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Assessment of cost-optimality and technical solutions in high performance multi-residential buildings in the Mediterranean area

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ABSTRACT

The European policy framework is focused on reducing energy consumption in the building sector. The recast of Energy Performance of Buildings (EPBD) Directive establishes that minimum energy performance requirements have to be set to achieve cost-optimal levels.

A methodology is developed to assess energy and cost effectiveness in new buildings located in the Mediterranean area. Several energy efficiency technical variants are applied to a multi residential reference building selected as a representative model of the national building stock. Primary energy consumption and global costs are evaluated in a number of configurations to derive the cost-optimal solution.

The paper shows how economical high efficient buildings can be obtained at a design stage for a warm climate. The selected configuration decreases primary energy consumption by 90% and CO_2 emissions by 88% with respect to the baseline building.

Results appear useful for comparison with other climates and building types. The paper also points out that the methodology is suitable to guide and support the choice of cost effective energy efficiency measures in compliance with EU requirements.

1. Introduction

1.1. The European framework

The European Climate and Energy package foresees a 20% reduction of energy consumption in buildings by 2020. The Programme also foresees a 20% increase of renewable energy production and a 20% decrease of greenhouse gas emissions. The European Union (EU) promulgates specific measures to reduce energy consumptions in buildings with Energy Performance of Building Directive (EPBD) in 2002 [1], its recast in 2010 [2], Energy Efficiency Directive (EED) [3] and Renewable Energy Directive (RED) [4], in order to improve the energy performance of Member States (MS) building stock.

EPBD recast requires that cost optimality has to be taken into account in the establishment of energy performance requirements in buildings. According to Article 5, MS have to consider initial investment costs, running costs and replacement costs over a building's life cycle. National minimum standards should be set based on cost effectiveness for construction and operational costs in new buildings and buildings undergoing major renovation [5].

The assessment of cost optimality and high performance technical solutions are strictly connected to the implementation of nZEBs, as stated in [6]. Explanatory Guidelines of Delegated Regulation No. 244/2012 of January 16, 2012 of the EC [7,8] describe a comparative methodological framework to derive a cost efficient configuration to be adopted in a building.

The overall aim of the calculation is to obtain a cost-optimal level to identify the solution that represents the lowest total costs without discriminating against or promoting any specific technology. A graph that reports global costs (€/m^2) on the ordinate and energy consumption (kWh/m^2 y) on the abscissa is derived to identify cost-optimality. The point of the curve that belongs to the lower part is indicative of the optimal configuration. The shape of the cost-curve is influenced by several factors, such as building typology, variants definition, discount rate, energy price, and cost data. Sensitivity analysis is suggested to add robustness to calculations, especially when a relatively flat curve is obtained.

The EU framework on cost optimality leaves MS to decide on many important aspects, such as reference buildings, selection of packages of measures, construction costs, maintenance costs of building elements, lifetime of building elements, discount rates,

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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^2 K/W)
T	period of the variations (s)
U	thermal transmittance under steady state boundary conditions (W/m^2 K)
Y_{mm}	thermal admittance (W/m^2 K)
Y_{mn}	periodic thermal transmittance (W/m^2 K)
c	specific heat capacity (kJ/kg K)
d	thickness of a layer (m)
f_d	decrement factor
Δt	time shift: time lead (if positive). or time lag (if negative) (s or h)
M_s	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
q	air flow CMV
SPF	specific power consumption
t_B	daily service time
n	air change
P	thermal capacity
$T_{h/w}$	design heating/water temperature
t_i	insulation thickness
T_{st}	average storage temperature
h_{st}	daily hours with accumulation in temperature
COP	performance factor
SEER	seasonal energy efficiency ratio
No	number of panels
P_{peak}	peak power
f_s	azimuth
f_n	zenith
PE	primary energy
RES	renewable energy sources
GC	global cost

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	emission
d	distribution
g	generation
r	regulation
e,w	dhw emission
d,w	dhw distribution
s,w	dhw storage
v,e	external air flow
v,tot	total air flow
θw,d	winter thermal recovery
θs,d	summer thermal recovery
θx,wd	hygrometric recovery
k	panels

Symbols

ˆ	complex amplitude
-	mean value

energy price trends, and starting energy prices. The impact of input parameters on the results has been investigated by Leutgob et al. [9]. An important factor influencing energy performance is also occupancy behaviour and auxiliary gains [10].

The first step of the cost-optimal methodology is the definition of reference building properties. A reference building represents 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 [8]. The methodological approach to be followed in the definition of reference buildings is still under discussion and it is an important field in the studies related to buildings energy performance [11,12].

This paper aims at the assessment of cost-optimality in multi-residential reference buildings situated in the Mediterranean area (Lecce, South of Italy). As a first step, a conventional baseline building is described in terms of physical characteristics, envelope and systems. Several energy efficient technical measures are subsequently selected as possible variants for the reference building at the design stage. Energy performance and global costs are evaluated for all the obtained combinations. The cost-optimal solution is identified for the case study. The selected and the initial configurations are finally compared in order to derive potential energy and CO_2 savings.

1.2. Cost-optimal methodology implementation

Results on cost-optimal levels strongly depend on the selected reference buildings (size, shape, compactness, share of window area) and climatic conditions. Generally, in warm climates it is easier to meet the nZEB target, while in cold climates, it is more challenging. Kurnitski et al. identified a solution with a specific heat loss of 0.33 W/K m^2 and a district heating of around 140 kWh/m^2 y as the cost-optimal level in office buildings located in the cold Estonian climate [13]. Labour costs, material costs, overheads, and value added tax (VAT) are included in energy performance calculations. In the same climate, the cost optimal solution was assessed at 110 kWh/m^2 y primary energy for a detached house, compared to national minimum requirement of 180 kWh/m^2 y [14]. Pikas et al. [15] furthermore develop this research considering alternative fenestration design solutions for offices. Among their findings