy consumption between 3.7% and 48.4%, for which all but one payback period would remain below 7 years.

Among active measures, retrofitting the heating and the lighting systems is the most effective solution from economic and environmental points of view. Reductions in energy consumption between 4.8% and 11.7% would be achieved by shifting from oil boilers to higher-efficiency boilers. In view of the impact that heating systems have on the economic performance of the suggested renovations, installing a centralized facility emerges as a logical alternative, either by using district heating or by installing ad hoc facilities in the vicinity of a group of buildings. Given the high power consumption that lighting systems incur in public buildings, replacing fluorescent and incandescent lights with LEDs could achieve an improvement in the reduction of energy consumption from 3.7% to 16.1%.

Energy performance and economic profitability range over wide intervals due to the as-built characteristics of buildings. These constructive differences ensure that reductions in the energy consumption achieved are not, in general, proportional to the investment required. Therefore, special attention must be paid to the update of the building code, which has been delayed in Spain relative to most of the EU MSs. Another key factor is the long-term perspectives adopted for the economic scenarios. According to the EPBD’s cost-optimal methodology, the period of calculation for public buildings is 30 years. Over such a long period, the economic uncertainty is substantial, and fluctuations in energy prices would change the feasibility among energy sources. Special caution must be taken when large investments are involved.

The comprehensive analysis of sets of buildings can support decision making in building energy renovations at different levels: design of public financial grants oriented to promote the reduction of GHG emissions at the national level, prioritization criteria among buildings in a given set to achieve optimal economic solutions (optimized energy management), or the maximization of the long-term energy savings. Several options are available depending on the targets: EU legislation is prompting national governments to reduce GHG emissions, building owners tend to pursue optimization of their economic resources, and energy-renovating investors pursue long-term profitability.

In short, starting from the “3% target” established by the EED for central governments, the information provided in the present study aims to support decision making in managing public buildings for any stakeholder so that renovations can be extended to the tertiary building stock. The key role of the energy source of buildings led to consider collective energy facilities. By bringing focus of energy policy to the urban scale, the philosophy of sustainability would reach more easily the energy transition that is required for future societies.

Acknowledgments

The authors thank the following students for their work regarding documentation and calculation in the energy performance certifications of the case studies. These certifications were carried out in several projects under the supervision of (author) and (author): Alba Fernández Rodríguez, Lucía Seco Núñez, Jéssica Iglesias Castro, David Fernández Rodríguez, Álvaro Domínguez Valle, Alejo Fernández González, Alejandro Trigo Méndez, Rubén Viñas Solla, José Ferradás Troitiño, Óscar Fandiño Pousada, Pedro del Solar Martínez, Luis Gandarela Campos, Héctor Pérez Velasco, Rubén López Rodríguez, María Viqueira Franco and Carmen Fontenla González.

References

AVEBIOM. (2018). Índice de precios del pellet doméstico en España: 1T 2012 – 1T 2018 (Spanish). Retrieved May 8, 2018, from https://www.dropbox.com/s/ohf675wjcl0c0uv/Indice_AVEBIOM_Precio_Pellets de Madera_Abril2018.pdf?dl=0

Balaras, C. A., Gaglia, A. G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., & Lalas, D. P. (2007). European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. *Building and Environment*, *42*(3), 1298–1314. https://doi.org/10.1016/j.buildenv.2005.11.001

Banyuls, J., & Recio, A. (2012). Spain: The nightmare of Mediterranean neoliberalism. In *A triumph of failed ideas: European models of capitalism in the crisis* (p. 284). Brussels, Belgium: ETUI. Retrieved from https://www.etui.org/content/download/21031/175760/file/C10+12+A+triumph+of+failed+ideas+WEB.pdf

Belusko, M., Bruno, F., & Saman, W. (2011). Investigation of the thermal resistance of timber attic spaces with reflective foil and bulk insulation, heat flow up. Applied Energy, 88(1), 127–137.

https://doi.org/https://doi.org/10.1016/j.apenergy.2010.07.017

Builidings Performance Institute Europe (BPIE). (2011). *Europe's Buildings under the microscope. A country-by-country review of the energy performance of buildings*. Brussels, Belgium. Retrieved from http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf

Buildings Performance Institute Europe (BPIE). (2017). *A snapshot of national renovation strategies – Examples from selected EU Member States*. Brussels, Belgium.

Chen, P.-Y., Chen, S.-T., Hsu, C.-S., & Chen, C.-C. (2016). Modeling the global relationships among economic growth, energy consumption and CO2 emissions. *Renewable and Sustainable Energy Reviews*, *65*, 420–431. https://doi.org/10.1016/j.rser.2016.06.074

Comission, E. (2016). Commission Recommendation 2016/1318 of 29 July 2016 on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016H1318&from=EN

D'Agostino, D., Zangheri, P., & Castellazzi, L. (2017). Towards nearly zero energy buildings in Europe: A focus on retrofit in non-residential buildings. *Energies*, *10*(117). https://doi.org/- 10.3390/en10010117

Delmas, A. (2015). Perspectives for revision of the Europe 2020 strategy. Les éditions des Jornaux officiels. Conseil économique, social et environnemental. République Française. Retrieved from https://www.eesc.europa.eu/resources/docs/strategieeurope2020.pdf

ECOEFYS. (2018). Programa CE3X de certificación energética de edificios existentes (Spanish). Retrieved May 23, 2018, from http://www.ecoefys.com/programa-ce3x-de-certificacion-energetica-edificios-existentes/

Eichhammer, W., Fleiter, T., Schlomann, B., Faberi, S., Fioretto, M., Piccioni, N., … Resch, G. (2009). Study on the energy savings potentials in EU member states, candidate countries and EEA countries. Final report for the European Commission. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/2009_03_15_esd_efficiency_potentials_final_report.pdf

European Commission. (2012). Guidelines accompanying Commission Delegated Regulation (EU) No. 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. *Off. J. Eur. Union*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012XC0419(02)&from=EN

European Commission. (2016). *EU Reference Scenario 2016. Energy, transport and GHG emissions. Trends to 2050*. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

European Commission. (2017). COM/2017/056 final – Report from the Commission to the European Parliament and The Council. 2016 assessment of the progress made by Member States in 2014 towards the national energy efficiency targets for 2020 and towards the implementation of the Energy . Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0056&from=EN

European Commission. (2018a). 2030 Energy Strategy. Retrieved June 6, 2018, from https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

European Commission. (2018b). Setting the 3% target for public building renovation. Retrieved April 30, 2018, from https://ec.europa.eu/energy/en/content/setting-3-target-public-building-renovation

European Environment Agency. (2017). *Trends and projections in Europe 2017. Tracking progress towards Europe’s climate and energy targets*. https://doi.org/10.2800/791520

European Parliament. (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)--. Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

European Parliament. (2012a). Commission Delegated Regulation 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-op. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0244&from=EN

European Parliament. (2012b). Directive 2012/27/EU of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN

European Parliament. (2016). Implementation report on the Energy Efficiency Directive. Retrieved May 28, 2018, from http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P8-TA-2016-0293

European Union. (2015). *Energy Efficiency Trends and Policies in the Household and Tertiary Sectors – An Analysis Based on the ODYSSEE and MURE Databases. Report co-funded by the Intelligent Energy Europe Programme*. Retrieved from http://www.odyssee-mure.eu/publications/br/energy-efficiency-trends-policies-buildings.pdf

Eurostat. (2012). *Eurostat pocketbooks. Energy, transport and environment indicators. 2012 edition*. Retrieved from http://ec.europa.eu/eurostat/documents/3930297/5968494/KS-DK-12-001-EN.PDF/9dc62b91-ffe4-48c4-bca7-0d80142934f2

Eurostat. (2016a). Energy dependence by product (sdg_07_50). Retrieved July 18, 2018, from https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_07_50&plugin=1

Eurostat. (2016b). *Eurostat statistical books. Energy, transport and environment indicators. 2016 edition*. Retrieved from http://ec.europa.eu/eurostat/documents/3217494/7731525/KS-DK-16-001-EN-N.pdf/cc2b4de7-146c-4254-9521-dcbd6e6fafa6

Eurostat. (2017a). Electricity prices for non-household consumers - bi-annual data (from 2007 onwards) (nrg_pc_205). Retrieved from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en

Eurostat. (2017b). Eurostat Eurobase data base Final energy consumption by sector (tsdpc320).

Eurostat. (2017c). Gas prices for non-household consumers - bi-annual data (from 2007 onwards) (nrg_pc_203). Retrieved June 8, 2018, from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_203&lang=en

Eurostat - European Environment Agency. (2016). Greenhouse gas emissions by source sector. Retrieved July 19, 2018, from http://ec.europa.eu/eurostat/product?code=env_air_gge&mode=view

Febrero, E., & Uxó, J. (2011). Constraints and alternatives for employment and output growth: Spain during the great recession. *Journal of Contemporary European Studies*, *19*(1), 63–81. https://doi.org/10.1080/14782804.2011.554194

Ferrari, S., & Beccali, M. (2017). Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. *Sustainable Cities and Society*, *32*. https://doi.org/10.1016/j.scs.2017.03.010

Filippidou, F., Nieboer, N., & Visscher, H. (2017). Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing using the national energy labelling database. *Energy Policy*, *109*, 488–498. https://doi.org/10.1016/j.enpol.2017.07.025

Gangolells, M., Casals, M., Forcada, N., Macarulla, M., & Cuerva, E. (2016). Energy mapping of existing building stock in Spain. Journal of Cleaner Production, 112, 3895–3904. https://doi.org/https://doi.org/10.1016/j.jclepro.2015.05.105

García Kerdan, I., Raslan, R., Ruyssevelt, P., & Morillón Gálvez, D. (2016). An exergoeconomic-based parametric study to examine the effects of active and passive energy retrofit strategies for buildings. Energy and Buildings, 133, 155–171. https://doi.org/https://doi.org/10.1016/j.enbuild.2016.09.029

Huang, B.-N., Hwang, M. J., & Yang, C. W. (2008). Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach. *Ecological Economics*, *67*(1), 41–54. https://doi.org/10.1016/j.ecolecon.2007.11.006

IDAE (Instituto para la Diversificación y Ahorro de la Energía). (2012). Guía IDAE: Manual de fundamentos técnicos de calificación energética de edificios existentes CE3X (Spanish). Madrid, Spain: IDAE. Retrieved March 12, 2018 from http://www6.mityc.es/aplicaciones/CE3X/Manual_usuario%20CE3X_05.pdf

IDAE (Instituto para la Diversificación y Ahorro de la Energía). (2018). Estudios, informes y estadísticas (Spanish). Retrieved July 24, 2018, from http://www.idae.es/estudios-informes-y-estadisticas

International Energy Agency (IEA). (2018). *Outlook for natural gas. Excerpt from World Energy Outlook 2017*. Retrieved from http://www.iea.org/publications/freepublications/publication/WEO2017Excerpt_Outlook_for_Natural_Gas.pdf

Irulegi, O., Ruiz-Pardo, A., Serra, A., Salmerón, J. M., & Vega, R. (2017). Retrofit strategies towards Net Zero Energy Educational Buildings: A case study at the University of the Basque Country. *Energy and Buildings*, *144*, 387–400. https://doi.org/10.1016/j.enbuild.2017.03.030

Kapelko, M., Oude Lansink, A., & Stefanou, S. E. (2014). Assessing dynamic inefficiency of the Spanish construction sector pre- and post-financial crisis. *European Journal of Operational Research*, *237*(1), 349–357. https://doi.org/10.1016/j.ejor.2014.01.047

Karimpour, M., Belusko, M., Xing, K., & Bruno, F. (2014). Minimising the life cycle energy of buildings: Review and analysis. Building and Environment, 73, 106–

114. https://doi.org/https://doi.org/10.1016/j.buildenv.2013.11.019

Kontonasiou, E. (BPIE). (2016). *Zebra 2020. Nearly zero-energy building strategy 2020. D 4.2: Overview of building-related policies*.

Lund, H., Möller, B., Mathiesen, B. V, & Dyrelund, A. (2010). The role of district heating in future renewable energy systems. *Energy*, *35*(3), 1381–1390. https://doi.org/10.1016/j.energy.2009.11.023

Macarulla, M., Casals, M., Gangolells, M., & Forcada, N. (2014). *Reducing energy consumption in public buildings through user awareness*. https://doi.org/10.1201/b17396-104

Mazzarella, L. (2015). Energy retrofit of historic and existing buildings. The legislative and regulatory point of view. *Energy and Buildings*, *95*, 23–31. https://doi.org/10.1016/j.enbuild.2014.10.073

Medrano, M., Martí, J. M., Rincón, L., Mor, G., Cipriano, J., & Farid, M. (2018). Assessing the nearly zero-energy building gap in university campuses with a feature extraction methodology applied to a case study in Spain. *International Journal of Energy and Environmental Engineering*. https://doi.org/10.1007/s40095-018-0264-x

Ministerio de la Presidencia. (2007). Real Decreto 47/2007, de 19 de enero, por el que se aprueba el Procedimiento básico para la certificación de eficiencia energética de edificios de nueva construcción (Spanish). Retrieved from https://www.boe.es/boe/dias/2007/01/31/pdfs/A04499-04507.pdf

Ministerio de la Presidencia de España. (2013). Real Decreto 235/2013, de 5 de abril, por el que se aprueba el procedimiento básico para la certificación de la eficiencia energética de los edificios (Spanish). Retrieved from https://www.boe.es/buscar/pdf/2013/BOE-A-2013-3904-consolidado.pdf

Ministry of Industry, Energy and Tourism (2014). *2014–2020 National energy efficiency action plan*. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/2014_neeap_en_spain.pdf

NASDAQ. (2018). Crude oil Brent. Latest Price & chart for crude oil Brent. Retrieved August 9, 2018, from https://www.nasdaq.com/markets/crude-oil-brent.aspx

Patiño-Cambeiro, F., Armesto, J., Patiño-Barbeito, F., & Bastos, G. (2016). Perspectives on near ZEB renovation projects for residential buildings: The Spanish case. *Energies*, *9*(8). https://doi.org/10.3390/en9080628

Renovate Europe. (2018). Spain – National supporting partner of the campaign. Retrieved August 7, 2018, from http://renovate-europe.eu/nationalinitiatives/spain

Rosenow, J., & Fawcett, T. (2016). *The Member States' plans and achievements towards the implementation of Article 7 of the Energy Efficiency Directive*. Retrieved from http://eng.janrosenow.com/uploads/4/7/1/2/4712328/s_2014_2019_plmrep_committees_itre_dv_2016_03-16_study_plans_achievements_en-1_1_.pdf

Salihbegović, A., Čaušević, A., Rustempašić, N., Avdić, D., & Smajlović, E. (2017). Austro-Hungarian public building refurbishment and energy efficiency measures - A case study on a public building in Sarajevo. In *IOP Conference Series: Materials Science and Engineering* (Vol. 245). https://doi.org/10.1088/1757-899X/245/4/042084

Spanish Standard. Código Técnico de la Edificación. Documento Básico. Ahorro de

Energía (CTE-DB-HE) (Spanish). (2016).

The Balance. (2018). Oil price forecast 2018 – 2050. Retrieved from https://www.thebalance.com/oil-price-forecast-3306219

The Coalition for Energy Savings. (2018). Public building renovations. Retrieved August 6, 2018, from http://eedguidebook.energycoalition.eu/public-renovation.html

The European Parliament and The Council. (2018). Directive (EU) 2018/844 of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. *Officical Journal of the European Union*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN

U.S. Energy Information Administration (EIA). (2018). Annual energy outlook 2018. Table 12 – Petroleum and other liquids prices. Retrieved from https://www.eia.gov/outlooks/aeo/tables_ref.php

United Nations Development Programme. (2018). Sustainable Development Goals. Retrieved May 15, 2018, from http://www.undp.org/content/undp/en/home/sustainable-development-goals.html

Werner, S. (2017). International review of district heating and cooling. *Energy*, *137*, 617–631. https://doi.org/10.1016/j.energy.2017.04.045

Zangheri, P., Armani, R., Pietrobon, M., & Pagliano, L. (2018). Identification of cost-optimal and NZEB refurbishment levels for representative climates and building typologies across Europe. *Energy Efficiency*, *11*(2), 337–369. https://doi.org/10.1007/s12053-017-9566-8