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Cost-optimal analysis and technical comparison between standard and high efficient mono-residential buildings in a warm climate

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ABSTRACT

The recast of EU (European Union) Directive on EPBD (Energy Performance of Buildings) requires nZEBs (nearly zero energy buildings) as the building target from 2018 onwards and the establishment of cost-optimal levels of minimum energy performance requirements in buildings.

This paper presents the results of the application of a methodology to identify cost-optimal levels in new residential buildings located in a warm climate. Mono-residential buildings have been considered as virtual reference buildings in this study. Different energy efficiency measures have been selected for the envelope and the systems.

A combination of technical variants has been then applied to the reference case in order to obtain several configurations to be compared in terms of primary energy consumption and global costs. The cost-optimal solution is identified assessing technical features and energy performance. Standard and high efficiency buildings are analysed to show how the selected configuration allows a decrease of primary energy consumption and CO_2 emissions at the lowest cost. Results are useful for comparison with other climates and building types. They also show the feasibility of the methodology to comply with EU requirements and to support the choice of economically efficient nZEBs solutions at the design stage.

1. Introduction

Energy consumption in buildings is one of the most urgent concerns in Europe. In recent years the construction sector has considerably increased the exploitation of natural resources in industrialized countries. It is estimated that this sector is responsible for the consumption of around 40% of electricity (with peaks around 70%) and 12% of potable water [1].

The recast of European Directive on EPBD (Energy Performance of Buildings) introduces some remarkable concepts to reverse the current trend related to building consumption [2]. Article 9 states that new buildings and properties occupied by public authorities have to be nZEBs (nearly zero energy buildings) by December 31, 2018 and that all new buildings have to be nZEBs by December 31, 2020. According to Article 2, a nZEB is a building that “has a very high energy performance with a low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”. EPBD also introduces the “cost-optimal” concept, defined as “the energy performance that leads to the lowest cost during the estimated economic life cycle”. Moreover, it enlarges this concept to cost effectiveness that has to be adopted in MS (Member States) to establish minimum energy performance requirements in buildings. Starting with the definition of reference buildings, the Directive further provides a comparative methodological framework which enables measures to improve energy efficiency and obtain cost-optimal levels in buildings [3,4]. Delegated Regulation No. 244/2012 and its Guidelines defines a reference building as a “typical building geometry and systems, typical energy performance for both building envelope and systems, typical functionality and typical cost structure”, being representative of a country considering its climate and geographic location. However, the process of reference building definition is still under discussion [5].

According to the methodological approach of cost-optimal calculations, alternatives must be considered when buildings are designed, including envelope, fenestration, energy sources, and building systems. Cost-optimality means the choice of energy efficient solutions with minimal life cycle cost. The introduction of

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Nomenclature

$A_{t.n}$	treated floor area (m^2)
V	volume at controlled temperature
S/V	shape factor
EP	energy performance index
R	thermal resistance (m^2K/W)
T	period of the variations (s)
U	thermal transmittance under steady state boundary conditions (W/m^2K)
Y_{mm}	thermal admittance (W/m^2K)
Y_{mn}	periodic thermal transmittance (W/m^2K)
c	specific heat capacity (J/kgK)
d	thickness of a layer (m)
fd	decrement factor
Δt	time shift: time lead (if positive). or time lag (if negative) (s or h)
Ms	total surface mass (Kg/m^2)
C_G	global costs
C_I	initial investment costs
C_a	annual costs
R_d	discount rate
R_R	real interest rate
R_p	rate of development of the price for products
$V_{f.\ \tau}$	final (or residual) value
n_τ	number of replacements
HVAC	heating ventilation air conditioning
CMV	controlled mechanical ventilation
DHW	domestic hot water
AHU	air handling unit
MS	Member States
PVC	polyvinyl chloride

Greek letters

κ	areal heat capacity (kJ/m^2 K)
λ	design thermal conductivity (W/m K)
ρ	density (kg/m^3)
η	efficiency
τ	calculation period
τ_n	lifespan
τ_0	starting year

Subscripts

m.n	for the thermal zones
a	air layer
1	internal
2	external
s	related to surface
w	winter
s.env	for the envelope in summer
e.h	heating emission
d.h	heating distribution
g.h	heating generation
r.h	heating regulation
e.w	dhw emission
d.w	dhw distribution
s.w	dhw storage
t.v	thermal recovery
I.v	hygrometric recovery

Symbols

ˆ	complex amplitude
—	mean value

this concept is innovative, as there are many studies that focus on reducing energy consumption in buildings achieving a ZEB target [6–9], but fewer that also consider cost-optimality [10–13].

The proposed methodology can be carried out defining energy efficiency measures and/or measures based on RES (renewable energy sources). The procedure of measures selection for improving energy efficiency in buildings is also treated in the Regulation. These measures should consider both external and internal conditions, and cost-effectiveness [14]. Energy flows have to be taken into account in performance calculations as schematized in Fig. 1. System boundaries are considered as in EN 15603 [15] with the inclusion of on-site renewable energy production in compliance with EPBD requirements. The Guidelines explain that renewable technologies are in direct competition with the solutions of the demand. The reference to RES and the request of a low energy demand are in accordance to the EPBD definition of nZEBs. Energy performance and global cost calculations have to be then performed according to UNI/TS 11300, parts 1–4 [16] and UNI EN 15459 [17], respectively.

Cost-optimal results strongly depend on the selected reference buildings (size, shape, compactness, share of window area) and climatic conditions. In a warm climate the nZEB target has a greater chance to match the cost-optimality area in comparison with cold climates. Kurnitski et al. identify cost-optimality with a heat loss of 0.33 W/Km^2 and a district heating of 140 kWh/m^2y in office buildings located in the cold Estonian climate [18]. In the same climate, the cost-optimal solution is assessed at 110 kWh/m^2y primary energy for a detached house, compared to national minimum requirement of 180 kWh/m^2y [19]. This research has been further developed by Pikas et al. [20]. The authors consider alternative fenestration design solutions for offices, finding the most energy efficient and cost-optimal solution in triple glazed argon filled windows with a small window to wall ratio, and 200 mm thick insulation walls [21]. According to the authors, cost-optimality will become more affordable in near future with energy escalation and reduction of construction costs of PV panels and/or windows with four panes.

The aim of this paper is to evaluate cost-optimal levels of minimum energy performance requirements in mono-residential reference building located in Lecce, a city of Southern Italy. Once the characteristics of the envelope and the systems are defined, a set of different energy efficient technical variants is selected and applied to the baseline case. Energy performance calculations are then performed for all the obtained combinations of measures. Global costs are finally derived for each combination in order to identify and evaluate the cost-optimal solution.

1.1. The Italian policy framework

The Italian Government implemented EPBD with Legislative Decree 192/05, and EPBD recast with Legislative Decree 63/13. Both Decrees introduce several novelties related to energy requirements, design methodology, and plants inspection. National Law 10/91 gives a comprehensive framework related to energy efficiency in buildings providing explicit regulations for a more efficient use of energy sources in all end-use sectors. It sets out specific energy