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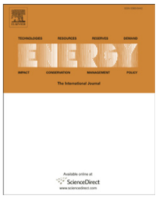

Extra cost analyses of two apartment buildings for achieving nearly zero and low energy buildings

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ABSTRACT

The nZEB (nearly zero energy building) requirements taking effect in 2021 have induced the interest about additional cost and technical solutions amongst real-estate developers, construction companies, architects and engineers. The objectives of this study are twofold, first to determine the cost-optimal energy efficiency level for two lately built apartment buildings in a cold climate of Estonia, and secondly, which are the proper measures to achieve low energy and nZEB requirement levels. The influence of high-efficiency external walls, roofs, windows, ventilation units and solar collectors on energy use and construction costs were studied by using multi-stage methodology for reducing the number of combinations. The results show that since 2010 the cost optimal primary energy level has shifted from 145 kWh/m^2 to 110 kWh/m^2, but achieving nZEB level of 100 kWh/m^2 still requires relatively high additional investments. With initial measures, nZEB requirements were not fulfilled in the studied cases, but the solutions close to nZEB required extra investment of 65 €/m^2 i.e. 4–7% compared to the actual buildings. Low energy building level needed additional investments up to 2%. In both case studies remarkably better energy efficiency level could have been achieved with lower construction costs.

1. Introduction

The nZEB (nearly zero energy building) requirements taking effect in 2021 in the EU [1–3] have induced interest amongst real-estate developers, construction companies, architects, engineers, owners and public organizations. It is generally recognized that achieving nZEB requires the use of two broad strategies: minimizing the energy consumption through energy-efficient measures [4] and using local energy production for reducing energy delivery to the site [5]. However, forthcoming requirements are also introducing new challenges, it is generally unknown what technical solutions we must use and what are the additional costs for fulfilling the nZEB requirements. We can start addressing these questions regarding feasibility and extra construction costs of nZEBs only when the requirements are well defined. Countries such as Denmark, Estonia, France, Cyprus, Slovakia, Belgium, Ireland, Netherlands, Latvia and Lithuania have already established national definitions for nZEB, but most of the Member States are still intensively working with national definitions and plan for achieving nZEB [6].

Up until now, there are only few case studies of nZEBs, which include Elithis Tower in France, Ympäristotalo in Finland, IUCN Headquarter in Switzerland, TNT Green Office in Holland and Hagaporten III in Sweden reported in the book “Cost Optimal and Nearly Zero-Energy Buildings” by Kurnitski [7]. Within these case studies, balanced heat recovery ventilation, free cooling combined with mechanical cooling, optimized facade with solar control, daylight utilization, high-efficiency HVAC systems and solar PV were the most common measures used for achieving nZEB level in these non-residential buildings. Following conclusions regarding additional cost were drawn: in French case study achieving nZEB level costs did not differ from traditionally built projects, but in the Finnish case the estimated extra cost for nZEB was between 70 and 100 € per heated m^2; i.e. additional cost required for constructing nZEB was 3–4% more expensive. However, the applicability of these results are limited as all of the buildings studied have a unique architecture and these were non-residential buildings. Therefore, more thorough analysis are required based on the more conventional residential buildings to understand which are the suitable technical solutions and thus, the extra costs for achieving nZEB level.

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For making these analysis, we need a base level; i.e. that we need to have a reference level against what we can compare the additional costs for upgrading or degrading the building to a certain energy performance level [8]. There are several possibilities, to compare the business as usual, cost optimal or low energy buildings to nearly zero energy buildings. EU Commission released a common methodology for calculating cost optimal level in 2012, which could be used to make different studies comparable [1]. Kurnitski and his research group have used this methodology to develop the cost optimal primary energy levels for detached houses [9–12], apartment buildings and office buildings [13,14], which were used for setting the minimum requirements on the energy performance of buildings in Estonia [15]. In case of a detached house approximately 20% extra cost to move from cost-optimality level to nZEB was reported [10], but additional investment required for renewable energy needed to achieve nZEB level were not described in case of apartment and office buildings [11].

Several other studies have used variety of other methods to optimize buildings' energy efficiency of. Asadi, da Silva [16] described an optimization methodology, a combination of TRNSYS, GenOpt and MATLAB, and applied it to an existing project. The developed methodology proved to be useful for supporting the decision making and choosing proper measures for retrofitting [16]. Ferrara, Fabrizio [17] used a combination of dynamic energy simulation software and a generic optimization program to calculate the cost-optimal level for a detached house in France. They suggested wooden envelope construction with high-performance windows either with pellet boiler or a reversible heat pump system as a solution, yet they noted that other heat sources might produce different results and a sensitivity analysis is needed. Machairas, Tsangrassoulis [18] described several building design optimization methods in their review article and noted that they can be very effective, but are often also time consuming. This is a great limitation and makes it impractical for designers in the industry. Machairas, Tsangrassoulis [18] pointed out that expert judgment can be used to simplify the problems and reduce the solution search space. Corrado, Ballarini [19] used sequential search-optimization technique considering discrete options something that is also applied in this study. Diakaki, Grigoroudis [20] proposed decision model for comparing different design alternatives. Their model is limited as it does not cover the life-cycle aspect of the investment, but only the initial investment and the primary energy savings.

The purposes of this study are twofold, first to determine the cost-optimal energy efficiency level for two lately built apartment buildings in a cold climate of Estonia. Secondly, to study, which measures are required to achieve nZEB, low energy, cost optimal and national minimum requirement levels. For doing that, we are establishing a method relying on expert knowledge and building energy simulation software for optimizing building energy consumption and at the same time maintaining or improving the cost performance (initial investment and life-cycle costs). For that we studied a set of energy efficiency related building elements and systems, including high-efficiency external walls, roofs, windows, ventilation units and solar collectors and their impact on energy use and construction costs. The main challenge was to determine a proper combinations of these elements and systems for reaching certain levels of energy efficiency while optimizing the costs. With that we aim to contribute to the life-cycle costing investigation as recommended by Li et al. [5] as an important subject.

2. Methods

According to [15], following primary energy requirements have been established for new apartment buildings:

- Minimum mandatory requirements (class C, to apply for construction permit): $\leq$150 kWh/m^2
- Low energy building (class B): $\leq$120 kWh/m^2
- Nearly zero energy building (class A): $\leq$100 kWh/m^2

For analyzing which measures are required for achieving these levels and cost optimality, we first calculated the energy use and construction cost of two existing apartment buildings – a base case. Then following parameters were studied: the insulation thickness for wall; insulation thicknesses for roof; window glazing types; ventilation units with different heat recovery solutions; and local renewable energy production (in this case solar collector areas). The objective was to define proper combinations of these single measure for complying with the certain levels of energy efficiency requirements. In this study, we did not use any particular optimization approach, but developed a method based on expert knowledge and simulations. Overall, the research steps are divided into five main stages:

1. Simulating energy efficiency levels and determining investment costs for actually built cases;
2. Analyzing and simulating every parameter separately within expert selected boundaries and calculating investment requirement for saving kWh of energy (this means €/kWh);
3. Reordering all the alternatives within all the parameters according to the investment required for saving kWh of energy, from small to large;
4. Arithmetically calculating different levels of energy efficiency;
5. Simulating the selected combinations for validating the calculations done in step 4 and calculating cost optimal solution based on NPV (net present value).

In following sections research methodology and selected projects and described more in detail.

2.1. Description of apartment buildings

In this study, two apartment buildings with relatively simple architecture and located in cold climate Estonia named building A and B (Fig. 1) were used for analysis and simulations.

Typical floor plans are illustrated in Fig. 2. The buildings have 8 and 7 stories respectively and both cases have basement partially above the ground level, which were not account as heated area; i.e. not included in energy simulations. The bottom floor in building A is used for parking, storage and technical rooms, and the bottom floor in building B is used mainly for storage and parking.

Table 1 summarizes general characteristics of selected buildings. Building A compared to building B has a smaller window areas, however, building B is more compact as the ratio of envelope and heated area is smaller. Small window areas and good compactness are considered as indicators for good energy-efficiency and thereby the apartment buildings have quite similar specific heat losses per heated area.

Table 2 shows that heat losses are largely caused by windows, external walls, infiltration and thermal bridges. The simulation program uses the internal surface areas of building envelope, so we had to take into account geometrical thermal bridges such as internal wall and external wall connections. This causes the large proportion of thermal bridges. Building B has relatively larger windows, which also have higher U-values and they form approximately 1/2 of total heat losses, while in building A the proportion is around 1/3. Building A is less compact and has smaller windows, therefore external walls make up 1/4 of heat losses, in building B the proportion of walls heat loos is only 1/8. It can be