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Implementing Cost-optimal Methodology in Existing Public Buildings

L. Aelenei[a]*, S. Paduos[b], H. Petran[c], J. Tarrés[d], A. Ferreira[a], V. Corrado[b], S. Camelo[a], E. Polychroni[e], K. Sfakianaki[e], H. Gonçalves[a], J. Salom[d], G. Riva[f], G. Murano[f]

[a]*LNEG, Paço do Lumiar 22, Lisbon, 1649-038, Portugal*
[b]*POLITO, C.so Duca degli Abruzzi 24, 10129, Torino, Italy*
[c] *URBAN-INCERC, Sos. Pantelimon266, 021652 Bucharest, Romania*
[d]*IREC, Josep Pla 2, B2, Ground floor, 08019, Barcelona,SPAIN*
[e]*CRES,19th klm Marathonos Ave., GR 190 09 Pikermi, Greece*
[f]*CTI, via Scarlatti, 29, Milano, 20124, Italy*

Abstract

This study presents some preliminary results of an on-going European Project, RePublic_ZEB [1], where an analysis is conducted for identifying the cost optimal levels for the existing buildings, towards nearly Zero Energy Buildings (nZEB) performance. The analysis is applied to the reference building for an existing office building in five different countries: Italy, Portugal, Romania, Spain and Greece. The evaluation tool uses a new cost optimization procedure based on a sequential search-optimization technique considering discrete options [2] is applied and the results will be presented in terms of optimal "package of measures", energy consumption and global costs. Finally a cross-country analysis will be performed.

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Keywords: public buildings; nZEB, cost-optimal

* Corresponding author. Tel.: +351 210 924 600; fax: + 351 217 166 966.
E-mail address: laura.aelenei@lneg.pt

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1. Introduction

1.1. Context and existing applications

Among other issues the EPBD [3] recast requires Member States (MS) to introduce a comparative methodology framework at national level in order to define cost-optimal levels of minimum energy performance requirements for buildings and building elements (EPBD recast, art. 4.1 and 14), and compare them with the national requirements set in building codes. It is already known that a cost-optimal level corresponds to the energy performance level which leads to the lowest cost during the estimated economic life-cycle, taking into account energy-related investment costs, maintenance and operating costs (including energy costs and savings, the category of building concerned, earnings from energy produced), and disposal costs, where applicable. The cost-optimal level shall lie within the range of performance levels where the cost-benefit analysis calculated over the estimated economic life-cycle is positive [2]. The methodology established by the European Commission [4], in finding the local minimum of the cost as a function of primary energy, was previously explored by the other initiatives as those proposed by Buildings Performance Institute Europe [5]. The same institution published lessons learned from three case studies (Austria, Germany and Poland) of applied methodology [6].

Nomenclature

A	area [m^2]	PN	lighting power density (LPD) [-]
C	cost [€]	R	rate [-]
COP	coefficient of performance [-]	t	time [h]
EER	energy efficiency ratio [-]	U	thermal transmittance [$Wm^{-2}K^{-1}$]
EP	energy performance [-]	V	volume [m^3]
$F_o(C_c)$	control systems (LCS) [-]	Val	value [€]
g	total solar energy transmittance [-]	η	efficiency [-]
PEI	primary energy indicator	τ	transmission coefficient [-]

Subscripts

a	annual	gl	glass
C	cooling	gn	generation (subsystem)
c	controllers	H	heating
ctr	improving control system (ICS)	I	initial
d	distribution (subsystem)	lw	lower
disc	discount (rate)	n	normal, net
e	emission (subsystem)	r	heat recovery system
env	envelope	sh	shading
f	floor	up	upper
F	final	W	hot water
fl	slab	w	window
g	global, gross	wl	wall

1.2. RePublic_ZEB Project

In this context and trying to respond as well to the European building legislation, RePublic_ZEB project started in 2014 focuses in the refurbishment of the public building stock towards nZEB in the countries of the South-East of Europe in line with the EU's Energy Performance of Building Directive and its energy targets for 2019 and 2021. The project's main objective is to support the participant countries to develop and promote on the market a set of concrete technical solutions for the refurbishment of the public building stock towards nZEB. To achieve this goal, RePublic_ZEB's includes an assessment of the current public sector building stock and the determination of reference buildings. The expected output is the definition of cost optimal and low-risk packages of measures for the refurbishment of the public buildings towards nZEB which will be included in guidelines and the promotion activities addressed to national and regional authorities as well as construction industry, housing organizations, owners of large building stock and developers. The present article provides some of the preliminary results of the applied methodology for identifying the cost-optimal levels of the energy performance requirements for five case studies: Italia, Portugal, Romania, Spain and Greece. The proposed comparative methodology framework is in accordance with the current legislation. The methodology is applied to a reference existing public building represented by the office typology, selected within RePublic_ZEB project.

2. Cost-optimal methodology framework

In order to set the cost-optimal energy, Member States should use the methodology established by the European Commission [5], which was previously explored by the Buildings Performance Institute Europe [6]. In line with the proposed holistic methodology, RePublic_ZEB project obeys to the following structure: define reference buildings, define energy efficiency measures (EEM) that apply to reference building, determine the reference building energy performance, and calculate the costs of the energy efficiency measures, during the reference building expected economic life-cycle.

2.1. Reference building in study

Within the RePublic_ZEB project has been developed a methodology for defining the reference building for various types of buildings taking into account the following parameters: built-up/conditioned floor area, building age, construction materials and corresponding thermal properties of the building envelope, occupancy profiles, technical systems/installations, operational pattern and energy carriers used for heating and cooling. In this study is will be used a common reference building for all five countries representing an office public building. The external envelope is characterized by the U-value of walls (U_{wl}=0,76), windows (U_w=3,20 and $g_{gl,n}$=0,75), roof ($U_{fl,up}$=0,85) and floor ($U_{fl,lw}$=0,25).

Table 1. Main parameters of the case study-reference building

Geometrical data			Building construction data			System data (mean seasonal values)		
Vg	[m3]	7200	Uwl	[Wm-2K-1]	0,76	Convectors	ηH,e	0,93
Af,n	[m2]	2007	Uw	[Wm-2K-1]	3,20	Room temperature control	ηH,c	0,94
Aenv/Vg	[m-1]	0,32	ggl,n	[-]	0,75	Central distribution (horizontal pipes)	ηH,d	0,98
Aw	[m2]	488,47	Ufl,up	[Wm-2K-1]	0,85	Natural gas standard generator	ηH,gn	0,876
No. floors	[-]	5	Ufl,lw	[Wm-2K-1]	0,25	Electrical storage water heater	ηW,gn	0,75
						Indoor units split systems	ηC,e	0,97

2.2. Proposed EEMs

The energy efficiency measures (EEMs) applied to the reference building, are listed in Table 2 for each of the five building location building. The measures cover the building envelope (wall, roof, floor, windows), building systems (heating, cooling, domestic hot water) and renewable energy systems (photovoltaic and solar thermal). For each measure, up to five energy efficiency options or levels (EEOs) have been defined.

2.3. Energy performance assessment

As recommended, for calculating building energy performance, the following CEN standards was used: EN 15603:2008 [7] provides a general procedure that allows to evaluate the primary energy need from the energy consumption for each final use and for each energy carrier (electricity, fuel), by considering as well the renewable energy generated and locally used. According to EN 15603:2008, each calculation term concurring to the primary energy evaluation is explained in a specific standard, such as: EN ISO 13790:2008 [8] on the thermal energy calculation for space, heating and cooling, EN 15316 [9] group of standards on the energy performance of heating and DHW systems, including cogeneration, district heating and renewable energy systems, EN 15243:2007 [10] for conditioning systems, EN 15193:2007 [11] to calculate the energy demand for lighting.

Table 2. Energy efficiency measures (EEMs) and related options (EEOs)

EEM	Ind.	Nr.	EEO Italy Milano	Portugal Lisbon	Romania Bucharest	Spain Barcelona	Greece Athens
External wall thermal insulation (EIFS-EW): exterior insulation finishing system	U_{wl} [$Wm^{-2}K^{-1}$]	1	0,45	0,7	0,7	0,38	0,50
		2	0,34	0,4	0,4	0,318	0,43
		3	0,29		0,3	0,273	0,30
		4	0,25			0,24	
		5	0,20			0,213	
External wall thermal insulation (CWI-EW): cavity wall insulation	U_{wl} [$Wm^{-2}K^{-1}$]	1	0,436			0,431	
		2	0,223			0,226	
Roof thermal insulation (INS-R)	$U_{fl,up}$ [$Wm^{-2}K^{-1}$]	1	0,40	0,9	0,7	0,259	0,45
		2	0,30	0,5	0,4	0,228	0,28
		3	0,27	0,3	0,2	0,204	0,20
		4	0,23				
		5	0,20				
Window thermal insulation	U_w [$Wm^{-2}K^{-1}$]	1	5,0	3,8	2,5	2,72	3,0
		2	2,2	3,0	2,0	2,0	2,0
		3	1,9	3,0	1,8	1,8	1,8
		4	1,6	2,7	1,1	1,1	1,2
		5	1,3				
Solar shading systems (SHAD)	τ_{sh} [-] F(fix)/M(movable)	1	0,4 F	0,4 M	0,4 M	0,4 M	0,4 M
		2	0,4 M		0,2 M		
High efficiency chiller (CHIL)	EER	1	3,5		2,9	3,5	
		2	4,0		3,2	4,0	
		3	5		4,1	5,0	
+ High efficiency combined generator for space heating and hot water	η_{gn}	1	0,88		1,03	1,04	
		2	0,944				
		3	1,03				
or Heat pump for heating, cooling and hot water	COP / EER	1	2,5 / 2,4	3,3 / 2,9	3,3 / 2,9	3,0 / 2,5	3,0 / 2,7
		2	2,9 / 2,8	3,41 / 3,01	3,41 / 3,01	3,5 / 3,5	3,5 / 3,0
		3	3,3 / 3,2	3,61 / 3,21	3,61 / 3,21		4,5 / 3,8
		4		4,2 / 3,8	4,2 / 3,8		
Thermal solar systems (SOL)	[m^2]	1	2			2	2
		2	6			6	6
		3	10			10	10
PV system (PV)	[kWp]	1	6	45	45	5	6
		2	12			12	12
		3	18			25	18
		4	20				20
Heat recovery ventilation system (ERVS)	η_r	1	0,6	nat. vent.	nat. vent.	0,6	0,6
		2	0,7	-	-	0,8	0,7
		3	0,9	0,6	0,6		0,9
Improving Control System (ICS)	η_{ctr}	1	0,94	0,94	0,94	0,94	0,94
		2	0,97	0,97	0,97	0,97	0,97
		3	0,995	0,995	0,995	0,995	0,995
Lighting power density (LPD) and control systems (LCS)	PN / $F_O(F_C)$	1	T5 no reg	LF with reg	LF with reg	T5 with reg	T5 with reg
		2	T5 with reg	LED with reg	LED with reg	LED with reg	LED with reg
		3	LED no reg				
		4	LED with reg				

3. Results and discussions

A new energy cost optimization procedure based on a sequential search-optimization technique was used and applied to the reference building, to calculate of the cost-optimal energy performance. The procedure refers to the model developed in US [2]. The cost optimization was applied to the common reference case study considering the differences between the five countries in terms of: EEMs (Table 2), weather data (Milano, Lisbon, Bucharest, Barcelona and Athens), energy price and primary energy indicators per energy carrier (Table 3).

Table 3. Energy cost and PEI in each country

	Energy carrier	Italy	Portugal	Romania	Spain	Greece
PEI	Electricity	2,17	2,5	2,62	2,461	2,90
	Natural Gas	1,0	1,0	1,17	1,195	1,50
Energy costs [€ kWh-1]	Electricity	0,163237	0,1597	0,132	0,1315	0,08259
	Natural Gas	0,05798	0,0934	0,045	0,05274	0,0614

Table 4. Optimal EEM in each country

EEM	Ind.	EEO				
		Italy Milano	Portugal Lisbon	Romania Bucharest	Spain Barcelona	Greece Athens
External wall thermal insulation (EIFS-EW): exterior insulation finishing system	U_{wl} $[Wm^{-2}K^{-1}]$		0,7	0,3		0,50
External wall thermal insulation (CWI-EW): cavity wall insulation	U_{wl} $[Wm^{-2}K^{-1}]$	0,223			0,431	
Roof thermal insulation (INS-R)	$U_{fl,up}$ $[Wm^{-2}K^{-1}]$	0,27	0,9	0,7	0,259	0,45
Window thermal insulation	U_w $[Wm^{-2}K^{-1}]$	1,6	3,8	2,0	2,72	3,0
Solar shading systems (SHAD)	τ_{sh} [-] F(fix)/M(movable)	0,4 F	0,4 M	0,2 M	0,4 M	0,4 M
High efficiency chiller (CHIL)	EER	3,5		2,9	3,5	
+ High efficiency combined generator for space heating and hot water	η_{gn}	0,944		1,03	1,04	
or Heat pump for heating, cooling and hot water	COP / EER		4,2 / 3,8			4,5 / 3,8
Thermal solar systems (SOL)	$[m^2]$	2			2	2
PV system (PV)	[kWp]	20	45	45	25	20
Heat recovery ventilation system (ERVS)	η_r	0,6	0,6	0,6	0,6	0,6
Improving Control System (ICS)	η_{ctr}	0,97	0,995	0,995	0,995	0,995
Lighting power density (LPD) and control systems (LCS)	PN / $F_O(F_C)$	LED with reg	LED with reg	LED with reg	LED with reg	LED with reg

Concerning the global cost, for Italy, Spain and Greece the value is higher than 500 € m^{-2}, while Romania shows the lowest value. In Fig. 1(b) it is possible to notice that in Italy as well as in Spain the energy costs are higher than the other countries; in Spain the EEMs costs are also high, while Romania obtains the lowest values in terms of energy, investments and maintenance costs. Fig. 1(a) shows results of the cost optimization procedure application and Table 4 the optimal EEMs: according to the Guidelines accompanying the Commission Delegated Regulation (EU) No 244/2012, for each country all the partial results leading to the optimal case have been plotted and the optimum is defined by the lowest point. Table 4 summarizes for each country the optimal global cost and the referred EP_g value; here the global energy consumption represents the non-renewable energy needed to satisfy the considered building uses, not taking into account any exported energy. Results show the global primary energy consumption ranges in between 54 kWh m^{-2} for Portugal and 137 kWh m^{-2} for Romania, but these value have to be correctly compared by considering the countries climatic conditions.

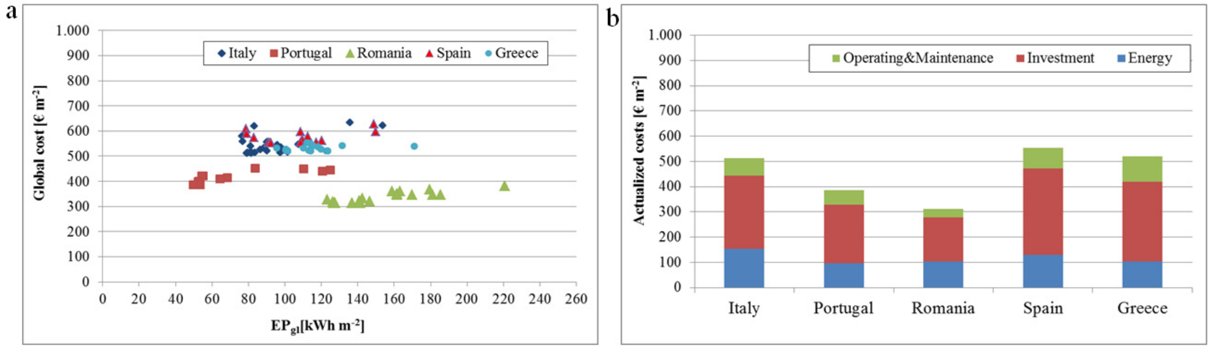

Fig. 1. (a) Optimization procedure application. Fig. 1. (b) Cost optimal solution actualized costs.

4. Conclusions

In the present work the application of the cost optimal methodology to a public reference building for different boundary conditions has been presented as an example of preliminary results of the on-going European Project RePublic_ZEB focused on the refurbishment of the public building stock towards nZEB. Results show a relevant difference among the considered countries in the total primary energy consumption values, against a global cost deviation between 300 and 550 € m^{-2}. The study highlights the importance of a detailed definition of the energy efficiency measures and referred costs and of the energy costs, according to the building end use for each country.

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