Evaluation of the refurbishment potential of Mediterranean schools towards nZEB

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ABSTRACT

EU energy policy encourages member states and public authorities to start converting building stock into nearly Zero Energy Buildings (nZEB) and adopting exemplary actions. ZEMedS project focuses on the issues related to the refurbishment of schools to nearly Zero Energy Buildings (nZEB) in France, Greece, Italy and Spain. Presently, there is a gap in national regulation of Mediterranean countries to embody the 2012/27 EED as far as renovation rates of public buildings are concerned. As there is no clear definition of nZEB concept, a roadmap for nZEB, with numerical indicator for energy demand and the share of renewable energy sources is needed. In this context, ZEMedS project aims to cover a complete renovation path, tackling strategies for the envelope, the systems and renewable energy applications as well as the energy management and users' behavior. Ten case studies of typical schools from Catalonia, Tuscany, Athens, Ancona, Montpellier, have been analyzed in terms of the energy efficiency and cost optimality so as to contribute to the ongoing development of a methodology on how to achieve energy efficient and cost optimal nearly zero energy schools while ensuring the IEQ aspects. The case studies are existent schools that do not fit the minimum energy standards and need a renovation. A number of measures dealing with the building envelope and energy systems, were taken into account and examined through energy auditing and simulations tools.

The results presented here ease the understanding of design and construction decisions on the rising cost of energy. In order to set up a common nZEB strategy and to analyze the available funding resources, this study proposes also an integrated Technical and Financial Toolkit. ZEMedS's Toolkit intents to clarify and unify various definition of nZEB, identifies main obstacles and restrictions that face its application and analyses possible social, environmental and economic impacts. Going one step further, the ZEMedS's Toolkit attempts to set-up requirements related to the annual energy balance, the share of RES and the IEQ issues for the renovation of MED Schools.

KEYWORDS

Schools, Renovation, nZEB, Mediterranean

1 CONCEPT OF ZEMEDS PROJECT

Buildings represent the largest available source of cost effective energy saving and CO_2 reduction potential within Europe. The aim to reduce energy consumption in buildings has led to Zero Energy Building (ZEB) concept. Within the European legislative framework [1, 2] nearly Zero Energy Buildings (nZEB) are arising much interest nowadays and European Union is committed to implement energy efficiency in buildings. This commitment requires efforts from all Member States to contribute to energy efficiency in the building sector, through the adoption of suitable regulatory and policy instruments.

In Mediterranean regions of Italy, Greece, Spain and France, there are approximately 87.000 schools, consuming in a rough estimation around 2Mtoe/year.

ZEMedS (**Z**ero **E**nergy **MED**iterranean **S**chools) [3], is 3-year Project Co-funded by the European Commission within the Intelligent Energy Europe Programme (IEE), which focuses on the issues related to the refurbishment of schools to nZEB. Currently, there is no clear definition of nZEB concept in national regulation of Mediterranean countries to embody the 2012/27 EED as far as renovation rates of public buildings are concerned. A roadmap for nZEB, with numerical indicator for energy demand and the share of renewable energy sources is needed.

The aim of ZEMedS project is to map the energy conservation potentials in Mediterranean schools in relation to the environmental quality perspectives. School buildings feature poor indoor air quality while their energy consumption and overall environmental quality could be improved significantly. Many studies have identified the lack of date base, knowledge, experience and best-practice examples as barriers in refurbishment projects.

The specific objectives of the project are:

- To increase the knowledge and know-how on the nZEB renovation of schools in Mediterranean climates and give support to several new initiatives on the nZEB refurbishment of schools in Mediterranean climate regions
- To promote the necessary actions for the renovation of school buildings in a Mediterranean climate to be nearly zero-energy buildings
- To ensure a reduced energy demand, to be partially covered by renewable energy sources and, at the same time, guarantee a good indoor environment that will impact positively on occupants' health and result in higher learning outcomes for the pupils concerned

2 APPROACH

ZEMedS gives priority to deep renovation; nonetheless well-designed step-by-step procedures can pave the way to nZEB when problems related to funding or schedule are encountered. In this context, this article presents the first results of ZEMedS toolkits and case studies.

Toolkits are addressed to building designers and policy makers and contain technical and financial resources, whereas case studies are real school buildings that have been energy and cost-analyzed so as to define specific renovation strategies. These include energy upgrade of the envelope, enhanced ventilation, re-sizing of heating and lighting equipment, installing renewable energy, controls and user behavior.

The nZEB's approach is ambitious as intends to both comply with zero energy consumption and current standards for indoor environments.

ZEMedS numerical indicators could be summarized along these lines:

Requirement 1. Reduction of energy demand & increase of RES share:
Annual Primary Energy Consumption **PE** (heating, cooling, ventilation, DHW and lighting) covered by RES

$$\mathbf{C_{PE} - Prod_{RES} \leq 0} \quad (1)$$

- C_{PE}: Primary energy consumption yearly for all uses. In accordance with national primary energy factors
- $Prod_{RES}$: Renewable energy supply

Requirement 2. Annual Final Energy Consumption (heating, cooling ventilation & lighting) **FE**:

$$\mathbf{C_{FE} \leq 25\ kWh/m_{reference\ area}^2.year}\ (2)$$

- Heating/Cooling and Ventilation: $C_{HVAC} \leq 20$ kWh/m².year
- Lighting: $C_{lighting} \leq 5$ kWh/m².year

Requirement 3. Indoor Air Quality guaranteed:

Concentration of $CO_2 \leq 1000$ ppm
Overheating should be limited to 40 hours annually:
$\mathbf{T_{air\ \ above\ 28\ °C} \leq 40\ hours/year}$ (3)

3 CASE STUDIES

Ten typical schools (Figure 1) from the regions of Catalonia, Tuscany, Athens, Ancona and Montpellier, have been analyzed in terms of the energy efficiency and cost optimality so as to contribute to the ongoing development of a methodology on how to achieve energy efficient and cost optimal nearly zero energy schools while ensuring the IEQ aspects.
A number of measures dealing with the building envelope and energy systems, were taken into account and are listed below:

- Renovation of the façade: External wall insulation system avoiding thermal bridges (with additional application of cool coating products);
- Renovation of the roof: (i) For terrace roofs, external roof insulation system including wind/moisture barriers with new tiles (cool roofs applied in two cases), (ii) For pitched roofs with unheated space under cover, insulation system applied internally;
- Replacement of existing windows with more efficient;
- Installation of external solar protections;
- Replacement of existing lighting with LED technology and installation of daylighting dimming control;
- Installation of ventilation system (i) natural, (ii) mechanical without heat recovery, (iii) mechanical with heat recovery;
- Change of heating system;
- Installation of PV systems

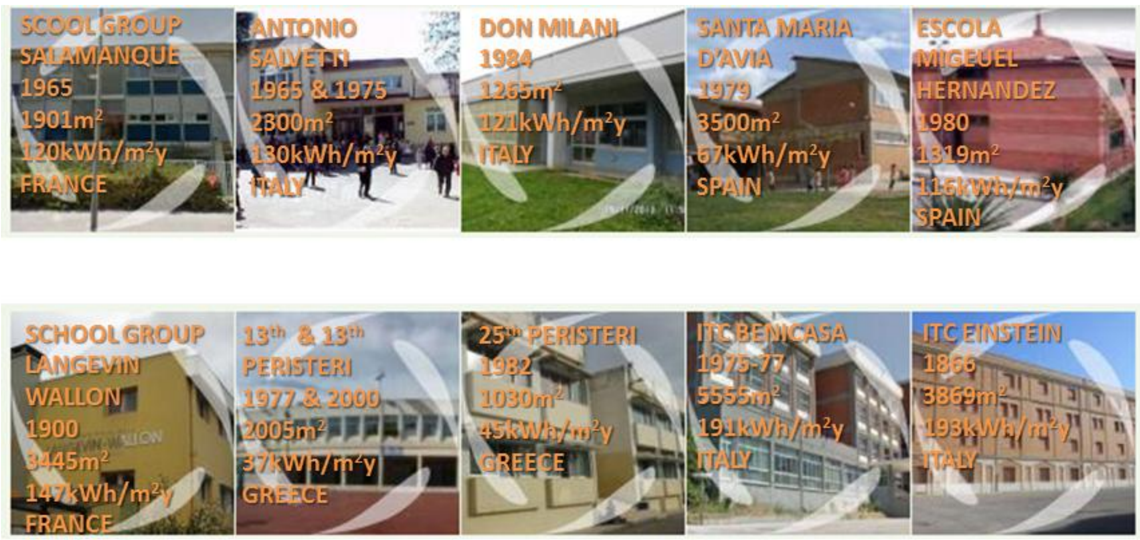

Figure 1: Photos of the ten case studies with values of construction year, heated surface & total consumption according to the bills (average 3 years)

According to the ZEMedS database the total energy consumption from bills varies between 37 kWh/m2y to 193 kWh/m2y (average 118kWh/m2y) and the indoor conditions are not sufficient.

The energy performance of the selected school buildings was calculated with Energy plus simulation program [4]. The measures were analyzed in order to comply with the ZEMedS nZEB requirements and payback calculation has been released for each case. The thickness of the insulation together with the windows quality, were examined step wisely, as fundamental variants.

Table 1 Basic variants related to the examined U values of walls, roofs and windows

U thermal transmittance (W/m^{2}K)	**Variant 1**	**Variant 2**	**Variant 3**
Walls	0.40	0.30	0.20
Roofs	0.30	0.22	0.15
Windows and external doors	1.80	1.50	1.30-1.40

Additionally:

- Thermal bridges considered in building envelope of existing building
- Occupancy: classrooms (0.44 per/m^2), offices (0.21 per/m^2), dining room (1 per/m^2)
- Mechanical ventilation when occupancy at 6,5 l/s person
- Infiltration rate of 30 m^3/h m^2 at 50 Pa when simulating the existing building and 6 m^3/h m^2 at 50 Pa when simulating the building with window renovation.
- Natural ventilation for opened windows (5 ACH)

The simulations have been performed step wisely (ITC Benincasa School, Figure 2)

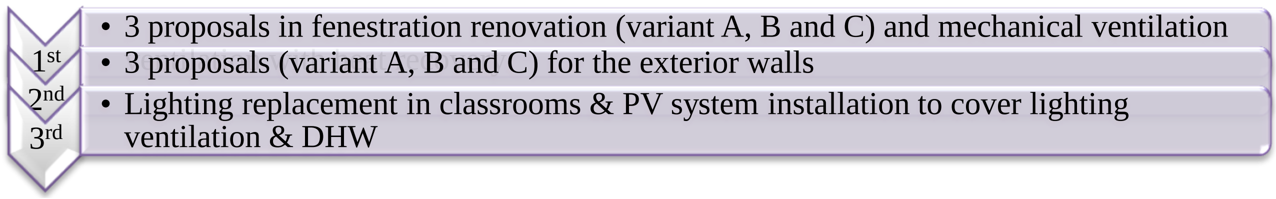

Figure 2: Deep renovation measures in 3 steps approach_ITC Benincasa

The input data of the simulations is presented at the table below.

Table 2 Input data_ Case Study 1_ITC Benincasa

		Variant A		**Variant B**		**Variant C**		**Current regulation D.Lgs. 311/06**
Step 1	Uwindows and doors	1.8	6mm/16mm(AIR)/6mm le (<0.04) aluminium window frame (with thermal break) . Ug=1.64 Uf= 2.2	1.5	6mm/16mm(ARGO)/6mm le (<0.04) aluminium window frame (with thermal break) . Ug=1.34 Uf= 2.2	1.4	6mm/16mm(ARGO)/6mm le (<0.04) wooden window frame. Ug=1.34 Uf= 1.8	Window Uw=2.2; Ug=1.9
	Solar protection	Mobile slats		Mobile slats		Mobile slats		Mobile slats
	Mechanical Ventilation	Ventilation system with heat recovery (control when occupancy) 6.5 l/s person, 70% heat recovery						no mechanical ventilation
Step 2	Uroof	current (U roof 0.42)						0.29 (interior insulation system)
	Uwall	0.4	Ventilated facade with insulation system	0.3	Ventilated facade with insulation system	0.2	Ventilated facade with insulation system	0.36 (exterior insulation system)
	Ugroundfloor	current (U groundfloor 0.9)						current (U groundfloor 0.9)

		Variant A	Variant B	Variant C	Current regulation D.Lgs. 311/06
Step3	Lighting	replacing T8 tubes for LED tubes in classrooms 6.3 W/m2. Daylight Regulation (dimming).			22 kWp / 6 kWh/m2 (50% of expeted energy consumption for DHW, heating, cooling)
	Heating system & DHW	current			
	Cooling system	current			
	PV system	34 kWp / 10 kWh/m2			

4 MAIN RESULTS

The results presented here ease the understanding of design and construction decisions on the rising cost of energy.

Here presented for four case studies the energy consumption from bills and simulations:

Table 3 Results for 4 School Buildings

Name school	Location	Conditioned area (m2)	Energy consumption in gas (kWh/m2) of current situation (bills)	Energy consumption in electricity (kWh/m2) of current situation (bills)	Energy consumption in gas (kWh/m2) of current situation (simulation)	Energy consumption in electricity (kWh/m2) of current situation (simulation)
Group school Bedarieux	Bédarieux, France	3445	155	24	107	28
Group school Salamanque	Montpellier, France	2303	81	18	86	21
ITC Benincasa	Ancona, Marche, Italy	4942	138	21	96	27
School Miguel Hernandez	Badalona, Catalonia, Spain	1147	92	42	81	35

A deep renovation strategy for each case is summarized at Table 4.

Table 4 Examined deep renovation strategies

Name school	Deep renovation strategies with energy measures in
Group school Bedarieux (result 1)	envelope + heating system (biomass boiler) + PV system covering (lighting, DHW by electricity)
Group school Bedarieux (result 2)	envelope + lighting and dimming control + heating system (biomass boiler) + PV system covering (lighting, DHW by electricity)
Group school Salamanque	envelope + lighting + mechanical ventilation with heat recovery + PV system covering (heating by natural gas, lighting, ventilation, DHW by electricity)
ITC Benincasa	envelope + mechanical ventilation with heat recovery + lighting and dimming control + PV system covering (heating by natural gas, ventilation, lighting, DHW by natural gas)
School Miguel Hernandez (result 1)	envelope + mechanical ventilation with heat recovery + lighting + PV system covering (heating by natural gas, ventilation, lighting, DHW by electricity (primary school) and natural gas (pre-school))
School Miguel Hernandez (result 2)	envelope + mechanical ventilation with heat recovery + lighting + heating & DHW system (gas condensing boiler) + PV system covering (heating by natural gas, ventilation, lighting, DHW by electricity (primary

	school) and natural gas (pre-school))
School Miguel Hernandez (result 3)	envelope + mechanical ventilation with heat recovery + lighting + heating & DHW system (geothermic) + PV system covering (heating by electricity, ventilation, lighting, DHW by electricity)

The results corresponding to the ZEMedS requirements are presented at Table 5.

Table 5 Results

	Energy balance in PE (kWh/m2 y) (heating, cooling, vent., DHW & lighting) (ZEMedS requirement 1) (data from simulations)			Energy result in FE (kWh/m2 y) (heating, cooling, vent. & lighting) per conditioned area (ZEMedS requirement 2) (data from simulations)			Payback (years)
Name school	Var 1	Var 2	Var 3	Var 1	Var 2	Var 3	-
Group school Bedarieux (result 1)	2	2	2	38	36	33	15-16
Group school Bedarieux (result 2)	1	1	1	31	28	26	18-19
Group school Salamanque	1	0	-1	40	39	38	26-27
ITC Benincasa	3	-1	-3	23	19	17	18-19
School Miguel Hernandez (result 1)	4	2	0	23	21	19	19-20
School Miguel Hernandez (result 2)	1	-1	-2	19	17	16	20-21
School Miguel Hernandez (result 3)	-1	-1	-1	10	9	9	22-23

The results to accomplish requirement 2 [$C_{FE} \leq 25$ kWh/m $_{\text{reference area}}^{2}$.year] depend strongly on the current situation of the case studies. According to the results obtained, the requirement 2 can be accomplished for the schools with relatively lower energy consumption of gas in the current situation (as School Miguel Hernandez). Furthermore, energy strategies such as the reduction of the internal loads with the improvement of lighting with daylight dimming control (ITC Benincasa) can contribute to less than 25kWh/m^2 in FE.
As regards to the requirement 1, the examined PV systems have been dimensioned to be able to cover the energy consumption established with a surface of panels more than 250 m^2. This leads to payback values no lower than 15 years.
In all cases, the indoor air quality is improved through mechanical ventilation and good design of solar protections, although the use of the building is fundamental for the well-being of the users. Payback calculations were implemented for the packages of examined measures. The main difficulty was a lack of information for the cost in maintenance and replacements regarding the existing buildings.

Table 6 Payback analysis for Case Study 1_ITC Benincasa

	Expected savings in gas	Expected savings in electricity	Overall cost of gas €/year	Overall cost of electricity €/year	Investment in €	Overall maintenance cost €/year	Cost of replacement in €	Items to be replaced	Payback (year)
variant 1 (fenestration & solar protection) & MVHR	72%	0%	14514	26990	617324	1325	0	-	13
variant 2 (fenestration &solar protection) & MVHR	73%	0%	13996	26990	624852			-	13
variant 3 (fenestration &solar protection) & MVHR	73%	0%	13996	26990	745642			-	15
variant 1 (fenestration & solar protection & ext. wall) & MVHR	86%	0%	7257	26990	1124335	1795	0	-	18
variant 2 (fenestration & solar protection & ext. wall) & MVHR	89%	0%	5702	26990	1157737			-	18
variant 3 (fenestration & solar protection & ext. wall) & MVHR	91%	0%	4665	26990	1307899			-	19
variant 1 (fenestration & solar protection & ext. wall) & MVHR & lighting dimm & PV	84%	34%	8294	17813	1266292	2677	76781	lighting T5 tubes (15-20 years lifetime) /inverters PV (15 years lifetime)	18
variant 2 (fenestration & solar protection & ext. wall) & MVHR & lighting dimm & PV	88%	34%	6220	17813	1299694				18
variant 3 (fenestration & solar protection & ext. wall) & MVHR & lighting dimm & PV	90%	34%	5184	17813	1449856				19

Although improving the building efficiency is often profitable, investments are hindered by barriers.

5 CONCLUDING REMARKS

The ZEMeds project intents to elucidate the relationship between nearly zero-energy and cost-optimal measures and to develop an argumentation on how to ensure a smooth transition from current MED schools to nearly zero energy school buildings. In this context, ten case studies

of school buildings have been analyzed in terms of the energy efficiency and cost optimality so as to define a detailed renovation action plan.
The ZEMeds integrated Technical and Financial Toolkit offers multiple best practices, techniques and methods that guide the implementation of nZEB actions in accordance to the unique necessities of each school, region and country in the Mediterranean area. Also the Toolkit attempts to set- up energy performance and IEQ requirements of MED schools with a view to achieving cost-optimal levels. These requirements have been validated through the examined case studies.

- Typical Mediterranean school built in the period 60-80's may consume around 118kWh/m^2/y (final energy), count with many overheating hours, has glare problems and inefficient ventilation;
- Once efficiency measures have been incorporated, the remaining energy needs can be met using renewable energy technology;
- With the suggested measures, classrooms used during summertime reduce overheating hours to less than 40h;
- The payback period varied 15-25 years

The hierarchy of priorities for building renovation of the examined schools is based on different needs (safety, maintenance, spatial requirements, energy savings, etc.) and profoundly depends on the budget availability and the existing funding channels.

6 REFERENCES

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