

# THE EFFECT OF OPAQUE-TRANSPARENT SURFACE RATIO ON BUILDING ENERGY PERFORMANCE

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## Abstract

Energy use in buildings accounts for a significant proportion of global energy consumption and improving energy efficiency plays a critical role in combating global warming and climate change. The use of opaque and transparent materials in the right proportions is an important factor in saving energy and reducing emission values. The aim of this study is to obtain the optimum opaque/transparent ratio according to climate zones and building facades by analysing the effect of opaque/transparent ratio and window type on building energy performance and the application cost of window types for different facades in residential buildings in different climate zones of Turkey. A building model has been created in provinces (Antalya, Istanbul, Ankara, Erzurum) representing four different climate zones (hot, temperate-humid, temperate-dry, cold) according to TS 825 - Thermal Insulation Rules in Buildings. Separate heating energy amounts were calculated for 4480 scenarios using 10 different opaque/transparent ratios (10%-100%), 7 different joinery types (wood, PVC 3-6 chamber, aluminium non-insulated-insulated) and 4 different glass types (12 mm and 16 mm spacer-double glazed, double glazed low-e coated) for four different facades (north, south, east and west). Heat gain and heat loss amounts were obtained by performing monthly analyses with TGÜB 825-Heat Insulation Calculation Program compatible with TS 825. In the literature, there are many studies showings that opaque/transparent surface ratios are important in energy efficient building design. This study gains originality by examining the effect of opaque/transparent surface ratios on energy efficiency and the relationship between the cost and energy demand of different window systems in four different climatic regions of Turkey. The data obtained will make an important contribution and guidance to the academia and the construction sector.

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**Keywords:** building energy performance, energy efficiency, energy efficient building, opaque/transparent ratio, window systems.

## 1. Introduction

In the world where the rate of urbanisation is constantly increasing, the demand for energy is increasing. The unconscious and excessive consumption of natural resources used to meet this demand leads not only to energy crisis but also to environmental problems. The fact that energy needs are largely met from fossil fuels leads to increased air and water pollution and damage to ecosystems. In addition, the increase in greenhouse gas emissions accelerates global warming and increases the frequency and severity of natural disasters due to climate change [1].

In the European Union (EU), the building sector is responsible for 40 per cent of energy and 36 per cent of greenhouse gas emissions. Approximately 35% of the EU's building stock is over 50 years old and

75% is energy inefficient. In order to reduce environmental problems and increase energy efficiency, the EU has set targets to reduce greenhouse gas emissions by at least 40% by 2030 (compared to 1990), to increase the share of renewable energy sources in energy consumption to at least 32% and to achieve an improvement of at least 32.5% in energy efficiency. In this context, studies on the integration of building envelopes, smart digitalisation and renewable energy have gained importance [2]. Energy efficient buildings stand out among these solutions. Energy efficient buildings provide the same level of comfort by consuming less energy, thus reducing energy costs and preventing problems such as global warming and environmental pollution [3].

The 'Building Envelope', as a criterion for energy efficient buildings, covers a wide research area related to the improvement of the thermophysical properties of transparent and opaque materials. The ratio of opaque and transparent surfaces of a building has a determinant effect on solar heat gains, heat losses and lighting requirements. This significantly determines the energy consumption of the building [4]. There are many studies on the ratio of opaque and transparent surfaces in order to save energy in buildings [5-11]. In the literature, it has been observed that these studies are generally carried out on a single climate zone and a single glazing combination. This study analyses the effect of various glass combinations and opaque and transparent surface ratios on energy efficiency in four different climate zones of Turkey. It also adds originality to the study by evaluating the relationship between the cost of glazing combinations and energy savings.

## **2. Method**

In the study, firstly, 4480 building models were created by determining the design parameters to be used in the calculations such as facade, opaque and transparent surface ratio, window joinery type, window glass type. In line with these parameters, heat loss and heat gain values of the building models were obtained by performing monthly analyses with the help of TGÜB 825 Program using TS 825 (Turkish thermal insulation standard) [12]. According to TS 825, a building model has been created in provinces (Antalya, Istanbul, Ankara, Erzurum) representing four different climate zones (hot, temperate-humid, temperate-dry, cold) of Turkey. In the building model, the optimum opaque and transparent surface ratio on different facades, glass combination and the investment cost generated by glass combinations are obtained and the results are analysed. The joinery and glass costs used are based on the unit prices in the catalogue for the materials included in the Republic of Turkey Ministry of Environment and Urbanisation Unit Price Catalogue. For the materials not included in the catalogue, price information was obtained by conducting market research.

### *2.1. Design Parameters*

In the building model created within the scope of the study, the opaque/transparent surface ratio and window combinations were determined as variable design parameters in such a way that the wall, ceiling slab and floor structural elements forming the envelope remain constant.

#### *2.1.1. Building model*

Within the scope of the study, the building type was selected as residential and the building model was designed as; gross volume 3375 m<sup>3</sup>, net usage area 1080 m<sup>2</sup>, ceiling height 3m, number of floors 5, fuel type natural gas, internal temperature 19°, internal relative humidity 65%. Ventilation type is natural ventilation, ventilation volume is 2700 m<sup>3</sup>, air exchange coefficient ( $n_a$ ) is 0,8h<sup>-1</sup>, ventilation losses ( $H_v$ ) is 712,8 W/K. The coefficient of thermal conductivity (U) is defined as 0,053 W/m<sup>2</sup>K for the wall with external air contact, 1,48 W/m<sup>2</sup>K for the roof slab (with roof) and 0,377 W/m<sup>2</sup>K for the floor with ground contact. Door area is disregarded in the building envelope. The solar energy transmission factor (g) of the windows is taken as 0.75 (multi-storey glass) and the shading factor is taken as 0.8 (split building zones). In the Building Model designed according to TS 825, these values were kept constant and the thermal transmittance coefficient ( $U_w$ ) values of the windows were determined as variable design parameters.

### 2.1.2. Opaque/transparent surface ratio

Building facades consist of a combination of both opaque and transparent building elements. Opaque elements are usually solid wall structures, while transparent elements usually consist of windows. In order to investigate how heat loss in buildings varies depending on the building facades of different opaque and transparent surface ratio, 10 different opaque/transparent surface ratio scenarios were created and applied separately on 4 different facades (north, south, east and west). The opaque/transparent surface ratio scenarios created within the scope of the study are presented schematically as shown in Fig. 1.

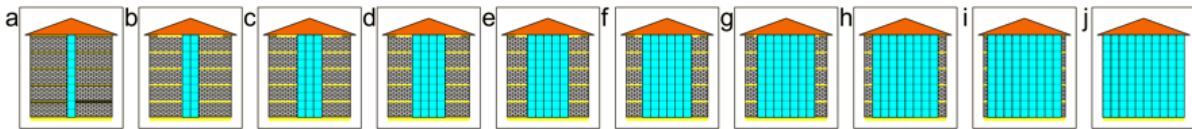


Fig. 1. Opaque/transparent surface ratio scenarios created on different facades; (a) %10; (b) %20; (c) %30; (d) %40; (e) %50; (f) %60; (g) %70; (h) %80; (i) %90; (j) %100.

### 2.1.3. Window combination

Windows, which form the transparent surface on building facades, consist of a combination of glass material and joinery surrounding the glass. Windows created by using glass and joinery types with different thermophysical properties have different heat loss and gain rates for the building under varying climatic conditions. In order to examine to what extent different window combinations affect energy consumption on different facades and in different climatic zones, 28 different window combinations were created using 7 different joinery types (wood, PVC 3-6 chamber, aluminium non-insulated and insulated) and 4 different glass types (4 mm+12 mm+4 mm, 4 mm+16 mm+4 mm uncoated glass and low-e coated glass). The combinations and their optical and thermophysical properties are presented in Table 1.

Table 1. Optical and thermophysical properties of window combinations [5].

Window frame type	Double-Glazed Windows-Uncoated Glazing U Value ( $W/m^2K$ )		Double-Glazed Windows-Low-e Glazing U Value ( $W/m^2K$ )	
	4mm+12mm+4mm	4mm+16mm+4mm	4mm+12mm+4mm	4mm+16mm+4mm
Wooden joinery	2,64	2,5	1,74	1,53
PVC window frame-3 chambers	2,7	2,56	1,8	1,59
PVC window frame-4 chambers	2,67	2,53	1,77	1,56
PVC window frame-5 chambers	2,64	2,5	1,74	1,53
PVC window frame-6 chambers	2,61	2,47	1,71	1,5
Aluminium frame	3,66	3,55	2,79	2,58
Aluminium frame-with insulation bridge	2,79	2,65	1,89	1,68

## 2.2. Account method

The energy consumption values of the building models created in the study were analysed monthly using the TGÜB 825 Program, which is fully compatible with TS 825, based on the heat loss calculation method and heat gain calculation method specified in TS 825. Using 4 different climate zones (hot, temperate-humid, temperate-dry, cold), 10 different opaque/transparent surface ratios (10%-100%) for 4 different building facades (north, south, east and west), 7 different joinery types (wood, PVC 3-6 chamber, aluminium non-insulated and insulated) and 4 different glass types (4 mm+12 mm+4 mm, 4 mm+16 mm+4 mm uncoated glass and low-e coated glass), the amount of heating energy required for a total of 4480 building models was calculated.

In the calculations, opaque/transparent surface ratios, optical and thermophysical properties of window combinations, building facade and climate zones were used as variable design parameters in a way that the thermophysical properties of the soil contact floor, outdoor air contact wall and roof slab forming the building envelope remain constant. In Table 2, the climate data of the cities selected to represent the climate zones within the scope of the study between 1991-2020 are presented.

Table 2. Climatic characteristics of Antalya, İstanbul, Ankara and Erzurum [13].

Parameters	Antalya	İstanbul	Ankara	Erzurum
Climatic region	Hot	Temperate-Humid	Temperate-Dry	Cold
Average Temperature (°C)	18,8	15,2	12	5,8
Average Highest Temperature (°C)	24,2	19,3	17,9	12
Average Lowest Temperature (°C)	13,8	11,9	6,3	-0,5
Average Sunshine Duration (hours)	8,2	1	6,7	7
Average Number of Rainy Days	73,6	116,4	103,3	121,6

### 2.3. Cost account

The glass costs used in the study are based on the unit prices in the catalogue for the materials included in the 2024 Unit Price Catalogue of the Ministry of Environment, Urbanisation and Climate Change of the Republic of Turkey. Joinery price information not included in the catalogue was obtained by conducting market research. Table 3 presents the total cost information generated by the windows.

Table 3. Cost information of window combinations.

Window Frame Type	Double-Glazed Windows-Uncoated Glazing		Double-Glazed Windows-Low-e Glazing	
	4mm+12mm+4mm (\$/m <sup>2</sup> )	4mm+16mm+4mm (\$/m <sup>2</sup> )	4mm+12mm+4mm (\$/m <sup>2</sup> )	4mm+16mm+4mm (\$/m <sup>2</sup> )
Wooden Joinery	133,47	134,28	136,70	138,32
PVC window frame-3 chambers	53,89	54,70	57,12	58,74
PVC window frame-4 chambers	55,22	56,03	58,45	60,07
PVC window frame-5 chambers	55,96	56,76	59,18	60,80
PVC window frame-6 chambers	57,14	57,95	60,37	61,99
Aluminium Frame	86,72	87,52	89,94	91,56
Aluminium Frame-with insulation bridge	95,82	96,63	99,05	100,67

### 3. Findings and discussion

In the study, a total of 4480 building models were created using 10 different opaque/transparent surface ratios, 7 different joinery types and 4 different glazing types for 4 different building facades in selected provinces representing 4 different climate zones. The change in the annual heating energy consumption of the created building models according to the glass combination, opaque/transparent surface ratios, facade factor, climate characteristics for wood joinery, PVC-6 chamber, aluminium-insulated joinery representing joinery types are presented in Fig. 2-4.

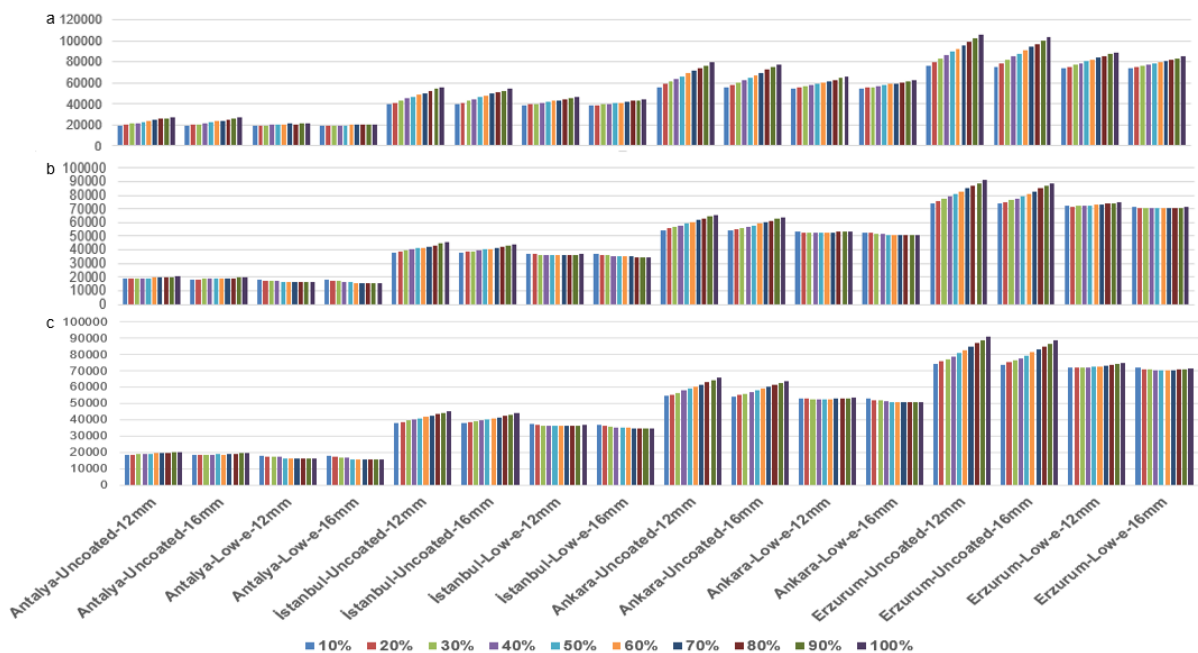


Fig. 2. Heating energy consumption according to wood joinery; (a) north facade; (b) south facade; (c) east-west facades.

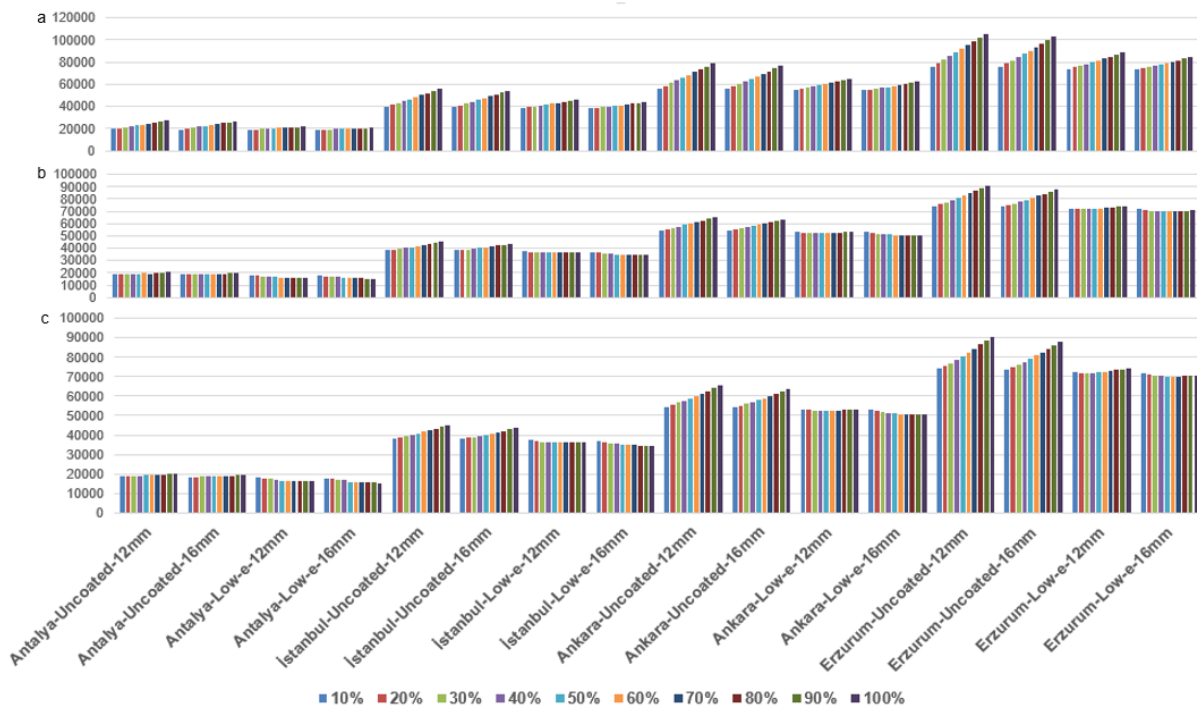


Fig. 3. Heating energy consumption according to PVC-6 chamber joinery; (a) north facade; (b) south facade; (c) east-west facades.

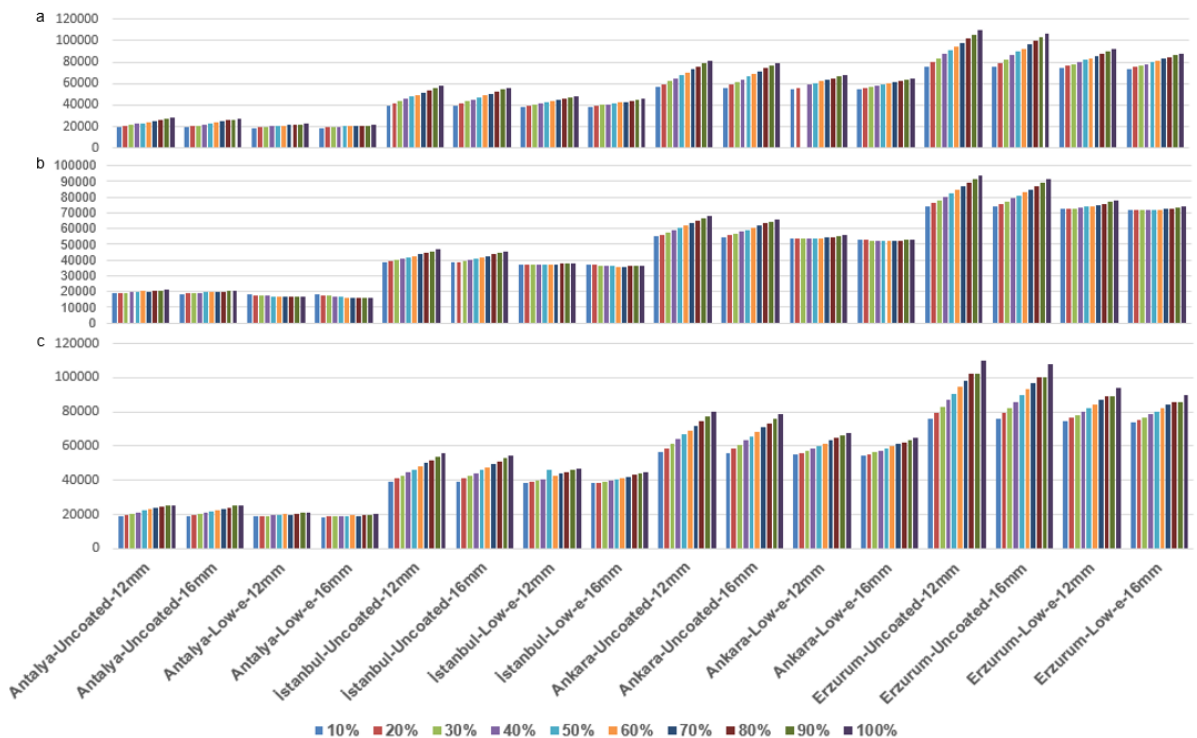


Fig. 4. Heating energy consumption according to aluminium-insulated joinery; (a) north facade; (b) south facade; (c) east-west facades.

When Figure 2-4 is analysed; it is seen that energy consumption for heating purposes in buildings varies significantly according to the facade direction. The fact that there are more windows on the south facades compared to the north facades provides less energy consumption. The reason for this is that the southern facades are the facades that receive the most intense sun rays. East-west facades show

an energy consumption level between north and south facades. The use of different types of joinery creates differences in terms of energy consumption in buildings. In general, the use of wooden joinery in windows causes more energy consumption in buildings than PVC joinery and less energy consumption than aluminium joinery.

The use of Low-e glass in windows saves energy by allowing less heat transfer in buildings compared to uncoated glass. When 16 mm air-gapped Low-e double glazing glasses are used instead of 12 mm air-gapped Low-e double glazing glasses, it is seen that an average of 3.24% energy saving can be achieved in Antalya, 3.20% in Istanbul, 1.55% in Ankara and 3.21% in Erzurum. In case of using 16 mm air gap Low-e glass instead of 12 mm air gap Low-e glass, it has been determined that maximum energy saving can be achieved on the north facade in Antalya and on the south facade in other provinces. In Erzurum, the energy saving on the south facade reached 4.34% on average, making this change in glass type the most efficient. Similarly, in the case of using uncoated double glazing with 16 mm air gap instead of uncoated double glazing with 12 mm air gap, it was observed that an average of 1.93% energy saving was achieved in Antalya, 1.78% in Istanbul, 1.72% in Ankara, 1.65% in Erzurum, and the facade with maximum energy saving was the south facade in all provinces. In general, it is seen that the use of Low-e glasses in windows provides an average of 14% less energy consumption compared to uncoated glasses. When the data obtained in the study are analysed; energy consumption varies significantly according to the cities. Energy consumption in Erzurum, which has the coldest climate, is the highest compared to other cities. This is followed by Ankara, Istanbul and Antalya. This shows that the climatic conditions of the cities and the insulation levels of the buildings have a significant effect on energy consumption.

In the study, although wooden joinery is the most expensive (92.3 \$/m<sup>2</sup>) and PVC joinery is the cheapest (average 14.4 \$/m<sup>2</sup>) joinery type, it is calculated that an average of 50.8 \$/year energy saving is achieved in windows with PVC joinery type compared to windows with wooden joinery type. Although the use of Low-e glasses instead of uncoated glasses in buildings causes an average 8.73% increase in window cost, it is calculated that an average of 2.80% savings in annual heating energy can be achieved in the building. In Fig. 5, the effect of opaque/transparent surface ratio on energy consumption according to facades is shown in detail.

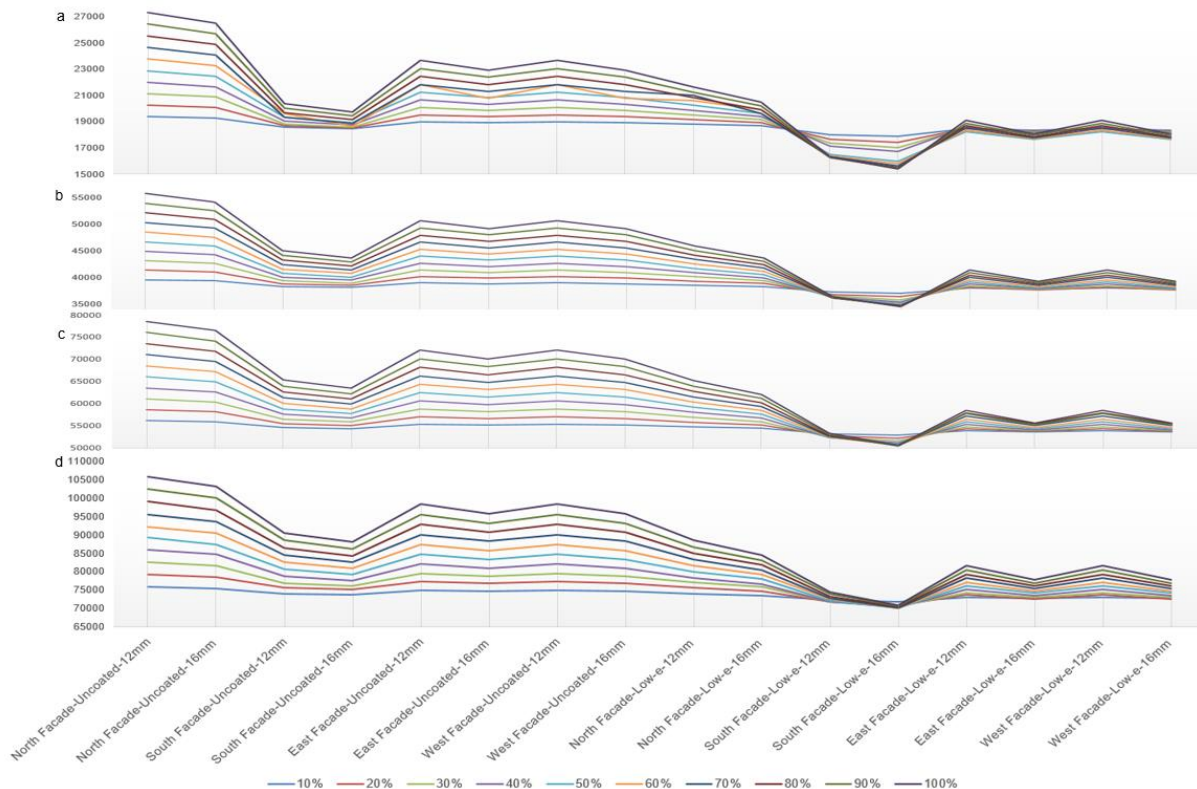


Fig. 5. Energy consumption for PVC window frame-6 chambers according to different opaque/transparent surface ratio ; (a) Hot climatic region; (b) Temperate-Humid climatic region; (c) Temperate-Dry climatic region; (d) Cold climatic region.

When Fig. 5. is analysed, it is seen that the energy required for heating in buildings increases as the opaque/transparent surface ratio increases in case of using uncoated glass in windows on all facades in all climate zones. In all climate zones and in all joinery (except aluminium joinery), if low-e coated glass is preferred instead of uncoated glass, it is seen that the need for heating energy in buildings decreases as the opaque/transparent surface ratio increases on the south facade. In all climate zones and in all types of joinery, it is calculated that when the transparent surface ratio in uncoated glasses is increased from 10% to 100%, the heating energy requirement of the building generally increases between 46.9%-53.4% on average. In this case, when the transparent surface ratio is increased from 10% to 100% with the preference of low-e coated glasses, the heating energy requirement of the building is calculated to increase between 5.9%-13.9%. When all glass types are taken into consideration, it is seen that the most advantageous glass type is low-e coated glass type as the transparent surface ratio increases.

According to TS 825, maximum energy consumption in buildings is limited. The energy requirement for the building model created in the study is 30510 kWh for Antalya, 56576 kWh for Istanbul, 72430 kWh for Ankara and 90788 kWh for Erzurum. In this context; if uncoated glass is used in wood, PVC 3-6 chamber joinery types in window combination in Erzurum, the ratio of transparent surface on the north facade is maximum 50%; this ratio is 70% on the east and west facades. In case of using aluminium and aluminium-insulation bridge joinery in window combination, the maximum transparent surface ratio is 30% and 40% on the north facade, 50% and 80% on the south facade, and 40% and 60% on the east and west facades, respectively. If these ratios are exceeded in building models, the building does not comply with TS 825. Low-e coated glass meets TS 825 in all joinery and transparent surface ratios except aluminium joinery.

When the data obtained in the study are analysed in detail; it is seen that optimum energy saving can be achieved by using PVC-6 chamber joinery and low-e coated 4mm+16mm+4mm glass combination in all facades and in all provinces selected to represent the climate zones of Turkey. Optimum opaque/transparent surface ratios in different climate zones vary according to the building facade and this situation is presented in Table 4.

Tablo 4. Optimum window combination and opaque/transparent surface ratios according to climate zones.

Parameters	Window Frame Type	Glass types	Opaque/transparent surface ratio			
			North facade	South facade	East facade	West facade
Hot climatic region- Antalya	PVC window frame-6 chambers	Low-e glazing/ 4mm+16mm+4mm	10%	100%	50%	50%
Temperate- Humidclimatic region- İstanbul	PVC window frame-6 chambers	Low-e glazing/ 4mm+16mm+4mm	10%	100%	20%	20%
Temperate-Dry climatic region- Ankara	PVC window frame-6 chambers	Low-e glazing/ 4mm+16mm+4mm	10%	80%	10%	10%
Cold climatic region- Erzurum	PVC window frame-6 chambers	Low-e glazing/ 4mm+16mm+4mm	10%	60%	20%	20%

The results show that window combination and opaque/transparent surface ratios significantly affect the heating energy consumption of buildings. It has been observed that the presence of windows on the south facades provides less energy consumption than the north facades. Among the different types of joinery, PVC joinery is the cheapest and generally the least energy consuming option, while wooden joinery is the most expensive and aluminium joinery is the most energy consuming. The use of Low-e glass in windows saves energy by allowing less heat transfer in buildings compared to uncoated glass.

The results of this study show that window types and opaque/transparent surface ratios should be determined optimally in order to save energy in buildings. In addition, the use of Low-e glass and the preference of PVC joinery play an important role in terms of energy saving. TS 825 calculates the energy requirement based only on heating energy. Therefore, in this study, energy analyses were made by considering only the heating energy requirement in buildings. In similar studies to be carried out in the future, the study can be carried to a better point by considering both heating and cooling energy consumption of the building. In this context, since the study focuses on sustainable energy and energy-cost relationship, it is thought that the results will make a significant contribution to the academia and the construction sector and will be guiding.

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