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Replication Studies paper

Impact of financial assumptions on the cost optimality towards nearly zero energy buildings – A case study

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ABSTRACT

The energy efficiency challenge in Europe is mainly concerned with existing buildings and the investment scenarios to implement deep renovations. The cost-optimal approach imposed on EU-Member states by the European Energy Performance of Buildings Directive aims to identify the investment gap and challenges to transform existing buildings into nearly Zero Energy Buildings (nZEBs). The investment gap is function of several volatile financial parameters including discount rate (r), developing of energy price (e), decline rate of technology price (d), as well as nZEB's incentives like feed-in-tariff (FiT) and investment grant (iG). In this context, the decision making process of individuals or investment institutions is hindered by complexity and uncertainty.

In order to assist the decision making process and improve the visibility of financial energy benefits, a novel optimization-based parametric analysis scheme (OptnZEB-I) is developed. The scheme is designed to investigate a large number of economic scenarios (i.e., combinations of financial assumptions) in a short computational time while a holistic optimization approach is adopting for exploring all possible design options including energy conservation measures (ESMs); renewable energy sources (RETs) and mechanical systems (Sys).

For demonstration, the scheme is applied to analyse the impact of several financial parameters on the cost-optimal energy performance level (CO-EPL) of a single family house in Finland. In line with the EU-directive, a large number of possible design options ($\sim 3 \times 10^9$million) are optimized for 4608 cases of economic scenarios. The results of the address case study show that, in average, the CO-EPL ranges from 90 to 160 [kWh/m^2]. The range has most frequent value of 145 kWh/m^2. The CO-EPL is significantly sensitive to the e, f, then i, respectively. Less sensitivity is found to the other financial parameters.

The robustness of the optimization results are verified by solving the addressed design problem by using four different optimization algorithms (i.e., pattern search, interior-point, simulated annealing and genetic algorithms).

Abbreviations: ASHP, air source heat pump; c, calculatioin period; CO-EPL, cost-optimal energy performance level; CO-IC, cost-optimal investment cost; CO-TM, cost-optimal technology mix; d, decline rate of technology price; dIC, additional investment cost (initial costs higher than 21k€); e, escalation rate of energy price; ESMs, energy saving measures; EPBD, European Energy Performance of Buildings Directive; f, inflation rate; FiT, feed-in-tariff; GA, genetic algorithm; GSHP, ground source heat pump; HVAC, heating ventilation and air conditioning system; i, nominal interest rate; iG, investment grants (25% discount of additional investment); LCC, life cycle cost; MG, money gain from exporting the surplus electricity to the grid; µCHP, micro-heating and power plants; nZEB, nearly zero energy buildings; NZEB, Nearly zero energy buildings; PHU, primary heating unit; PV, photovoltaic; PVAF, present value annuity factor; PVEC, present values of energy cost; PVMC, present values of annual maintenance cost; PVOC, present values of all operating costs; PVRC, present values of replacement cost; PVRI, present values of residual investments; PVSC, present values of annual subscription fees; PS, pattern search; RESs, renewable energy sources.

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1. Introduction

1.1. Background

The long-term economic uncertainty in building's life cycle cost (LCC) analysis is mainly associated with the selection of energy price, energy price development, energy demands, performance of systems, life spans of technologies, investment costs, prevalent discount rate, as well as calculation period. This study extends the scope of nZEB relevant studies by investigating a larger number of economic assumptions and a larger number of possible design options. According to a previous literature review conducted by the authors [1], it is concluded that few economic scenarios or design options are addressed in nZEB related studies. None of the studies of Kumbaroglua and Madlener [2], Hasan et al. [3], Papadopoulos et al. [4], Georges et al. [5], Kurnitskia et al., [6], Marszal et al [7], Munjur et al. [8]. and Attia [9] investigated comprehensively the impact of the economic assumptions on the cost-optimal energy performance level (CO-EPL) towards nZEBs, in line with the EBPD-recast 2010 [10].

Here, we introduce a novel optimization-based parametric analysis scheme (OptnZEB-I) designed particularly to provide fast and detailed hourly calculations considering the current and future challenges which face applying the EBPD methodology. A holistic optimization approach is adopted to consider the significant interactions between available options of ESMs, HVACs, and RETs, simultaneously. The scheme enables the user to repeat the calculations quickly addressing different economic and/or environmental assumptions. In accordance with the Directive 2010/31/EU (EPBD recast) [10], all EU Member States are obliged to perform analysis on cost optimal levels of minimum energy performance requirements. Member States should apply and continuously use the cost-optimal methodology from now and onwards, and have to repeat it at least every 5 years. OptnZEB-I scheme is introduced to reduce the computational efforts and enhance the visualization of the building cost-optimality analysis.

1.2. The EPBD-recast comparative framework methodology

"The recast Energy Performance of Buildings Directive (EPBD, 2010/31/EU) [10] stands as an important milestone for building policies, requiring all European Member States to:

a) Introduce minimum energy performance requirements for buildings, building elements and technical building systems,
b) Set these requirements based on a cost-optimal methodology taking into account the lifetime costs of the building, and
c) Construct only nearly Zero-Energy Buildings (nZEB) from 2020 onwards." [11].

In order to determine cost-optimal energy performance level (energy performance level leads to the lowest cost during the estimated economic lifecycle) for EU buildings, a comparative framework methodology [12] is established to evaluate the economic and environmental feasibility of all the possible designs (all the possible combinations of compatible energy efficiency and energy supply measures). The methodology can be used also for determining cost-effective nZEB.

Fig. 1 shows the comparative methodology flowchart. After combining reference buildings with all available designs (at least 10 packages of energy-efficient measures and technical systems including RETs), the calculation splits into two: the calculation of the energy performance (using e.g., the 31 CEN standards18 [13]) and the calculation of the financial performance (using e.g., the European Standards EN 15459 [14]) of the different combinations of reference buildings and packages. The calculation of energy costs is thereby fed by the results of the energy performance calculations. A cost curve shows the assessed combinations of energy performance (x-axis) and financial performance (y-axis). It is the way that the cost optimum/cost optimal level can be derived. The relationship between current requirements and the position of the cost optimum is submitted to the commission in a reporting cycle and can be used to update requirements, if suitable. The comparison with future environmental targets could feed into a new loop, represented by the dotted line. This loop enables the effect of improved framework conditions (e.g. the introduction of economic incentives such as soft loans, feed in tariff, investment grants, etc.) to be assessed, shifting the economic optimum towards medium- or long-term targets, such as the introduction of nZEB by 2020, and the 2050 decarbonisation goals. Therefore, it is recommended to include ambitious (as well as very ambitious) measures among selected packages in order to identify the remaining performance and financial gaps and to use accordingly these results to shape further policies and market support programs. Ambitious low-energy building standards should also be considered in order to have a timely evaluation of costs for the introduction of nZEB.

1.3. The economic and environmental feasibility of the EPBD-recast methodology

The economic and environmental feasibility of the EPBD-recast comparative framework methodology has been validated, before [15–19] and after [1,20–23] stipulating the directive.

In line with the European Standard EN 15459 [24], the base of the EBPD cost-optimality framework, Coninck and Verbeeck [16], Renard et al. [25], Achten et al., [26], and Georges et al., [21], investigated the cost-effectiveness of energy saving measures and/or energy supply systems for different building typologies in the context of Brussels, Flanders, and Wallonia in Belgium, respectively. They found that the global economic optimum is located at low-energy level and not at standard or passive ones. Achten et al., [26] found that for new buildings, the legal requirements (EPB 2006: E100 and K45) of Belgium are much more inefficient than the economic optimum. Compared to the referential dwellings, the average energy saving potential for this economic optimum was 35–40% and the average economic saving over a life span of 30 years reached 15%.

In line with the EPBD framework methodology, Hamdy et al., study [20] showed that the cost-optimal energy performance level of a single family house in Finland could reach 40% lower than the D3-2012 [27] standard level. The study explored the economic and environmental feasibility of a hung number of possible combinations of building envelope, HVAC, and renewables options and determined the global optimums using a transparent and time-effective optimization method. In March 2013, the Buildings Performance Institute Europe (BPIE) published a report [11] summarizes the cost-optimal energy performance level calculations for Austria, Germany, and Poland. The report showed that in Austria, the difference between actual/standard and cost-optimal energy performance level could be from 10.5% to 21.6%, according to different assumptions. In Germany, the minimum energy performance requirements could be tightened by about 15% to achieve cost-optimal levels and by about 25% to achieve the same global costs as the current requirements (EnEV 2009). The cost-optimal calculation for Poland revealed that there is a very big gap between current requirements (NF40 standard) and achieved results. Cost optimal energy performance level of Estonian reference detached house was significantly (39%) lower than the current minimum requirement [28]. For selected houses built after 1990 in Portugal, Oliveira Panão [23] found that the cost optimal level should be from 22 to 33% lower than the current practice.