Renewables and HVAC retrofit on an existing building in Spain

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This article describes a project carried out to retrofit the HVAC facilities and to install renewable energies on a university building located in eastern Spain. The main objective of the proposal is to minimize the consumption of non-Renewable Primary Energy of the building at an affordable cost.

Keywords: nZEB, Energy Efficiency, Building Retrofit, Renewable Energies, HVAC Replacement.

The present paper describes a project carried out to retrofit the HVAC facilities and to install renewable energy facilities in a university building located in Orihuela (Alicante) Spain.

The building in question is fourty-five years old and experiences grave malfunction within its equipment. Thus, the university proposes replacing the building's facilities, with the additional aim of improving efficiency. The concept is:

- To replace the HVAC facilities as the current ones are defective or do not work properly.
- The university is ready to assume additional costs in order to make the building energy efficient.
- The building envelope is not considered for reformation: windows and insulation will remain unchanged.

Spanish legislation does not yet define "Nearly Zero Energy Buildings". However, regulations involving Energy Performance Certificates are well established and used regularly. It is required that new public buildings attain, at the very least, an Energy Rating Letter 'B', but nothing is said concerning refurbishment of existing buildings.

This being said, there are very promising financial support schemes in place that encourage rehabilitation projects that entail an enhanced energy performance level.

If the energy performance ratings reach levels 'A' or 'B', the financial incentives are even greater. Therefore, an approach to obtain an energy performance rating 'A' is proposed, considering that this will be similar to having a Nearly Zero Energy Building.

Site description and climatic relevant aspects

The building is located on the outskirts of agricultural fields, 4 km away from the nearest town (Orihuela with 90 000 inhabitants). It is very close to the river Segura and is thus a very humid area. It is located about 20 km from the sea and at only 20 m above sea level.

Climatic data of the capital (Alicante), situated 40 km away are available. However, experience corroborated by measurements, confirms that in summer the temperature on campus is 3–4°C higher than in the capital yet in winter it is 3–4°C lower.

The Orihuela campus (**Figure 1**) is home to the School of Agricultural Engineers with its own cultivation land that generates a significant amount of biomass. Furthermore, it has a pelletizer, thus making biomass an attractive solution.

Figure 1. Site Location.

Description of building geometrical features and envelope thermal properties before and after retrofit

The building in question (**Figure 2**) is completely detached, but the south facing façade receives shade from a nearby building. Also, the windows have overhangs that perform as awnings very effectively in summer.

Figure 2. Photo of Building.

The constructed surface area is 5 800 m², 4 640 m² being air-conditioned. The building is used 8:00–22:00, Monday through Friday and 8:00–15:00 on Saturdays. It closes in August, making up a total of 3 696 hours per year 'of use'.

The windows are old and single glazed with 6mm glass and an aluminium frame without thermal breaks.

Description of systems features before and after retrofit

Before retrofit

The facilities are found mostly on the roof of the building: there are two reversible heat pump units and a cooling unit. All of them are included in **Figure 3.**

Figure 3. View from Top. HVAC Installations.

Table I shows the energy performance simulation of the building before retrofit, where Final Energy Consumption, Non-Renewable Primary Energy Consumption and CO_2 Emissions are included. The non-Renewable Primary Energy conversion factor for delivered electricity in Spain is 1.954 kWh_{nRPE}/ kWh_E.

Figure 4 shows the results from the simulation about the monthly final energy consumption before retrofit.

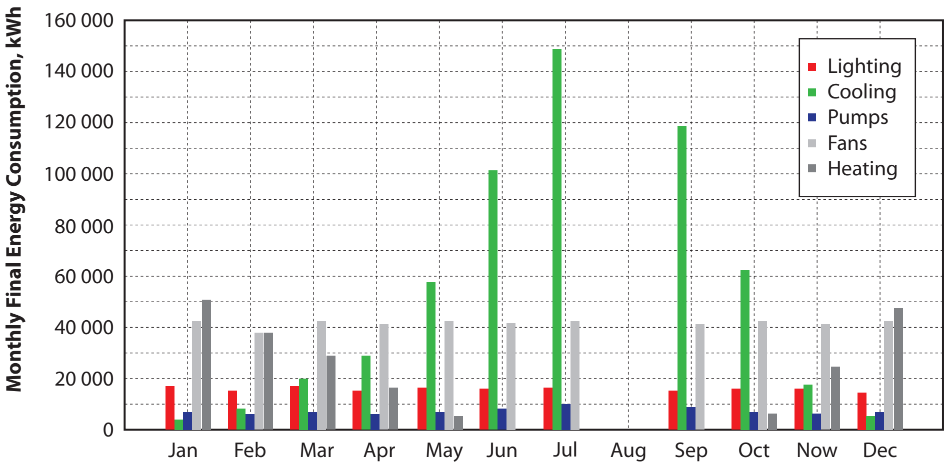

Figure 4. Monthly Final Energy Consumption by Each System before retrofit.

Currently the units are fitted with fixed speed reciprocating compressors and the water flow both in the primary circuit and the distribution system are constant. The building works on a cooling or heating only basis. The lecture rooms, hallways and canteen are conditioned with the building's fourteen AHUs (twelve on the roof and two indoor). The building also has thirty-four offices and one fan-coil unit per office.

After retrofit

Tables II and **III** show the simulation results after retrofit.

The heat pump's user experience has been unsatisfactory. The units have proved to be unreliable and their performance at low temperatures has been poor, in part due to the area's high humidity on cold mornings.

Therefore, a biomass boiler is installed with a power rating of 500 kW, thus covering for 100% of the required heating demand and 100% of energy demand. An additional propane boiler will be fitted as a redundant system to guarantee adequate service in case the biomass boiler becomes defective, thus will not be taken into account in this study.

To cover for cooling demands, two Daikin EWAD TZPS 345 cooling units are chosen. Enclosing inverter screw compressors and with a nominal power of 339 kW, said units are highly efficient with an EER=3.34 and an ESEER=5.46 (according to EN14511-3-2011).

The building's renovation must conform to current Spanish legislation that requires the installation of heat recovery systems. Thus the existing AHUs are modified and a heat recovery system is added to them. In addition, the control systems are improved to take advantage of free cooling through enthalpy controllers, as well as perform night cooling when convenient. Similarly, VFDs are incorporated to both the return and supply fans.

Table I. Energy Performance Certificate before retrofit.

Concept	Studied Building	Reference Building
Final Energy (kWh/year)	1 511 983.0	1 547 290.0
Final Energy (kWh/ m²year)	275.8	282.3
Primary Energy (kWh/year)	3 935 691.8	2 634 266.3
Primary Energy (kWh/ m²year)	718.0	480.6
Emissions (kg CO_2/year)	**981 276.9**	**672 794.8**
Emissions (kg CO_2/ m²year)	**179.0**	**122.7**

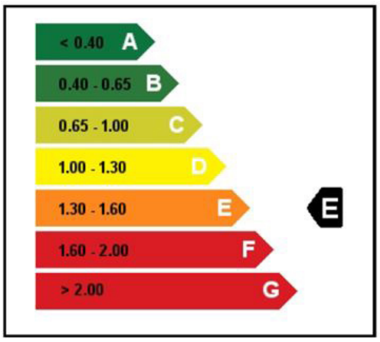

Table III. Energy Performance Certificate after retrofit.

Concept	Studied Building	Reference Building
Final Energy (kWh/year)	452 677.4	106 439.1
Final Energy (kWh/ m²year)	82.6	194.2
Primary Energy (kWh/year)	862 678.0	2 075 804.1
Primary Energy (kWh/ m²year)	157.4	378.7
Emissions (kg CO_2/year)	**186 134.1**	**525 533.8**
Emissions (kg CO_2/ m²year)	**34.0**	**95.9**

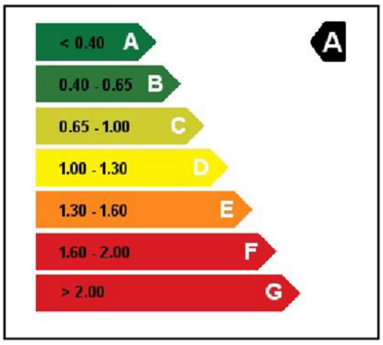

Table II. Monthly final energy consumption by each system after retrofit.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Lighting	5 945.8	5 437.9	5 997.20	5 437.9	5 971.5	5 730.4	5 971.5	0.0	5 463.6	5 971.5	5 704.7	5 171.2	62 803.1
Cooling	256.8	199.1	969.50	2 013.4	3 389.8	4 186.8	8 083.3	0.0	6 062.8	4 459.8	883.7	383.4	30 888.5
Pumps	2 551.3	2 029.4	1 666.80	11 35.3	1 709.8	2 684.1	3 587.4	0.0	2 975.9	1 822.2	1 529.3	2 275.4	23 966.9
Fans	23 147.5	18 503.9	17 935.50	19 446.0	20 235.7	18 301.3	19 256.2	39.4	1 9067.1	1 9692.9	18 289.1	24 293.8	218208.5
Heating	157.5	121.4	76.60	29.8	1.3	0.0	0.0	0.0	1.8	14.7	84.5	147.3	635.0
TOTAL	32 058.9	26 291.7	26 645.5	28 062.4	31 308.1	30 902.6	5 971.5	0.0	5 463.6	5 971.5	5 704.7	5 171.2	62 803.1

Table IV. Table of components before and after.

COMPONENTS	BEFORE RETROFIT		Power	Effi or η	AFTER RETROFIT		Power	Effi or η
	Uts.		Σ kW	EER / COP	Uts		Σ kW	EN14511-3:2011
Cooling Plant	3	2 Heat Pump +1 Chiller, R_22 Reciprocating Comp	690	2.19	2	Chillers, R-134a, Inverter Screw	678	EER / ESEER 3.34 / 5.46
Heating Plant	2	Heat Pump, R-22, Reciprocating Comp	460	2.60	1	Biomass Boiler	250	90%
Renewable Energy Systems	0				1	Photovoltaic system, Instant self-consumption (60 kWp)	50	85%
1º Pump System	3	Constant Water Flow	9	49%	3	Constant Water Flow	7.5	60%
2º Pump System	6	Constant Water Flow	11	49%	6	Variable Water Flow	9	60%
AHU'S	14	Constant Air Flow, Constant Water Flow, Thermal Free Cooling, No Heat Recovery, No_CO_2 Detection	34,5		14	Variable Air Flow, Variable Water Flow, Enthalphy Free Cooling, CO_2 Detection, 65%_Heat_Recovery	34.5	
Fan Coils	34	Constant Air and Water Flow	6,3		34	Constant Air and Water Flow	6.3	
Control		Centralized Analogical Control of AHU's. No Monitoring				Centralized Digital Control of AHUS's, Chillers and Boiler. WebServer Monitoring		

Table V. Demand and emissions comparison.

Demand and emissions	Before	After	Savings
Heating Demand (kWh/ m^2)	22.60	18.40	4.20
Cooling Demand (kWh/ m^2)	153.00	134.80	18.20
Primary Energy (kWh/ m^2)	718.00	157.40	560.60
Cooling Emissions (kg CO_2/ m^2)	157.90	27.60	130.30
DHW Emissions (kg CO_2/ m^2)	0.00	0.00	0.00
Lighting Emissions (kg CO_2/ m^2)	**21.20**	**6.30**	**14.90**
Total Emissions (kg CO_2/ m^2)	**179.10**	**33.90**	**145.20**

Seeing as the secondary pumping system will now be fed via a hydraulic variable displacement pump, the current three-way valves within each AHU are replaced by two-way valves.

All analogous control systems are replaced to ensure optimal performance within the pumping-production-distribution loop, guaranteeing therefore that demand and production are as close as possible at all times.

The building's lighting makes up 14% of the total energy demand and is henceforth an aspect of the building to be considered. Thus a light controlled LED lighting system is proposed, to replace all existing and out-dated systems.

As there are no domestic hot water systems in this building, except for a small electric boiler in the canteen, the DHW systems and its calculations are not taken into account in this study.

Description of utilized res

Under Spanish legislation an efficient building (Class 'A') is defined as a building with a non-renewable primary energy consumption; due to air conditioning, lighting and hot water systems, 40% lower compared to its own "reference building".

The debate about what constitutes as renewable energy and what does not, has no effect over certification, it can therefore be understood that it will not affect future Class A buildings.

Renewable energies used are:

1. **Biomass:** Biomass produced on campus; consisting of the campus's and nearby farm's agricultural crop residues, as well as forest and garden waste and any other material found on the river slopes is used. The chosen boiler is poly-combustible, though it is primed for the use pellets; it will also be capable of working with chips and biomass with a humidity of up to 30%.

2. **Photovoltaics.** A 60 kWp PV system is installed in order to supply energy to the air conditioning equipment. The system has been dimensioned to accommodate for the demand produced by the AC pumps and fans. Therefore the primary energy savings due to the use of the PV system is only justified through its use in the HVAC facilities. PV energy sale to the grid is not considered, neither is its consumption in any other facility within the building.

Table VI. Energy and emissions by each system before and after.

SYSTEM	Before			After		
	Final Energy (kWh/year)	Primary Energy (kWh/year)	Emissions (kg CO_2/year)	Final Energy (kWh/year)	Primary Energy (kWh/year)	Emissions (kg CO_2/year)
Heating	220 358.10	573 592.20	143 012.40	116 810.50	117 587.80	362.40
Cooling	574 003.70	1 494 131.50	372 528.30	30 888.50	68 523.30	17 084.70
Pumps	83 332.30	216 914.00	54 082.70	23 966.90	53 168.50	13 256.40
Fans	455 483.90	1 185 624.20	295 609.00	218 208.50	484 076.00	120 693.50
Lighting	178 805.40	465 430.30	116 044.70	62 803.10	139 323.00	34 737.10
TOTAL	**1 511 983.40**	**3 935 692.20**	**981 277.10**	**452 677.50**	**862 678.60**	**186 134.10**

Table VII. Economic ratios and return periods by system.

SYSTEM	Energy and Emission Savings			Money Saving and Repayment Period			
	Final Energy (kWh/year)	Primary Energy (kWh/year)	Emissions (kg CO_2/year)	Costs of investment (€)	Cost of final kWh Before	Annual Savings (€)	Years to repayment
Heating	103 547.60	456 004.40	142 650.00	119 348.00	0.05	5 476.08	21.79
Cooling	543 115.20	1 425 608.20	355 443.60	279 653.00	0.06	34 099.70	10.43
Pumps	59 365.40	163 745.50	40 826.30	34 568.00	0.11	6 530.19	6.73
Fans	237 275.40	701 548.20	174 915.50	43 359.00	0.11	26 100.29	2.11
Lighting	116 002.30	326 107.30	81 307.60	68 456.00	0.11	12 760.25	6.82
PV60 kWp				115 624.00			9.58
TOTAL	**1 059 305.90**	**2 617 009.20**	**652 493.00**	**661 008.00**		**84 966.51**	**7.78**

Energy performance indexes

As mentioned above, Spanish certification practice is based upon a comparison with a reference building. Not only is this paper concerned with comparing the university building with a reference building, but also and more importantly, with its former self.

The improved indexes are produced via: the upgraded air conditioning units, the utilization of biomass, the improvement in lighting and the introduction of VFDs to the facilities' pumps and fans. Ratios by system are shown in **Table VI**.

Economic indexes

Investment in equipment is necessary as existing equipment was obsolete. The proprietor (the university) is uniquely concerned primary energy savings and the use of renewable energies. Furthermore, the use of biomass is fully justified given the campus's characteristics.

The building's Energy Performance Certificate has been upgraded from 'E' to 'A'.

The investment budget is € 690 906. The economic savings will be analysed through subsystems.

The average simple payback period of investment is 7.78 years (**Table VII**). Which is more than satisfactory given that the life expectancy of the facilities is at least fifteen years.

The price of the heat recovery systems has been included in the cooling system's price. The cost implications of the automatic regulation and control system have been shared out proportionately amongst all systems.

Lessons learned

The use of biomass fuel entails significant savings in terms of the use of non-renewable, primary energy and eases the procurement of the Energy Performance Certificate 'A'.

The improved LED lighting system improves the building's efficiency, having such a fast return on investment.

ESEERs of above 5 are achieved using cooling systems with inverter screw compressors, this dramatically improves the building's efficiency.

Though clearly not as remarkable as it could have been in a colder climate, the energy recovery systems clearly contribute towards the improvement in the building's cooling and heating demand. Moreover, in cases like these, they are a requirement under Spanish regulations.

Not only do the fans, pumps and VFDs prove to contribute actively towards the improved energy consumption and emission ratings, but they also prove to be one of the more interesting ventures, due to their fast return on investment.

The use of solar PV energy for instant self-consumption within the HVAC system has proven to be the best method to increase efficiency on these types of systems.

The annual consumption consequences of running fans and pumps are very clear. During the building's operating hours, said systems are permanently on and in this particular case, account for approximately 50% of final energy consumption. This can be effectively offset through the utilization of renewable energy sources such as solar PV (in Spain, only self-consumed PV electricity can be considered). ■