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Nearly-Zero Energy Buildings: Cost-Optimal Analysis of Building Envelope Characteristics

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Abstract

Energy consumption in the building sector continues to increase in the entire world and therefore, the determination of cost-optimal solutions towards nearly zero-energy buildings is a serious challenge. The present study is focused on the optimal thermal features of the building envelope, including thermal insulation on wall, roof and ground floor as well as the optimal window properties, in order to achieve nearly-zero energy buildings in the climate conditions of Cyprus. A systematic and robust scientific procedure was adapted in order to determine levels of energy performance leading to minimum life-cycle cost. Energy simulations of different reference test-cell buildings were performed, based on the external envelope's surface to total building volume ratio, and the cost-optimal performance levels were calculated in accordance with Regulation 244/2012/EU, taking into consideration three different climate areas of Cyprus – the cities of Limassol and Nicosia and the mountainous area of Saittas. Both the optimal thermal transmittance coefficient of the external envelope elements and the optimal window properties for each reference test-cell building were calculated. The results demonstrate that the cost-optimal energy performance levels of reference test-cell buildings in Cyprus are considerably higher than the national minimum requirements. Moreover, a linear correlation was found between the optimal (mean) thermal transmission coefficient and the study area, a result that underlines the necessity of forming three independent climate zones in Cyprus instead of one that exists today.

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Keywords: Nearly Zero Energy Building (nZEB); Building envelope; Cost-Benefit analysis; Thermal insulation; Glazing properties; EnergyPlus

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Nomenclature

$c_g(\tau)$ global cost referred to starting year τ_o
c_i initial investment cost
$c_{\alpha,i}(j)$ annual cost for component j at the year i (including running and replacement costs)
$V_{f,\tau}(j)$ final value of component j at the end of the calculation period
$R_d(i)$ discount rate for year i
r real discount rate for year i
U_g thermal transmittance of glazing
U_f thermal transmittance of frame
g total solar energy transmittance
τ_v light transmittance

1. Introduction

The building sector contributes greatly to global energy demand [1]. More specifically, buildings account for approximately 40% of the final energy consumption and three-quarters of global GHG emissions [2]. At this point, the influence of the building envelope cannot be underestimated on the building's energy needs, since in 2010, 37% of the total primary energy in the United States was utilized for buildings' heating and cooling [3]. It is therefore evident that there is a close relationship between building energy consumption and the building envelope.

In order to address this issue, the European Union published the Energy Performance of Building Directive 2002/91/EC (EPBD) which eventually evolved in the recast Directive 2010/31/EU. The EPBD recast focuses on the improvement of building energy performance by setting minimum requirements for buildings and building components and establishing nearly-zero energy buildings (nZEB) as a political target [4]. In addition to nZEB policy, EPBD recast goes a step further and sets a comparative methodology framework with a view to achieving cost optimal performance levels for buildings. The legal framework for the cost-optimal methodology has been published in the delegated regulation 244/2012/EU and leads to the lowest cost in accordance with the estimated economic life-cycle [5].

Along with the European legal framework, researchers focused on the cost-optimal approach, both by studying new and existing constructions. Becchio et al. presented a study investigating the different cost-optimal solutions of building and technical systems for nZEBs in Italy [6]. Bojic et al. found the optimum thickness of the insulating layer for both polystyrene and mineral wool through the development of a life-cycle cost sensitive analysis [7]. Hamdy et al. studied the combination of energy efficient measures with the parallel implementation of alternative renewable energy systems in a single family house located in Finland [8]. In addition, Kurnitski et al. presented a scientific procedure to identify nZEB energy performance levels along with the cost-optimal solutions by means of building simulation of a reference house and an office building located in Estonia [9].

The objective of the present study is to investigate and analyze the optimal energy performance levels under a cost-optimal approach in line with EBPD recast and nZEB requirements. The introduced method is applied to find the efficient combination comprising the above main aspects by using reference buildings in the form of test-cells in Cyprus. In particular, the methodology structure of the study is designed with the view of identifying the optimal thermal characteristics of the building envelope (e.g. building envelope U-values) the implementation of which lead to adequate near zero energy performance. The energy and economic assessment for each reference test-cell building is achieved by using the national requirements and energy framework as well as by taking into account the local climate conditions.

2. Methodology

2.1. Defining the energy design variables

According to the methodology, the combination of two main energy design variables related to building envelope was examined in order to obtain the optimal energy performance levels: the thermal transmittance of external