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Effect of Economic Indicators on Cost-Optimal Energy Performance Levels of Residential Buildings Retrofits in the Mediterranean Region of Turkey

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ABSTRACT

This study aims to analyse the effect of economic indicators on cost-optimal levels of residential building retrofits in Mediterranean region of Turkey. Sensitivity analyses were applied on the cost-optimality calculation results for the residential reference building. The sensitivity analyses address discount rate and potential investment cost decreases. Results reveal that 6% variation in the discount rate corresponds to more than 30 kWh/m^{2}y difference in the primary energy consumption of the cost-optimal solutions. Potential investment cost decreases for certain retrofit measures are also effective on identified cost-optimal levels and subsidy opportunities appear as an effective tool to achieve higher energy efficiency in existing buildings and to stimulate building energy retrofits.

KEYWORDS

Residential building retrofits, Building energy efficiency, Cost-optimal analysis, Economic indicators, Subsidy opportunities.

INTRODUCTION

Cost-optimality concept, introduced by the European Commission (EC), is one of the key determinants driving policy and targets related to energy efficiency of European building stock (2016). By means of this concept, the Commission expects gradual progress in building energy performance requirements towards nearly-zero energy building (NZEB) target (2013).

The cost-optimality concept mainly assesses energy consumption levels of buildings by associating them with the corresponding costs occurred as a consequence of energy consumption and other expenses linked with components and systems influencing the energy performance of buildings. Having regard to Directive 2010/31/EU (EPBD Recast), EC introduced a methodology framework representing this assessment procedure in 2012 (The European Parliament and the Council of the European Union, 2010; The European Parliament and the Council of the European Union, 2012). This methodology framework requires to couple energy performance and cost calculations to identify the cost-optimal level for Reference Buildings (RBs) representing the building stock. Sensitivity analysis is an important stage of this methodology since it has the potential to reveal outcomes contributing further policy and targets. It displays the alteration in cost-optimal solutions under different economic situations and options.

The specific focus of this study is on the sensitivity analyses directed to the effect of economic indicators and possible investment cost decreases on cost-optimal energy performance level of building retrofits. Towards this aim, retrofit alternatives for a high-rise residential reference building in Mediterranean region of Turkey was analysed. Since the main focus is on the sensitivity analyses, previous stages of cost-optimality calculations are explained briefly in order to keep entirety. A detailed information about the analysed reference building and initial stages of cost-optimal calculation procedure for this building can be found in research of Ganiç Sağlam et al. (2017).

The procedure presented in this study responds challenges faced in consequence of unsteady economic indicators that extend the range of aspects required to be considered in determination of future energy efficiency targets. It also considers energy retrofit of identical high-rise residential buildings constructed without considering the character of Mediterranean climate they face with. The adapted cost-optimality calculation procedure is presented below together with the sample implementation and policy implication.

METHOD

This study mainly follows the perspective of cost-optimal methodology framework and implements it for residential reference building retrofit actions.

The Reference Building

The analysed reference building (RB) represents high-rise apartments constructed between 1985 and 1999 in Turkey. As shown in Figure 1, it has an unconditioned basement and 12 superior floors. Overall heat transfer coefficients of building envelope components are 1.04 W/m^{2}K and 1.09 W/m^{2}K for external wall types, 1.25 W/m^{2}K for basement ceiling and 0.71 W/m^{2}K for attic slab. The windows consist of double glazing with polyvinyl chloride frame. Overall heat transfer coefficient of the window glazing (U_{window}) is 2.9 W/m^{2}K, visible transmittance (T_{vis}) is 0.80 and solar heat gain coefficient (SHGC) is 0.75. Internal heat gains including occupancy, activity level and appliances were set to represent recent Turkish family structure surveys and accordingly, it is assumed as each apartment flat accommodates a family consisting parents and two children.

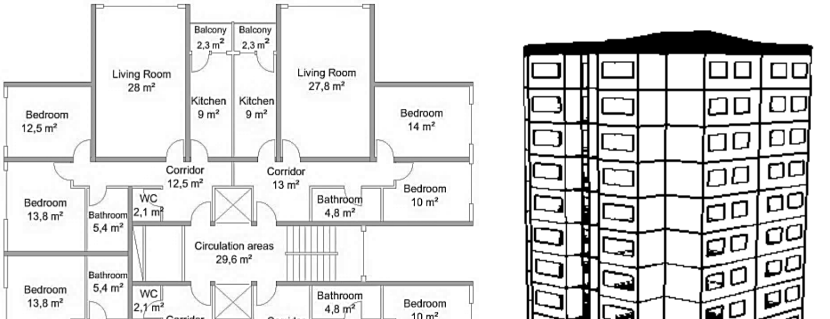

Figure 1. Typical floor plan and the geometry of the reference building.

The RB has a central natural gas boiler and radiators. The nominal thermal efficiency of the boiler is 80%. The cooling energy demand is met by individual split air conditioners using electricity. Seasonal energy efficiency ratio of the split air conditioners are 5.8. Domestic hot water (DHW) system of each flat is individual electric water heater with 80% efficiency. The heating and cooling systems were assumed as being operated continuously with 20◦C and 26◦C set points respectively. Air change rate is assumed as 0.5 h^{-1} (Yilmaz et. al, 2015).

Lighting system provides 200 lux illuminance level for kitchen, 300 lux for children bedroom and 100lux for living room, bedroom, corridor and bathroom with compact fluorescent lamps.

Energy efficiency measures

Various energy efficiency measures referring to building envelope and building energy systems were applied on the RB. The retrofit measures shown in Table 1 were applied to the RB both as individual retrofit measures and as packages of measures combining these individual retrofits. 472 retrofit scenarios were analysed in total.

Table 1. Retrofit measures applied to the RB.

	Definition of the retrofit measure
IN	Thermal insulation applied on external walls (W), floor (F), roof (R) or on the whole envelope (E). Different levels of thermal insulation result in following overall heat transfer coefficients: 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 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 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 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	Window glass replacement. Following glass alternatives were considered: GL1: U_{window} = 1.8 W/m²K, T_{vis} = 0.79, SHGC = 0.56 GL2: U_{window} = 1.6 W/m²K, T_{vis} = 0.79, SHGC = 0.56 GL3: U_{window} = 1.6 W/m²K, T_{vis} = 0.71, SHGC = 0.44 GL4: U_{window} = 1.3 W/m²K, T_{vis} = 0.71, SHGC = 0.44 GL5: U_{window} = 1.1 W/m²K, T_{vis} = 0.71, SHGC = 0.44 GL6: U_{window} = 0.9 W/m²K, T_{vis} = 0.69, SHGC = 0.48 GL7: U_{window} = 0.9 W/m²K, T_{vis} = 0.63, SHGC = 0.39
SHD	SHD1: Fixed aluminium shading device installation: 60cm width overhang or fins. SHD2: Installation of external semi-transparent textile blinds.
BOI	Central boiler replacement with a condensing boiler having 95% thermal efficiency.
RF	Replacement of the existing heating system with radiators to radiant floor system
CHW	Change of the individual domestic hot water systems to the central hot water system.
AC	Upgrade SEER value of split type air conditioners to 8.5 kWh/kWh by replacement.
VRV	Installation of a central variable refrigerant volume (VRV) system in substitution for split air conditioners. Gross rated cooling coefficient of performance (COP) is equal to 3.1.
LED	Installation of LED lamps to provide same illuminance levels in the spaces.
SP	Installation of 48 solar thermal panel at roof with 120m^2 total gross area.
PV	Installation of photovoltaic system at roof with 11 kW rated power

Energy performance calculations

Energy performance of the RB under the retrofit scenarios were calculated using conduction transfer function algorithm in EnergyPlus building energy simulation tool. The thermal model constituted for the calculations regards each flat as a thermal zone and the common circulation areas as different thermal zones at each floor. Energy consumptions were calculated for space heating and cooling, lighting and DHW. In order to obtain results in primary energy, national primary energy conversion factors, 1 for natural gas and 2.36 for electricity, were used. Calculated primary energy consumption of the RB is 7.7 kWh/m^{2}y for space heating, 92kWh/m^{2}y for space cooling, 30.6 kWh/m^{2}y for domestic hot water, 28.8 kWh/m^{2}y for lighting and 1.9 kWh/m^{2}y for fans and pumps.

Global cost calculations

Global cost reflects the present value of the sum of investment, replacement, maintenance and operation costs and residual value of the building. The calculations were made using Net Present Value Method (NPV) according to EN15459 standard (CEN, 2007). The fixed expenses and the costs related to the building elements that does not affect the energy performance of the building were not included in the cost calculations. Initial investment costs of retrofit measures can be found in research of Ganiç Sağlam et al. (2017) as indicated above.

Since the calculation beginning year is 2015, prices of that year were considered in this study. Market costs were used for investment costs of the system and components. For energy costs, average unit prices of the year were used. Tax included prices are 0.1213 €/kWh for electricity and 0.0368 €/kWh for natural gas in Antalya. For the economic rates, averages of the last five years were considered. In this context, inflation rate (R_i) is 8.054% and market interest rate (R) is 14.3%. Using these average economic rates and Equation 1, real discount rate (R_R) was calculated as 5.78. Calculated global cost of the RB is 114.9 €/m^2.

$$R_R = \frac{R - R_i}{1 + R_i} \tag{1}$$

Determination of cost-optimal energy performance level

Cost-optimal level, the energy performance level which results in minimum global cost for the RB, is determined by comparing the primary energy consumption and global cost results obtained for RB retrofit scenarios. Findings are presented in Results section below.

Sensitivity Analyses

Effects of the alterations in the discount rate and potential investment cost decreases on the cost-optimal results were examined within the sensitivity analyses. Besides the calculated discount rate (5.78%), the sensitivity analyses focused on two different discount rate alternatives: 3% as required by EU regulation and 9%.

Sensitivity analyses on investment cost decrease focused on a discount which is equal to value added tax (VAT) of the retrofit investments. Although the analyse seems as focusing on tax exemption, the same amount of investment cost decrease may also be obtained by autogenous decrease in the cost or as the result of technological development or may be triggered by other subsidy and incentives. In the analyses, effect of investment cost decreases for VRV (installation of central variable refrigerant volume system) and SP (installation of solar thermal system) measures were analysed since these measures were seen as the opportunity for decreasing the global cost of the retrofit scenarios which were slightly higher in comparison to the cost-optimal scenario. These options were also analysed under different discount rates.

RESULTS

Results obtained by the cost-optimality calculations are presented in Figure 2. The cost-optimal result was achieved by the retrofit package combining GL7, CHW, LED and PV retrofits. This package results with 96.4 kWh/m^{2}y primary energy consumption and 97.8 €/m^2 global cost. This package provides 40% energy saving and 26% cost saving with 4.3 years payback period. By 4.6 €/m^2 higher global cost afforded for VRV and SP measures, 52.6 kWh/m^{2}y primary energy consumption level can be achieved. Further retrofit measure addition in the package results in rapid increase in global cost with unsatisfactory energy performance improvement.

Results of sensitivity analyses show that cost-optimal results for the RB retrofits are sensitive to the changes in discount rate as displayed with Figure 3 below. Decrease in the discount rate enables moving towards 61.8 kWh/m^{2}y cost-optimally by adding VRV retrofit within the retrofit package. Another opportunity to achieve more ambitious cost-optimal energy performance level is to ensure investment cost decrease around VAT for VRV and SP retrofits. With this cost decrease, 52.6 kWh/m²y primary energy consumption level is achievable in case the discount rate is equal to 3%. In order to achieve this level, SP retrofit should also be included in the retrofit package.

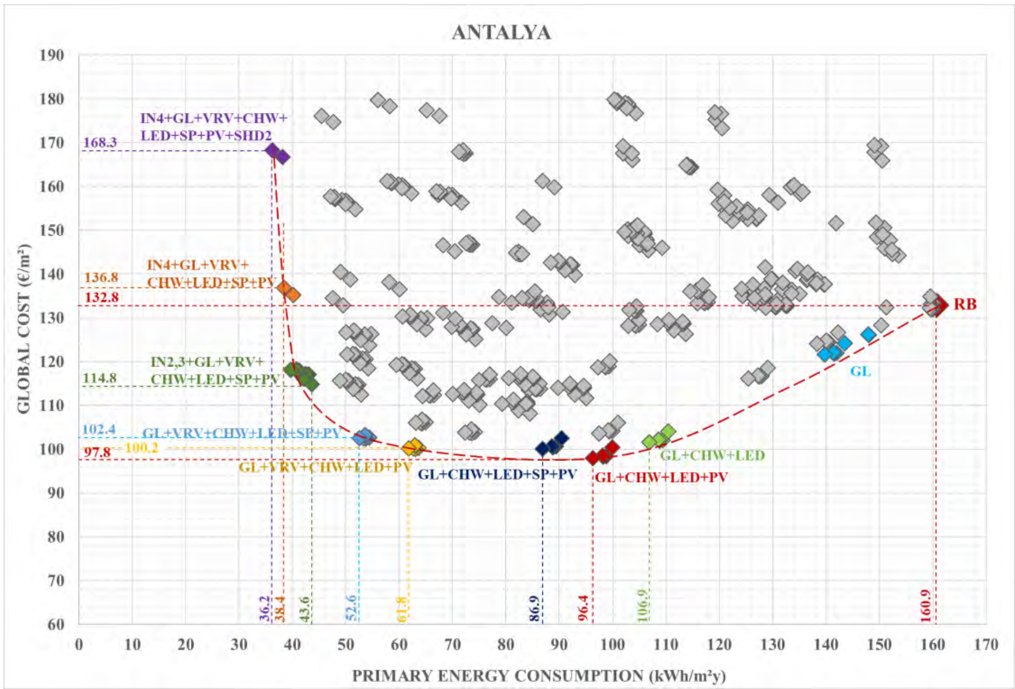

Figure 2. Results of cost-optimality analyses performed for the RB retrofits.

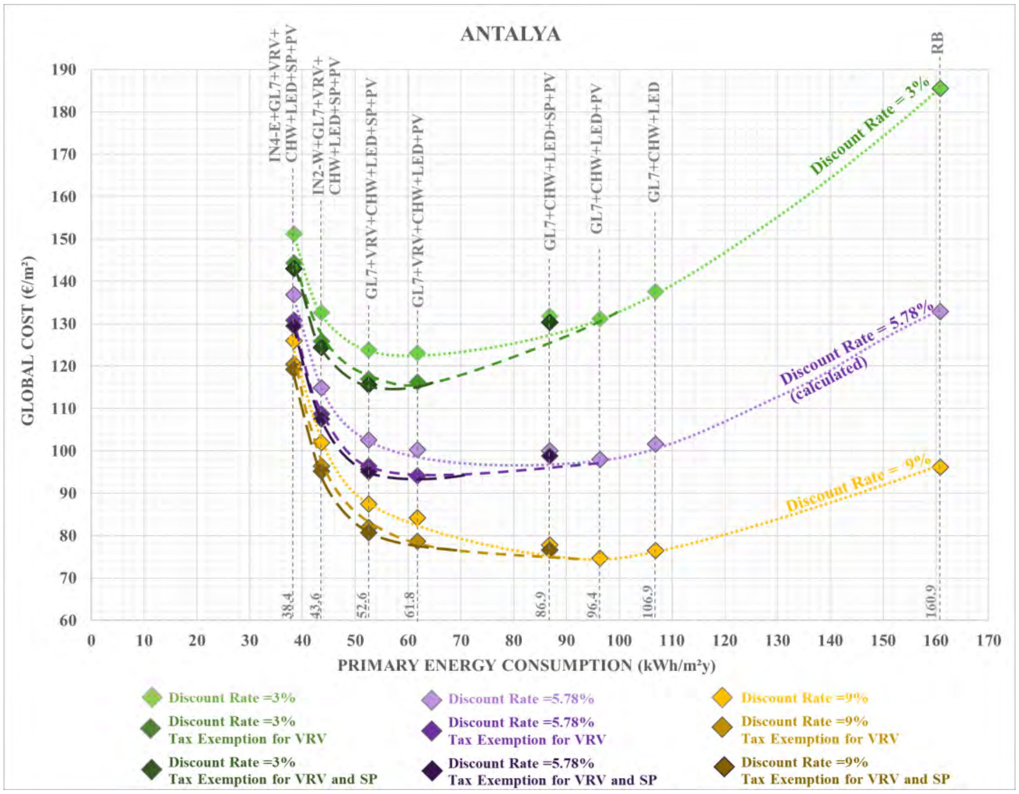

Figure 3. Results of sensitivity analyses.

When the discount rate is equal to reference assumption (5.78%), cost-optimal level remains at 61.8 kWh/m²y even an investment cost decrease is provided. However, only with 1 €/m² higher global cost, SP retrofit can be included in the retrofit package in order to achieve 52.6 kWh/m²y primary energy consumption level cost-optimally in case of an investment cost decrease in SP and VRV. Moreover, the payback period of this retrofit package (including GL7, VRV, CHW, LED, PV retrofits) decreases from 8.3 years to 7.5 years.

DISCUSSION AND CONCLUSION

Results reveal that 6% variation in the discount rate corresponds to more than 30 kWh/m^{2}y difference in the cost-optimally achieved primary energy consumption level. Therefore, strong forecasts on the economic indicators are required to point reliable targets for cost-optimal and NZEB levels.

Specific to Mediterranean climate, VRV and SP measures have a critical role to move towards higher energy performance level. In order to move towards 52.6 kWh/m²y primary energy consumption level cost-optimally, cost decreases for solar thermal system and VRV system should be provided for high-rise apartments. If an investment cost decrease is not expected naturally in time or as the result of technological development, it may be triggered by some subsidy and incentives put forward by policy-makers. Climate responsive tax exemption appears as an effective tool to stimulate building retrofits in Mediterranean building market.

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