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Bina Kabuk Renginin Farklı İklim Koşullarında Bina Enerji Performansına Etkilerinin Araştırılması

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Öne Çıkanlar:
- Çalışma, doğru renk seçiminin enerji tüketimini azaltabileceğini göstermektedir.
- Beyaz dış cepheler, soğutma için gerekli enerji tüketimini %51-76 oranında azaltabilir.
- Siyah dış cepheler, ısıtma için gerekli enerji tüketimini %6-28 oranında azaltabilir.
- Soğuk iklimlerde koyu renkler, toplam enerji tüketimini %18-41 oranında azaltabilir.

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Amaç:
Bu çalışma, farklı bina dış cephe renklerinin, bina enerji performansı üzerindeki etkilerini incelemek amacıyla gerçekleştirilmiştir.

Metot:
Çalışmada, bina dış cephe renklerinin enerji verimliliği üzerindeki etkilerini incelemek amacıyla, dört farklı iklim (derece-gün) bölgesinde bulunan Antalya, Balıkesir, Konya, Erzurum şehirleri için, bina enerji performansları analitik olarak hesaplanmıştır. TS825 standardına göre, dört farklı renk ve dört farklı cephe için 48 senaryo oluşturulmuş ve yüzey sıcaklıkları hesaplanmıştır. Dış cephe renklerinin ısıtma ve soğutma enerjisi tüketimi üzerindeki etkilerini analiz etmek için güneş ışınımı, dış ortam sıcaklıkları, absorptivite ve emissivite değerleri kullanılmıştır. Ayrıca, ısıtma ve soğutma enerji tüketimleri, Isıtma Derece Gün (HDD) ve Soğutma Derece Gün (CDD) hesaplamalarıyla belirlenmiştir.

Sonuçlar:
Beyaz renkli dış cephelerin, Antalya gibi sıcak iklimlerde soğutma enerjisi tüketimini %51'e kadar azaltma imkânı vardır. Siyah renkli dış cepheler, soğutma amaçlı enerji tüketimini artırırken, ısıtma amaçlı enerji tüketimini düşürmüştür. Balıkesir'de, koyu mavi duvarların, siyah duvarlara kıyasla %50 daha az soğutma amaçlı enerji tüketimi gerektirdiği, kışın ve yazın düşük sıcaklıklar nedeniyle, kullanımının daha uygun olduğu belirlenmiştir. Konya'da, siyah renk ısıtma amaçlı enerji tüketimini %31 oranında azaltırken, beyaz duvarların en yüksek enerji tüketimine sebep olacağı belirlenmiştir. Erzurum'da, siyah duvarlar ısıtma amaçlı enerji tüketimini %26 oranında azaltmıştır. Soğuk iklimlerde, ısıtma amaçlı enerji tüketimi önemli bir gider kalemi olduğundan, siyah veya koyu renkli duvarların daha avantajlı olduğu değerlendirilmektedir. Genel olarak çalışma, bina dış cephesinde doğru renk seçiminin enerji tüketimini azaltabileceğini göstermektedir.

Anahtar kelimeler:
Dış cephe renkleri, Bina enerji tüketimi, Isıtma enerjisi, Soğutma enerjisi, Enerji verimliliği, İklim koşulları, Yansıtma

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Research Article

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Investigation of the Effect of Building Shell Colors on Energy Performance in Different Climate Zones

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Highlights:
- The study examines the impact of building façade colors on energy efficiency, highlighting that the right color choice can reduce energy consumption.
- White facades can reduce cooling energy consumption by 51-76%.
- Black facades can decrease heating energy consumption by 6-28%.
- Dark colors can lower total energy consumption by 18-41% especially in cold climates.

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Abstract
This study investigates the effects of building exterior wall colors on heating and cooling energy consumption. Analyses conducted in four different climate zones of Turkey (Erzurum, Antalya, Konya, Konya and Balıkesir) reveal that there are significant differences in energy efficiency between black, white, yellow and dark blue wall colors. In the study, the energy performance of a sample building and the effect of building envelope color on solar radiation were analytically calculated. Black shell color is good for saving energy for heating, while white shell color is good for saving energy for cooling. Depending on the climatic conditions, the most suitable wall colors for Erzurum, Konya and Balıkesir are black or dark colors, and white or light colors for Antalya. This study highlights the strategic importance of color selection in building design to reduce energy consumption. The results show that light colored building envelope reduces the cooling load by 51-76% and increases the heating load by 6-28%. On the other hand, the dark building envelope increases the cooling load by 50-76% and reduces the heating load by 18-41%.

Keywords: Building envelope color, Building energy consumption, Heating energy, Cooling energy, Energy efficiency, Climate conditions, Emission, Reflectance

1. Introduction

Energy efficiency and sustainability are of increasing importance in today's architecture and construction industry. In this context, the exterior color of buildings is an important factor affecting energy consumption. Beyond aesthetic concerns, the choice of color in building design directly affects the thermal performance of the building and thus the energy consumption for heating and cooling. Global warming, climate change, and rising energy costs are driving the need for energy-efficient solutions, making the choice of exterior wall color an important factor [1].

Nowadays, energy efficiency studies are of vital importance for many reasons such as the problems related to global warming [2] and the burden of energy supply on the economy [3]. If energy efficiency is not ensured, it will not be possible to leave a country or a livable world suitable for human living standards to future generations [4]. It has been stated that 85% of the energy spent in buildings is for air conditioning [5]. Reducing external dependence on energy, reducing energy costs and environmental pollution, reducing supply in order to ensure energy security, the trend towards energy efficiency is increasing day by day [6]. It is recommended that energy efficiency studies for a sustainable world should start from the sector with the highest energy consumption. This sector is defined as the building sector in many regions with different climatic conditions from desert climate [7] to temperate climate [8]. In the literature, it is stated that the share of buildings in total energy use is 40% in Europe [9], 50% in the UK [10] and more than 60% in Palestine. Studies and research on efficient and sustainable energy practices are of critical importance for countries with foreign energy dependence [11-12]. In order to reduce external dependence, the amount of fuel consumed can be reduced by thermal insulation in houses [4,13]. The most of the energy is consumed in buildings is used for heating and cooling purposes [14]. Because of this, the widespread effect of the smallest improvement in thermal performance of the buildings on total energy efficiency and total carbon footprint will be significant [15].

The building envelope is a critical structural component that separates the exterior and interior environments of a building while providing durability and insulation to the building. It includes elements such as exterior walls, roofs, floors, and window glazing, and these components not only protect the structure from external factors but also control the heating, cooling, and ventilation requirements of the interior space. Approximately 50% of the energy is transmitted through the building envelope [16]. Therefore, the building envelope plays a significant role in thermal comfort and building energy performance. The impact of the envelope's color on energy consumption is crucial because the envelope affects heat transfer between the building's interior and exterior environments. In summer, a significant amount of heat is gained through the envelope, and a substantial amount of energy is expended to dissipate this excess heat [17]. Appropriate color selection can help to minimize heat gain by reducing the solar radiation absorbed by the building envelope [18]. The use of low-emissivity colored exterior walls can significantly reduce the energy consumption required for cooling [19].

The capacity of the exterior surfaces of buildings to reflect or absorb sunlight significantly affects the internal temperatures of buildings and consequently the energy consumption for cooling. Light colors reflect sunlight and keep buildings cooler, reducing cooling costs, especially in hot climates [9].

Inversely, dark colors absorb more sunlight, increasing the thermal gain of buildings and can contribute to lower heating costs in cold climates [20]. To save energy, it's important to understand how wall color affects energy use in different climates and seasons [21]. This is linked to albedo, which is a measure of how much sunlight a surface reflects. Surfaces with high albedo, like white or light-colored walls, reflect more light and stay cooler, reducing cooling costs in hot climates [22-23]. On the other hand, dark colors have low albedo, absorbing more heat and helping to save on heating costs in cold climates [24].

This paper highlights how choosing the right color for a building's exterior can improve energy efficiency. There are few studies that thoroughly explore how the color of a building's exterior affects its overall energy use. This article fills that gap by analyzing the impact of exterior color on energy performance in four different climate zones. Improving energy efficiency through better color choices can reduce energy consumption, enhance thermal comfort, and provide sustainable benefits both environmentally and economically. By improving the thermal performance of buildings, lower global energy demand can be achieved. Therefore, choosing the right exterior color should be seen as a crucial part of sustainable building design.

2. Material And Method

In this study, based on information from TS825, four different Degree-Day regions were selected, and 48 different scenarios were created using radiation intensity values for four different colors and four different facades.

Surface temperatures of exterior walls based on color was calculated by:

$$T_{gh}=T_0+\frac{\alpha.I_g}{h_b}-\frac{\sigma.\varepsilon.(T_0{}^4-T_{sky}{}^4)}{h_b} \quad (1)$$

$$T_{sky}=0.0552\,T_0{}^{1.5} \quad (2)$$

Table 1. Absorption and Emissivity Values of Colors

Exterior Wall Color	Absorptivity (α)	Emissivity (ε)
White	0.26	0.9
Black	0.98	0.25
Yellow	0.3	0.7
Dark Blue	0.45	0.55

The thermal performance of the building was calculated based on TS 825 standard (assuming months are 30 days long); where T_0 represents the outside temperature, α represents the surface absorptivity, ε represents the wall surface emissivity, I_g represents solar radiation (taken separately for south, north, and east/west directions), h_b represents the external surface heat transfer coefficient, T_{sky} represents the sky temperature, and σ represents the Stefan-Boltzmann constant [25-27].

According to data from the General Directorate of Meteorology, in Antalya, located in the 1st Degree-Day Region, the lowest outside temperature is 10°C in January, and the highest temperature is 28.6°C in July. In Balıkesir, located in the 2nd Degree-Day Region, the lowest outside temperature is 4.7°C in January, and the highest temperature is 25.6°C in August. In Konya, located in the 3rd Degree-Day Region, the lowest outside temperature is -0.2°C in January, and the highest temperature is 23.5°C in July. In Erzurum, located in the 4th Degree-Day Region, the lowest outside temperature is -9.1°C in January, and the highest outside temperature is 19.5°C in August. The Degree-Days of the considered cities are calculated by using the following equations.

When

$T_{gh} \leq T_i \quad HDD = 30, \sum_1^{12}(T_i - T_{gh})$ (3)

When

$T_{gh} > T_i \quad HDD = 0$ (4)

When

$T_{gh} > Ti \quad CDD = 30, \sum_1^{12}(T_{gh} - T_{\text{i}})$ (5)

When

$T_{gh} \leq T_i \quad CDD = 0$ (6)

Here, HDD represents the heating degree day, CDD represents the cooling degree day, T_{gh} represents the solar air temperature, and T_i represents the indoor temperature (assumed to be 20°C) [28]. The heating energy consumption (E_h) and cooling energy consumption (E_c) from the exterior wall were calculated by using the following equations:

$$E_{\text{h}} = \frac{0.024 \ U \ HDD}{\eta_{\text{h}}} \quad (7)$$

$$E_{\text{c}} = \frac{0{,}0024 \ U \ CDD}{COP} \quad (8)$$

where, U is the total heat transfer coefficient (W/m^2 C) for the exterior wall. The U is taken from TS 825 as 0.66 for the 1st climate region, 0.57 for the 2nd climate region, 0.48 for the 3rd climate region, and 0.38 for the 4th climate region. η_h is the efficiency of the heating system (assumed to be 0.93 for natural gas). COP is the coefficient of performance for the cooling system (assumed to be 2.5) [25, 27, 29].

3. Results and Discussion

This study examined the effects of building exterior wall colors on heating and cooling energy consumption through analyses

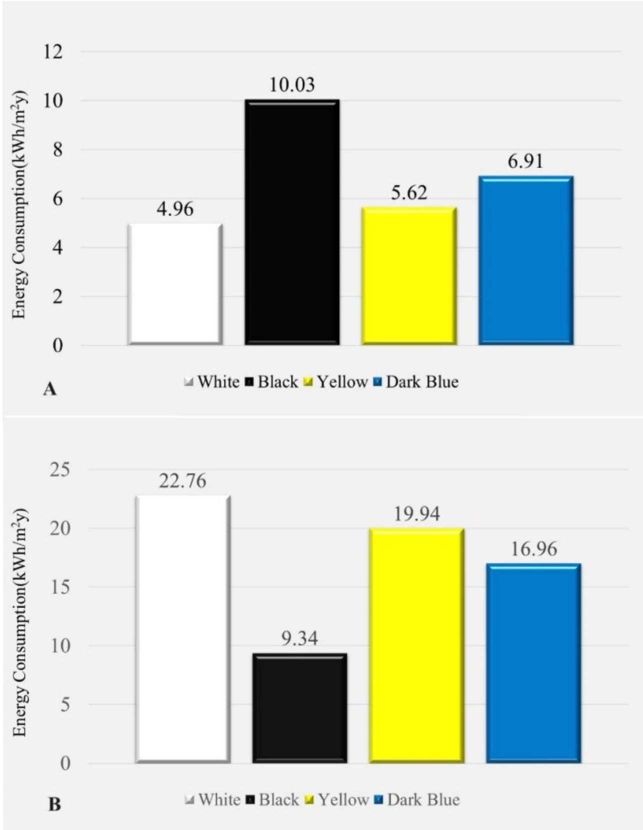

Figure 1. Heating (B) and Cooling (A) Energy Consumption for Antalya Province

conducted in four cities with different climatic conditions ın Turkiye (Erzurum, Antalya, Konya, and Balıkesir). The lowest exterior wall temperature was recorded in January at 6.2°C on the north-facing wall painted white, and the highest exterior wall temperature was recorded in July at 30.7°C on the west/east-facing wall painted black for Antalya. In Balıkesir, the lowest temperature was 0.8°C in January on a north-facing white wall, and the highest temperature was 27.44°C in July on a west/east-facing black wall. Similarly in Konya, the lowest temperature was -4.1°C in January on the north-facing white wall, and the highest temperature was 25.3°C in August on the west/east-facing black wall. In Erzurum, the lowest exterior wall temperature was recorded -13.1°C in January on the north-facing white wall, and the highest exterior wall temperature was 26.9°C in June on the west/east-facing black wall.

As seen in Figure 1(A) white wall color requires the least cooling energy, while black wall color requires the most cooling energy. White walls consume approximately 51% less energy for cooling compared to black walls. In Figure 1(B), black wall color requires the least heating energy.

Antalya has a hot climate, making cooling energy an important factor. The low cooling energy requirement of white wall color makes it a suitable choice for this city's climate conditions. Since heating energy consumption is low, the advantage of black wall color for heating can be disregarded.

Dark blue walls consume approximately 50% less energy for cooling compared to black walls. For heating energy, black walls consume approximately 41% less energy compared to white walls, and dark blue walls consume approximately 18% less energy compared to white walls. Balıkesir experiences significant seasonal temperature changes and has a Marmara climate, making both heating and cooling energy important. During winter, low temperatures and mild temperatures in summer are encountered. Using dark colors that save energy in winter for exterior wall color selection can reduce heating costs.

As seen in Figure 3, white wall color requires the least cooling energy, while black wall color requires the most cooling energy. For heating energy, black wall color requires the least heating energy, while white wall color requires the most heating energy.

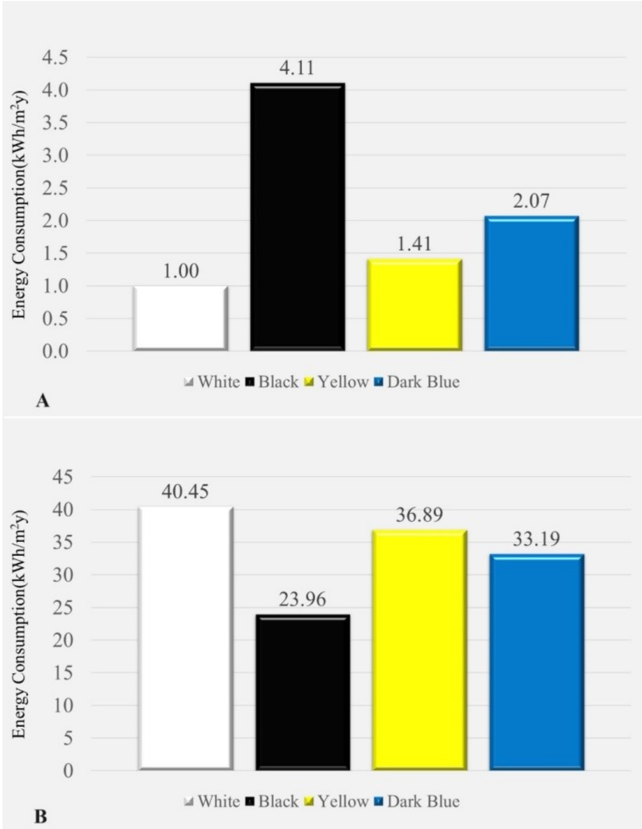

Figure 2. Heating (B) and Cooling (A) Energy Consumption for Balıkesir Province

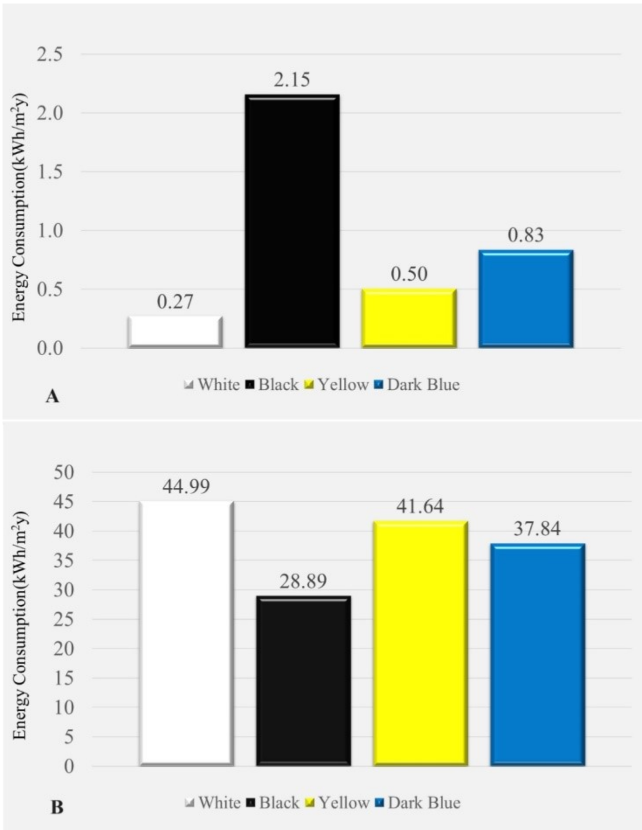

Figure 3. Heating (B) and Cooling (A) Energy Consumption for Konya Province

Konya has a continental climate with low temperatures in winter and high temperatures in summer. Heating energy consumption is high during winter in Konya. Black walls provide the lowest energy consumption for heating, while white walls show the highest consumption. Considering total energy consumption (black 31.04 kWh/m²y, white 45.19 kWh/m²y), black or dark colors are more efficient in terms of total energy consumption. Black wall color consumes approximately 31.33% less heating energy compared to white wall color.

For cooling energy, white walls consume approximately 76% less energy compared to black walls, yellow walls consume approximately 68% less energy compared to black walls, and dark blue walls consume approximately 56% less energy compared to black walls. Black walls consume approximately 28% less energy for heating compared to white walls, yellow walls consume approximately 6% less energy compared to white walls, and dark blue walls consume approximately 12% less energy compared to white walls.

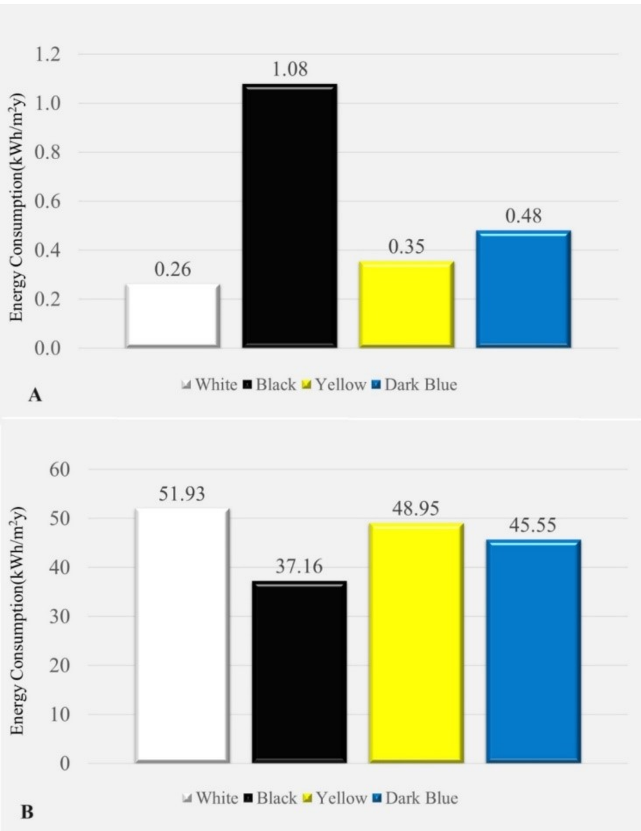

Figure 4. Heating (B) and Cooling (A) Energy Consumption for Erzurum

In Erzurum, due to cold climate conditions, heating energy consumption is a priority. Black or dark colors are advantageous in terms of total energy consumption. Black wall color consumes approximately 26.73% less energy compared to white wall color. The heating energy savings of black wall color make it a suitable choice for this city's climate conditions.

4. Conclusion

This research investigated the effects of exterior wall colors on the energy efficiency of buildings. It was found that in four different degree day zones, light-colored building envelope reduced the cooling load by 51-76% and increased the heating load by 6-28%; dark-colored building envelope increased the cooling load by 50-76% and reduced the heating load by 18-41%. The findings show that the choice of exterior wall colors plays an important role in energy consumption according to climatic conditions. In cold climate regions, the choice of black or dark colors saves heating energy. This is because black or dark colors absorb sunlight better and heat the interior of the building. In hot climate zones, white or light colors should be preferred, taking cooling energy into account. These colors keep the interior of the building cooler by reflecting sunlight. In continental and Marmara climates, dark exterior walls stand out as a more suitable option in terms of total energy consumption.

By choosing thermochromic materials optional in the building envelope, it is thought that it will prevent the negative effects of color differences on energy efficiency and save energy by reducing the heating load in winter and the cooling load in summer. Therefore, it is recommended to investigate the effect of using thermochromic materials in the building envelope on energy savings in future studies.

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