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The Effects of Window Alternatives on Energy Efficiency And Building Economy In High – Rise Residential Buildings In Cold Climates

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ABSTRACT

Currently, special care is given to determining the performance of windows and meeting the requirements of buildings. In terms of energy efficiency and building economy, window design and the selection of appropriate glazing systems are significant. This paper deals with double-glazing window units that are composed of, respectively, tinted glass, clear reflective glass, low emissivity (low-e) glass, and smart glass-one surface consisting of a high-performance heat-reflective glass and the other surface with a low-emissivity coating, which reduces the heating and cooling loads of buildings by providing both solar control and heat conservation. This study is aimed at investigating the effects of these different alternative units, instead of readily, available double-glazing units, in two flats that have the same construction and operation system, but with a different plan type, on building energy consumption and building economy in terms of a life cycle cost analysis. For study, Ankara is selected, as it has a cold climate, in Climate Region III of Turkey. F- and C- type high-rise residential blocks with flats with two and three bedrooms, respectively, constructed by the Republic of Turkey Prime Ministry Housing Development Administration of Turkey -TOKİ in Ankara, are used as models for the simulation. The flat plans in these blocks are modelled by means of DesignBuilder 1.8 v energy simulation software.

Key Words: *Energy efficiency; Heating load; Cooling load; Life cycle cost; Double glazing window; Computer simulation.*

1. INTRODUCTION

When developments in technology and industry, population growth, energy and increased construction costs are considered, it is observed that the ratio of production to consumption had decreased dramatically worldwide. The United States constitutes 5% of the world's population, yet US citizens account for nearly 80,000 kWh per person per annum; UK citizens consume 45,800 kWh each year, compared to an average of 36,400kWh per capita for Europe [1]. In Turkey, where 66% of the total energy demand was imported in 2000, it

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is suggested that in 2010 and 2020, 73% and 77% of the total energy used, will be imported, respectively. The effect of these energy incomes on a country's economy is substantially high. According to the Prime Ministry For Foreign Trade in 2009, Turkey has been spending $45 million annually on energy. In addition, energy efficiency in Turkey is considered to be of primary importance due to problems such as global warming, environmental pollution, and increasing energy costs [2].

According to energy statistics, energy consumption in the residential sector constitutes 30% of total energy consumption in Turkey [3]. Measures to reduce the heating and cooling loads of a building and the use of passive sytems are important in energy efficient house design. As a result, technical engineers, architects and building authorities should find methods to reduce energy consumption in homes. In this context, the energy savings that energy-efficient window designs provide are significant. In recent years, solar-control glass (absortive, reflective glass), heat-conservation glass (low-e coating glass), and both solar-control and heat-conservation glass (reflective+low-e coating glass) have been produced. By using these glass alternatives, the heating and cooling loads of a building may be considerably reduced. Many homes in Turkey still have single-glazed windows that have poor thermal performance values. For instance, 87% of the residential building stock in Turkey has single-glazed windows, 9% has double-glazed, and only %4 has low-e glass [4].

Developing and under-developed countries can either prepare their own norms or use international norms to evaluate the energy performance of buildings. In Turkey, TS 825 'Heat Insulation Code in Building' is the only regulation adressing this issue. In this document, Turkey is separated into four climatic regions, and the maximum heat transmittance coefficient (U- value) of windows in these regions is determined. According to this, the U-value for Climate Regions I, II, III and IV should be 2.4 W/m^2K [5]. This norm calculates only the heating loads of buildings. In cooling load calculations, TS EN 15255 'Energy performance of buildings/Sensible room cooling load calculation/General criteria and validation procedures' is used.

There have been several studies on the energy efficiency and cost analysis of different windows units. Sekhar et al. [6] presented a study in 1998, in which the energy performances and life cycle costs of the smart window, a double-glazing unit in which one pane consists of a high-performance heat- reflective glass and the other is coated with a low-emissivity (low-e) coating, were compared with the performance of double-glazing units composed of clear, low-e, and reflective glasses, respectively. Energy performances and atmospheric pollutant levels were calculated for the window alternatives in a twenty-story building model. They found that the smart windows met the technical and economic targets set, thus making these units a viable long-term investment for high-rise commercial buildings. Bojic et al. [7] published a study in 2001 in which they investigated the energy performances of multiple-glazing units in high-rise residential buildings in Hong Kong in hot and humid climates. For the study, they selected a two-flat plan that was modelled using HTB2 simulation software. In these flats, tinted, reflective, and tinted-reflective glasses were used in different orientations. The energy performances of the flats were evaluated by calculating the yearly cooling load and the peak cooling load.

Karlsson et al. [8] published a study in 2001 in which they further developed a simple model for the annual energy balance of windows, taking solar radiation and heat losses into consideration. Hourly meteorologic data for the solar radiation and the outside temperature were used together with the optical and thermal performance of the window to evaluate the net energy heat flow through a window. The model rendered a very simple way to compare different advanced windows in different geographical locations, orientations, and buildings using basically only the balance temperature as the building input. As an example, the energy balance and the cost efficiency for several glazing combinations were evaluated for buildings with different balance temperatures in a typical mid-Swedish climate.

In 2004, Çetiner et al. [9] suggested an approach for evaluating energy and economic efficiency using different single- and double-glazing facade configurations in an office block with 30 stories in İstanbul. This approach included aims/limitations, the problem of formulation involving performance criteria and alternative solutions, a building model involving thermal-optical properties, heat gains/losses, total energy loads and life cycle costs calculated by using simulation software, and a conclusion section containing a comparison of energy efficiency and an exploration of efficient alternatives. They found that the most energy efficient double-skin glass facade is about 22.84% more efficient than the most energy efficient single-skin glass facade. Additionally, the most cost efficient single-skin glass facade is about 24.68% more efficient than the most cost efficient double-skin glass facade.

Gugliermetti et al. [10], in 2005, investigated the effect of reversible windows on the energy performance of a building. The investigated window was a double-glazing unit, where one layer is absortive glass and the other is clear glass. This study was realized for four cities representing a Mediterranean climate, and the energy performance of a room 3x4 m in size without heating-cooling was calculated. In conclusion, double-glazed window systems made of an absorbing and a clear glass pane can reduce yearly energy requirements if they are turned by 180^0, with the absorbing pane facing the indoor side during the heating season and the outdoor side during the cooling one.

Maçka [11] , in 2008, developed Win-Energy 1.0 software to calculate the thermal performance criteria and the energy loads of different window alternatives and, using this software, tested eight types of single-pane glass by using them in different surfaces of double- and triple-glazing units and compared these glazing units in terms of energy efficiency in Turkish climate regions. Yaşar et al. [12], in 2009, calculated heat gains/losses for January 21 and June 21 and the thermal performance criteria of double-glazing units with soft and pyrolytic low-e coatings, with emissivity values ranging from 0.84 to 0.03, by means of Win-Energy 1.0 software for Turkish climate regions, and compared the energy efficiency performances of these alternatives.

Urbikain et al. [13] presented a study in 2009 in which the heating loads and energy savings of a residential building with different types of windows were obtained in three different ways. First, the energy lost through the window was evaluated, considering only the climatic conditions. Second, the window was evaluated by taking the energy used for the heating system, taking the climate and the type of building into account. Finally, different cases were simulated using TRNSYS16 and WINDOWS5. These methods were applied to ten window types for different orientations and window-to-wall ratios. Method 1 was found to be too simple to predict heating savings in the actual building. Method 2 predicted energy savings similar to the simulation results, except in the case of solar control or spectral-selective glazing.

The aim of this study is to determine the effects that different types of glazing units (solar control, heat conservation and solar control+heat conservation glazing units) used in high-rise residential buildings have on building energy peformance and life cycle costs in the cold climate regions of Turkey.

2. METHOD

The current study uses F- and C-type high-rise residential blocks with eight and twelve stories, respectively, constructed by the Republic of Turkey Prime Ministry Housing Development Administration of Turkey-TOKİ for all of the Turkish climate regions. The main target in the selection of this project is that criteria affecting the building energy performance and the life cycle cost for the four climate regions of Turkey, for the same type of building forms in future studies, are compared. These blocks are located in Ankara, in Climate Region III, a cold climate. Two flats in these blocks with different dimensions were simulated by means of DesignBuilder energy simulation software using the available construction and HVAC systems. Later, in these flats, data related to energy loads and interior conditions are determined. To investigate the effect of different glass types on heating and cooling loads, all parameters except for the glazing units of the windows were kept constant. The glazing units used were double-glazing units with a low-e coating, tinted (blue, green) units, clear reflective units, blue reflective + low-e coating units, and green reflective+low-e coating units, instead of the widely available clear double-glazing units. Heating and cooling loads through these glasses were calculated monthly and annually by means of the software. For each flat, eight simulation outputs were obtained.

Next, the initial capital investment of each window alternative was calculated according to the unit price per square meter of the eight different glass types. By summing the initial capital investment and the energy cost of the windows, the life cycle cost is determined. In Turkey, since costs related to maintenance, repair, and replacement are not determined by institutions or firms, these costs were the same for all of the window alternatives. Finally, the energy and economy efficiency of the glazing unit alternatives were discussed, and appropriate alternatives were determined for the flats.

2.1. Glass Buildings

Windows, a key element of buildings, fulfill several tasks in terms of architecture and the environment. Whereas roofs and walls provide heat and moisture impermeability, windows allow heat and light transmission and resist heat. Currently, special care is given to determining the performance of windows and meeting the requirements of buildings. In terms of energy efficiency and building economy, window design and the selection of an appropriate glazing system are significant [14].

Criteria such as the solar control performance and the heat conservation performance of glass, building function, orientation, window area, window location, and climatic factors strongly affect energy efficient window design. These criteria should be known so that designers can make the best possible selection [11]. The heat conservation performance of any given glass depends on the heat transmittance coefficient (U-value,W/m^2K). A low U-value corresponds to high heat conservation performance. The solar heat gain coefficient (SHGC) is significant in determining the solar control performance of a glass. A low SHGC represents a high solar control performance [15].

Glass Types;

Glass technology is driven by glass firms developing energy efficient products, ranging from clear glass to glass that is absortive, reflective, with a low-e coating, and heat mirroring, with smart glass--photocromic, gazocromic, and elektrocromic glass--to be produced in the near future. The most important goal in recent years has been to develop zero-energy glass types providing economic efficiency [16].

Instead of the available glass typically used in flats, we used low-e coating glass with 0.15 and 0.10 emissivity values for surface numbers 2 and 3 facing the gap of the double-glazing unit, blue and green absorbtive glass, clear reflective glass, blue high performance reflective+low-e coating glass, and green high performance reflective+low-e coating. The thermophysical-optical and dimensional properties of the single glasses used in the double-glazing units are given in Table 1.

Table 1. Thermophysical-optical and dimensional properties of single pane glass [11].

Glass types	d (mm)	λ (W/mK)	T_{sol}	R_{sol1}	R_{sol2}	T_{vis}	R_{vis1}	R_{vis2}	e_1	e_2
S1. Clear glass	6	1	0,77	0,07	0,07	0,88	0,08	0,08	0,84	0,84
S2. Low-e glass(pyrolytic coating)#3	6	1	0,66	0,11	0,10	0,81	0,10	0,10	0,15	0,84
S3. Low-e glass(soft coating)#2	6	1	0,33	0,20	0,23	0,52	0,09	0,10	0,84	0,10
S4. Absorbtive glass (blue)	6	1	0,30	0,04	0,04	0,42	0,05	0,05	0,84	0,84
S5. Absorbtive glass(green)	6	1	0,33	0,04	0,04	0,66	0,06	0,06	0,84	0,84
S6. Reflective glass(clear)	6	1	0,49	0,27	0,20	0,37	0,34	0,26	0,84	0,84
S7. Smart glass (absorbtive+reflective+low-e-blue)	6	1	0,23	0,21	0,07	0,38	0,26	0,12	0,20	0,84
S8. Smart glass (absorbtive+reflective+low-e-green)	6	1	0,23	0,21	0,08	0,47	0,27	0,15	0,20	0,84

d: thickness,λ: thermal conductivity, T_{sol}: solar transmittance, R_{sol1}: solar reflectance that direction coming radiation,R_{sol2}: solar reflectance that opposite direction coming radiation,T_{vis}: visible transmittance, R_{vis1}: visible reflectance that direction coming radiation, R_{vis2}: visible reflectance that opposite direction coming radiation, e_1: emissivity value that direction coming radiation, e_2: emissivity value that opposite direction coming radiation.

The thermal performance criteria-calculated by means of Win-Energy 1.0 software-of the double-glazing units composed of the single glasses in Table 1 are given in Table 2. As can be seen in Table 2, the glass with the lowest U-value has the most efficient performance during the heating period. However, its SHGC value should be sufficiently low so that it can be efficient during the cooling period. In addition to energy savings, a cost analysis of these glazing units is described in the following sections, using a life cycle cost analysis method.

Table 2.Thermal performance criteria of the double-glazing units used in the building model simulation [11].

Double glazing unit (6-12-6 mm)	U W/m^2K	SHGC	T_{SOL}	$T_{VİS}$
CLR	2,7	0,70	0,60	0,78
LECLR3	1,9	0,66	0,53	0,72
LECLR2	1,8	0,36	0,27	0,46
HABLU	2,7	0,38	0,24	0,37
HAGRN	2,7	0,40	0,27	0,58
HRCLR	2,7	0,45	0,37	0,34
HRBLULE2	2,7	0,32	0,19	0,34
HRGRNLE2	2,7	0,32	0,19	0,42

2.2. DesignBuilder Energy Simulation Software

DesignBuilder 1.8.1 v, a dynamic building energy simulation software, was used to determine the interior conditions, including the heating and cooling loads in the flats throughout the year. It is the first comprehensive user interface to use the EnergyPlus dynamic thermal simulation engine. It can calculate the thermal performance of a building with multiple rooms for different climates and variable usage conditions.

The user is allowed to determine occupancy schedules, operation periods of heating and cooling, air conditioning systems, lighting, and home appliances. Thus, this software can determine heat gains/losses through building elements, energy loads through heating and cooling, air conditioning, lighting systems, and occupants and interior conditions such as air temperature, radiant temperature, operation temperature, and relative humidity [17].

2.3. Meteorological Data

The building model was located in Ankara (40,12^0 N, 33,00^0 E, altitude 949 m), in Climate Region III, representing the cold climate of Turkey [18]. Meteorologic data for Ankara are given in Table 3.

Table 3. Meteorologic data for Ankara [19].

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Outside dry bulb temperature-^{0}C	-2,4	0,5	2,6	8,9	13,6	16,9	21,5	21,1	17,0	10,3	3,8	0,8
Dew-point temperature-^{0}C	-5,5	-4,6	-3,5	2,3	6,1	7,2	9,3	8,1	6,9	2,9	-0,8	-2,0
Wind speed-m^2/s	1,2	2,6	2,8	2,6	2,1	2,3	3,4	3,3	2,4	2,1	2,4	1,6
Wind direction	46,4	99,2	139,4	136,1	108,7	120,3	92,9	92,8	67,6	85,5	88,7	82,5
Atmospheric pressure -Pa	91298,1	90850,1	90732,8	90529,0	90586,5	90458,6	90432,3	90419,3	90883,3	91073,5	90826,6	91286,9
Direct normal radiation-W/m^2	37,6	65,9	56,3	62,8	91,8	138,4	180,6	182,5	149,4	73,9	42,6	17,4
Horizontal diffuse radiation-W/m^2	34,7	41,0	70,0	88,7	103,8	95,0	88,1	70,5	59,7	56,0	37,2	30,95

2.4. Building Model

F- and C-type high-rise residential blocks with eight and twelve stories, respectively, constructed by the Republic of Turkey Prime Ministry Housing Development Administration (TOKİ) were used for the energy and cost efficiency analysis. Figures 1 and 2 show typical F and C high-rise residential buildings in Ankara, which comprise a total of four flats. The flat height is 2.8 m. The simulation study is based on the layout of Flat 1 of the F and C blocks. The flat in the F block has two bedrooms, and the flat in the C block has three bedrooms.

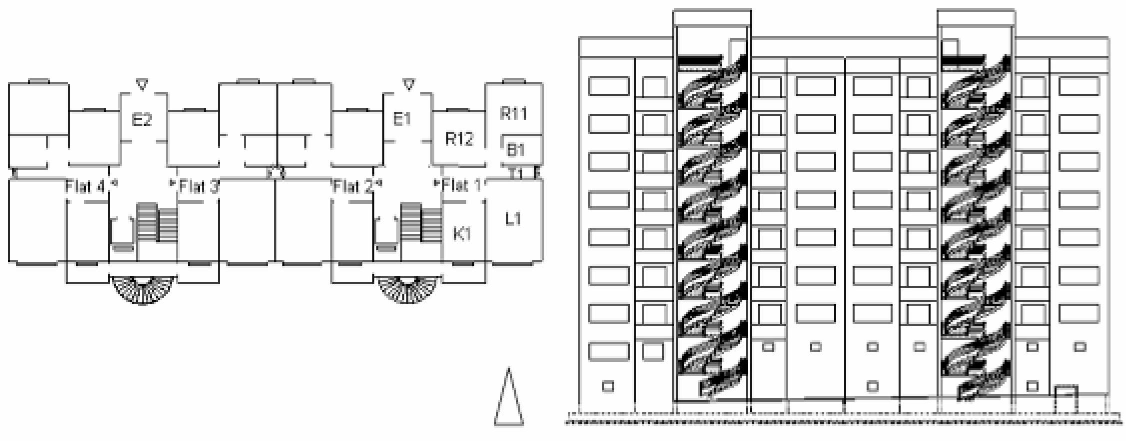

Figure 1. Plan and elevation of F-type high-rise residential blocks [20].

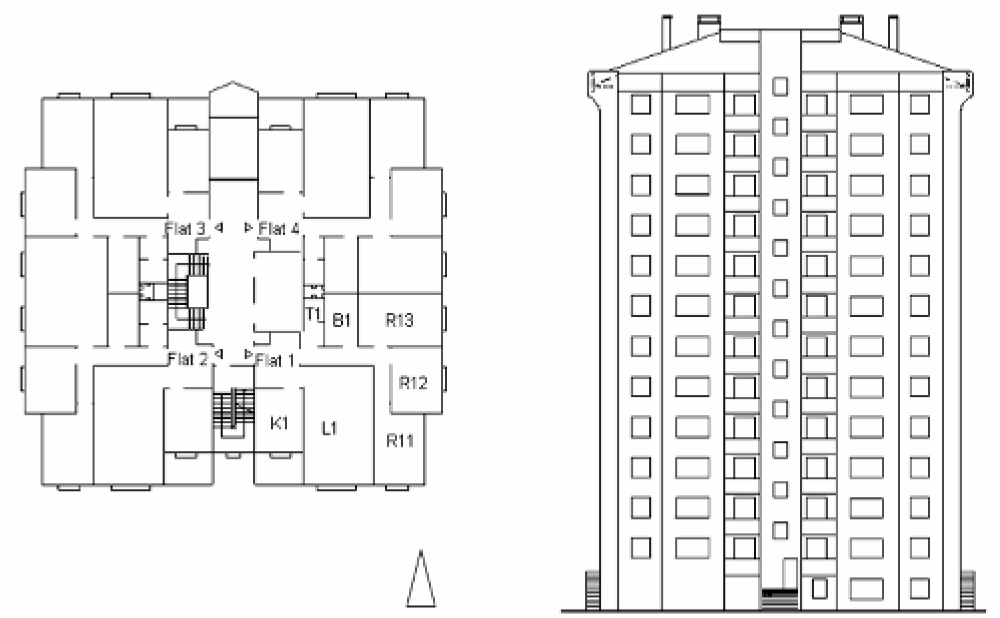

Figure 2. Plan and elevation of C-type high-rise residential blocks [20].

These flats, with seven and eight thermal zones, respectively, face southeast. Flat 1 in the F block with a total floor area of 56.85 m^2, has two bedrooms, one living room, one bathroom, one toilet, and one kitchen; Flat 1 in the C block, with a total floor area of 99.42 m^2, has three bedrooms, one living room, one bathroom, one toilet, and one kitchen. There are different window orientations in the flats. For Flat 1 in the F block, 40% of the windows face north, 57% face south, and only 1.4% face southeast. For Flat 1 in the C block, 63% of the windows face south, and 34% face east. The room and window dimensions of the flats are given in Table 4. Figures 3 and Figure 4 show the modelled flats.

Table 4. Room and window dimensions of the flats.

	Flat 1 ('F' type- 2 bedrooms)	Window dimensions and orientation				Flat 1 ('C' type - 3 bedrooms)	Window dimemsions and orientation			
		*L (m)	*H (m)	Area (m^2)	Direction		L (m)	H (m)	Area (m^2)	Direction
Bedroom 1	10,45	1,3	1,3	1,69	N	12,15	1,4	1,35	1,89	S
Bedroom 2	9,60	1,3	1,3	1,69	N	10,40	1,4	1,35	1,89	E
Bedroom 3	-	-	-	-	-	14,20	1,4	1,35	1,89	E
Living room	15,84	2,4	1,3	3,12	S	27,86	2,4	1,35	3,24	S
Kitchen	7,48	1,2	1,3	1,56	S	8,80	1,3	1,35	1,75	S
Bathroom	3,36	0,2	0,6	0,12	S	5,70	0,2	0,6	0,12	*İV
Toilet	1,98	0,2	0,6	0,12	E	3,55	0,2	0,6	0,12	*IV
Hall	8,14	-	-	-	-	16,76	-	-	-	-
Total	56,85	-	-	8,3	-	99,42			10,9	

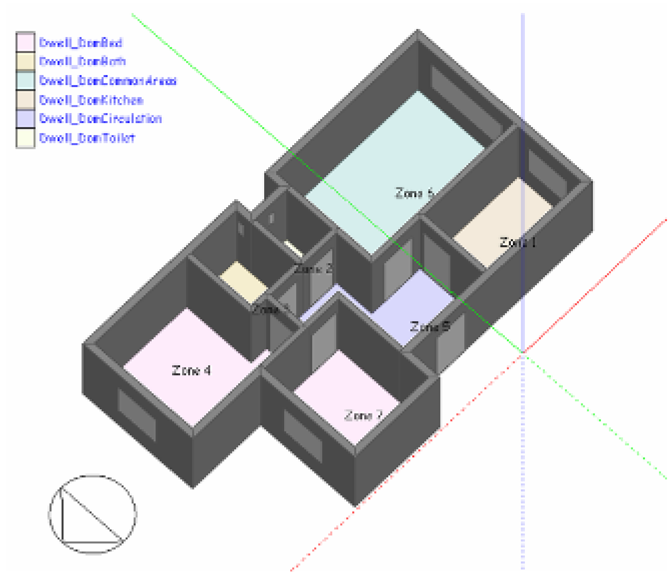

Figure 3. F-type flat model.

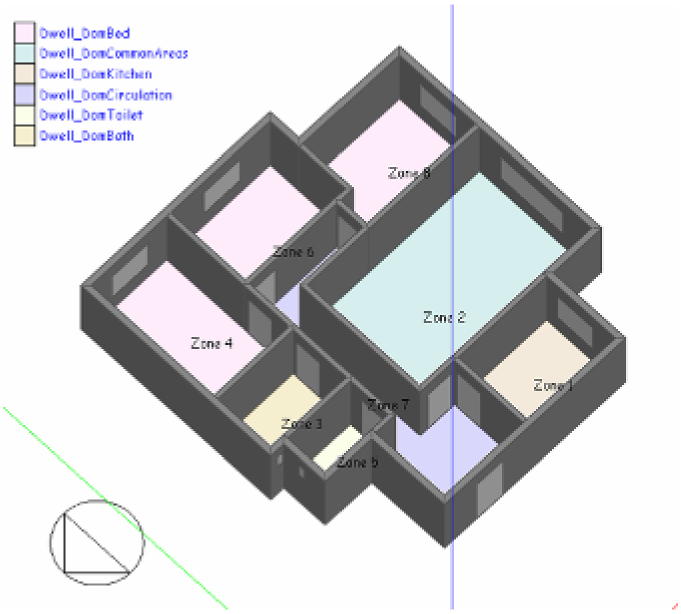

Figure 4. C-type flat model.

Building model construction

The compositons of the walls of both flats are the same. Each flat has both exterior and partition walls. The exterior walls consist of four layers of material: a 20-mm-thick plaster layer on each side, a 190-mm-thick brick layer, and a 50-mm-thick expanded polystyrene – EPS heat insulation (on the outer surface). The heat transmittance coefficient (U-value) of the exterior walls is 0.57 W/m^{2}K. The partition walls consist of three layers of material: a 140-mm-thick brick layer and a 20-mm-thick plaster layer on each side. For all of the walls, the plaster layers are gypsum.

The heat transmittance coefficient (U-value) of the partition walls is 2.01 W/m^{2}K. The flat floors consist of four layers of material, listed from the lowest to highest surface: a 20-mm-thick gypsum plaster layer, a 140-mm-thick concrete layer, a 40-mm-thick morter, and a 20-mm-thick carpet/textile. The ceiling and floor constructions are the same, because the investigated flats are on intermediate floors. The heat transmittance coefficient (U-value) of the floor and ceiling construction is 1.34 W/m^{2}K. The properties of the building materials used in the flats are given in Table 5.

Table 5. Properties of building materials used in the flats [17].

	Density (kg/m^3)	Specific heat capacity (J/kg K)	Thermal conductivity (W/mK)
Concrete	1800	1000	1,35
Gypsum Plaster	1000	1000	0,40
Expanded Polystyren-EPS	15	1400	0,04
Morter	2800	896	0,88
Brick	1700	800	0,84
Carpet	200	1300	0,06

The existing windows in the flats are composed of polyvinyl chloride (PVC) – 20 mm thick and 40 mm wide-- and a double-glazing unit with two 6-mm-thick panes and a 12-mm-thick air gap [20]. In the double-glazing unit, a moisture-proof spacer with insulation is used. The heat transmittance coefficient (U-value) and shading coefficient (SC) of the double-glazing unit are 2.7 W/m^2K and 0.81, respectively [11].

Utilization of model flats

To obtain accurate energy simulation results using DesignBuilder, general data related to occupancy schedules, lighting use, power device use, and heating, ventilation, and air conditioning (HVAC) systems are required. These data are given in the following paragraphs.

Both flats were assumed to be the dwelling of a three-person family with two working adults and a studying child.

Households generally use the flats in the evening and at night. Weekend and weekday occupancy schedules for both flats are given in Table 6, including schedules for public holidays.

Table 6. Occupancy schedule for the investigated flats [17].

Time (h)	Rooms													
	Bedroom R1		Bedroom R2		Bedroom R3		Living room L1		Kitchen K1		Bathroom B1		Toilet T1	
	W.D	W. E	W. D	W. E	W. D	W. E	W. D	W. E	W. D	W. E	W. D	W. E	W. D	W. E
00:00-07:00	1	1	1	1	1	1	0.05	0	0	0	0	0	0	0
07:00-09:00	1	1	1	1	1	1	0.3	0.05	0.5	0	0	0	0	0
09:00-10:00	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0	0	0.5	0	0.1	0
10:00-11:00	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0.1
11:00-12:00	0	0.25	0	0.25	0	0.25	0	0	0	0.5	0	0.5	0	0
12:00-13:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13:00-14:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
14:00-15:00	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0
15:00-16:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16:00-17:00	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0.1
17:00-18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18:00-19:00	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
19:00-20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20:00-21:00	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0
21:00-22:00	0.25	0	0.25	0	0.25	0	0	0	0	0	0	0.1	0	0
22:00-23:00	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0	0	0.1	0	0.1	0
23:00-00:00	1	1	1	1	1	1	0.05	0.05	0	0	0	0	0.05	0.1

*Values represent number of person in the investigated rooms.

Lights in the room were thought to be turned on or off during the daytime and evening in relation to the occupancy schedules, except for the bedrooms, where the lights would be turned on only in the evening.

Many different power devices consume electricity or fuel in the flats: for example, televisions and computers in the living room and bedrooms, a refrigerator, washing machine, and stove in the kitchen, and gas water heaters in the bathroom. Except for the refrigerator, these devices consume energy only during the occupancy of the rooms, according to the occupancy schedule. When the kitchen is not occupied, the refrigerator consumes electricity due to continuous running.

The living room and all of the bedrooms in the flats are heated and cooled; the kitchen and bathroom are only heated, and the toilet and the common areas are not heated or cooled. The existing heating system in the flats is a central heating unit. It will run on natural gas. The heating system is operated six months out of each year, from the beginning of October until the end of March, between 08:00 and 18:00. It is assumed that the cooling system in the flats is an air conditioner running on electricity. Bathrooms and toilets would be continuously naturally ventilated. The ventilation rates are assumed to be 3 air-changes per hour (achs).

2.5. Life Cycle Cost Analysis

The life cycle cost is the total cost of ownership of machinery and equipment, including its cost of maintenance/repair, replacement, and operation.The life cycle cost is a summation of cost estimates from inception to disposal for both the equipment and operation as determined by an analytical study and an estimate of the total cost experienced, accrued annually, for the building life, with consideration given to the time value of money [21]. For the evaluation of a unit in terms of life cycle cost, all future costs during the unit life were discounted to the present value, except for the initial capital investment of the project. The following formula is used to calculate the life cycle cost (LCC) [22] :

$$LCC = I + M\text{-}R\text{-}O + R - RV \quad (1)$$

To realize accurate benefit and cost estimations for the duration of the project life in terms of energy efficiency, energy price, estimations related to rising energy prices, maintenance/repair, operation costs, and future and present cost values of investment must be determined. In addition, replacement treatment frequencies, tax rates, the value of money, and government programs must also be known.

The objective of the LCC analysis is to choose the most cost-effective approach from a series of alternatives to achieve the lowest long-term cost of ownership [23]. The factors used in the LCC analysis are given in Table 7.

Table 7. Factors used in the life cycle cost analysis.

Analysis type	General LCC analysis-non-federal,no taxes,
Beginning date for LCC	2009
Study period	30 years
Planning/Construction period	2 years
Service date	2011
Discount rate	%15
Life of glazing	60 years
Fuel type	Natural gas, electricity
The unit cost of natural gas	0,07368 TL/kWh (for 2009)
The unit cost of electricity	0,1983 TL/kWh (for 2009)

Initial capital investment calculation

Square-meter unit prices of the glazing units in this study were obtained from the Republic of Turkey Ministry of Public Works and Settlement and from glass companies in Turkey. In accordance with the total glazing area in the flats, for each flat, a total of eight initial capital investments are calculated.

While Table 8 shows the square-meter unit prices of the glazing units, Table 9 shows the total initial capital investment for the glazing units in the flats.

Data related to maintenance/repair and replacement are not presently available from the Republic of Turkey Ministry of Public Works and Settlement or from Turkish glass companies. Thus, these data are ignored in the LCCA, and only the initial capital investment and operation costs are used.

Table 8. Cost of glazing units/m^2 (TL) [24-25].

Glazing type	Supply price /m^2 (TL)
CLR	55
LECLR3	63
LECLR2	62
HABLU	56
HAGRN	56
HRCLR	60
HRBLULE2	68
HRGRNLE2	68

Table 9. Total initial capital investment for glazing units used in the flats (TL).

	CLR	LECLR3	LECLR2	HABLU	HAGRN	HRCLR	HRBLULE2	HRGRNLE2
FLAT 1 (F type)	456,5	522,9	514,6	464,8	464,8	498	564,4	564,4
FLAT 1 (C type)	599,5	686,7	675,8	610,4	610,4	654	741,2	741,2

Operation cost calculation

The operation costs of a building include total energy expenditures for heating and cooling of the building due to annual heat gains and losses and maintanence/repair costs in more specific periods. In this study, since there are not accurate data related to maintenance and repair costs, the energy expenditures are used for operation cost calculation.

Since energy expenditures are paid regularly, these expenditures are updated by using a present worth analysis for a study period of 30 years, using a discount rate of 15% applied by the International Finance Association for projects in Turkey [22]. A yearly inflation rate of 12% is used for Turkey. In this method, the present value of energy expenditures is attained by multiplying the single present worth factor (SPW), which depends on the year, and the discount rate of 15% obtained from discount rate tables [23]. The yearly energy costs of the glazing units used in the study flats are given in Table 10.

Table 10. Yearly energy costs of the glazing units used in the study flats –TL.

	CLR	LECLR3	LECLR2	HABLU	HAGRN	HRCLR	HRBLULE2	HRGRNLE2
FLAT 1 (F type)	262,999	256,779	139,322	138,851	149,686	170,548	133,079	133,925
FLAT 1 (C type)	448,853	437,724	238,568	239,789	257,872	292,006	226,444	227,851

3. RESULTS AND DISCUSSION

For the flats under investigation, which are located in Ankara, with a cold climate, monthly and yearly heat gains and losses and the total energy consumed by lighting, heating/cooling systems, and occupants were obtained from the simulation. In this section, evaluations are performed for the monthly heat gains and losses through the glazing units and for the yearly heating and cooling loads of these units. Finally, the calculated life cycle costs of individual glazing units are compared by using the method described in Section 2.5.

3.1. Comparing Energy Consumption Through the Different Windows

The monthly heat gains/losses of the windows are shown in Figures 5 and 6. The values in these figures are the mean monthly net energy flows through the windows, obtained by summing the heat gains/losses for each month from the simulation results. The evaluations are performed by considering the heating period from the beginning of October until the end of March, with the cooling period extending from the beginning of April until the end of September.

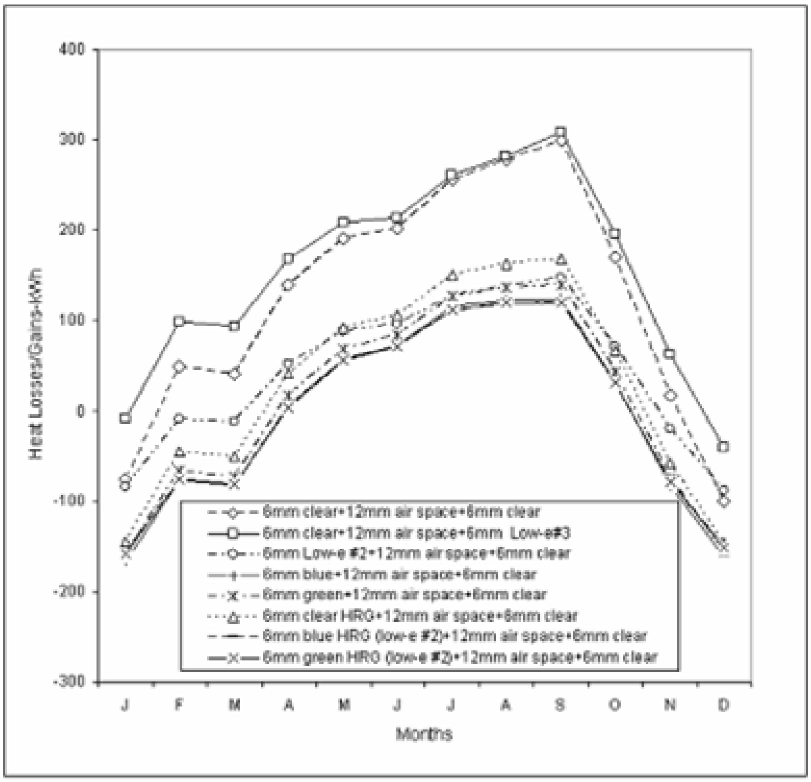

Figure 5. Monthly total heat gains/losses through double-glazing units in the investigated flats in the F-type block- kWh.

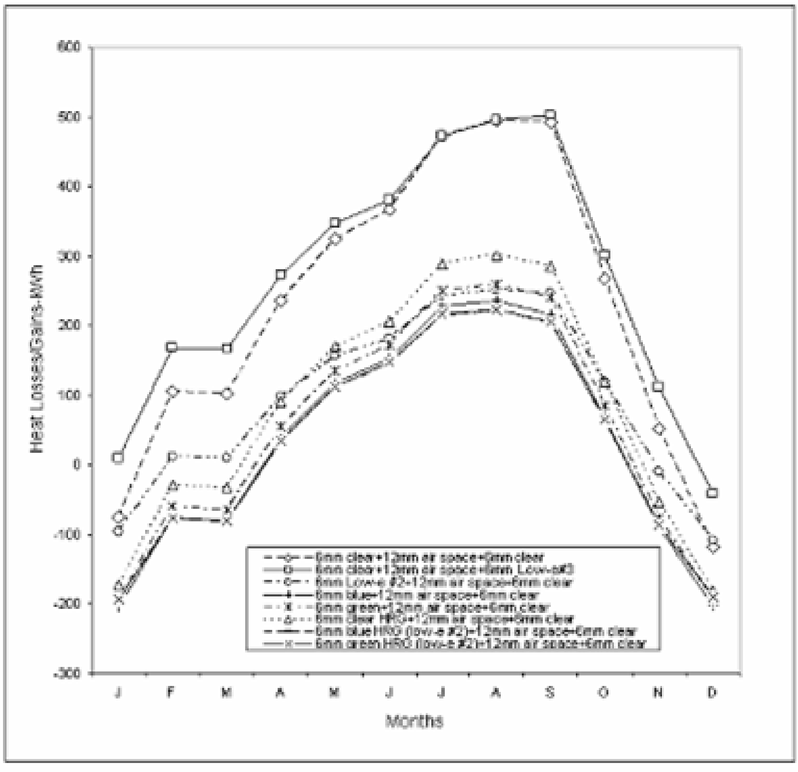

Figure 6. Monthly total heat gains/losses through double-glazing units in the investigated flats in the C-type block- kWh.

In winter, appropriate glazing units in terms of reducing heat losses are LECLR3, CLR, and LECLR2, as shown in Figures 5 and 6. In Flat 1 of block F, when looking at January, when the highest heat losses occur, LECLR3 provides 87.50 % more energy savings than CLR. LECLR2, HRCLR, HRGRNLE2, HRBLULE2, HAGRN, and HABLU cause 9.2 %, 47.57%, 52.12%, 52,31%, 52,56 % and 54.69% more heating energy consumption than CLR, respectively. Since the smart glazing units (HRGRNLE2, HRBLULE2) prevent the desired solar gains in winter due to their high solar control properties, they cause more heating energy consumption than CLR.

In summer, appropriate glazing units in terms of reducing heat gains are HRBLULE2, HRGRNLE2 and HABLU, as shown in Figures 5 and 6. In Flat 1 of the F block, for July, when the highest heat gains occur, HRBLULE2, HRGRNLE2, HABLU, HAGRN, LECLR2, HRCLR provide 56.81%, 56.43%, 55.02%, 50.27%, 49.80%, and 41.40% more cooling energy savings, respectively, than CLR. LECLR3 cause 1.76% more cooling energy consumption than CLR. The smart glazing units (HRGRNLE2, HRBLULE2) show higher solar control performance than the other units, since they can absorb and reflect a large percentage of the solar radiation.

Yearly heating and cooling loads are calculated using the total heat losses through the glazing units during the heating period and the total heat gains through the glazing units during the cooling period, respectively. Figures 7 and 8 show the yearly heating and cooling loads of the glazing units used in the respective study flats.

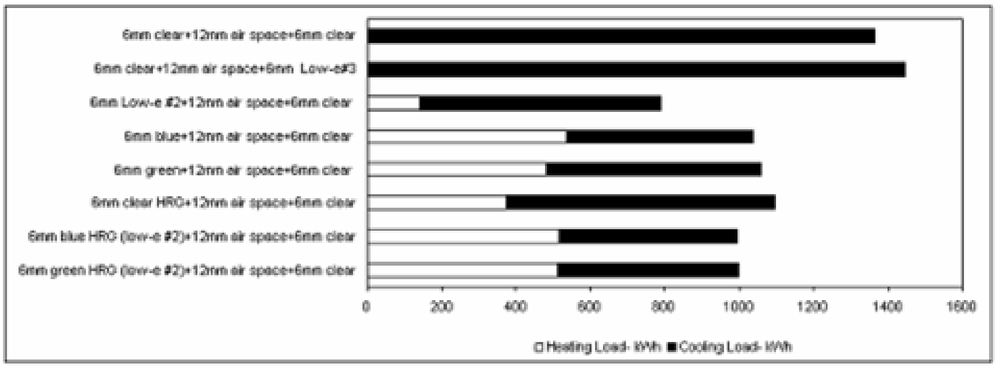

Figure 7. Yearly heating and cooling loads of the glazing units used in the investigated flats in the F-type block - kWh/y.

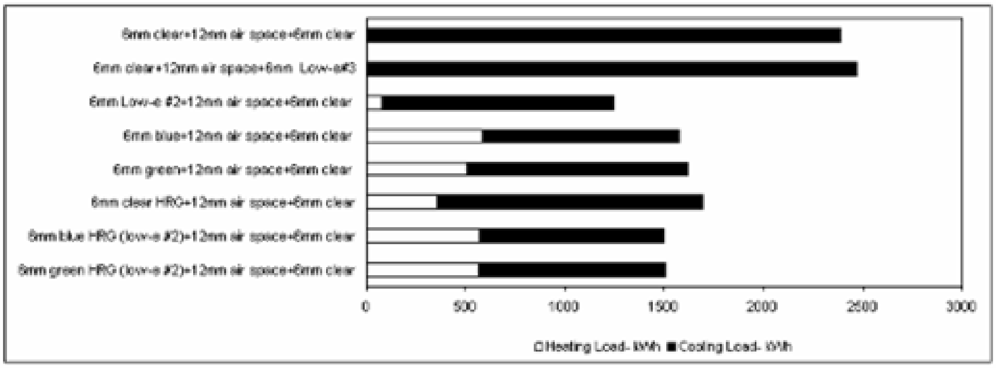

Figure 8. Yearly heating and cooling loads of the glazing units used in the investigated flats in the C-type block - kWh/y.

In calculating life cycle costs of the glazing units, the heating-cooling energy costs should be considered. Thus, Figures 7 and 8 should be examined in terms of total energy consumption, including heating and cooling energy. The fact that the heating source – natural gas – is cheaper than the cooling source –electricity–should be considered in the criteria.

In Figures 7 and 8, it can be seen that LECLR2 – the unit with a low-e coating applied to number of surface two - and the smart glazing units (HRGRNLE2, HRBLULE2) show the most efficiency in terms of yearly total energy consumption (heating and cooling energy). In Flat 1 of the F block, LECLR2, HRBLULE2, HRGRNLE2, HABLU, LECLR3, HAGRN, and HRCLR, provide 470.88, 265.66, 264.17, 223.55, 219.33, 202.72, and 166.45 kWh more energy savings than CLR, respectively. In Flat 1 of the F block, LECLR3 and CLR do not incur heating loads and contribute 401.09 and 102.0 kWh to the heating energy during the heating period.

In Flat 1 of the C block, LECLR3 and CLR do not incur heating loads and contribute 715.78 and 333.28 kWh to the heating energy during the heating period. Since the reflectance and absorbtion performances of LECLR2— the unit with a low-e coating applied to a number of surface two in a double-glazing unit-are less than those of the smart glazing units, these reduce the heating loads. Although the cooling load of this glazing unit is higher than that of the smart glazing units, LECLR2 greatly reduces the heating load, so the total energy consumption of these units is the lowest in the studied flats. Figures 7 and 8 show only the heating and cooling loads for the glazing units, determined by calculating the total energy loads of these units; the heating energy savings that are provided by the glazing units that are not under heating loads are considered.

Comparing energy consumptions through glazing units in the investigated flats

Table 11 shows that glazing area and total energy consumption are linearly proportional. Since the glazing units in the studied flats have different orientations, we cannot say that each glazing unit has the same linear proportionality.

Table 11. Energy consumption through the glazing units in the flats.

Double Glazing Unit Type	Flat 1 ($56,85\ m^2$)			Flat 1 ($99,42\ m^2$)		
	Total glazing area -m^2	Yearly total energy consumption-kWh	Net energy consumption for glazing area of $1m^2$ -kWh	Total glazing area -m^2	Yearly total energy consumption-kWh	Net energy consumption for glazing area of $1m^2$ -kWh
CLR	8,3	1262,12	152,06	10,9	2054,06	188,44
LECLR3		1042,84	125,64		1757,56	161,24
LECLR2		791,29	95,33		1249,88	114,66
HABLU		1038,62	125,13		1577,68	144,74
HAGRN		1059,45	127,64		1620,19	148,64
HRCLR		1095,72	132,01		1694,39	155,44
HRBLULE2		996,51	120,06		1500,85	137,69
HRGRNLE2		998	120,24		1503,96	137,97

3.2. Percentages (%) of Heat Gains and Losses in Flat 1 of the F block

Heat losses occur through glazings, walls, floors, roofs, doors and ventilation, external infiltration, and external ventilation, while heat gains occur through general lighting, miscellaneous systems, occupancy, domestic hot water, heat generation, solar gains from exterior windows, lighting, and chillers in building. In Figures 9 and 10, it can be seen that 8% of the total heat losses in the flat occur through the existing CLR window. In contrast, when LECLR2, HRBLULE2, and HRGRNLE2 are used, 3%, 2%, and 2% heating energy savings are provided, respectively.

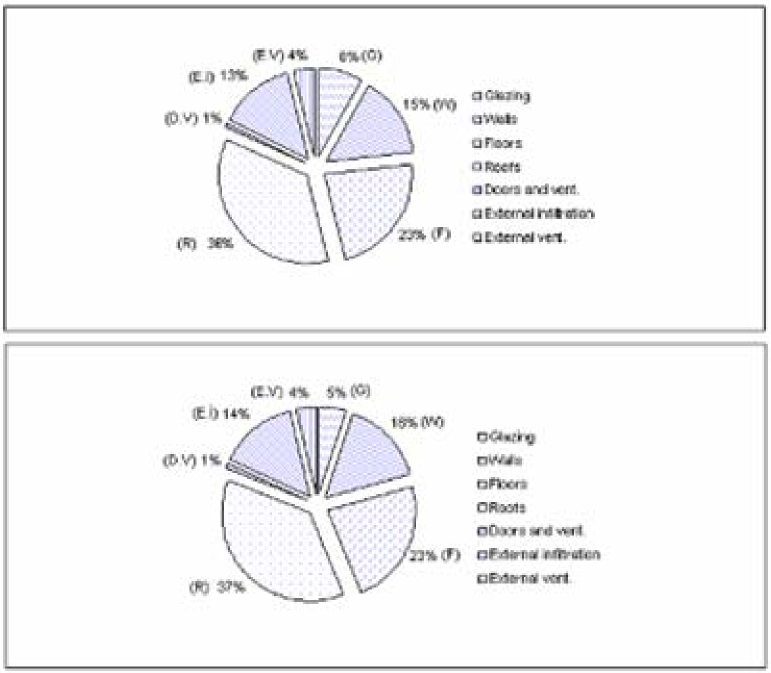

Figure 9. Heat losses (%) through the building elements of the F-type blocks obtained from the simulation results- existing window-CLR, proposal window-LECLR2.

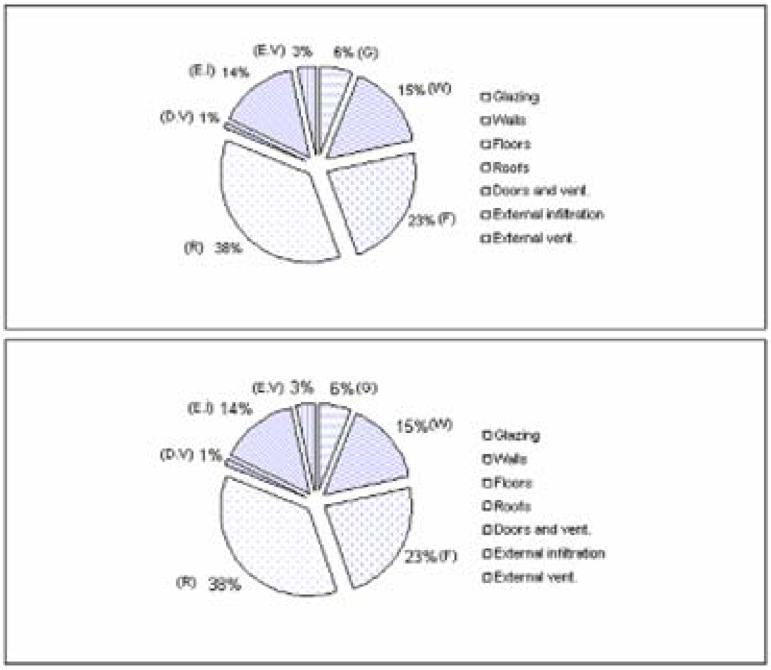

Figure 10. Heat losses (%) through the building elements of the F-type blocks obtained from the simulation results- proposal windows-HRBLULE2, HRGRNLE2.

Figures 11 and 12 show that 11% of the total heat gain in the flat occurs through the existing CLR window. In contrast, when LECLR2, HRBLULE2, and HRGRNLE2 are used, 6%, 7%, and 7% cooling energy savings are provided, respectively.

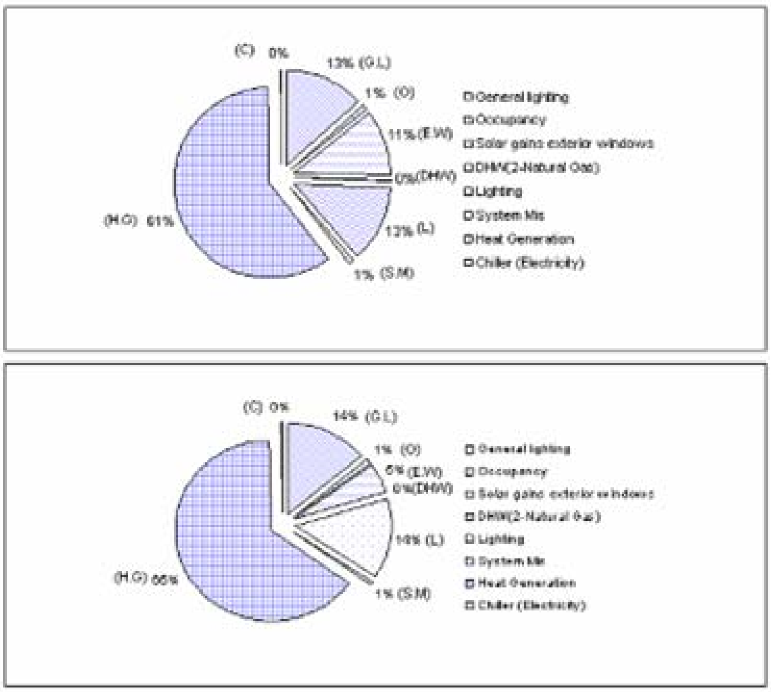

Figure 11. Heat gains (%) in the F-type blocks obtained from the simulation results- existing window-CLR, proposal window-LECLR2.

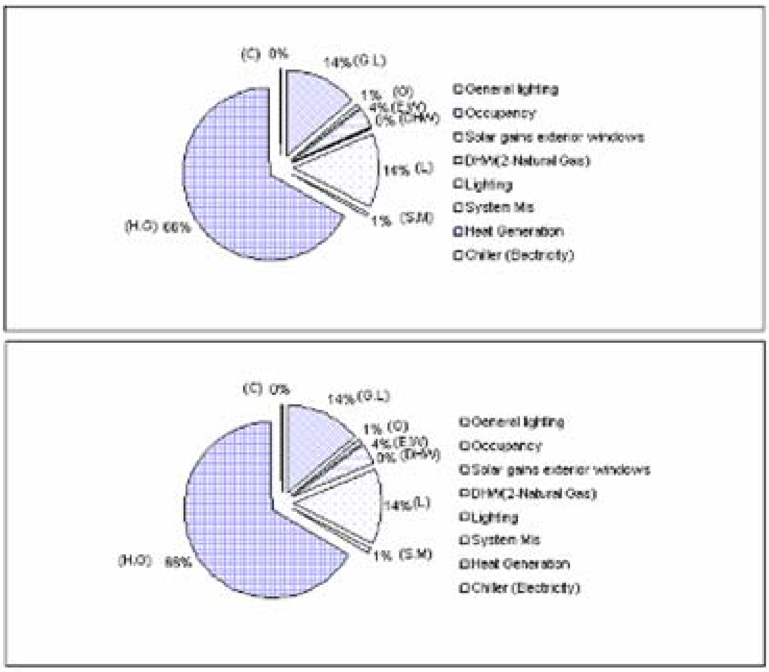

Figure 12. Heat gains (%) in the F-type blocks obtained from the simulation results- proposal windows-HRBLULE2, HRGRNLE2.

Table 12 and Table 13 show heat losses and gains (kWh) through the building elements of the F-type blocks obtained from the simulation results according to windows types.

Table 12. Heat losses (kWh) through the building elements of the F-type blocks obtained from the simulation results according to windows types.

Heat Losses-kWh (Flat 1-Ftype)							
	Glazing	Walls	Floors	Roofs	Doors and Ventilation	External infiltration	External ventilation
CLR	1294,34	2323,06	3548,51	5551,56	156	2094,96	613,89
LECLR3	569.05	2339.63	3566.48	5598.89	157.05	2102.01	632.15
LECLR2	720,25	2235,81	3334,43	5302,87	150,21	2065,25	506,19
HABLU	1048.49	2206.50	3273.29	5220.21	148.33	2056.08	483.13
HAGRN	1074.31	2216.26	3296.80	5247.98	148.97	2059.32	493.44
HRCLR	1332.55	2237.25	3353.48	5307.16	150.35	2065.32	513.47
HRBLULE2	886,21	2204,3	3263,85	5213,47	148,15	2055,73	481,69
HRGRNLE2	891,18	2205,1	3265,86	5215,74	148,21	2055,98	482,54

Table 13. Heat gains (kWh) through the building elements of the F-type blocks obtained from the simulation results according to windows types.

Heat Gains-kWh (Flat 1-Ftype)								
	General lighting	Occupancy	Solar gains exterior windows	DHW(2-Natural Gas)	Lighting	System Misc.	Heat Generation	Chiller (Electricity)
CLR	3294,76	225,32	2760,52	54,07	3294,76	187,37	14996,75	64,67
LECLR3	3294,76	225.18	2414.08	54.07	3294,76	187.37	14573.82	64.23
LECLR2	3294,76	226,16	1229,73	54,07	3294,76	187,37	15257,91	43,98

HABLU	3294,76	226.36	1010.12	54.07	3294,76	187.37	15791.40	44.23
HAGRN	3294,76	226.27	1164.38	54.07	3294,76	187.37	15723.34	45.83
HRCLR	3294,76	226.11	1678.26	54.07	3294,76	187.37	15595.77	48.51
HRBLULE2	3294,76	226,36	847,1	54,07	3294,76	187,37	15754,85	43,47
HRGRNLE2	3294,76	226,35	862,43	54,07	3294,76	187,37	15749,37	43,6

3.3. Comparing the Life Cycle Costs of Glazing Units

The fact that the lowest life cycle cost is the most economically efficient alternative is accepted in the evaluation of life cycle costs. As shown in Figure 13, HRBLULE2, HABLU, HRGRNLE2, LECLR2, HAGRN, HRCLR, and LECLR3 provide 2259.65, 2254.06, 2244.23, 2195.68, 2056.61, 1643.24, and 46.95 TL more cost savings, respectively, than the CLR in Flat 1 of the F block.

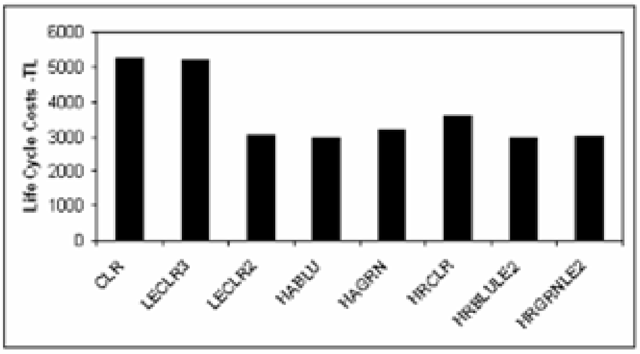

Figure 13. Life cycle costs of the investigated glazing units in Flat 1 of F type block, TL.

As can be seen in Figure 14, HRBLULE2, HRGRNLE2, HABLU, LECLR2, HAGRN, HRCLR, and LECLR3 provide 3911.30, 3885.37, 3798.91, 3755.76, 3469.39, 2803.74, and 115.60 TL more cost savings, respectively, than CLR.

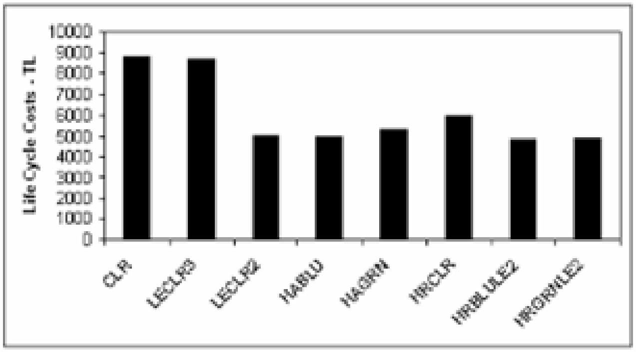

Figure 14. Life cycle costs of the investigated glazing units in Flat 1 of C type block, TL.

Table 14 shows a comparison of percentages (%) of life cycle cost of glazing units according to CLR in Flat 1 and Flat 2

Table 14. A comparison of percentages (%) of life cycle cost of glazing units according to CLR in Flat 1 and Flat 2.

	CLR	LECLR3	LECLR2	HABLU	HAGRN	HRCLR	HRBLULE2	HRGRNLE2
FLAT 1 (F type)	-	0,89	41.82	42.94	39.17	31.30	43.04	42.75
FLAT 1 (C type)	-	1.31	42.78	43.27	39.51	31.93	44.55	44.26

4. CONCLUSIONS

In this study, the energy and economy efficiency of eight double-glazing units with clear (existing glazing unit), low-e coating, tinted (blue, green), clear reflective, blue reflective+ low-e coating, and green reflective+low-e coating were used in model flats and were evaluated according to simulation results for cold climates.

In light of the simulation results, Table 15 shows the energy efficiency and economic efficiency of the investigated double-glazing units.

Table 15. A comparison of the energy efficiency and economy efficiency of the investigated double-glazing units.

Double Glazing Unit	F type block, Flat 1		C type block, Flat 1	
	Energy Efficient Performance	Economy Efficient Performance	Energy Efficient Performance	Economy Efficient Performance
*CLR	••••••••	••••••••	••••••••	••••••••
LECLR3	•••••	•••••••	•••••••	•••••••
LECLR2	•	••••	•	••••
HABLU	••••	••	•••••	•••
HAGRN	••••••	•••••	••••	•••••
HRCLR	•••••••	••••••	••••••	••••••
HRBLULE2	••	•	••	•
HRGRNLE2	•••	•••	•••	••

*Reference glazing unit (•) the best performance, (••••••••) the poorest performance

For both flats, LECLR2 has the highest energy efficiency performance in terms of total yearly energy consumption. In the F and C blocks, it provides, respectively, 37.51% and 39.16% more energy savings than CLR.

In terms of heating energy savings, LECLR3 is the most efficient unit according to Figure 5 and Figure 6. It provides heating energy gains during the heating period. In the F and C blocks, it contributes 401.09 and 715.78 kWh, respectively, to the heating energy during the heating period but LECLR3 shows low performance due to their high cooling loads in cooling period.

Although the smart glazing units (HRBLULE2, HRGRNLE2), composed of glasses with absortive + reflective + low-e coating, are the most efficient units in terms of cooling energy savings, they have poorer peformance than LECLR2 in terms of heating energy savings. While in the F block, the total energy consumptions of HRBLULE2 and HRGRNLE2 are 20.60% and 20.72% higher, respectively, than that of LECLR2, in the C block, the total energy consumptions using HRBLULE2 and HRGRNLE2 are 16.73% and 16.90% higher, respectively, than that of LECLR2. In comparison to CLR, LECLR3 provides 74.57% heating energy savings, and HRBLULE2, HRGRNLE2, HABLU, and LECLR2 provide 64.91%, 64.48%, 63.34%, and 52.35% cooling energy savings, respectively, in Flat 1 of the F type block.

In terms of life cycle costs, HRBLULE2, HABLU and HRGRNLE2 are the most economically efficient units. These units have a 1.22%, 1.12% and 0.93% lower life cycle cost, respectively, than LECLR2 in Flat 1 of the F block. LECLR2 is 41.82% more economically efficient than CLR. These glazing units show the same effects in Flat 1 of the C block but while HABLU is the second most economically efficient unit in F block, it is the third most economically efficient unit in C block. In the F and C blocks, it has a 42.94 and 43.27% lower life cycle cost, respectively, than CLR.

Consequently, in terms of energy and economic efficiency, smart glazing units and LECLR2 should be preferred in Ankara, with cold climate, for long-term investments, as opposed to CLR (the existing glazing unit). For different climate regions of Turkey, energy and economy analysis of glazing units will be performed for different orientations and different building shapes in future studies.

REFERENCES

[1] Wiggington, M., Harris, J., "Intelligent Skins", ***Architectural Press***, Oxford, 7-17 (2002).

[2] Internet: Turkish Republic Ministry of Foreign-Trade Counselorship http: // www. dtm. gov.tr/dtadmin/upload/EAD/KonjokturIzlemeDb/teut.doc (2009).

[3] Dilmaç, Ş., Tırıs, M., "The Energy Saving in Housing Sector in Turkey", ***Tesisat***, 22: 10-13 (1995).

[4] MVV Consultants and Engineers, "In the Frame of the Project: Improvement Energy Efficiency in Turkey", Report of MVV, Berlin, 1-20 (2004).

[5] Turkish Standardization Institute (TSE), "Heat Insulation Rules in Building. TS 825", Ankara, 1-80 (2008).

[6] Sekhar, S.C., Toon, K.L.C., "On the study of energy performance and life cycle cost of smart Windows", ***Energy and Buildings***, 28: 397-316 (1998).

[7] Bojic, M, Yik, F., Sat, P., "Energy peformance of Windows in high-rise residential buildings in Hong Kong", ***Energy and Buildings***, 34:71-82 (2002).

[8] Karlsson, J., Karlsson, B., Roos, A., "A simple model for assessing the energy performance of Windows", ***Energy and Buildings***, 33:641-651(2001).

[9] Çetiner, I., Özkan, E., "An approach for the evaluation of energy and cost efficiency of glass façades", ***Energy and Buildings***, 37:673-684 (2005).

[10] Gugliermetti, F., Bisegna, F., "Saving energy in residential buildings: the use of fully reversible Windows", ***Energy***, 32:1235-1247 (2007).

[11] Maçka, S., "Determination of energy efficient window types according to Turkish Climate Regions", Master of Thesis, Natural & Apllied Science, Karedeniz Technical University, Trabzon, Turkey (2008).

[12] Yaşar, Y., Pehlevan, A., Maçka, S., "Comparing the energy performance of double glazed Windows with different low-e coatings according to Turkish Climate Regions", ***4th International Building Physics Conference***, 15-18 June, İstanbul, Turkey (2009).

[13] Urbikain, M.K., J.M., Sala, "Analysis of different models to estimate energy saving related to Windows in residential buildings", Energy and Buildings, 41:687-695(2009).

[14] Muneer, N., Abodahab, N., Weir, G., Kubie, J., "Windows in Buildings, Thermal, Acoustic, Visual and Solar Performance", ***Architectural Press***, Oxford, 6-10 (2000).

[15] Apsen Research Corporation, "Integrated Energy Efficient Window – Wall Systems, Phase 1: Concept Development", Report of Apsen, USA, 1-19 (2001).

[16] Amstock, S.J., "Handbook of Glass in Conctruction", ***McGraw – Hill Press***, New York, 11-30 (1997).

[17] Internet: DesignBuilder, Building Design,Simulation and Visualisation http : // www. designbuilder. co. uk (2009).

[18] Turkish State Meteorological Service 1996-2006 Meteorological Data, CD, Ankara, Keçiören (2007).

[19] Internet: Building Technologies Program, ***EnergyPlus***: Weather Data. http: // apps1. eere. energy. gov / buildings/ energyplus/ cfm/ Weather_ data.cfm.(2009).

[20] Republic of Turkey Prime Ministry Housing Development Administration of Turkey– TOKI, Planning Office, Applications Projects, F and C Type TOKI Housing Project Drawings, CD, Ankara, Kızılay (2009).

[21] Boussabaine, A., Kirkham, R., "Whole Life-Cycle Costing: Risk and Risk Responses", ***Wiley-Blackwell***, Oxford, 3-10 (2003).

[22] Manioğlu, G., "An approach fot the determination of building envelope and operation period of heating system according to energy conservation and life cycle cost", PhD Thesis. İstanbul Technical University Natural and Applied Sciences Institute, İstanbul, 14-25 (2002).

[23] Giritli, H., "Project and Construction Management Methods of Economic Evaluation in Construction", Lecture Document , İstanbul Technical University, 1-35 (2003).

[24] Republic of Turkey Prime Ministry of Public Works and Settlement, "List of building material unit price", ***Document***, Ankara, Kızılay (2009).

[25] Ardıc Glass Company Technical Document about Cost Price of Glass Products, Ankara, (2009).

NOMENCLATURE

CLR	: 6 mm clear glass + 12 mm air space + 6 mm clear glass
LECLR3	: 6 mm clear glass + 12 mm air space + 6 mm Low-E glass #3
LECLR2	: 6 mm Low-E glass #2 + 12 mm air space + 6 mm clear glass
HABLU	: 6 mm blue glass + 12 mm air space + 6 mm clear glass
HAGRN	: 6 mm green glass + 12 mm air space + 6 mm clear glass
HRCLR	: 6 mm clear glass + 12 mm air space + 6 mm clear glass
HRBLULE2	: 6 mm heat reflective blue - Low-E glass #2 + 12 mm air space + 6 mm clear glass
HRGRNLE2	: 6 mm heat reflective green - Low-E glass #2 + 12 mm air space + 6 mm clear glass
LCC	: Life cycle cost
I	: Initial capital investment
M-R-O	: Maintain-repair-operation cost
R	: Replacement cost
RV	: Residual value