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A study on determining the optimal energy retrofit strategies for an existing residential building in Turkey

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Abstract:
In today's world, improving the energy efficiency level constitutes a focal point in Turkey's energy policies, just as in other countries, in order to achieve a fast and cost effective solution to globalising energy and environmental problems and to create a sustainable, resource efficient economy which encompasses transformation and growth. In this context for Turkey, while the importance of studies on energy efficiency to ensure energy supply security is increasing, housing constructions which lead to a very high level of energy consumption are also growing. Therefore in this study strategies which are effective in improving energy performance of residential buildings with the goal of achieving optimum benefit for country resources and decision makers are developed for the different climate regions and the energy, economic and environmental performance of residential buildings related to these strategies are evaluated by means of the comparative approach. Thus, it is possible to obtain data from design and retrofit of buildings, which may provide a basis for relevant laws and regulations on optimising energy, economic and environmental performance of buildings and support for preparing technical information required to improve energy and cost efficiency levels of both existing and new residential buildings.

Keywords: *Residential buildings, energy and cost efficiency, energy retrofit, life cycle cost, CO_2 emission.*

1. Introduction

Energy efficiency is a critical factor which should be taken into consideration when constructing residential buildings. Energy not only constitutes a large portion of the total usage cost of a building but it also plays an effective role in providing the conditions for climatic and visual comfort for the occupants. Thus, ensuring energy efficiency in residential buildings is considered by many countries as a fundamental component for developing cost efficient energy and climate change policies. Residential buildings represent a significant percentage in global energy consumption and associated CO2 emissions, therefore having very high potential to reduce such consumption in a cost effective way.

In this regard, it is observed that existing buildings have a very inefficient structure in terms of energy use, and although new buildings aim to achieve higher performance levels, they fail this goal and remain at similar performance levels of those of existing buildings. Therefore, the fact that most residential building use, directly or indirectly, fossil fuel in very high amounts and that the resources used are scarce and non-renewable with associated impacts on the environment and high energy costs entail an improvement in the residential building's energy performance.

When studies carried out concerning improving energy performances of residential buildings are reviewed and analysed, it is possible to say that these can be categorised under three different approaches: (1) evaluation of building envelope systems, HVAC systems and other energy saving strategies (Lopes, L., Hokoi, S., Miura, H., Shuhei, K., 2005; Lollini, Barozzi, Fasano, Meroni, Zinzi, 2006; Guertler, P., Smith, W., 2006; Sartori, I., Wachenfeldt, B.J., Hestnes, A.G., 2009; Uihlein, A., Eder, P., 2010; Morissey, J., Horne, R.E., 2011; Ramesh, T., Prakash, R., Shukla, K.K., 2012; Fesanghary, M., Asadi, S., Geem, Z.W., 2012; Brown, N.W.O., Malmqvist, T., Bai, W., Molinari, M., 2013), (2) evaluation of renewable energy systems such as cogeneration, solar photovoltaic systems, solar water heating systems (Nawaz, I., Tiwari, G.N., 2006; Dorer, V., Weber, A., 2009; Bayod-Rujula, A.A., Ortego-Bielsa, A., Martinez-Gracia, A., 2011; Golić, K., Kosorić, V., Krstić Furundžić, A., 2011; Bianchi, M., Ferrari, C., Melino, F., Perotto, A., 2012; Liu, G., Rasul, M.G., Amanullah, M.T.O., Khan, M.M.K., 2012), and (3) evaluation of energy saving strategies and renewable energy systems together (Sadineni S.B., France, T.M., Boehm, R.F., 2011; Marszal, A.J., Heiselberg, H., 2011; Magrini, A., Magnani, L., Pernetti, R., 2012; Famuyibo, A.A., Duffy, A., Strachan, P., 2013; Ristimäki, M., Säynäjoki, A., Heinonen, J., Junnila, S., 2013). Based on these studies, in terms of energy and cost efficiency, many strategies and strategy combinations to improve energy performance of residential buildings can be developed and the effects of these strategies and strategy combinations on the existing energy performance level can be evaluated. However, methods to evaluate energy, economic and environmental performance of residential buildings are contextual and subject to change based on climatic conditions, occupants' requirements, building physics and relevant regulations. Thus, adapting existing methods which have been used before or developing suitable approaches should be used as a basis in the studies concerning how to improve performances of both existing and new residential buildings nationwide.

Therefore in this study it is aimed to develop strategies for different climate regions which are effective for improving energy performance of residential buildings with the goal of achieving optimum benefit for country resources and decision makers and to evaluate the energy, economic and environmental performance of residential buildings related to the strategies by means of the comparative approach. In this respect, impacts of the scenarios concerning energy saving strategies and renewable energy systems on energy consumption, CO_2 emissions and life cycle costs for different climate regions of Turkey are evaluated using a holistic approach.

2. Methodology

This study considers solutions to determine retrofit strategies in which optimum performance is achieved in terms of energy saving, reduction in CO_2 emission and life cycle costs and to determine optimal retrofit combinations suitable for different climate regions. In this regard, an integrated approach is taken into consideration, including identifying energy savings, CO_2 emission reduction and economic potentials for the strategies effective in improving residential building energy performance, evaluating energy and cost effective measures with which optimum performance is achieved based on climatic conditions and in comparison to the applicable laws and regulations, and making suggestions to decisions makers for optimum retrofit combinations for different climate regions. This approach includes the following stages:

- defining a reference residential building,
- defining retrofit strategies,
- conducting energy performance analysis,
- conducting economic performance analysis,
- evaluating the optimal performance in terms of energy and cost efficiency,
- defining and evaluating optimal retrofit combinations suitable for different climate regions.

Through this approach, an integrated method on improving energy performances of existing residential buildings can be discussed, opportunities to implement solution oriented strategies can be identified and the effects of these strategies on energy saving, life cycle costs and environmental sustainability in different climate regions of Turkey can be evaluated. Thus with the system to define optimal retofit strategies it is not only possible to contribute to the evaluation of the requirements of specific laws on buildings but also it is possible to help to create a projection concerning the steps that Turkey should take in its middle and long term building policies to improve existing residential buildings in an energy and cost effective manner.

2.1 Defining the reference residential building

Detailed analysis should be made and statistical data obtained in order to define a reference residential building. Since there are limited statistical data concerning existing building stock, it is not possible to define a nationwide reference residential building. Therefore, for this study as a reference residential building, a mass housing building project which was completed in 2008 in Istanbul under the title of “resource development project” by TOKİ has been chosen; this project reflects the impact of applicable national laws and regulations on building construction and involves common construction technologies and design criteria. This mass housing project consists of 7 building blocks and 408 apartments on an area of 25 decares. One of the apartment buildings in the mass housing project is defined as the reference residential building and is treated as if it is in three separate cities which represent different climate regions of Turkey. The characteristics of the reference residential building and the climate regions are shown in Tables 1-2 respectively.

It is assumed that the reference residential building of which orientation and form is shown in Figure 1a is not left in the shade by other surrounding buildings. Layer details of the opaque elements of the reference building, heat conductivity of the materials in the layers and U values of the opaque elements are given in Table 3. As transparent elements, double glazed windows (4 mm clear glass + 12 mm air + 4 mm clear glass, U:2.725 W/m2 K) with plastic window frames (60 mm, U:1912 W/m2K) are used.

Table 1. *Characteristics of the reference building.*

Parameter	Value
No. of floors Floor to floor height Building height Floor area Total floors area Building length/building depth in the plan	17 (two basement floor) 2.79m 48.28 m 573 m^2 8131 m^2 1.37
Total external surface area / building volume	0.19
Total transparent area /total façade area	15% (north, south), 24% (east), 30% (west)
Constant air change rate	0.5 ac/h
Occupant density	25.9 m^2/person
Occupant clothing type	1 clo (heating period), 0.5 clo (cooling period)
Occupied period Heating set point	07:00-09:00,16:00-23:00(weekdays), 07:00-23:00(weekend) 21°C (occupied period), 16°C (other hours)
Cooling set point	25°C (occupied period), 28°C (other hours)
Minimum fresh air	10 l/s
Heating system	penthouse condensing boiler type central system, energy type natural gas
Cooling system	COP 4.50, energy type electric energy
Hot water system	individual water heaters, energy type natural gas

Table 2. *Characteristics of the climate regions.*

Climate region	Representative city	Latitude-Longtitude (°)	Heating degree days	Cooling degree days	Global horizontal radiation (kWh/m^2y)
Temperate humid	Istanbul	40.97-28.82	1886	2152	1465
Hot humid	Antalya	36.70-30.73	972	3345	1798
Cold	Erzurum	39.95-41.17	4785	856	1555

2.2 Defining the energy retrofit strategies

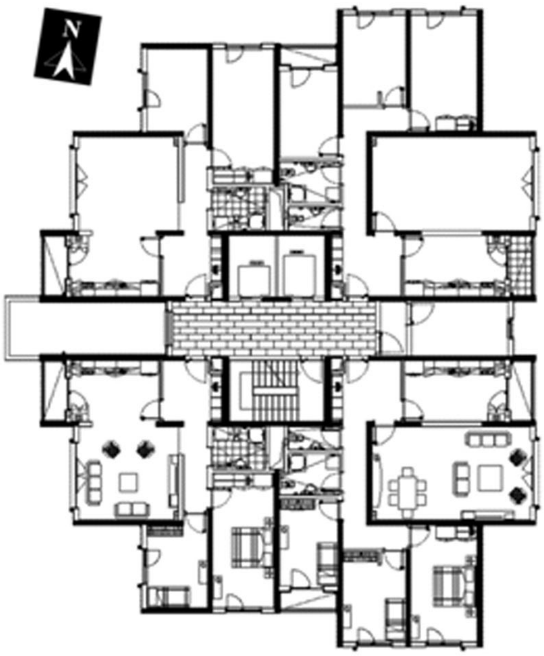
When defining energy retrofit strategies, existing conditions and design flexibility of the reference residential building as well as the applicable regulations on minimum performance requirements that affect the planned efficiency of the building are all taken into consideration to develop appropriate strategies. In this regard, the approach to define retrofit strategies consists of defining possible appropriate strategies for the reference building and multipurpose optimization of these strategies. Retrofit strategies within the scope of the preferred approach are taken as:

- energy saving strategies and
- renewable energy systems.

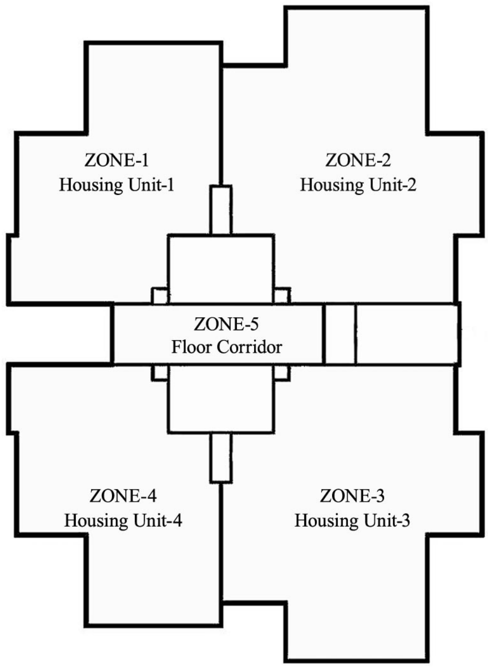
Table 3. *Details on opaque elements of the reference building (from outside to inside).*

Opaque component	Material	Thickness (m)	λ (W/mK)	U (W/m²K)
Exterior wall (type$_1$)	External plastering	0.03	1.60	$U_{wall,1}$ =0.37
	Heat insulation (XPS)	0.05	0.035	
	Aerated concrete block	0.20	0.193	
	Gypsum plastering	0.02	0.51	
Exterior wall (type$_2$)	External plastering	0.03	1.60	$U_{wall,2}$ =0.58
	Heat insulation (XPS)	0.05	0.035	
	Reinforced concrete	0.20	2.50	
	Gypsum plastering	0.02	0.51	
Ground floor	Reinforced concrete	1.00	2.50	U_{g_floor} =0.51
	Concrete	0.03	1.65	
	Heat insulation (XPS)	0.04	0.035	
	Concrete	0.03	1.65	
	Screed	0.05	1.40	
	Laminated parquet flooring	0.01	0.08	
Flat roof	Ceramic tile	0.01	1.30	U_{roof} =0.55
	Concrete	0.03	1.65	
	Roofing felt	0.0017	0.19	
	Heat insulation (EPS)	0.05	0.033	
	Water proofing (EPDM)	0.006	0.30	
	Sloping concrete	0.04	1.65	
	Reinforced concrete	0.14	2.50	
	Gypsum plastering	0.02	0.51	

Among the energy saving strategies, heat insulation of the exterior wall components, improvement of glazing systems and the use of solar control devices are taken into consideration and under the renewable energy systems the use of photovoltaic (PV) systems are studied considering the high solar energy potential of Turkey.



(a)



(b)

Figure 1. Plan view of the reference building (a) and conditioned zone areas (b).

The scenarios developed for the heat insulation strategies on exterior wall components include (1) the situation in which no heat insulation layer is available (EW-0), (2) the existing situation of the heat insulation layer in the reference residential building (Ref), (3) situations where the heat insulation layer complies with the maximum total heat transfer coefficient specified in Turkish Standart (TS) 825 (U,W/m^{2}K) and where the heat insulation has lower U coefficients (EW-1).

The scenarios developed for the retrofitting glazing systems include (1) the situation where single glazing is available (G-0), (2) the existing situation of the glazing system in the reference residential building (Ref), (3) situations where the glazing system complies with the maximum total heat transfer coefficient specified in TS 825 (U,W/m^{2}K) and where the glazing system has lower U coefficients (G-1). In these scenarios, the existing glass thickness (4mm + 4mm), the gap between the glass (12 mm) and window frames (PVC) are kept unchanged. Gas in the gap (air or argon gas) and coating (heat control, heat and solar control) on different glass surface (2nd or 3rd) types are included within parameters that have been changed. Layering details, heat transfer coefficient of glazing ($U_{glazing}$), thermal conductivity coefficient of transparent elements depending on the window frame and glass properties (U_{pen}), and solar heat gain coefficient (SHGC) values used in the scenarios are given in Table 4.

As for the strategies defined in relation to the use of solar control devices (SC-1), it is assumed that solar control devices are used on the exterior surfaces of the south, east and west façades of the reference residential building. A venetian blind system is used as the solar control device. In order to reduce the current cooling load of the reference residential building, solar control devices are considered as active only during the period when cooling is required (Berkoz, E., et al., 1995).

Table 4. *Details on opaque elements of the reference building (from outside to inside).*

Glazing system	Gap (mm)-Gas	$U_{glazing}$ (w/m²K)	U_{window} (w/m²K)	SHGC
Clear-single glazing	-	5.9	4.9	0.85
Clear-double glazing	12-air	2.7	2.6	0.74
Low-E (heat cont.) e2=0.04	12-air	1.7	1.8	0.44
Low-E (heat cont.) e2=0.04	12-argon	1.4	1.5	0.44
Low-E (heat cont.) e3=0.03	12-air	1.7	1.8	0.51
Low-E (heat cont.) e3=0.03	12-argon	1.4	1.5	0.51
Low-E (heat-solar cont.) e2=0.02	12-air	1.6	1.8	0.30
Low-E (heat-solar cont.) e2=0.02	12-argon	1.3	1.5	0.30

For the strategy defined in relation to the use of a photovoltaic (PV) system, over the entire existing terrace roof area at the +39.06 level of the reference building (510.70m^2), PV systems assumed to be grid connected have been designed. When making these designs, variables such as PV cell types which play an effective role in the energy performance of PV systems, orientation of PV panels, PV panel inclination angle, shading distances between PV module strings are taken into consideration and suitable values for these variables for Istanbul, Antalya and Erzurum are determined. In this regard, assumptions concerning PV systems are described below.

- Monocrystalline silicon PV modules (190 Wp) which are suitable for use on terrace roof areas with high efficiency are used.
- PV modules face south.
- Analyses have been made in order to determine optimum inclination angles for the PV panels used in the terrace roof areas for the cities covered. The optimum angles of inclination determined for the PV panels based on the analysis results are 31° for Istanbul, 32° for Antalya and 30° for Erzurum.
- Analyses are made in order to determine optimum shading distances between PV module strings. Based on the analyses performed in terms of both final PV system yield and optimisation of energy generation, values with which yield loss caused by shading is minimum should be considered as suitable shading distances between module strings for all climate regions. Furthermore, it is accepted that PV systems which are used in the entire terrace roof area are not affected by the shading effect caused by other obstacles (such as chimneys, elevator towers, trees).

Scenarios concerning the strategies, which are defined as a result of all assumptions and methods followed can be seen in Table 5.

2.3 Energy performance analysis

Energy performance analysis of the reference residential building based on the strategies considered includes the following four processes;

- calculating final energy consumptions (heating, cooling, illumination, hot water, auxiliary energy) (kWh/a),

• calculating final energy generations (electrical energy - PV) (kWh/a),
• calculating energy usage (primary energy) (kWh/a),
• calculating CO_2 emissions ($kgCO_2$/a).

Table 5. *Scenarios concerning the strategies.*

Sc. No	Code	$U_{wall,1}$, $U_{wall,2}$ (W/m²K)	U_{roof} (W/m²K)	U_{g_floor} (W/m²K)	U_{window} (W/m²K)	SHGC	Solar control devices	PV system output (kWp)
Sc1	EW-0	0.79, 3.25	0.55	0.51	2.60	0.74	-	-
Sc2	EW-1	0.42, 0.69	0.55	0.51	2.60	0.74	-	-
Sc3	REF	0.37, 0.58	0.55	0.51	2.60	0.74	-	-
Sc4	EW-1	0.34, 0.49	0.55	0.51	2.60	0.74	-	-
Sc5	EW-1	0.31, 0.43	0.55	0.51	2.60	0.74	-	-
Sc6	EW-1	0.28, 0.39	0.55	0.51	2.60	0.74	-	-
Sc7	EW-1	0.26, 0.35	0.55	0.51	2.60	0.74	-	-
Sc8	EW-1	0.24, 0.32	0.55	0.51	2.60	0.74	-	-
Sc9	EW-1	0.20, 0.25	0.55	0.51	2.60	0.74	-	-
Sc10	EW-1	0.18, 0.22	0.55	0.51	2.60	0.74	-	-
Sc11	EW-1	0.16, 0.18	0.55	0.51	2.60	0.74	-	-
Sc12	EW-1	0.14, 0.17	0.55	0.51	2.60	0.74	-	-
Sc13	G-0	0.37, 0.58	0.55	0.51	4.90	0.85	-	-
Sc14	G-1	0.37, 0.58	0.55	0.51	1.80	0.44	-	-
Sc15	G-1	0.37, 0.58	0.55	0.51	1.50	0.44	-	-
Sc16	G-1	0.37, 0.58	0.55	0.51	1.80	0.51	-	-
Sc17	G-1	0.37, 0.58	0.55	0.51	1.50	0.51	-	-
Sc18	G-1	0.37, 0.58	0.55	0.51	1.80	0.30	-	-
Sc19	G-1	0.37, 0.58	0.55	0.51	1.50	0.30	-	-
Sc20	SC-1	0.37, 0.58	0.55	0.51	2.60	0.74	available	-
Sc21	PV-1	0.37, 0.58	0.55	0.51	2.60	0.74	-	29.26
Sc22	PV-1	0.37, 0.58	0.55	0.51	2.60	0.74	-	29.64
Sc23	PV-1	0.37, 0.58	0.55	0.51	2.60	0.74	-	29.83

2.3.1 Calculating final energy consumptions

Final energy consumptions of the models created based on the current condition of the reference residential building and energy saving strategies are calculated using the DesignBuilder simulation programme representing a detailed dynamic calculation method. In the simulations performed using the Designbuilder programme, housing units and floor corridors of the reference building are accepted as one independent region in terms of zoning criteria (Figure 1b). The model of the mass housing included in this study, which is created with the Designbuilder programme, can be seen in Figure 2.

2.3.2 Calculating final energy generations

Final energy generations of the models created for the use of PV systems on the roof and façades of the reference residential building are calculated using the PV*SOL Expert simulation programme representing a detailed dynamic calculation method. In order to determine the integration level of the PV systems to the reference building, in other words to determine to what extent the amount of energy generated by the PV systems meets the electrical energy consumption of the reference building, energy cover factor (C_{PV}) is taken into account and calculated using the equation given below (Verbruggen, B. et al., 2011; Cellura, M. et al., 2012):

$$CPV = \frac{E_{pv}}{E_{cons,e}} x100 \quad (1)$$

where E_{PV} is the annual energy amount generated by the PV system (kWh/a) and $E_{cons,e}$ is the electrical energy consumption of the reference residential building (kWh/a).

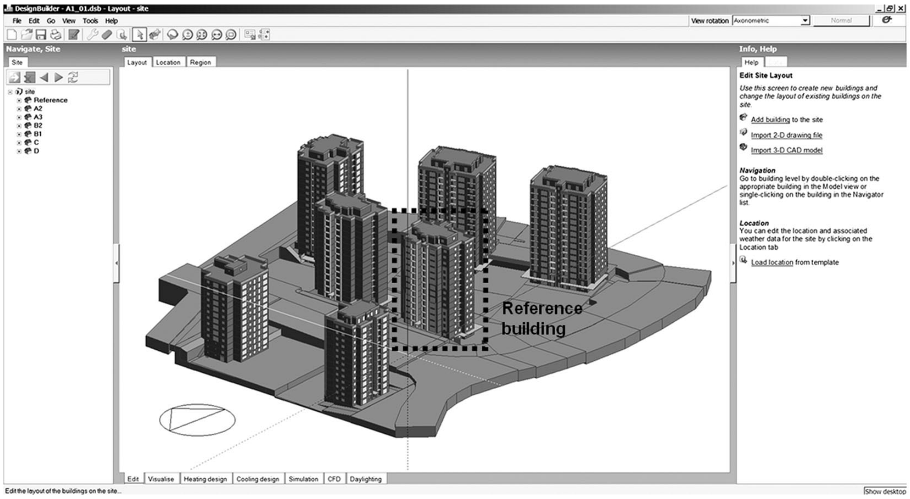


Figure 2. *DesignBuilder's user interface with a 3D view of the mass housing.*

2.3.3 Calculating energy usage

When calculating energy usage, primary energy consumptions associated with final energy consumptions and primary energy savings associated with final energy generations are taken into consideration.

Energy usage (E_{usage}) values (kWh/a) of the models created for the reference residential building and the strategies considered can be calculated using the equation given below (CEN/BT/WG 173, 2006):

$$E_{usage} = \sum\left(E_{cons,fuel} \times f_{\mathrm{p,fuel}}\right) - \sum\left(E_{PV} \times f_{\mathrm{p,PV}}\right) \quad (2)$$

where $E_{cons,fuel}$ is the energy consumption per fuel type (kWh/a), E_{PV} is the energy generated by the PV system (kWh/a), $f_{p,fuel}$ is the primary energy conversion factor for each fuel type and $f_{p,PV}$ is the primary energy conversion factor for electrical energy generated by the PV system.

Based on the equation, primary energy conversion factors for the fuel types consumed in Turkey are given as 1.00 for natural gas and 2.36 for electrical energy (BEP-TR, 2010). Regarding the primary energy conversion factor for electrical energy generated by the PV system, depending on the efficiency level of the grid; it is accepted that in order to obtain 1kWh energy, 3.23 kWh primary energy is consumed (Alsema, E.A., de Wild-Scholten, M.J., 2005; Ecoinvent, 2005; IEA, 2006; TETC, 2013).

2.3.4 Calculating CO_2 emissions

In order to evaluate environmental performance of the strategies taken to improve energy performance of the reference residential building, in other words in order to calculate CO_2 emissions caused by energy consumption, as integrated to the energy performance analysis, Tier 2 (T2) method specified in the IPCC Guidelines is used. With the T2 method, CO_2 emission values of the reference residential building are calculated using the following equation (IPCC, 2006):

$$Emission_{co2} = \sum \left(E_{cons,fuel} \times f_{CO_2,\text{fuel}} \right) - \sum \left(E_{PV} \times f_{CO_2,\text{PV}} \right) \quad (3)$$

where $E_{cons,fuel}$ is the energy consumption per fuel type (kWh/a), E_{PV} is the energy generated by the PV system (kWh/a), $f_{co_2,fuel}$ is the CO_2 emission conversion factor for each fuel type ($kgCO_2$/kWh) and $f_{co_2,PV}$ is the conversion factor for the CO_2 emissions which is prevented as a result of the electrical energy generated by the PV system ($kgCO_2$/kWh).

In the equation, the conversion factors for CO_2 emissions of the fuel types consumed in Turkey are taken as 0.20 for natural gas and 0.55 for electrical energy (Ozkal, S., 2013). The conversion factor for the CO_2 emission which is prevented as a result of the electrical energy generated by the PV system is taken as 0.88 $kgCO_2$/kWh (GEMIS, 2013).

2.4 Economic performance analysis

With the analysis which aims to evaluate the economic convenience of the strategies concerning the improvement of energy performance of the reference residential building and to determine optimum efficiency level in terms of cost efficiency, economic performance analyses integrated with the energy performance analyses are performed.

For the economic variables required for economic performance analysis, the discount rate is taken as 6% (TSI, 2013; ISBANK, 2013), the analysis period is taken as 30 years (European Commission, 2012) and the analysis start year is taken as 2013. The estimated economic life of these strategies is accepted as equal to the duration of the analysis used for the calculation. Initial investment cost and usage cost are studied under the scope of cost data. In this study, for the cost calculations concerning each strategy, strategy combination and variable; (1) costs which are the same for all strategies, strategy combinations and scenarios and (2) costs of the building elements which do not have any effect on the energy performance of the reference residential building are not taken into consideration. In this study, current applicable taxes are excluded in the cost calculations and the foreign exchange rate published by the Central Bank of the Republic of Turkey (CBRT) is used for the current exchange rate (CBRT, 2013).

Economic performance analysis of the reference residential building based on the strategies in this study includes the following four processes;

- calculating initial investment costs (euro),
- calculating usage costs (euro),
- calculating life cycle costs (euro),
- calculating the discounted payback period (year).

2.4.1 Calculating initial investment cost

Initial investment costs of the scenarios developed for the strategies are calculated by performing material analysis of the components of the building envelope and PV system in m² and determining unit costs. The following equation is used for this calculation:

$$C_I = \sum A_i C_{unit,i} \quad (4)$$

where C_I is the initial investment cost of the building (euro), A_i is the amount of the building materials or elements (m²), and $C_{unit,i}$ is the unit cost per each material or element (euro/m²).

The most recent market unit prices based on price quotations received from relevant companies regarding the strategies are determined in order to calculate initial investment costs (Table 6). These unit costs determined include only material prices.

Table 6. *Unit costs concerning the strategies.*

Strategies	Scenarios	U value (W/m²K)	Cost (€/m²)
Heat insulation of exterior wall components	Sc1	2.02	-
	Sc2	0.55	2.61
	Sc3	0.47	3.21
	Sc4	0.42	3.85
	Sc5	0.37	4.49
	Sc6	0.33	5.13
	Sc7	0.30	5.82
	Sc8	0.28	7.14
	Sc9	0.23	8.34
	Sc10	0.20	9.62
	Sc11	0.17	12.28
	Sc12	0.15	13.85
Improvement of glazing systems	Sc13	4.9	4.23
	Sc3	2.6	9.61
	Sc14	1.8	14.14
	Sc15	1.5	16.06
	Sc16	1.8	14.14
	Sc17	1.5	16.06
	Sc18	1.8	15.74
	Sc19	1.5	17.66
Solar control device	Sc20		Cost (€)
			6434.48
PV systems	Sc21-Sc23		Cost (€/Wp)
			1.50

2.4.2 Calculating usage cost

Energy costs and maintenance and repair costs are included in the usage cost and can be calculated using the following equation:

$$C_{Usage} = C_E - C_{M\&R} \tag{5}$$

where C_{Usage} *is* the usage cost (euro/year), C_E is the energy cost (euro/a) and $C_{M\&R}$ is the repair and maintenance cost (euro/a).

In order to determine energy costs of the strategies studied, (1) energy consumption for each fuel type, (2) unit cost for each fuel type, (3) final energy generation by PV systems, and (4) unit cost of electrical energy generated by the PV systems are taken into account and calculated using the following equation:

$$C_E = \sum \left(E_{cons,fuel} \times \mathrm{C}_{\mathrm{unit,fuel}} \right) - \sum \left(E_{PV} \times \mathrm{C}_{\mathrm{unit,PV}} \right) \tag{6}$$

where C_E *is the energy cost* (euro/a), $E_{cons,fuel}$ is the energy consumption per fuel type (kWh/a), E_{PV} is the the energy generated by the PV system (kWh/a), $C_{unit,fuel}$ is the unit cost per fuel type (euro/kWh) and $C_{unit,PV}$ is the unit cost of the electrical energy generated by the PV system (feed-in tariff) (euro/kWh).

For $E_{cons,fuel}$, based on the simulations performed by the Designbuilder programme within the scope of the energy performance analysis, final energy consumptions for natural gas and electrical energy consumption are taken into consideration. Unit price for the electrical energy is 0.109108 €/kWh which has been applied as the list price for residential buildings set by the Turkish Electricity Distribution Company (TEDC) (TEDC, 2013). Unit prices of natural gas are the unit prices applied by the natural gas distribution companies working in the climate regions included in this study and set as 0.03313958 €/kWh for Istanbul, 0.02894697 €/kWh for Antalya and Erzurum (IGDAS, 2013; OLIMPOSGAZ, 2013; PALEN, 2013).

For E_{PV}, based on the simulations performed by the PV*SOL Expert programme within the scope of the energy performance analysis, final energy generations for PV systems are taken into consideration. Unit cost of the electrical energy generated by the PV systems, in other words selling price to the grid, is 0.10 €/kWh (0.133$/kWh) which is applied for electrical energy generated by solar energy (Official Gazette, 2011).

When calculating usage costs; since not enough data have been obtained, repair and maintenance costs are not included in the calculations.

2.4.3 Calculating life cycle costs

When calculating life cycle costs (LCC) of the scenarios developed in relation to the strategies, the following equation is used which takes into account the present values of the initial investment costs and the life cycle usage costs:

$$LCC = C_I + C_{Usage,P} \tag{7}$$

where LCC is the life cycle cost (euro), C_I is the initial investment cost (euro) and $C_{Usage,P}$ is the present value of the usage cost (euro).

Usage cost is the cost which is repeated for the duration of the economic performance analysis of the reference residential building. Therefore, in order to calculate usage cost correctly, annual costs which will occur within the duration of economic performance depending on the current energy and repair-maintenance costs should be multiplied with the present worth factor (PWF) to convert into updated (present) values. The PWF value is calculated using the following equation based on the discount rate and time (Morton, R., Jaggar, D., 2003):

$$PWF = \frac{1}{\left(1+i\right)^{n}} \tag{8}$$

where *PWF* is the present worth factor, *i* is the discount rate (%) and *n* is the analysis period (year).

Accordingly, the following equation is used to find the present value of the usage cost (Morton, R., Jaggar, D., 2003):

$$C_{Usage,P} = \left(C_E \, x \sum_{n=1}^{t} \frac{1}{(1+i)^n} \right) + \left(C_{M\&R} \, x \sum_{n=1}^{t} \frac{1}{\left(1+i\right)^n} \right) \tag{9}$$

$$C_{Usage,P} = C_{E,P} + C_{M\&R,P} \tag{10}$$

where $C_{Usage,\,P}$ is the present value of the usage cost (euro), $C_{E,P}$ is the present value of the energy cost (euro) and $C_{M\&R,P}$ is the present value of the repair-maintenance cost (euro).

2.4.4 Calculating discounted payback period

For the economic performance analysis performed regarding the scenarios developed for the strategies, a discounted payback period method based on the defined data and assumptions is used. Thus, it is possible to determine how long it takes for the strategies included in the study can pay for themselves considering the time value of money. The discounted payback period (DPP) for the strategies is calculated using the equation given below (Fuller, S.K., Petersen, S.R., 1995):

$$\sum_{n=1}^{t} \frac{\left[\Delta C_{Usage}\right]}{(1+i)^n} \geq C_I \tag{11}$$

where ΔC_{Usage} is the total of the saving achieved in the usage cost (euro) and C_I is the initial investment cost (euro) for the strategy.

2.5 Evaluating optimal performance in terms of energy and cost efficiency

Scenarios where optimum performance is achieved in energy and cost efficiency based on the values achieved in energy and economic performance analysis performed separately for each strategy developed for different climate regions in order to improve residential building performance can be determined with a comparative method.

In the comparative method, the scenario with the highest energy consumption, CO_2 emission and cost is assumed to provide no benefit and therefore its effectiveness level is accepted as zero. Effectiveness levels of other scenarios are determined according to the comparisons made based on the scenario with an assumed effectiveness level of zero. In the comparisons, if there are scenarios with the same life cycle costs, the scenario with the lowest energy consumption and therefore the lowest CO_2 emission is taken into consideration.

Among the strategies employed for energy and cost efficiency:

- The scenario which uses the resources (such as natural gas, electricity) at the minimum and therefore which has lower energy consumption and CO_2 emission level,
- which has the lowest life cycle cost and is self-financing,

is accepted as the energy retrofit strategy with the optimum performance.

2.6 Defining and evaluating optimal retrofit combinations suitable for different climate regions

After scenarios which deliver optimal performance in terms of energy and cost efficiency for different climate regions have been identified, optimal retrofit combinations in which these scenarios are combined together can be defined. Therefore the combined effect of the strategies in terms of energy consumption, CO_2 emission and life cycle cost can be determined with repeated energy and economic performance analyses and compared with the reference residential building's existing performance level. Thus, the effectiveness level of the optimal combinations on the existing energy, economic and environmental performance, in other words, the improvement rate in energy and cost efficiency can be determined.

3. Results

3.1 Results of energy performance analysis

Energy performance analyses of the reference residential building in relation to the strategies included in this study are performed for Istanbul representing the temperate humid climate region, for Antalya representing the hot humid climate region and for Erzurum representing the cold climate region. The results can be seen in Figures 3-5.

As can be seen in Figure 3, in the scenarios concerning heat insulation on the external walls for the city of Istanbul (Sc1-Sc8), as the insulation thickness increases, final energy consumption, energy usage and therefore CO_2 emissions decrease. In the scenarios considered compared to the scenario Sc1 in which no heat insulation layer is present, a decrease of 29-33% in final energy consumption, 22-25% in energy usage and 20-24% in CO_2 emissions are achieved. Among the scenarios concerning improvement of glazing systems (Sc13-Sc15,Sc18,Sc19), the lowest final energy consumption, energy usage and CO_2 emissions are observed in the scenario Sc15. In the scenario Sc15, with the glazing system defined as Low-E (heat control, e2=0.04) coating filled with argon gas, when compared with the scenario Sc13 in which a single glazing system is defined, a decrease of 15% in the final energy consumption and of 12% in the energy usage and CO_2 emissions are found. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc20 in which an exterior venetian blind system is used as the solar control device, a reduction of 1-2% is found to be achieved in the final energy consumption, energy usage and CO_2 emissions. In the scenario Sc21 in which a PV system consisting of monocrystalline silicon PV modules which cover the entire terrace roof area is used, final annual energy consumption is calculated as 46.38 MWh/a and the energy cover factor is calculated as 25%. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc21, a reduction of 7% in the final energy consumption, 17% in energy usage and 22% in CO_2 emission are seen to be achieved.

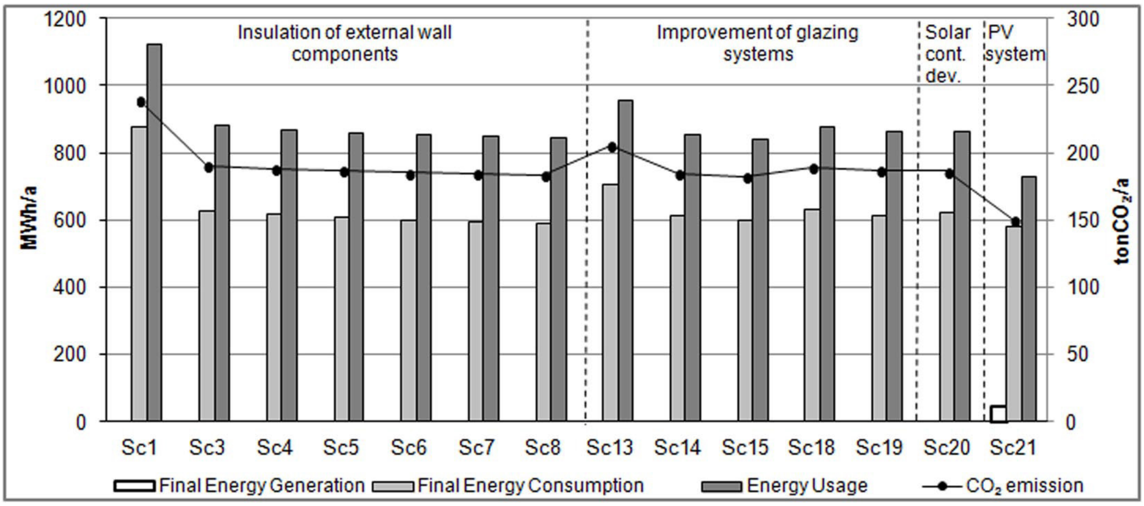


Figure 3. *Energy performance analysis results for Istanbul.*

Among the scenarios concerning the heat insulation on the exterior walls for the city of Antalya (Sc1-Sc8), as the insulation thickness increases, there is a varying situation where both decreases and increases are seen in the final energy consumption, energy usage and therefore CO_2 emissions (Figure 4). In the scenarios studied; compared to the scenario Sc1 in which no heat insulation layer is present, a decrease of 19-23% in final energy consumption, 13-16% in energy usage and 12-14% in CO_2 emissions is achieved. Among the scenarios concerning improvement of glazing systems (Sc13,Sc18,Sc19) which are taken into account for Antalya, the lowest final energy consumption, energy usage and CO_2 emissions are observed in the scenario Sc19. In the Sc19 scenario, with the glazing system defined as Low-E (heat and solar control, e2=0.02) coating filled with argon gas, when compared with the scenario Sc13 in which single glazing system is defined, a decrease of 8% in the final energy consumption and of 9% in the energy usage and CO_2 emissions are found to be achieved. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc20 in which an exterior venetian blind system is used as the solar control device, a reduction of 4% in the final energy consumption, and 6% in energy usage and CO_2 emissions are found to be achieved. In the scenario Sc23 in which a PV system consisting of monocrystalline silicon PV modules which cover the entire terrace roof area is used, final annual energy consumption is calculated as 51.01 MWh/a and the energy cover factor is calculated as 22%. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc22, a reduction of 12% in the final energy consumption, 22 % in energy usage and 22% in CO_2 emissions is seen to be achieved.

As can be seen in Figure 5, among the scenarios concerning the heat iAs can be seen in Figure 5, among the scenarios concerning the heat insulation on the exterior walls for the city of Erzurum (Sc1-Sc12), as the insulation thickness increases, final energy consumption, energy usage and therefore CO_2 emissions decrease. In the scenarios considered, compared to the scenario Sc1 in which no heat insulation layer is present, a decrease of 34-43% in final energy consumption, 30-37% in energy usage and 29-36 % in CO_2

emissions are achieved. Among the scenarios concerning improvement of glazing systems (Sc13,Sc16,Sc17) which are taken into account for Erzurum, the lowest final energy consumption, energy usage and CO_2 emissions are observed in the scenario Sc17. In the Sc17 scenario with the glazing system defined as Low-E (heat control, e3=0.03) coating filled with argon gas, when compared with the scenario Sc13 in which a single glazing system is defined, a decrease of 18% in the final energy consumption, 15% in the energy usage and 14% in CO_2 emissions are found to be achieved. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc20 in which an exterior venetian blind system is used as the solar control device, no change is found in CO_2 emissions. In the scenario Sc22 in which a PV system consisting of monocrystalline silicon PV modules which cover the entire terrace roof area, final annual energy consumption is calculated as 42.86 MWh/a and the energy cover factor is calculated as 26%. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc22, a reduction of 4% in the final energy consumption,11% in energy usage and 14% in CO_2 emissions are seen to be achieved.

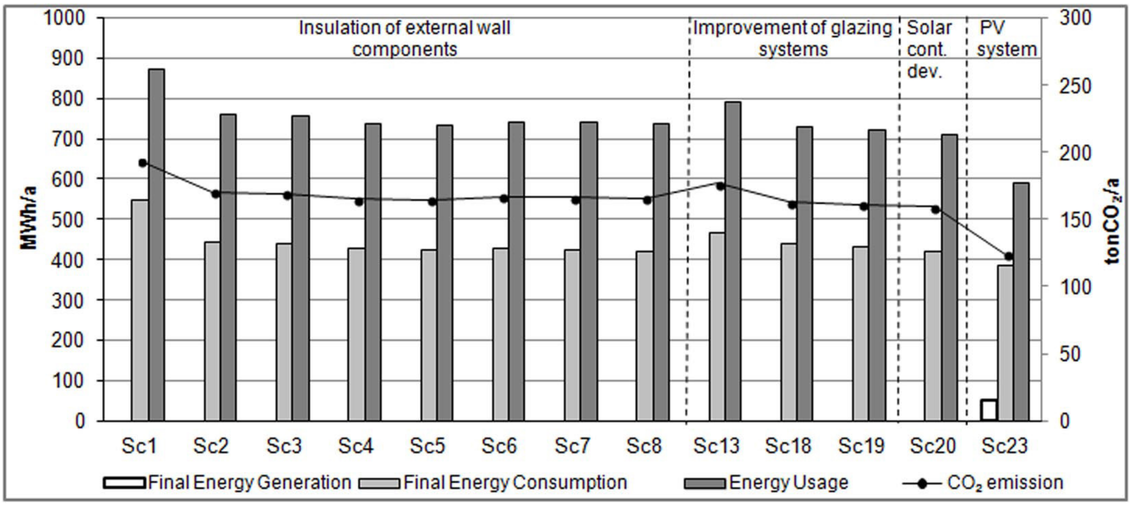


Figure 4. Energy performance analysis results for Antalya.

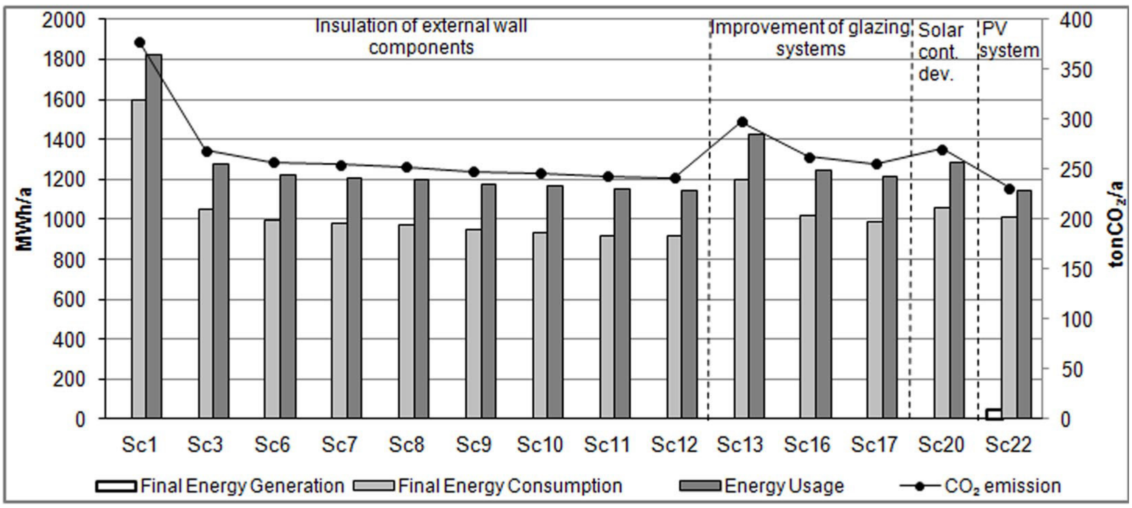


Figure 5. *Energy performance analysis results for Erzurum.*

3.2 Results of economic performance analysis

Economic performance analyses integrated to the energy performance analyses concerning strategies included in the study are performed for Istanbul representing the temperate humid climate region, for Antalya representing the hot humid climate region and for Erzurum representing the cold climate region. The results concerning initial investment cost, usage cost and life cycle cost are shown in thousand of euros (TEUR) and the results concerning discounted payback period are shown in years which can be seen in Figures 6-8 respectively.

As can be seen in Figure 6, among the scenarios concerning the heat insulation on the exterior walls for the city of Istanbul (Sc1-Sc8), it is possible to say that the lowest life cycle cost level is achieved with the scenario Sc6. Compared to the scenario Sc1 concerning the situation where there is no heat insulation layer, in the scenario Sc6, there is a decrease of 22% in the annual usage cost and 17% in the life cycle cost. The initial investment cost in the scenario Sc6 can be paid back in 2.7 years with an annual saving of €8,872.62 on the usage cost. In the scenarios regarding the improvement of glazing systems (Sc13-Sc15,Sc18,Sc19), the lowest life cycle cost level is found to be achieved in the scenario Sc15. Compared to the scenario Sc13 in which a single glazing system is defined, in the scenario Sc15 annual usage cost decreases 11% and the life cycle cost decreases 9%. The initial investment cost in the scenario Sc15 can be paid back in 3.7 years with an annual saving of €4,011.41 on the usage cost. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc20 in which an exterior venetian blind system is used as the solar control device, annual usage cost decreases 3% and the life cycle cost decreases 1%. The initial investment cost in the scenario Sc20 can be paid back in 10.1 years with an annual saving of €869.28 on the usage cost. In the scenario Sc21 in which a PV system consisting of monocrystalline silicon PV modules which covers the entire terrace roof area, annual energy consumption decreases 13% and the life cycle cost decreases 3%. The initial investment cost in the scenario Sc21 can be paid back in 14.5 years with an annual saving of €4,623.16 on the usage cost.

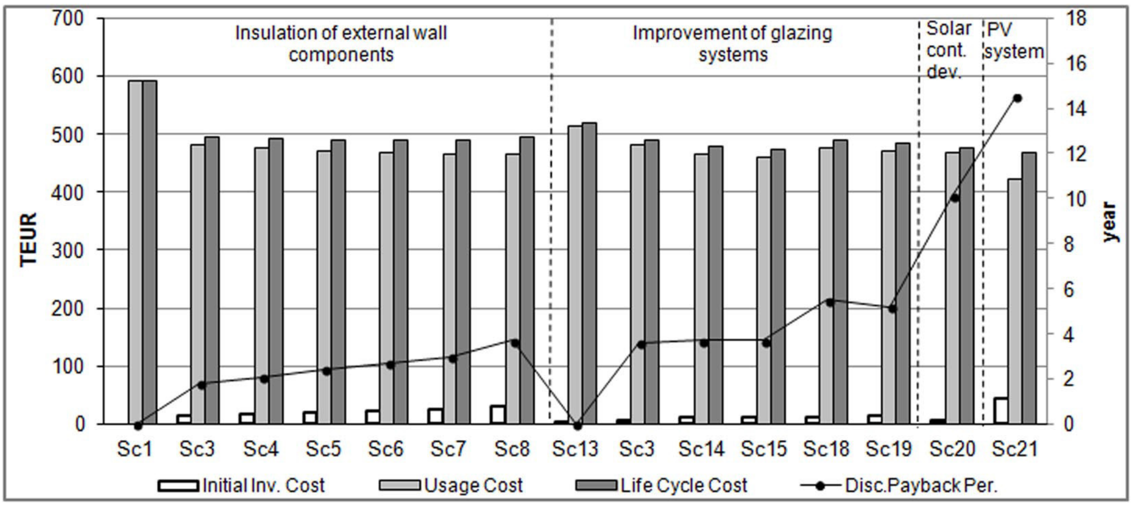


Figure 6. *Economic performance analysis results for Istanbul.*

Among the scenarios concerning the heat insulation on the exterior walls for the city of Antalya (Sc1-Sc8), it is possible to say that the lowest life cycle cost level is achieved with the scenario Sc4 (Figure 7). In the scenario Sc4 annual usage cost decreases 13% and the life cycle cost decreases 9%. The initial investment cost in the scenario Sc4 can be paid back in 4.3 years with an annual saving of €4,372.69 on the usage cost. In the scenarios regarding the improvement of glazing systems (Sc13,Sc18,Sc19), the lowest life cycle cost level is found to be achieved in the scenarios Sc19. Compared to the scenario Sc13 in which a single glazing system is defined, in the scenario Sc19, annual usage cost decreases 9% and the life cycle cost decreases 7%. The initial investment cost in the scenario Sc19 can be paid back in 5.8 years with an annual saving of €2,940.61 on the usage cost. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc20 in which an exterior venetian blind system is used as the solar control device, annual usage cost decreases 6% and the life cycle cost decreases 5%. The initial investment cost in the scenario Sc20 can be paid back in 3.7 years with an annual saving of €2,001.11 on the usage cost. In the scenario Sc23 in which a PV system consisting of monocrystalline silicon PV modules which covers the entire terrace roof area, annual energy consumption decreases 16% and the life cycle cost decreases 4%. The initial investment cost in the scenario Sc23 can be paid back in 12.9 years with an annual saving of €5,084.91 on the usage cost.

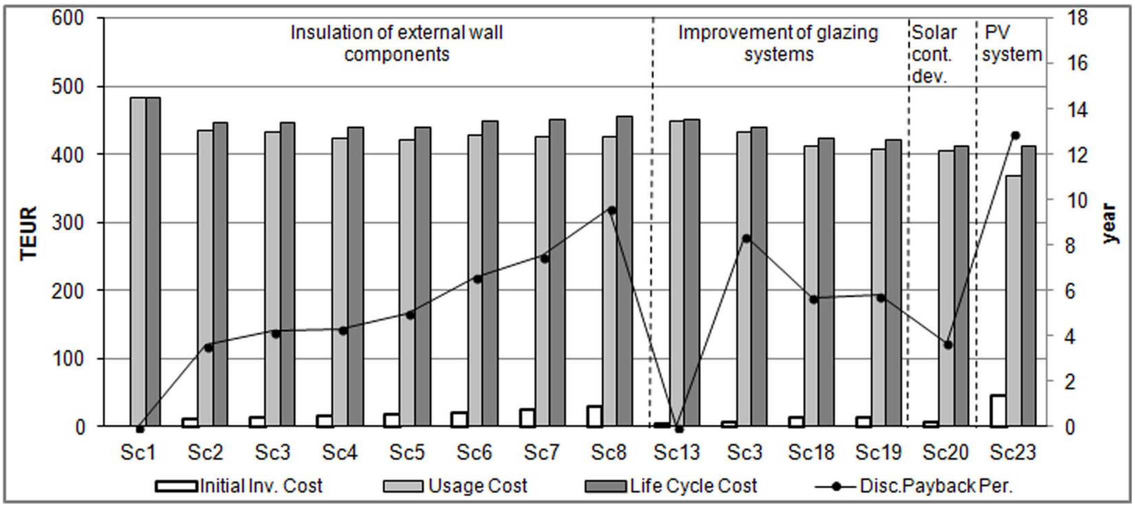


Figure 7. Economic performance analysis results for Antalya.

As can be seen in Figure 8, among the scenarios concerning the heat insulation on the exterior walls for the city of Erzurum (Sc1-Sc12), it is possible to say that the lowest life cycle cost level is achieved with the scenario Sc9. With the scenario Sc9, the annual usage cost decreases 31% and the cost of life cycle decreases 27%. The initial investment cost in the scenario Sc9 can be paid back in 2.1 years with an annual saving of €18,638.74 on the usage cost. Among the scenarios regarding the improvement of glazing systems (Sc13,Sc16,Sc17), the lowest life cycle cost level is found to be achieved in the scenario Sc17. Compared to the scenario Sc13 in which a single glazing system is defined, in the scenario Sc17 the annual usage cost decreases 13% and the life cycle cost decreases 11%. The initial investment cost in the scenario Sc17 can be paid back in 2.4 years with an annual saving of €6,026.34 on the usage cost. When compared with the scenario Sc3 in which the existing reference situation is defined, in the scenario Sc20 in which an exterior venetian blind system is used as the solar control device, no significant change is observed. In the scenario Sc22 in which a PV system consisting of monocrystalline silicon PV modules which covers the entire terrace roof area, the annual energy consumption decreases 10% and the life cycle cost decreases 2%. The initial investment cost in the scenario Sc22 can be paid back in 16.8 years with an annual saving of €4,272.47 on the usage cost.

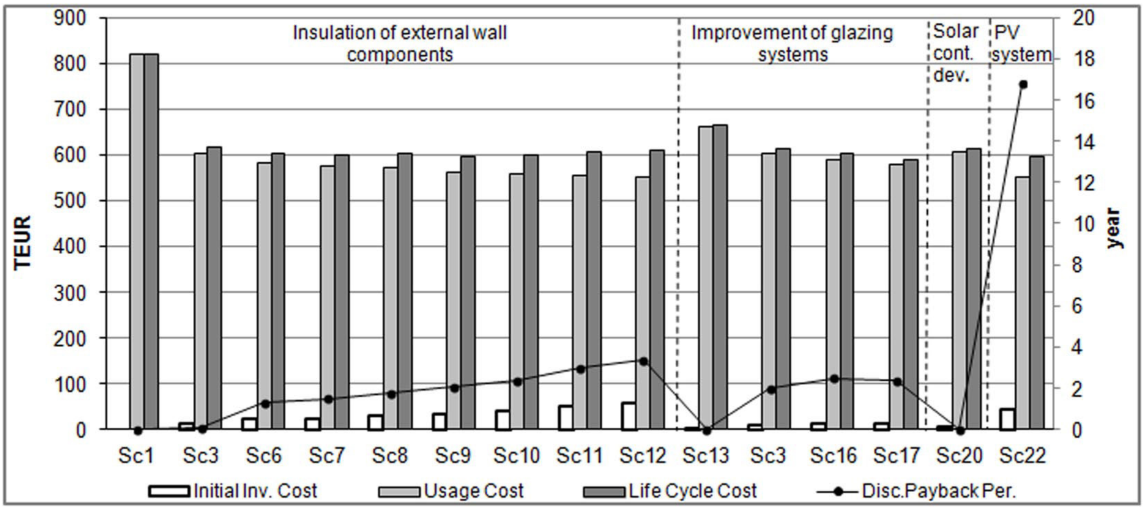


Figure 8. *Economic performance analysis results for Erzurum.*

3.3 Results of the evaluation of optimal performance in terms of energy and cost efficiency

Evaluation of optimum performance in terms of energy and cost efficiency is done based on the criteria that "*the scenario which has the lowest life cycle cost and is self-financing among the scenarios with minimum energy consumption and CO_2 emission level is the scenario showing the optimum performance"* in comparison to the scenario with the highest energy consumpion and CO_2 emission, developed according to the defined strategies. Thus, Figures 9-11 which show the effects of the strategies employed for the cities representing different climate regions on energy consumption (MWh/a) and life cycle cost (TEUR) are used in the evaluations.

The scenarios which show optimal performance in terms of energy and cost efficiency with the strategies employed are as follows:

- Concerning heat insulation on exterior wall components: Sc6 in which a heat insulation thickness of 8 cm is determined for Istanbul, Sc4 in which a heat insulation thickness of 6 cm is determined for Antalya, Sc9 in which a heat insulation thickness of 13 cm is determined for Erzurum;
- Concerning glass system retrofits: Sc15 in which a glass type with a heat control coating (e2:004, 12 mm argon gas) is determined for Istanbul, Sc19 in which a glass type with a heat and solar control coating (e2:0.02, 12 mm argon gas) is determined for Antalya, Sc17 in which a glass type with a heat control coating (e3:0.03, 12 mm argon gas) is determined for Erzurum;
- Concerning the use of solar control elements: the scenario Sc20 in which external venetian blind systems are used for Istanbul and Antalya but not for Erzurum;
- Concerning installation of PV systems: Sc21 in which a PV system of

29.26 kWp is installed on the roof for Istanbul, Sc23 in which a PV system of 29.83 is installed on the roof for Antalya, Sc22 in which a PV system of 29.64 is installed on the roof for Erzurum.

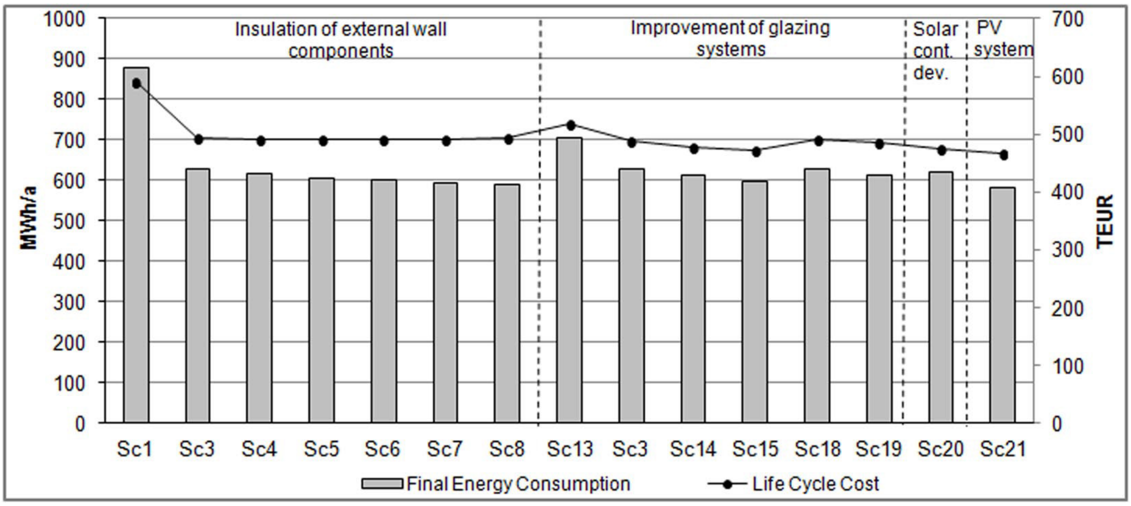


Figure 9. *Final energy consumption and life cycle costs concerning the scenarios taken for Istanbul.*

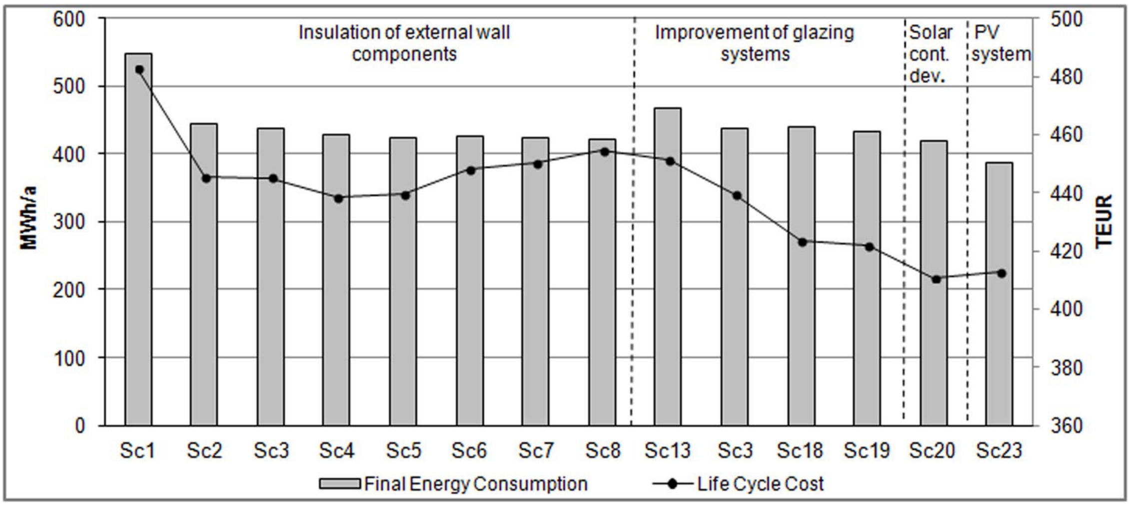


Figure 10. *Final energy consumption and life cycle costs concerning the scenarios taken for Antalya.*

3.4 Results of defining and evaluating optimal retrofit combinations suitable for different climate regions

Optimal retrofit combinations identified for different climate regions are seen in Table 7.

In order to determine combined effectiveness of the strategies developed under the optimal retrofit combinations in terms of energy consumption, CO_2 emission, and life cycle cost and in order to compare with the current performance level of the reference residential building, Figures 12-13 which show energy and economic performance analysis results are used.

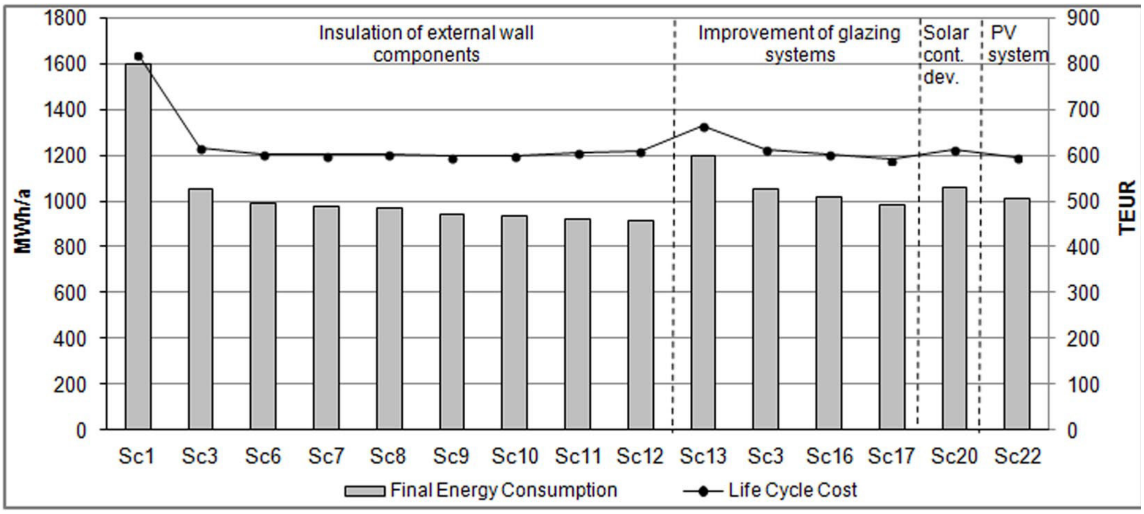


Figure 11. *Final energy consumption and life cycle costs concerning the scenarios taken for Erzurum.*

The effectiveness level of the optimal combinations (Sc_{opt}) on the existing energy, economic and environmental performance (Sc3), in other words improvement rate in energy and cost efficiency, is given below for the cities included in the study:

- *Istanbul (temperate humid climate region)*

According to the energy performance analysis results with the scenario $Sc_{opt,ist}$ developed for Istanbul, the annual final energy consumption decreases 21%, the annual usage energy decreases 28% and the annual CO_2 emission decreases 32% (Figure 12). The energy coverage factor in relation to the scenario $Sc_{opt,ist}$ is 26%. According to the economic performance analysis results, the annual usage cost decreases 23%, and the life cycle cost decreases 8% in the $Sc_{opt,ist}$ for Istanbul (Figure 13). The initial investment cost in the $Sc_{opt,ist}$ can be paid back in 18.5 years with an annual saving of € 8,069.48 on the usage cost.

- Antalya (hot humid climate region)

According to the energy performance analysis results with the scenario $Sc_{opt',ant}$ developed for Antalya, the annual final energy consumption decreases 16%, the annual usage energy decreases 29% and the annual CO_2 emission decreases 34% (Figure 12). The energy coverage factor in the scenario $Sc_{opt,ant}$ is 24%. According to the economic performance analysis results, the annual usage cost decreases 24%, and the life cycle cost decreases 8% in the scenario $Sc_{opt,ant}$ for Antalya (Figure 13). The initial investment cost in the $c_{opt,ant}$ can be paid back in 20.0 years with an annual saving of € 7,248.19 on the usage cost.

- Erzurum (cold climate region)

According to the energy performance analysis results with the scenario $Sc_{opt,erz}$ developed for Erzurum, the annual final energy consumption decreases 27%, the annual usage energy decreases 30% and the annual CO_2 emission decreases 32% (Figure 12). The energy coverage factor in relation to the scenario $Sc_{opt,erz}$ is 25%. According to the economic performance analysis results, the annual usage cost decreases 26%, and the life cycle cost decreases 12% in the scenario $Sc_{opt,erz}$ for Erzurum (Figure 13). The initial investment cost in the $Sc_{opt,erz}$ can be paid back in 12.9 years with an annual saving of € 11,167.49 on the usage cost.

Table 7. *Data concerning optimal retrofit combinations.*

Rep. cities	Sc. No.	U_{wall1}, $U_{wall,2}$ (W/m²K)	U_{roof} (W/m²K)	U_{g_floor} (W/m²K)	U_{window} (W/m²K)	SHGC	Solar cont. dev.	PV system output (kWp)
Istanbul	$Sc_{opt, ist}$	0.28,0.39	0.55	0.51	1.50	0.44	available	29.26
Antalya	$Sc_{opt, ant}$	0.34,0.49	0.55	0.51	1.50	0.30	available	29.83
Erzurum	$Sc_{opt, erz}$	0.20,0.25	0.55	0.51	1.50	0.51	-	29.64

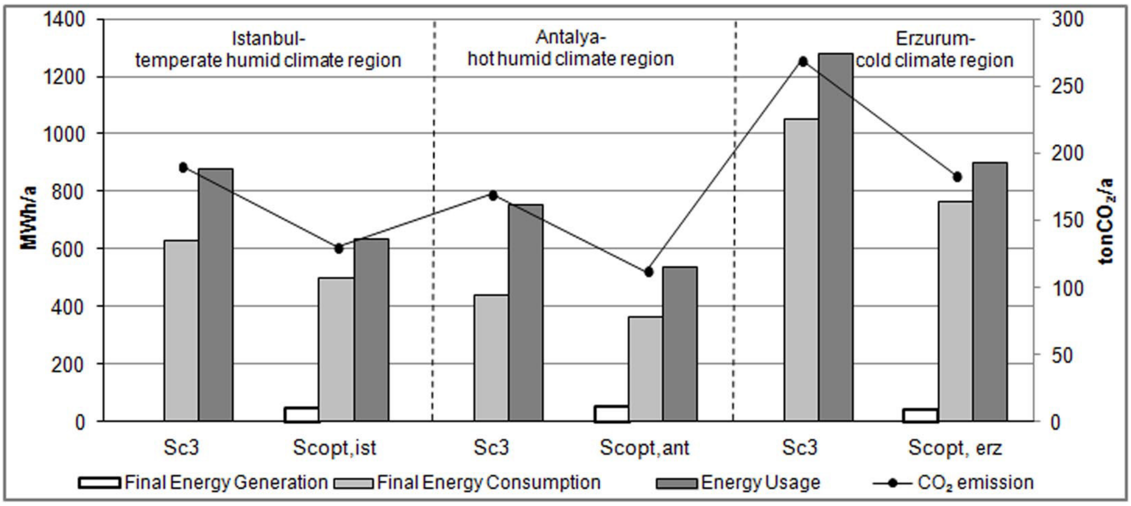


Figure 12. *Energy performance analysis results concerning optimal retrofit combinations.*

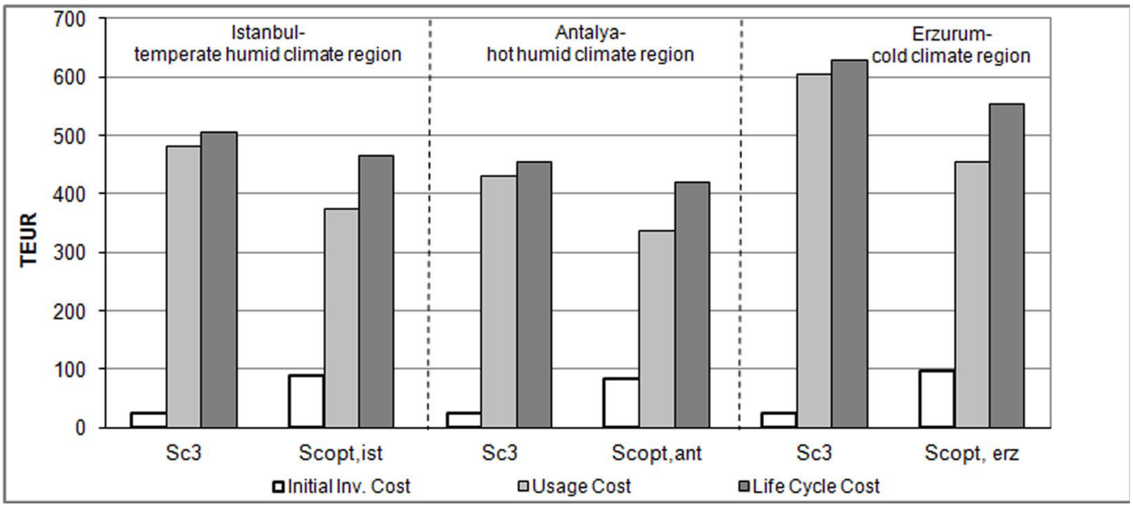


Figure 13. *Economic performance analysis results concerning optimal retrofit combinations.*

4. Conclusion

Residential buildings, as in the rest of the world, are significantly responsible for energy consumption and associated CO_2 emissions in Turkey and failure to pay attention to the efficiency or improvement of design or retrofit of residential buildings and to the environmental aspects lead to a situation where many permanent impacts become inevitable. Many countries develop various policies in order to capitalise on a high level of saving potentials both in the construction and retrofit of residential buildings which are defined as the priority efficiency areas within the framework of sustainable improvement goals. The aim is to achieve long term climate and energy goals by developing effective strategies with the policies produced, creating optimum solutions and promoting feasibility of these solutions with financial supports. In order to determine the combined effectiveness of the strategies developed under the optimal retrofit combinations in terms of energy consumption, CO_2 emission, and life cycle cost and in order to compare with the current performance level of the reference residential building, energy and economic performance analyses on optimal retrofit combinations are repeated. According to the results of the analyses, a reduction of 16-27% in final annual energy consumption, a reduction of 28-30% in annual usage energy, and a reduction of 32-24% in annual CO_2 emission are found, and the annual usage cost and life cycle cost are reduced 23-26% and 8-12%, respectively.

Therefore in this study, energy, economic and environmental performance of residential buildings with the retrofit strategies considered for different climate regions are evaluated by means of the comparative approach. In this study, strategies are applied in the reference residential building which is assumed to be located in the cities representing temperate humid, hot humid and cold climate regions of Turkey. Scenarios in which optimum performance is achieved in terms of energy and cost efficiency in the reference residential building are developed separately for each climate region based on the minimum energy consumption and therefore minimum CO_2 and the scenarios which have the lowest life cycle cost are found to be the ones which show optimum performance.

Thus it is possible to obtain results which may provide data and basis for laws and regulations on designing and retrofitting buildings and to make decisions which may provide maximum benefit for decision makers and the country's resources by evaluating complicated impacts of the strategies effective in enhancing energy performance on energy, economic and environmental performances in a holistic manner.

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Türkiye'de bir konut binası için optimum enerji iyileştirme stratejilerinin belirlenmesine ilişkin bir çalışma

Günümüzde, küreselleşen enerji ve çevre sorunlarının hızlı ve maliyet etkin olarak çözüme ulaştırılması ve sürdürülebilir, dönüşüm ve büyümeyi kapsayan kaynak etkin bir ekonominin oluşturulması açısından enerji etkinlik düzeyinin geliştirilmesi, tüm dünya ülkelerinin enerji politikalarının odak noktasını oluşturmaktadır. Enerji etkinlik, giderek ağırlaşan çevresel sorunlar karşısında çevresel gelişme ve ekonomik kalkınma arasındaki dengeyi koruyarak enerji, ekonomi ve çevre ile ilgili politikaların üretilmesini ve sürdürülebilirliğini önemli ölçüde belirleyen bir olgudur.

Bu bağlamda, dünya genelinde tüketilen enerji ve bu tüketimlere bağlı CO_2 salımlarından yüksek düzeyde sorumlu olan konut binalarının enerji, ekonomik ve çevresel açıdan gösterdikleri performans, enerji tüketim artış hızının düşürülmesine ve hatta azaltılmasına katkı sağlayabilecek en önemli unsurlardan biridir. Dolayısıyla, konut enerji performanslarının iyileştirilmesi ile konut binalarının enerji etkinlik düzeyinin artırılılabileceği ve böylelikle önemli oranda enerji tasarrufunun sağlanabileceği bilinen bir gerçektir. Bu nedenle, tüm dünyada "bina enerji performansına" ilişkin çalışmalar, binaların toplam ekonomik ve çevresel etki ve performanslarını dikkate alan bütüncül süreçlerin tanımlanması çerçevesinde gelişerek devam etmektedir. Özellikle, konut binaların enerji performanslarının geliştirilmesine yönelik düzenlenen yasal mevzuatlar aracılığı ile her ülke kendi koşulları çerçevesinde uyulması gereken zorunlulukları belirlemektedir.

Türkiye, bugün içinde bulunduğu koşullar çerçevesinde, Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi (BMİDÇS)'ne (2004) ve Kyoto Protokolü'ne (2009) taraf ve AB'ye aday ülke konumunda olması nedeniyle yerine getirmesi gereken yükümlülükler ile ilgili mevzuatların geliştirilmesini ve uygulanmasını esas alan çalışmalara devam etmektedir. Ancak bugün için Türkiye, enerji kaynakları açısından büyük oranda dışa bağımlı bir ülke olup dünya ortalamasının üzerinde gerçekleşmeye devam eden bir enerji talebi ile karşı karşıyadır. Bu kapsamda, Türkiye için enerji arz güvenliğini sağlamaya yönelik enerji verimliliği çalışmalarının gündemdeki önemi artarken diğer taraftan çok yüksek düzeyde enerji tüketiminin gerçekleştiği konut üretimi ise hız kazanmaktadır. Bununla birlikte, yüksek enerji tasarruf potansiyelinin belirlendiği ve önemli ölçüde yeni üretimlerin öngörüldüğü konut sektörü için enerji ve çevresel faktörler, çoğunlukla yasal mevzuatlar ile belirlenen gerekliliklerin sağlanıp sağlanmadığının sorgulanması ile sınırlı kalmaktadır. Dolayısıyla, Türkiye'nin sürdürülebilir kalkınma hedeflerine ulaşabilmesi için gerek mevcut konut stoğunun enerji ve maliyet etkin iyileştirilmesine gerekse yeni konut üretim sürecine enerji ve maliyet etkin yaklaşımın entegre edilmesine yönelik kapsamlı çalışmaların yapılması ve böylelikle yol gösterici kriterlerin oluşturulması zorunluluğu doğmaktadır.

Bu çalışma ile ülke kaynakları ve karar vericiler açısından optimum faydanın elde edilmesi hedefine yönelik konut enerji performansını iyileştirmede etkili olan stratejiler farklı iklim bölgeleri için geliştirilmiş ve bu stratejilere ilişkin konut binalarının enerji, ekonomik ve çevresel performansları karşılaştırmalı yöntem esas alınarak değerlendirilmiştir. Böylelikle, binaların tasarımı ya da iyileştirilmesinde, binanın enerji, ekonomik ve çevresel performansının optimize edilmesi ile ilgili yönetmeliklere veri oluşturabilecek sonuçlar elde edilebilmekte ve gerek mevcut gerekse yeni yapılacak konut binalarının enerji ve maliyet etkinlik düzeylerinin geliştirilmesinde gereksinim duyulan teknik bilginin hazırlanmasına destek sağlanabilmektedir.