Identification of the Retrofit Actions to Achieve Cost-Optimal and NZEB Levels for Residential Buildings in Istanbul Considering the Remaining Building Lifetime

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Abstract. Cost-optimal and nearly-zero energy building (NZEB) levels are two interrelated concepts identified for upgrading energy performance of buildings in Europe. In parallel, many research activities on retrofitting existing buildings in Turkey follow the methodology framework introduced by the European Commission. However, in Turkey, there is a process called "urban transformation" due to the earthquake risk, but the practice is based on new construction after demolishment of existing buildings. Especially in Istanbul, this process has been conducted rapidly. This specific aspect requires assessment of cost-optimal retrofit analyses considering the remaining lifespan of analysed buildings.

This study presents a cost-optimality assessment method for retrofitting towards NZEB in Turkey. The method integrates payback period and investment cost assessment to the methodology in order to obtain whole picture for retrofit alternatives. In the paper, suggested method is applied to a reference residential building in Istanbul. After the initial cost-optimal analyses, payback periods and initial investment costs for selected retrofit packages are assessed considering the future lifespan of the building. Together with these, possible subsidy opportunities are also investigated. Results show that, if the expected future lifespan is higher than 10 years, retrofit actions achieving 56.2kWh/m^{2}y primary energy consumption level are considerable. Subsidies are beneficial to obtain reasonable initial investment costs.

1 Introduction

Cost-optimal level and nearly-zero energy building (NZEB) concepts were identified for assessing and upgrading energy performance of buildings in Europe. The concepts were introduced with the recast of the Directive on the Energy Performance of Buildings (EPBD) [1] and related requirements are binding for both new and existing buildings. The focus on existing building retrofits became more significant with the recent revision of EPBD in 2018. A newly inserted article specific to long-term renovation strategy refers to the requirement of planned actions to achieve retrofitted NZEB stock [2].

Determining achievable targets for retrofitted NZEBs requires specific approaches coherent with national building sector practices. In Turkey, many research activities have been focused on retrofitting existing buildings towards cost-optimal and NZEB levels [3,4,5]. These studies mainly built their methods on cost-optimal methodology framework introduced by the European Commission [6]. However, specifically in Turkey, there is a process called "urban transformation" due to the earthquake risk and insufficient quality of existing buildings. Especially in Istanbul, where fifteen million citizens live in, the urban transformation process has been conducted rapidly. In example, the housing organization of the Municipality, named Kiptas, produced 9410 housing units only between 2015 and 2017 which were constructed in the place of demolished buildings in order to operationalize urban transformation procedure [7,8,9]. On the other hand, research studies focusing on reference building establishment for cost-optimal analyses, consider the building features affecting energy performance without distinguishing their construction quality and durability against earthquake since the target is not directly related to these aspects. However, while cost-optimality analyses related to building retrofits regard 20 or 30 years of calculation period and longer building lifespans, a part of existing buildings represented by the same reference building may not be this much long-lasting in Turkey. Moreover, beside the earthquake risk requiring urgent interventions, there are other aspects which may result in demolishing and reconstructing (such as the changes in the legal or economic status of an already constructed land in a way that enables higher income for the investor). This practice requires to consider estimated remaining lifespan of the buildings to plan actions for retrofitting buildings towards NZEBs in Turkey. Therefore, a

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simple, quick and building-specific assessment procedure considering the remaining lifetime of a building is also required for cost-optimality analyses before the retrofit plan and operation.

This study presents a method which proposes to take estimated lifespan of a building as an assessment criterion while evaluating the results of cost-optimality analyses. Correspondingly, it aims to support long term renovation strategy for existing buildings in Turkey with the aim of achieving NZEB stock.

In the paper, the method was applied to a reference residential building in Istanbul. This method and the sample application are presented together in the following section.

2 The Method and Sample Implementation

The method followed in this research is originated from the cost-optimal methodology framework published by European Commission [6]. Correspondingly it includes reference building establishment, identification of energy efficiency measures to be applied on the reference buildings, energy performance and cost calculations for these measures and determination of the cost-optimal levels. The analyses also include the effect of subsidy opportunities on the cost-optimal levels. Considering the practices in national buildings sector, a new assessment criterion is added to the assessment procedure of obtained results. The proposed method integrates simple payback period calculations and investment cost assessment to the cost-optimal methodology in order to obtain a whole picture to decide on the appropriate retrofit actions.

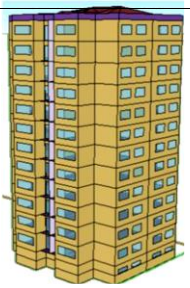
Sample implementation of the method is presented through a reference residential building below. Since this paper mainly focuses on the results' assessment process, the cost-optimality calculations are briefly summarized in Section 2.1 before proceeding to Section 2.2 explaining the proposed assessment method. More detailed information about the reference building and the cost-optimality calculations can be found in Ganiç Sağlam et al. (2017) where necessary [10].

2.1. Cost-optimality calculations

The cost-optimality calculations were applied to a reference residential building established within a national research project [11]. This building is a multi-storey residential building. Brief information about this building is provided with Table 1.

Energy performance and cost calculations were performed for different retrofit scenarios identified to improve energy performance of the reference building. Analysed retrofit scenarios include energy efficiency measures referring to the building envelope improvement, upgrade of building systems (heating, cooling, hot water, lighting) and components and building integrated renewable energy systems.

Table 1. Reference building properties.

Represented period	1985-1999
Picture of building geometry	
Heat transfer coefficients of building envelope components	$U_{\text{external wall}} = 1.04$ W/m^{2}K $U_{\text{attic slab}} = 0.71$ W/m^{2}K $U_{\text{basement ceiling}} = 1.25$ W/m^{2}K $U_{\text{window}} = 2.9$ W/m^{2}K
Occupant Assumption	Four occupants in every flat
Heating system	Central natural gas boiler and radiators. Nominal thermal efficiency = 80%.
Cooling system	Split air conditioners SEER = 5.8
Hot water system	Electric water heater 80% efficiency
Set points	Heating: 20°C, Cooling: 26°C
Air change rate	0.5 h^{-1}

Although 500 scenarios were analysed for this reference building in the previous study [refff], 22 retrofit scenarios, which enable to explain the proposed method in the best way, were analysed with the proposed method in this study. Therefore, only the measures included in these 22 scenarios are briefly explained below. Building envelope improvement alternatives include the measures related to thermal insulation installation (IN) and replacement of window glasses (GL). Explanations about the thermo-physical properties of these materials are presented in Table 2.

Table 2. Retrofit measures for envelope improvement.

	Definition of the retrofit measure
IN	Thermal insulation applied on external walls (W) or on the whole envelope (E). Overall heat transfer coefficients for different thermal insulation levels are as below: **IN1**: $U_{wall}= 0.60$ W/m^{2}K, $U_{roof}=0.39$ W/m^{2}K, $U_{floor}=0.66$ W/m^{2}K **IN3**: $U_{wall}= 0.31$ W/m^{2}K, $U_{roof}=0.18$ W/m^{2}K, $U_{floor}=0.29$ W/m^{2}K **IN2**: $U_{wall}= 0.48$ W/m^{2}K, $U_{roof}=0.32$ W/m^{2}K, $U_{floor}=0.48$ W/m^{2}K **IN4**: $U_{wall}= 0.16$ W/m^{2}K, $U_{roof}=0.11$ W/m^{2}K, $U_{floor}=0.17$ W/m^{2}K
GL	Glazing properties are as below: **GL1**: $U_{window} = 1.8$ W/m²K, $T_{vis} = 0.79$, SHGC = 0.56 **GL7**: $U_{window} = 0.9$ W/m²K, $T_{vis} = 0.63$, SHGC = 0.39

Retrofit measures targeting heating system improvement refer to boiler replacement with a condensing boiler having 95% thermal efficiency (BOI) and switching to radiant floor system (RF). For cooling system improvement, a variable refrigerant volume (VRV) system installation was analysed where COP is 3.1. There is also a retrofit measure for the hot water system which represents installation of a central hot water system (CHW). Installation of LED lamps instead of fluorescent (LED) refers to the lighting system improvement. Finally, for renewable energy systems, use of 48 solar thermal panels at roof (SP) and installation of 11kW photovoltaic system at roof (PV) were considered. Analysed scenarios include both single retrofit measures and packages of measures.

Energy performance levels achieved with the implementation of retrofit scenarios were calculated using a building energy modelling and simulation tool. The energy model of the reference building was constituted in detailed dynamic simulation software EnergyPlus. Through the simulations, energy consumed in the reference building for space heating, space cooling, domestic hot water preparation and lighting were calculated for each retrofit scenario. Energy performance assessment is based on primary energy consumptions. The primary energy conversion factors in Turkey are 1 for natural gas and 2.36 for electricity. Total energy consumption of the reference building is 145.3 kWh/m^{2}y in primary energy. Breakdown of this primary energy consumption shows that 39.4 kWh/m^{2}y is used for space heating, 36.3 kWh/m^{2}y for space cooling, 38.4 kWh/m^{2}y for hot water preparation and 28.8 kWh/m^{2}y for interior lighting.

Meanwhile, calculations were also performed to show the overall long-term costs of the retrofit scenarios. The cost calculations aimed to obtain the global cost following the method presented in EN 15459 standard [12]. Investment cost, replacement cost, maintenance and operation costs, energy costs and residual value are considered in the calculations. Calculation period is 30 years. Assumptions on the economic indicators are based on the 5 years average between 2010 and 2014. Accordingly, the inflation rate is 8.05%, market interest rate is 14,3% and real discount rate is 5.78% in the calculations [12]. Energy price development rate is assumed as equal to the inflation rate. The exchange rates represent the average of year 2015 where Euro/Turkish Lira is equal to 3.02 [13]. Similarly, unit price for electricity is 0.12 €/kWh and unit price for natural gas is 0.037 €/kWh [14,15]. Total global cost of the reference building is 114.7€/m^2.

After energy performance and cost calculations had been performed, results were comparatively analysed in order to investigate cost-optimal levels which identify the highest energy performance level achieved with the lowest global cost.

Afterwards, effect of subsidies provided for the retrofit scenarios which resulted with a better energy performance level according to the cost-optimal level but have higher global cost.

2.2 Assessment of the results considering remaining lifespan of the building

Aim of the cost-optimal analyses is to determine the building energy performance targets. Therefore, the process examines the reference buildings representing the building stock. When the issue is a retrofit practice on a building, every building and every investor has specific conditions to consider.

Due to the market practices and legal arrangements in Turkey, remaining lifespan of the existing buildings become important for the retrofit decision of a single building. In order to provide a simple view to the building owners, results identifying the cost-optimal level should be examined together with the initial investment cost and payback periods. By this way, it is possible to classify the proper retrofit actions according to the building lifespan.

At this stage, cost-optimal scenario, scenarios meeting the national standard and scenarios that are potentially able to represent the national target are analysed in terms of investment cost and payback periods of their investment. Subsidy opportunities are also included in the assessment. Results are presented in the following section.

3 Results

Results of the cost-optimality analyses are presented with Figure 1. This figure shows the results of 22 retrofit scenarios which are determinant for the cost-optimal curve by representing the primary energy consumption levels achieved with the lowest global cost. It also shows the effect of possible subsidies applied for thermal insulation (IN) and installation of solar thermal energy system (SP) since cost decreases in these two measures have the potential to enable further energy efficiency investments. Therefore, investment cost decrease around the VAT of these measures were analysed as alternate scenarios.

As shown in the graph, the retrofit scenario consisting of GL7, BOI, CHW, LED and PV retrofits result in 79.8 kWh/m^2 annual primary energy consumption and 83.8 €/m^2 global cost as the cost-optimal scenario under the existing assumptions. Comparing to the reference building, 45% primary energy and 27% global cost savings are achievable with this exact cost-optimal retrofit scenario.

As seen from the graph, investing also on SP retrofit results with achieving 70.4 kWh/m^2 annual primary energy consumption level with 1.6 €/m^2 additional global cost. With the subsidy on this retrofit, the difference in the global cost decreases to 0.9 €/m^2 in comparison to the current cost-optimal scenario.

Another considerable retrofit scenario consists of IN3-E, GL7, BOI, CHW, LED, SP and PV retrofits which results in 51.7 kWh/m^{2}y primary energy consumption level and 100.5 €/m^2 global cost. Subsidies on IN and SP retrofits are able to decrease the global cost until 96 €/m^2.

Primary energy consumption level between 51.7 kWh/m^{2}y and 79.8 kWh/m^{2}y seem to be considerable as the future targets and may be examined as the potential NZEB level as well. Therefore, payback periods and investment costs of these scenarios are analysed in the further stage. Moreover, scenarios meeting the national standard are also included in these analyses as shown in Figure 2 [16].

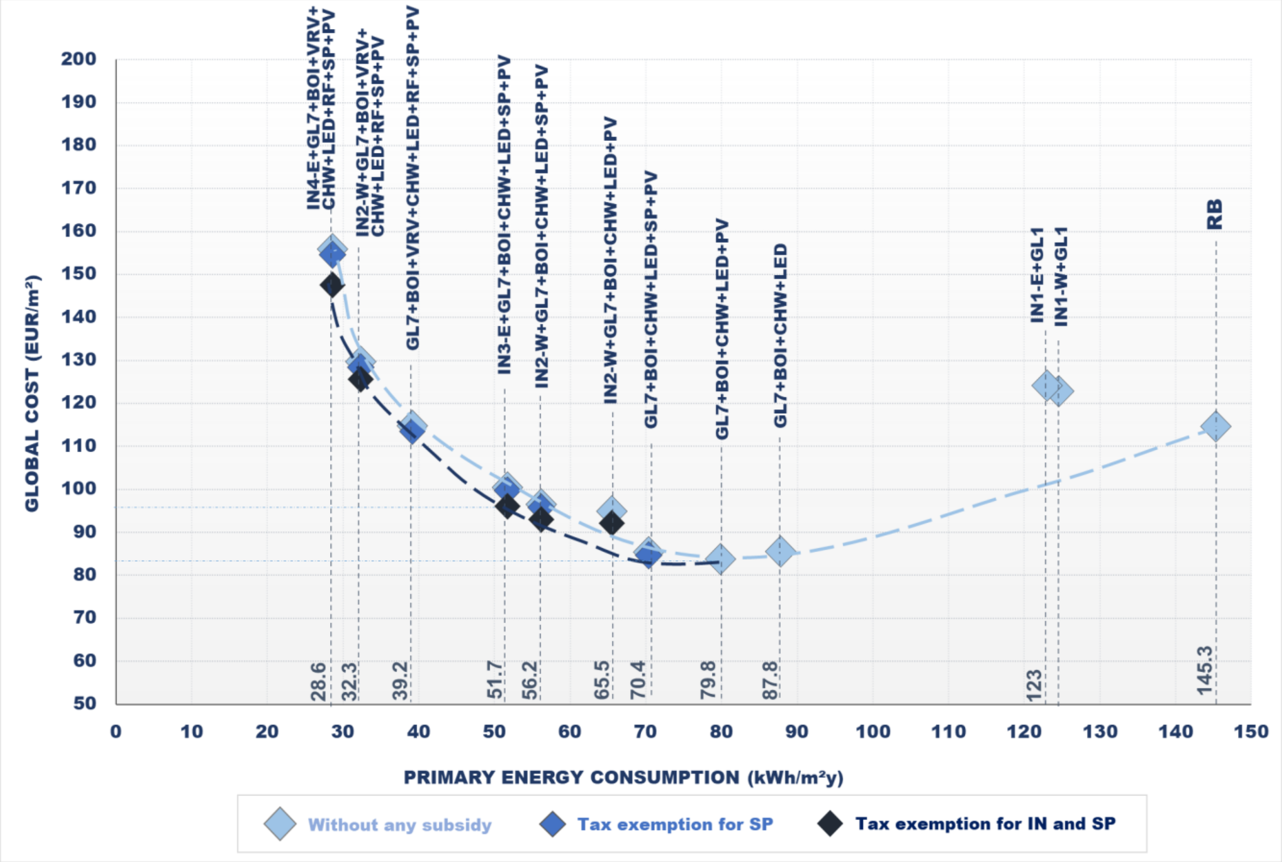


Fig. 1. Results of cost-optimality analyses.

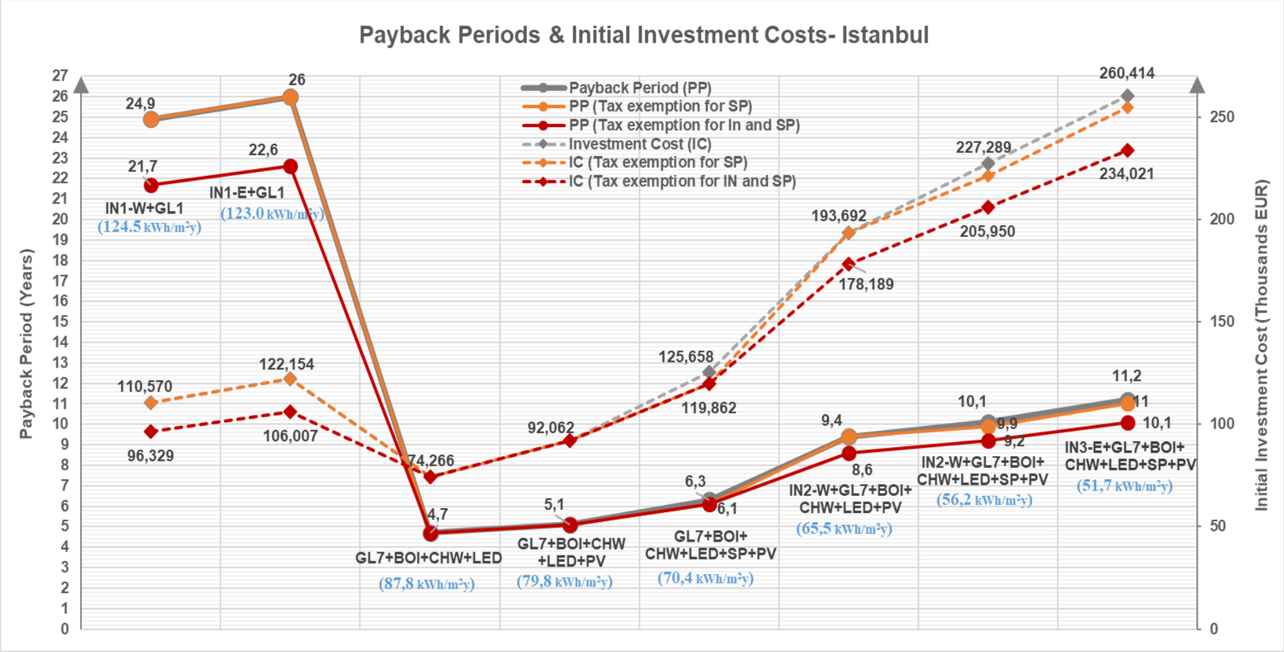


Fig. 2. Payback periods and initial investment costs for retrofit scenarios.

As seen from Figure 2, payback periods of the scenarios representing the national heat insulation standard are higher than 20 years for this reference building. On the other hand, there are some other retrofit possibilities which correspond to a lower primary energy consumption with lower investment cost and shorter payback period although building retrofits should comply with the standard. Payback period of the cost-optimal scenario is 5.1 years while the investment cost is around 92000€. Payback period of the retrofit investment required for achieving 51.7kWh/m^{2}y primary energy consumption level is 11.2 and investment cost is around 260400€. In case of any subsidy or cost decrease around VAT of solar thermal systems (SP) and thermal insulation retrofits, investment cost of this retrofit package decreases to 234000€ and payback period decreases to 10.1 years. These results show that 51.7kWh/m^{2}y level may be a future target for the existing high-rise residential buildings that have a lifespan higher than 10 years. Considering that there are 48 flats, the investment cost is 4875€ per flat in case of a subsidy or any investment cost decrease.

4 Discussion

The cost-optimal analyses already consider a standard building lifespan in order to calculate the residual value of the retrofit investments. However, this consideration is based on an assumption for the whole building stock represented by the reference building with the aim of setting a national target. In order to provide support for the unique aspects of the buildings, there should be an easy process providing a basic and preliminary opinion on retrofit decision. This study presented an assessment method for cost-optimal analyses to help retrofit decisions of building owners related to the national building energy performance targets,

Results show that, in case of tax exemption for IN and SP retrofits and low cost loan provision for suitable retrofit package, NZEB level may be defined as 56.2 or 51.7 kWh/m²y in Istanbul. A loan around 234 000 € with ten years of repayment period is able to provide a cost effective energy retrofit and after 10 years this retrofit saves money together with the energy saving. The loan around 4 875 € for every flat owner seems affordable with 10 years of repayment. Primary energy consumption level between 51.7 and 79.8 kWh seem to be considerable as the future targets and should be examined in detail.
The study also reveals that, in order to boost the market for building retrofits, low-interest loans are beneficial. Moreover, based on the future expectations and politic approach, it is possible to define more ambitious NZEB levels.

5 Conclusion

The assessment method presented in this study aims to help retrofit decisions of building owners/investors by relating the decision-making procedure with the national NZEB targets. The obtained results are only valid for multi-storey apartments in Istanbul but the method may be applied to other reference buildings representing the building stock.

This study presents a general point of view on a specific national aspect. Some other methods may also be useful for focusing on the urban transformation procedure in Turkey, such as analysing the demolishment and reconstruction as a different case in cost-optimality analyses. Another approach may be differentiating the reference buildings representing different lifetimes. Further studies may also consider these aspects in their analyses.

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