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Effect of Window Size on Residential Buildings' Energy Costs

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Abstract: Today, with the rapid depletion of fossil energy sources and the increasing environmental problems caused by fossil fuels, supervision and management of energy consumption becomes more important. Looking at the breakdown of energy consumption by sectors, the buildings sector is seen as one of the priority areas for energy efficiency after industry and transportation. A large amount of energy is consumed during the utilization phase of the building. Therefore, priority is given to applications that reduce the amount of energy consumed during the utilization phase throughout the lifetimes of buildings. In the design phase, decisions regarding building window sizes have a considerable effect on the building energy costs. Therefore, this study will analyze the extent to which changes in building transparency rate affect building heating energy costs and thereby provide pre-design information for future reference for residential buildings with less energy consumption and less environmental pollution. To this end, residential buildings with the same characteristics have been used by differentiating only window sizes, orientations and envelope alternatives to assess the changes they cause in energy costs.

Key words: Window size · Transparency rate · Energy efficiency · Envelope design · Energy cost

INTRODUCTION

Today, control and management of energy consumption is becoming more and more important due to the rapid depletion of fossil energy resources and the increased environmental problems caused by them. In line with the targets identified under the Kyoto protocol, studies are being undertaken for 20% less energy consumption, 20% less carbon emission and to ensure that 20% of the total energy production is from renewable energy resources by the year of 2020 compared to figures from 1990 [1].

Looking at the breakdown of energy consumption by sectors, the building sector is seen as one of the priority areas where energy efficiency can be achieved, following the industry and transportation sectors. In the Strategic Research Agenda (SRA) Vision 2003 Report, it is stated that the European building sector should go for information-based and sustainable building production that also meets the client-user requirements. In the European building sector, which accounts for 40% of the overall energy consumption with 70% thereof consumed for residential buildings, emphasis is placed on the measures that should be taken with regard to energy, water and material use [2].

In many countries, the energy required for space heating in buildings makes up the highest share of energy use and represents about 40% of the total energy consumed in the residential sector (Table 1) [3]. Heating accounts for the largest share of energy consumption in the residential and tertiary sectors in Greece (60.9% and 52.5%, respectively) and for an average of 57% of consumption in the EU [4, 5]. According to energy statistics, energy consumption in residential sector constitutes about 30% of total energy consumption in Turkey [6]. Therefore, this study will focus only on heating energy costs of residential buildings.

The design parameters, affecting the conservation of energy are; location, orientation, building shape, thermophysical and optical features of the building envelope, size, accommodation type, distance between buildings and natural ventilation arrangement [7].

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Table 1: Distrubution of energy consumption in buildings, in % [3]

	Space heating	Water heating	Air condition ventilation	Lighting illumination	Cooling freezing	Other
Houses	40	17	7	7	12	17
Commercial	32	5	22	25	-	16

Design parameters, affecting the conservation of heating energy are; building shape and thermophysical and optical properties of building envelope. Optical properties of building envelope are; coefficients of absorption, permeability and reflectivity of solar radiation. Thermophysical properties of building envelope, on the other hand, are: total heat permeability coefficient (U (k)) and transparency rate. These properties are determinants of the heat gain and loss from building envelope unit of area, due to exterior temperature and solar radiation.

A large portion of the overall energy used from the erection till demolition of a building is spent during the utilization phase. Therefore, priority should be given to practices oriented to reduce the energy spent during the utilization phase throughout the lifetime of buildings. The energy consumption in our country is increasing year by year, particularly in the industry and residential building sectors; and a large portion of the energy used in residential buildings is consumed for heating and cooling purposes. In the design phase, decisions regarding transparency rate (window size) have a considerable effect on building heating energy costs. Therefore, this study will analyze the extent to which changes in building form affect energy costs and thereby provide pre-design information for future reference for residential buildings with less energy consumption and less environmental pollution. To this end, residential buildings with the same characteristics have been used by differentiating only the transparency rate, orientation and envelope alternatives to assess the changes they cause in energy costs.

Yildiz, Ozbalta and Arsan used the energy analysis software EnergyPlus in order to investigate the impact of window-to-wall-ratio with different glazing types and wall orientations on energy consumption of a school building located in Izmir, which has a warm and humid climate. Results indicate that window-to-wall area ratios, wall orientation and glass types are important factors in building's total energy consumption. When the window-to-wall area ratio is increased from 10% to 60%, the winter heating load of the building decreases in maximum amount on the south side of the building and reduces in minimum amount on the east side of the building. [8]. Macka and Yasar 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. 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 [9]. Tavil, Yaman, Cetiner and Coskun used a dynamic model to help selecting energy and cost efficient window systems for residential buildings in temperate-humid, temperate-dry and warm-humid climate zones in Turkey and assessed the functioning of the model. Assessments on the energy and cost performance of window alternatives revealed that climate, building typology, orientation, transparency ratio and sun control devices impact the energy and cost performance of window systems [10]. Persson, Ross and Wall investigate how decreasing the window size facing south and increasing the window size facing north in these low energy houses would influence the energy consumption and maximum power needed to keep the indoor temperature between 23 and 26 °C. Different orientations have been investigated as well as the influence of window type. The results show that the size of the energy efficient windows does not have a major influence on the heating demand in the winter, but is relevant for the cooling need in the summer. This indicates that instead of the traditional way of building passive houses it is possible to enlarge the window area facing north and get better lighting conditions. To decrease the risk of excessive temperatures or energy needed for cooling, there is an optimal window size facing south that is smaller than the original size of the investigated buildings [11]. Bektas and Aksoy used a hypothetical single-story house in Elazig, located in Turkey's cold climate zone, to estimate its heating energy consumption with five different facade orientations, three different types of joinery and two different types of glazing. They found out that it is possible to save 20 to 30% heating energy, when calculations are made by taking all these parameters into account [12]. Turan studied building orientation, different types of plans and different glazing ratios to estimate annual heating energy. She has found out that among different orientations and different glass ratios, the optimum alternative for all plan types had the highest glass ratio on the southern side of the buildings [13]. Kontoleon and Bikas model and analyze thermal zone with south orientation in order to determine the influence of glazing openings percentage and type of glazing on the indoor temperatures and energy efficiency, in winter and summer. Overheating can be avoided and energy savings can be obtained with the proper selection of glazing openings percentage as well as the type of glazing and position of slab insulation [14].

There are studies which have taken into account different types of glazing when investigating the impact of window size on energy consumption. However, there are no studies which investigate the impact of alternative window ratios on the transparency ratio by taking into account different external wall alternatives. Therefore, this study investigates the impact of building window sizes on energy costs by taking into account thermophysical properties and orientations of external wall alternatives.

MATERIALS AND METHODS

Window sizes (transparency rate), properties of building envelope and orientation which are the parameters affecting the development of an energy-efficient environment and conservation of energy on building scale, are discussed in this study.

Determining the Window Sizes: Within the scope of the study, a model residential building was selected and different window size (transparency ratio) groups have been identified by changing window sizes of the model building and keeping all other characteristics the same. The model building that will be the basis of the study has a square plan with 5 storeys accommodating 4 flats on each floor, with a storey height on 2.70m, without basement and with a window-to-wall ratio of 20%. Transparency rates of buildings which constitute the transparency rate groups are 20%, 25%, 30% and 35%. Window sizes are increased by 48%, 96% and 141% in the model building to identify transparency rate (window size) groups. Minimum lighting level is provided in all selected buildings, including the building with the lowest transparency rate, for a natural lighting. Building properties are given in Table 2.

Determining the Envelope Alternatives: Most heat loss in residential buildings occurs through construction elements such as the walls, floor, roof, windows and heat bridges. The rate of heat loss from these locations varies depending on the architecture and position of the building, the level of thermal insulation and the properties of the construction material used [15].

With current technology, we can refer to a wall both as a one-layer structure and as a construction element of multiple layers that contains insulating material. The most frequently used thermal insulating materials seem to be fibre and foam materials. Fibre materials should be mineral wools, such as rock wool, glass wool and wood wool. Also, foam materials should be polystyrene foams and polyurethane foams, such as expanded polystyrene foam (EPS) and extruded polystyrene foam (XPS). The insulating materials to be used on the external walls should not negatively affect the structure of the building and its insulating features should not change in humid conditions.

Table 2: Properties of buildings with different window sizes used in the study

	transparency percentage (%20)	transparency percentage (%25)	transparency percentage (%30)	transparency percentage (%35)
Number of stories	5	5	5	5
Number of flats	20	20	20	20
Storey height (m)	2.70	2.70	2.70	2.70
External wall area (m^2)	1,080.00	1,080.00	1,080.00	1,080.00
Floor area (m^2)	400.00	400.00	400.00	400.00
Total floor area (m^2)	2,000.00	2,000.00	2,000.00	2,000.00
Envelope area (A) (m^2)	1,879.90	1,879.90	1,879.90	1,879.90
Volume (V) (m^3)	5,400.00	5,400.00	5,400.00	5,400.00
A/V	0.348	0.348	0.348	0.348
External wall area 1 (m^2) (wall body material)	549.95	497.43	443.35	391.74
External wall area 2 (m^2) (concrete)	315.60	315.60	315.60	315.60
Window area (m^2)	110.50	163.02	217.10	265.98
External door area (m^2)	103.95	103.95	103.95	106.68
Facade opacity rate (%)	80	75	70	65
Facade transparency rate (%)	20	25	30	35

External walls are insulated with four different systems that differ in the location of the thermal insulating materials:

- Thermal insulation on the external side of the walls (exterior thermal sheathing),
- Thermal insulation on the internal side of the walls,
- Thermal insulation between two walls (sandwich walls), or
- External walls with ventilation (curtain walling system).

The external insulation system, used commonly in Europe and America, has also been used more frequently in Turkey in recent years. With this system, the insulation surrounds the building like a jacket and no heat bridges are formed. Thus, stress and cracks due to heat change are avoided and the ventilation helps to keep the construction dry at all times. Although the cost of external insulation is higher than other systems, it is the most appropriate method for buildings used over a long period of time, such as housing [16].

This study takes into consideration not only the window sizes but also the building envelope characteristics for heating energy savings and energy-effective environments; however, residential buildings are evaluated only as per their window size (transparency rate) characteristics. The building components forming a building envelope are the walls, roof and ground flooring. Different body and insulation materials used in the walls, roof and flooring and different thicknesses will result in different construction, operating and life cycle costs of a building. The materials that can be used in walls, floors and roofs as specified in the unit prices of the Ministry of Public Works [17] and TS 825 [18] were identified. A fixed wooden roof is approved. Extruded polystyrene foam (XPS) with a thickness of 4 cm has been deemed appropriate for use as an insulation material in ground flooring and 10 cm thick glass wool has been found appropriate for use in roofs. It is assumed that brick and gasbeton will be used as wall body materials. Different alternatives include the use of extruded polystyrene foam (XPS), expanded polystyrene foam (EPS) and rock wool in different thicknesses as wall insulation materials. Since it is a more convenient system in buildings that are used for a prolonged period, such as housing and there is a reduced risk of condensation as a result of steam diffusion, it is assumed that insulation is applied externally on the walls. Envelope alternatives of buildings generated by differentiating body and insulation materials in construction compounds are displayed in Table 3. In building alternatives, double-glazed windows with wood casing were used as the transparent component type.

Calculating the Energy Costs: This study covers only residential buildings, therefore, calculated energy costs include only the heating energy costs. As shown in Table 1, the major portion of residential energy consumption is associated with space heating. Since minimum conditions are provided in all of the selected buildings, in terms of natural lighting, costs associated with lighting energy are not taken into account.

Table 3: Envelope alternatives

	Wall body material	Wall insulation material	Roof insulation material	Ground floor insulation material
t	19 cm brick		10 cm glasswool	4 cm XPS
t10c	19 cm brick		10 cm glasswool	4 cm XPS
t2x10c	19 cm brick	2 cm XPS	10 cm glasswool	4 cm XPS
t3x10c	19 cm brick	3 cm XPS	10 cm glasswool	4 cm XPS
t4x10c	19 cm brick	4 cm XPS	10 cm glasswool	4 cm XPS
t5e10c	19 cm brick	5cm EPS	10 cm glasswool	4 cm XPS
t5t10c	19 cm brick	5 cm rockwool	10 cm glasswool	4 cm XPS
t5x10c	19 cm brick	5 cm XPS	10 cm glasswool	4 cm XPS
g	19 cm gasbeton			
g10c	19 cm gasbeton		10 cm glasswool	4 cm XPS
g2x10c	19 cm gasbeton	2 cm XPS	10 cm glasswool	4 cm XPS
g3x10c	19 cm gasbeton	3 cm XPS	10 cm glasswool	4 cm XPS
g4x10c	19 cm gasbeton	4 cm XPS	10 cm glasswool	4 cm XPS
g5t10c	19 cm gasbeton	5 cm rockwool	10 cm glasswool	4 cm XPS
g5e10c	19 cm gasbeton	5cm EPS	10 cm glasswool	4 cm XPS
g5x10c	19 cm gasbeton	5 cm XPS	10 cm glasswool	4 cm XPS

Table 4: Window areas and percentage ratios of the windows based on different directions

	Window area (m²)				Window area (%)			
	Transparency percentage (20%)	Transparency percentage (25%)	Transparency percentage (30%)	Transparency percentage (35%)	Transparency percentage (20%)	Transparency percentage (25%)	Transparency percentage (30%)	Transparency percentage (35%)
Direction 1								
North	36.40	44.20	52.00	63.70	32.94	27.11	23.95	23.95
South	35.10	40.82	48.10	59.28	31.76	25.04	22.16	22.29
West	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
East	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
Direction 2								
North	35.10	40.82	48.10	59.28	31.76	25.04	22.16	22.29
South	36.40	44.20	52.00	63.70	32.94	27.11	23.95	23.95
West	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
East	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
Direction 3								
North	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
South	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
West	36.40	44.20	52.00	63.70	32.94	27.11	23.95	23.95
East	35.10	40.82	48.10	59.28	31.76	25.04	22.16	22.29
Direction 4								
North	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
South	19.50	39.00	58.50	71.50	17.65	23.92	26.95	26.88
West	35.10	40.82	48.10	59.28	31.76	25.04	22.16	22.29
East	36.40	44.20	52.00	63.70	32.94	27.11	23.95	23.95
Total Window Area (m²)	110.50	163.02	217.10	265.98				

It is important that buildings also provide the required climatic comfort conditions for their users. In TS 825, Turkey is divided into four climatic regions by provincial centres. Region 1 represents the areas that require the least energy for heating and Region 4 represents the areas that require the most energy for heating. The heating energy demand and annual fuel amounts for project alternatives are calculated for second climate zone, which is a temperate climate zone and which also covers Istanbul. Wall alternatives were checked for the presence of condensation and no condensation was found in these wall alternatives. In order to calculate heating energy costs, "TS 825 Heat Requirement Calculations" computer program was used. This calculation program, designed by Izoder, is based on the "TS 825 Heat Insulation Rules in Buildings" standard and Turkey's meteorological data for the last 20 years. Using this program, it is possible to calculate condensation values and the specific heat loss as defined in the "TS 825 Thermal Insulation Requirements for Buildings" standard and compare the calculated values to the thresholds defined in the standard and hence evaluate the conformity of the designed building to national legislation on energy efficiency. The program operation is basically parallel to the TS 825 standard. First, data regarding the building subject to the standard are entered into the program and then the building's annual heating energy demand and condensation values are calculated and checked against the criteria set forth in the standard. In the defined calculation method, annual heating energy demand is calculated by adding the monthly heating energy demand for the heating period. Hence, it becomes possible to make a more realistic evaluation of the thermal performance of the building. In addition, the program enables the designer to evaluate the proposed design's capacity to take advantage of solar energy (http://www.izoder.org.tr).[1]

It is assumed that natural gas is consumed in all project alternatives. Calculation of heating energy costs are based on the gas prices applicable for the month of February 2012 in Istanbul (http://www.igdas.com.tr).[2] Annual energy costs are calculated both based on different envelope alternatives and also different orientations. Taking into consideration the solar gain of the surface of the buldings, annual energy costs are calculated based on each transparency rate and envelope alternative with four different orientations. Annual energy costs that were calculated in TL were changed to dollars. The exchange rate to dollars was taken from data from the Central Bank of the Republic of Turkey (http://evds.tcmb.gov.tr).[3] The window areas and percentage ratios of the windows based on different directions are given in Table 4.

[1]Izoder, Association of Thermal Insulation, Waterproofing, Sound Insulation and Fireproofing Material Producers, Suppliers and Applicators, web page, http://www.izoder.org.tr, March 2012.

[2]IGDAS, web page, http://www.igdas.com.tr, March 2012.

[3]Central Bank of the Republic of Turkey, web page, http://tcmb.gov.tr, March 2012.

RESULTS AND DISCUSSION

The annual energy cost of each of the buildings with 4 different transparency rates; are evaluated on the basis of 16 different envelope and 4 different orientation alternatives in Table 5, 6, 7, 8 taking into consideration the solar gain. In transparency rate 20% and different envelope alternatives, the lowest energy costs are seen in the 2nd orientation alternatives and the highest energy costs are seen in the 3th and 4th orientation alternatives. The increase in energy expenditures is between 0.07% and 0.32% and on average 0.17% due to solar gain based on variations in orientation. In transparency rate 25% of buildings, the 1st orientation alternatives have the highest energy costs and the lowest energy costs are seen in the 2nd orientation alternatives. Due to solar gain based on variations in orientation, the increase in energy expenditures is between 0.02 % and 0.37 % and on average 0.21 %.

Table 5: Energy costs of the buildings with a transparency rate %20 and different envelope alternatives based on different orientations

Envelope alternative	Direction 1 Annual energy cost ($)	Direction 2 Annual energy cost ($)	Direction 3 Annual energy cost ($)	Direction 4 Annual energy cost ($)	Minimum Annual energy cost ($)	Minimum Relative Annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost
t	12,438.55	12,430.62	12,449.78	12,449.78	12,430.62	100.00	12,449.78	100.15
t10c	9,040.27	9,038.35	9,046.53	9,046.53	9,038.35	100.00	9,046.53	100.09
t2x10c	5,418.94	5,411.77	5,415.65	5,415.65	5,411.77	100.00	5,418.94	100.13
t3x10c	5,023.07	5,021.21	5,031.14	5,031.14	5,021.21	100.00	5,031.14	100.20
t4x10c	4,767.61	4,760.60	4,764.51	4,764.51	4,760.60	100.00	4,767.61	100.15
t5x10c	4,584.13	4,577.17	4,591.48	4,591.48	4,577.17	100.00	4,591.48	100.31
t5t10c	4,702.49	4,700.67	4,715.56	4,715.56	4,700.67	100.00	4,715.56	100.32
t5e10c	4,702.49	4,700.67	4,715.56	4,715.56	4,700.67	100.00	4,715.56	100.32
g	11,373.37	11,365.52	11,373.45	11,373.45	11,365.52	100.00	11,373.45	100.07
g10c	7,980.26	7,972.67	7,986.78	7,986.78	7,972.67	100.00	7,986.78	100.18
g2x10c	5,089.92	5,088.00	5,092.54	5,092.54	5,088.00	100.00	5,092.54	100.09
g3x10c	4,792.68	4,790.48	4,794.39	4,794.39	4,790.48	100.00	4,794.39	100.08
g4x10c	4,594.20	4,587.24	4,601.55	4,601.55	4,587.24	100.00	4,601.55	100.31
g5x10c	4,446.74	4,445.02	4,449.61	4,449.61	4,445.02	100.00	4,449.61	100.10
g5t10c	4,546.87	4,545.43	4,549.53	4,549.53	4,545.43	100.00	4,549.53	100.09
g5e10c	4,546.87	4,545.43	4,549.53	4,549.53	4,545.43	100.00	4,549.53	100.09
					average	100.00		100.17

Table 6: Energy costs of the buildings with a transparency rate %25 and different envelope alternatives based on different orientations

Envelope alternative	Direction 1 Annual energy cost ($)	Direction 2 Annual energy cost ($)	Direction 3 Annual energy cost ($)	Direction 4 Annual energy cost ($)	Minimum Annual energy cost ($)	Minimum Relative Annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost
t	12,569.27	12,548.93	12,559.93	12,559.93	12,548.93	100.00	12,569.27	100.16
t10c	9,189.72	9,176.84	9,187.63	9,187.63	9,176.84	100.00	9,189.72	100.14
t2x10c	5,605.41	5,604.64	5,604.17	5,604.17	5,604.17	100.00	5,605.41	100.02
t3x10c	5,228.44	5,217.20	5,227.36	5,227.36	5,217.20	100.00	5,228.44	100.22
t4x10c	4,966.69	4,965.15	4,958.89	4,958.89	4,958.89	100.00	4,966.69	100.16
t5x10c	4,795.26	4,789.65	4,799.67	4,799.67	4,789.65	100.00	4,799.67	100.21
t5t10c	4,917.55	4,905.63	4,909.77	4,909.77	4,905.63	100.00	4,917.55	100.24
t5e10c	4,917.55	4,905.63	4,909.77	4,909.77	4,905.63	100.00	4,917.55	100.24
g	11,492.78	11,472.57	11,483.55	11,483.55	11,472.57	100.00	11,492.78	100.18
g10c	8,144.43	8,124.99	8,135.73	8,135.73	8,124.99	100.00	8,144.43	100.24
g2x10c	5,294.10	5,287.25	5,286.17	5,286.17	5,286.17	100.00	5,294.10	100.15
g3x10c	4,989.43	4,978.27	4,988.42	4,988.42	4,978.27	100.00	4,989.43	100.22
g4x10c	4,799.27	4,800.06	4,804.77	4,804.77	4,799.27	100.00	4,804.77	100.11
g5x10c	4,655.32	4,643.54	4,653.54	4,653.54	4,643.54	100.00	4,655.32	100.25
g5t10c	4,765.41	4,747.70	4,757.72	4,757.72	4,747.70	100.00	4,765.41	100.37
g5e10c	4,765.41	4,747.70	4,757.72	4,757.72	4,747.70	100.00	4,765.41	100.37
					average	100.00		100.21

Table 7: Energy costs of the buildings with a transparency rate %30 and different envelope alternatives based on different orientations

Envelope alternative	Direction 1 Annual energy cost ($)	Direction 2 Annual energy cost ($)	Direction 3 Annual energy cost ($)	Direction 4 Annual energy cost ($)	Minimum Annual energy cost ($)	Minimum Relative Annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost
t	12,688.23	12,679.32	12,680.87	12,680.87	12,679.32	100.00	12,688.23	100.07
t10c	9,355.10	9,332.47	9,341.21	9,341.21	9,332.47	100.00	9,355.10	100.24
t2x10c	5,822.73	5,801.76	5,809.27	5,809.27	5,801.76	100.00	5,822.73	100.36
t3x10c	5,426.62	5,419.63	5,419.12	5,419.12	5,419.12	100.00	5,426.62	100.14
t4x10c	5,191.93	5,178.05	5,177.44	5,177.44	5,177.44	100.00	5,191.93	100.28
t5x10c	5,007.95	4,994.91	4,986.87	4,986.87	4,986.87	100.00	5,007.95	100.42
t5t10c	5,133.39	5,112.93	5,120.17	5,120.17	5,112.93	100.00	5,133.39	100.40
t5e10c	5,133.39	5,112.93	5,120.17	5,120.17	5,112.93	100.00	5,133.39	100.40
g	11,642.29	11,625.06	11,626.44	11,626.44	11,625.06	100.00	11,642.29	100.15
g10c	8,329.54	8,307.32	8,307.90	8,307.90	8,307.32	100.00	8,329.54	100.27
g2x10c	5,503.48	5,482.73	5,490.11	5,490.11	5,482.73	100.00	5,503.48	100.38
g3x10c	5,221.81	5,201.30	5,200.70	5,200.70	5,200.70	100.00	5,221.81	100.41
g4x10c	5,010.14	5,004.98	4,996.94	4,996.94	4,996.94	100.00	5,010.14	100.26
g5x10c	4,881.00	4,866.73	4,873.84	4,873.84	4,866.73	100.00	4,881.00	100.29
g5t10c	4,973.32	4,958.82	4,965.94	4,965.94	4,958.82	100.00	4,973.32	100.29
g5e10c	4,973.32	4,958.82	4,965.94	4,965.94	4,958.82	100.00	4,973.32	100.29
					Average	100.00		100.29

Table 8: Energy costs of the buildings with a transparency rate %35 and different envelope alternatives based on different orientations

Envelope alternative	Direction 1 Annual energy cost ($)	Direction 2 Annual energy cost ($)	Direction 3 Annual energy cost ($)	Direction 4 Annual energy cost ($)	Minimum Annual energy cost ($)	Minimum Relative Annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost
t	12,815.59	12,795.64	12,805.94	12,805.94	12,795.64	100.00	12,815.59	100.16
t10c	9,502.42	9,477.09	9,492.92	9,492.92	9,477.09	100.00	9,502.42	100.27
t2x10c	6,004.06	5,980.60	5,988.74	5,988.74	5,980.60	100.00	6,004.06	100.39
t3x10c	5,632.58	5,625.03	5,617.42	5,617.42	5,617.42	100.00	5,632.58	100.27
t4x10c	5,376.21	5,353.25	5,358.64	5,358.64	5,353.25	100.00	5,376.21	100.43
t5x10c	5,214.20	5,191.48	5,190.39	5,190.39	5,190.39	100.00	5,214.20	100.46
t5t10c	5,325.57	5,309.97	5,316.08	5,316.08	5,309.97	100.00	5,325.57	100.29
t5e10c	5,325.57	5,309.97	5,316.08	5,316.08	5,309.97	100.00	5,325.57	100.29
g	11,773.82	11,747.85	11,757.94	11,757.94	11,747.85	100.00	11,773.87	100.22
g10c	8,491.28	8,466.44	8,475.57	8,475.57	8,466.44	100.00	8,491.28	100.29
g2x10c	5,687.06	5,686.34	5,685.50	5,685.50	5,685.50	100.00	5,687.06	100.03
g3x10c	5,398.76	5,383.13	5,382.14	5,382.14	5,382.14	100.00	5,398.76	100.31
g4x10c	5,215.78	5,201.88	5,200.79	5,200.79	5,200.79	100.00	5,215.78	100.29
g5x10c	5,077.62	5,061.34	5,060.84	5,060.84	5,060.84	100.00	5,077.62	100.33
g5t10c	5,172.24	5,156.88	5,164.56	5,164.56	5,156.88	100.00	5,172.24	100.30
g5e10c	5,172.24	5,156.88	5,164.56	5,164.56	5,156.88	100.00	5,172.24	100.30
					Average	100.00		100.29

Table 9: The comparison of the minimum and maximum energy costs of the buildings with different transparency rates (window sizes) considering different envelope alternatives and orientations

	Transparency rate (%20)				Transparency rate (%25)			
Envelope alternative	Minimum Annual energy cost ($)	Minimum Relative annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost	Minimum Annual energy cost ($)	Minimum Relative annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost
t	12,430.62	100.00	12,449.78	100.00	12,548.93	100.95	12,569.27	100.96
t10c	9,038.35	100.00	9,046.53	100.00	9,176.84	101.53	9,189.72	101.58
t2x10c	5,411.77	100.00	5,418.94	100.00	5,604.17	103.56	5,605.41	103.44
t3x10c	5,021.21	100.00	5,031.14	100.00	5,217.20	103.90	5,228.44	103.92
t4x10c	4,760.60	100.00	4,767.61	100.00	4,958.89	104.17	4,966.69	104.18
t5x10c	4,577.17	100.00	4,591.48	100.00	4,789.65	104.64	4,799.67	104.53
t5t10c	4,700.67	100.00	4,715.56	100.00	4,905.63	104.36	4,917.55	104.28
t5e10c	4,700.67	100.00	4,715.56	100.00	4,905.63	104.36	4,917.55	104.28
g	11,365.52	100.00	11,373.45	100.00	11,472.57	100.94	11,492.78	101.05
g10c	7,972.67	100.00	7,986.78	100.00	8,124.99	101.91	8,144.43	101.97
g2x10c	5,088.00	100.00	5,092.54	100.00	5,286.17	103.89	5,294.10	103.96
g3x10c	4,790.48	100.00	4,794.39	100.00	4,978.27	103.92	4,989.43	104.07
g4x10c	4,587.24	100.00	4,601.55	100.00	4,799.27	104.62	4,804.77	104.42
g5x10c	4,445.02	100.00	4,449.61	100.00	4,643.54	104.47	4,655.32	104.62
g5t10c	4,545.43	100.00	4,549.53	100.00	4,747.70	104.45	4,765.41	104.75
g5e10c	4,545.43	100.00	4,549.53	100.00	4,747.70	104.45	4,765.41	104.75
average		100.00		100.00		103.51		103.55

Table 9: continue

	Transparency rate (%30)				Transparency rate (%355)			
Envelope alternative	Minimum Annual energy cost ($)	Minimum Relative annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost	Minimum Annual energy cost ($)	Minimum Relative annual energy cost	Maximum Annual energy cost ($)	Maximum Relative annual energy cost
t	12,679.32	102.00	12,688.23	101.92	12,795.64	102.94	12,815.59	102.94
t10c	9,332.47	103.25	9,355.10	103.41	9,477.09	104.85	9,502.42	105.04
t2x10c	5,801.76	107.21	5,822.73	107.45	5,980.60	110.51	6,004.06	110.80
t3x10c	5,419.12	107.92	5,426.62	107.86	5,617.42	111.87	5,632.58	111.95
t4x10c	5,177.44	108.76	5,191.93	108.90	5,353.25	112.45	5,376.21	112.77
t5x10c	4,986.87	108.95	5,007.95	109.07	5,190.39	113.40	5,214.20	113.56
t5t10c	5,112.93	108.77	5,133.39	108.86	5,309.97	112.96	5,325.57	112.94
t5e10c	5,112.93	108.77	5,133.39	108.86	5,309.97	112.96	5,325.57	112.94
g	11,625.06	102.28	11,642.29	102.36	11,747.85	103.36	11,773.87	103.52
g10c	8,307.32	104.20	8,329.54	104.29	8,466.44	106.19	8,491.28	106.32
g2x10c	5,482.73	107.76	5,503.48	108.07	5,685.50	111.74	5,687.06	111.67
g3x10c	5,200.70	108.56	5,221.81	108.92	5,382.14	112.35	5,398.76	112.61
g4x10c	4,996.94	108.93	5,010.14	108.88	5,200.79	113.38	5,215.78	113.35
g5x10c	4,866.73	109.49	4,881.00	109.70	5,060.84	113.85	5,077.62	114.11
g5t10c	4,958.82	109.09	4,973.32	109.32	5,156.88	113.45	5,172.24	113.69
g5e10c	4,958.82	109.09	4,973.32	109.32	5,156.88	113.45	5,172.24	113.69
average		107.19		107.32		110.61		110.74

In the transparency rate 30% of bulidings, the lowest energy costs are seen in the 2nd, 3th and 4th orientation alternatives and the highest energy costs are seen in the 1st orientation alternatives. The increase in energy expenditures is between 0.07% and 0.42%, 0.29% in average due to solar gain based on variations in orientation. In the transparency rate 35% of bulidings, the 2nd, 3th and 4th orientation alternatives provide for the lowest energy costs and 1st orientation alternatives have the highest energy costs. The increase in energy expenditures is between 0.03% and 0.46% and on average 0.29% due to solar gain based on variations in orientation.

In buildings with a transparency rate of 20%, the lowest energy costs are obtained with the highest window ratio (32.94%) on their southern sides. In the 3rd and 4th orientations, walls with the lowest window ratios (17.65%) are on the southern side and these orientations give the highest energy costs. Since the window ratio is low, solar energy gain decreases. In buildings, with a transparency rate of 25%, window rates on facades are closer to each other. Highest energy costs are calculated with the 1st orientation, where the north-side window ratio is the highest. The lowest energy costs are predominantly associated with the 2nd orientation. Although window ratios are close to each other, 2nd orientation has the highest south-side window area. In buildings with transparency rates of 30% and 35%, window ratios on all sides are closer to each other. While the highest energy cost is associated with the 1st orientation, lowest energy costs are associated with 2nd, 3rd and 4th orientations. The 1st orientation alternative, which gives the highest energy cost in buildings with a transparency rate of 30% and 35%, has the lowest south-side window ratio. It is seen that the lowest heating energy cost is achieved when more window areas of buildings are facing south, whereas the highest heating energy cost occurs when most of the windows are facing north.

In Table 9, buildings with different transparency rates and envelope alternatives are compared in terms of minimum and maximum annual energy costs considering 4 different orientatation alternatives. The minimum energy cost with a transparency rate 25% and different envelope alternatives is between 0.94% and 4.75% and in average 3.51% (min energy cost) and 3.55% (maximum energy cost) more than that of the buildings with a transparency rate 20% and different envelope alternatives. The annual energy cost of residential buildings with a transparency rate of 30% is between 1.92% and 9.70% and on average 7.19% (minimum) and 7.32% (maximum) more than that of the residential buildings with a transparency rate of 20%. The annual energy cost of the residential buildings with transparency rate of 35% is between 2.94% and 14.11% and in average 10.61% (minimum) and 10.74% (maximum) more than that of the transparency rate 20% of buildings.

When all transparency rate alternatives are evaluated, among all alternatives with different the transparency rates, the alternative with the lowest energy cost is; the one whose wall structure material is gasbeton and which has a 5 cm XPS wall insulation, 10 cm glasswool roof insulation and transparency rate 20%. The alternative with the highest energy cost is the one whose wall structure material is brick and which does not have a roof or wall insulation and has a transparency rate of 35%.

CONCLUSION

In this study, taking into consideration the building envelope alternative and the solar gain based on variations in orientation; the impact of the decisions made regarding the window sizes (transparency rate) of the building during the design phase on energy costs are evaluated. The energy cost increase; as the window area/ external wall area ratio increases. The solar gain based on variations in orientation also causes variations in energy cost. However, the cost variations caused by the solar gain is insignificant when compared with the cost variations caused by changes in transparency rate. The increase in energy cost due to orientation is maximum 0.46% and the increase in costs due to changes in building transparency rate reaches up to 14.11%.

As it can be seen in this study, the orientation of buildings during the design phase is an important factor for the energy cost of the buildings in terms of solar gain. As well as that, the building transparency rate factor has a significant impact on energy costs. Thus, it is shown in this study that the decisions made regarding the window sizes of buildings during the design phase has a very significant impact on the energy costs of the buildings. As the external window area/ external wall area ratio increases, energy cost also increases. Thus while decisions are taken it is vital to have the awareness for designing buildings that consume minimum energy and provide the necessary comfort.

REFERENCES

1. Calis, A.C., A. Tereci and U. Eicker, 2009. Example of an Ecological Settlement: Scharnhauser Park. Yapi, 333: 48-52.
2. European Construction Technology Platform (ECTP), 2005. Strategic Research Agenda for European Construction Sector, Achieving a sustainable and competitive Construction sector by 2030.
3. Cengel, Y.A., 1998. Heat Transfer: A Practical Approach. McGraw Hill, New York.
4. Bakos, G.C., 2000. Insulation protection studies for energy saving in residential and tertiary sector. Energy and Buildings, 31: 251-259.
5. Chwieduk, D., 2003. Towards sustainable-energy buildings. Applied Energy, 76: 211-217.

6. Altas, M., H. Fikret and E. Celebi, 1994. Energy Statistics. In the proceedings of Turkish 6th Energy Congress, Izmir.
7. Berkoz, E., M.S. Kucukdogu, Z.Y. Aygun, D. Enarun, R. Unver, G. Kocaaslan, K.A. Yener, E. Yildiz, F. Ak and D. Yildiz, 1995. Enerji Etkin Konut ve Yerlesme Tasarimi (Energy efficient house and urban design). TUBITAK-INTAG 201, Research Report, Ankara.
8. Yildiz, Y., T.G. Ozbalta and Z.D. Arsan, 2011. Farklı Cam Türleri ve Yönlere Göre Pencere/Duvar Alanı Oranının Bina Enerji Performansına Etkisi: Eğitim Binası, Izmir (Impact of Window-to-Wall Surface Area for Different Window Glass Types and Wall Orientations on Building Energy Performance: A Case Study for a School Building Located in Izmir, Turkey). Megaron, 6(1): 30-38.
9. Macka, S. and Y. Yasar, 2011. The Effects of Window Alternatives on Energy Efficiency And Building Economy In High-Rise Residential Buildings In Cold Climates. Gazi University Journal of Science, 24(4): 927-944.
10. Tavil, A., H. Yaman, I. Cetiner and K. Coskun, 2010. Energy and Cost Efficient Window Selection Model for Residential Buildings in Different Climatic Regions of Turkey. Journal of itu/a architecture, planning, design, 9(1): 143-154.
11. Persson, M., A. Roos and M. Wall, 2006. Influence of Window Size on the Energy Balance of Low Energy Houses. Energy and Buildings, 38: 181-188.
12. Bektas, B. and T. Aksoy, 2005. Energy Performance of Window Systems of Buildings in Cold Climate Regions. Science and Engineering Journal of Fırat University, 17(3): 499-508.
13. Turan, N.D., 2004. Eğitim Yapılarının Tasarım Ölçütlerinin Yıllık Isıtma Enerjisi Harcamalarının Azaltılmasına Yönelik Olarak Belirlenmesi (Determine design criteria of educational buildings for minimizing annual heating energy consumptions). Master Thesis, Yıldız Technical University Institue of Science, Istanbul.
14. Kontoleon, K.J. and D.K. Bikas, 2002. Modelling the influence of glazed openings percentage and type of glazing on the thermal zone behavior. Energy and Buildings, 34: 389-399.
15. Karagoz, N., 2004. Investigation and Evaluation of Thermal Insulation Between Two Walls in Dwellings. Master Thesis, Uludag University Institue of Science and Technology, Bursa.
16. Sezer, F.S., 2005. Progress of Thermal Insulation Systems in Turkey and Exterior Wall Insulation Systems in Dwellings. Journal of Uludag University Faculty of Engineering and Architecture, 10(2): 79-85.
17. Akcali, U., 2011. 2011 Construction Unit Price Analysis I-II. Safak Press Ind.Com.Ltd.Com., Ankara.
18. Turkish Standard Number 825 (TS 825), 2008. Thermal Insulation Requirements for Buildings. Turkish Standards Institution, Ankara.