Renovation Strategies for Energy Conservation in Multi-Story Residential Buildings in Turkey

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ABSTRACT

Reducing the energy consumption of existing and new buildings is necessary in the context of energy efficiency. This study emphasizes the importance of energy-efficient renovation of existing housing stock and the development of renovation strategies according to the TS 825 standard and climate characteristics across the different degree day zones of Turkey. The research proposes an energy-efficient renovation of a public housing project and analyzes the impact of these suggestions on building energy performance. The impact of renovations to improve the thermal performance of opaque and transparent components on the energy performance of the building is calculated using the Design-Builder simulation program, and the heating-cooling loads, electricity, natural gas, and total energy consumption are analyzed in the four zones. With the most cost-saving renovation suggestions, total energy consumption is reduced by 35.7% in Erzurum, 32.2% in Ankara, 27.3% in Istanbul, and 19.3% in Antalya. In residential building renovations in Turkey, especially in hot climates, it is essential to focus on energy-efficient design principles, increase the insulation thickness of opaque components, improve the thermal performance of transparent components, and install solar control where necessary to improve the energy efficiency of the building.

Keywords-building energy performance; existing multi-story residence; energy-efficient renovation; opaque and transparent components

I. INTRODUCTION

Energy-efficient retrofit strategies for building exteriors are essential to reduce CO_2 emissions and improve energy efficiency. Combining thermal renovation initiatives with updates to heating systems proves to be a cost-effective approach to achieve substantial reductions in CO_2 emissions across the building stock within the EU [1]. Mitigating the adverse environmental effects of the construction sector involves minimizing non-renewable energy usage during building operation phases, with a strong emphasis on energy-efficient building designs [2]. Optimal energy efficiency enhancement in buildings necessitates carefully optimizing thermal resistance in transparent and opaque envelope structures, considering environmental factors such as solar radiation and wind impacts [3]. Additionally, integrating renewable energy technologies into building envelopes, such as solar and geothermal power systems, holds considerable promise to advance energy efficiency standards [4].

Efficient methods for updating building exteriors to save energy involve using simulation techniques to choose the best facade updates [5], testing various strategies with accurate simulations [6], exploring passive design changes such as adjusting shading and window properties [7], combining energy simulations with orthogonal array tests for renovations aiming at nearly zero energy consumption [8], and employing hybrid retrofit approaches that use both design and energy-saving methods along with advanced materials for facades [9]. These methods aim to reduce energy usage, improve building functionality, and reduce carbon emissions. Considering aspects such as energy efficiency, visual appeal, cost-effectiveness, and local climate conditions, decision-makers can make wise choices for sustainable and high-performing building exteriors early in the planning process. Many studies have focused on improving the heat regulation of building elements to improve energy efficiency and indoor comfort. Opaque structures are critical in minimizing heat loss during the colder months and preventing overheating in warmer seasons [10, 11]. Transparent features, such as windows, are often identified as weak spots in the building's shell due to their high thermal transmittance values (U-values), resulting in considerable heat loss during winter and unwanted heat gain during summer [12]. Novel approaches involve developing glazing components infused with Phase Change Materials (PCMs) to increase heat retention and transfer rates, thereby enhancing energy efficiency and indoor comfort [13]. Furthermore, research on ventilated opaque facades has shown their potential to reduce heat transfer, increase indoor comfort, and reduce cooling requirements in hot climates [14]. Optimizing the thermal characteristics of both opaque and transparent elements is crucial for sustainable building design and energy efficiency.

Ensuring the energy efficiency of existing and new buildings is essential to reduce energy consumption and CO_2 emissions caused by buildings. This study focused on the importance of energy-efficient renewal of the existing housing stock in Turkey by developing renovation strategies based on climatic characteristics. In [15], the global benefits of well-insulated buildings were demonstrated by determining the appropriate roof, wall, and floor insulation levels of a single-story house and a tower building in six different climatic zones in Italy. The results showed that high-performance building envelopes provide significant economic advantages [15]. In [16], a high insulation level was shown to increase the cooling load in Botswana, which is a hot-dry climate zone. In [17], the thermal performance of different glazing types in low-rise residential buildings in Turkey's day zones was compared during the period requiring heating. The results showed that the use of double-layer, Low-Emission (Low-E), and antireflective coatings together increases the performance of the glass under Turkey's climatic conditions, especially in the provinces of the 4^{th}-degree day zone [17]. In [18], the appropriate combination of exterior shading elements and glazing types was examined to reduce the cooling load in a multi-story residential building in Singapore considering the cost. A 30° sloped horizontal sunshade was suitable for the east and west facades, and a square lattice sunshade suited the north and south facades. In [19], the effect of shading elements on indoor air temperature was determined in multi-story residential buildings in Malaysia, located in a hot-humid climate zone. The results showed that the square lattice type sun shade had a more positive effect on preventing unwanted solar gains in tropical climates as it reduced the indoor air temperature the most.

II. INCREASING THE THERMAL PERFORMANCE OF THE BUILDING ENVELOPE

The building envelope separates the internal and external environment and comprises all horizontal, vertical, and inclined building components [20-22]. It is the physical and thermodynamic boundary between the constant indoor and variable outdoor atmospheric conditions. The outer shell, subject to variations in diurnal temperature, significantly affects indoor comfort and is constantly exposed to various energy flows that seek equilibrium. As a result, the material and structure of the building envelope must comply with the requirements of building physics, including heat, humidity, air tightness, sound, and light [23-27]. Energy-efficient renovation has become critical for sustainability and environmental protection. In this context, studies aiming to increase the energy efficiency of buildings stand out as an essential field. In these studies, the thermal performance of opaque and transparent building components plays a significant role in energy efficiency and comfort [11, 28-31].

A. Improving the Thermal Performance of Building Opaque Components

Building opaque components are building elements such as walls, roofs, and floors on the exterior. The thermal performance of these components directly affects the energy consumption of buildings. Thermal insulation is one of the important steps taken to reduce the energy consumption of buildings. Well-insulated opaque components save energy while maintaining the interior heat balance. Many studies have emphasized the importance of increasing the thermal resistance of building envelopes to minimize heat loss or gain, thus reducing the energy consumption required to maintain indoor thermal comfort [32-35]. In the context of residential buildings in Turkey's diverse climate zones, enhancing the insulation thickness of opaque components is crucial to improve energy efficiency. Increasing the insulation thickness at an appropriate rate based on the heat loss of opaque components can significantly reduce energy consumption [36]. Furthermore, using Phase Change Materials (PCMs) integrated into opaque envelope components has been identified as a promising strategy to enhance thermal performance and reduce energy consumption in buildings, and is a growing trend that indicates a shift towards more energy-efficient building designs [37-40]. The implementation of adaptive opaque facades presents an innovative approach to reducing thermal energy consumption in residential buildings, showcasing the potential s achieving low-carbon energy structures [41, 42].

B. Increasing the Thermal Performance of Building Transparent Components

Building transparent components are light-transmitting elements such as windows, doors, and façade glasses. The thermal performance of these components is also essential. Well-insulated transparent components ensure adequate daylight utilization while maintaining the heat balance of the interior. At the same time, it prevents unnecessary heat losses and saves energy. Various applications and developments have been proposed to improve the thermal performance of transparent building components. The focus is on developing advanced building materials that combine high thermal insulation and optical properties to replace glass, emphasizing the importance of energy-efficient applications [28]. Transparent components can be upgraded by replacing them with climate-controlled windows that offer improved thermal performance. Transparent insulation materials have been identified as practical solutions to improve energy savings and daylight comfort in buildings. Increasing the thermal resistance of transparent elements can minimize heat transfer, reducing energy demands for heating and cooling [35, 43]. Several technological advances have been made to adapt to dynamic properties in building facade systems, which has contributed to improving thermal performance and energy efficiency [44]. Ultra-broadband transparent conductive electrodes have been developed, effectively modulating the optical and thermal energy required to achieve zero-energy buildings [45]. Smart windows with adaptive and controllable features are explored in the context of their energy-saving potential. In this context, investigations and simulation studies have been performed on thermochromic, photochromic, and electrochromic technologies to compare energy-saving potentials [46]. Furthermore, electrochromic windows have resulted in 10-20% energy savings on the perimeter of office buildings [47]. In [48], the impact of a Low-E window film on energy consumption was investigated, showing that it improved energy performance. Moreover, solar and thermal radiation modulation materials have been developed for building applications, addressing the need for materials with low infrared thermal emission to suppress radiative heat loss in winter and accelerate radiative heat dissipation in summer [49]. In addition, the effect of solar control elements on heating and cooling loads and comfort was evaluated in this context [50]. Finally, it is emphasized that accurate measurement of the U-value is very important to evaluate energy performance and can be tested by simulation to control heating and cooling [51].

III. MATERIALS AND METHODS

This study analyzes the energy performance of an existing multi-story residential building that is inadequate in terms of energy conservation, the determination of economic improvement techniques for the building envelope by the climatic characteristics of the TS 825 "Thermal Insulation Rules in Buildings" standard, and the evaluation of the energy gains obtained. The objective is to reduce heating load, cooling load, electricity consumption, natural gas consumption, and total energy consumption by replacing opaque and transparent components. Although the recommendations differ according to the climatic characteristics, they include insulating the exterior walls, ceiling, and ground floor according to the thermal conductivity values required by TS 825, replacing the windows with suitable climate-controlled ones according to the day zone degree, and adding sunshades to the windows when necessary (Table I).

TABLE I. ENERGY-EFFICIENT RENOVATION STRATEGIES FOR THE BUILDING ENVELOPE

	Renovation of components	I. Zone (Antalya)	II. Zone (İstanbul)	III. Zone (Ankara)	IV. Zone (Erzurum)
Opaque	Insulating walls	$U_D \leq 0.70$	$U_D \leq 0.60$	$U_D \leq 0.50$	$U_D \leq 0.40$
	Insulation of earth contact slab	$U_t \leq 0.70$	$U_t \leq 0.60$	$U_t \leq 0.45$	$U_t \leq 0.37$
	Insulating the ceiling slab	$U_t \leq 0.45$	$U_t \leq 0.40$	$U_t \leq 0.30$	$U_t \leq 0.25$
Transparent	Renovation of windows	Solar Low-E (glass no 1)	Solar Low-E (glass no 1)	Low-E glass (glass no 2)	Low-E glass (glass no 2)
	Addition of sunshades	Sun control (sun shading 1)	Sun control (sun shading 1)	Night insulation (sun shading 2)	Night insulation (sun shading 2)

It was assumed that the multi-story residential building, referred to as the existing building, had the same topographical characteristics in the provinces in 4 different degree day zones (Antalya, Istanbul, Ankara, Erzurum) specified in TS 825. Renovation proposals for this building were calculated in the Design-Builder simulation program, and different energy consumption and savings results were determined for each region. The plan type shown in Figures 1 and 2 was chosen because a square plan minimizes thermal changes due to orientation and has been built in many settlements in Turkey. The climate data of the settlements to be simulated were obtained from the existing library of the Design-Builder program and Meteonorm. Under the "settlement" heading of the program, the plan was modeled by dividing it into a total of five zones: four circles and a core. The basement, ground floor, 4th floor, and 9th floor were modeled as building blocks, and the other floors were modeled as adiabatic blocks. Table II shows some simulation parameters.

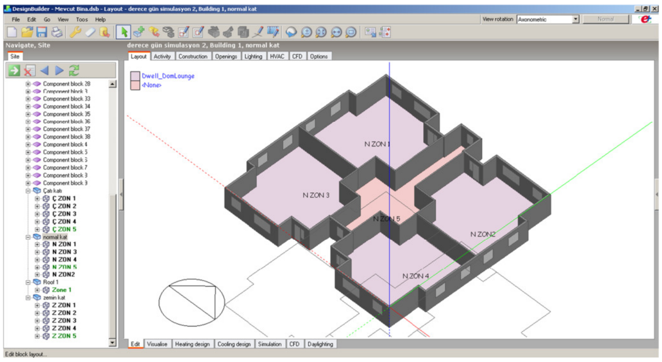

Fig. 1. Schematic of the type of plan analyzed.

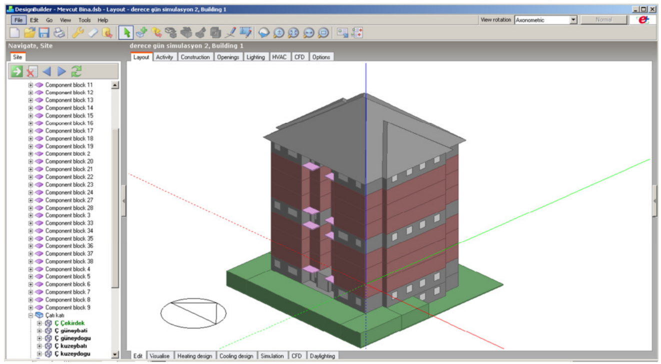

Fig. 2. 3D model image of the analyzed plan type.

TABLE II. SIMULATION PROGRAM PARAMETERS

Number of people per area:	0.027 people/m^2
Metabolic rate	0.9 met
Occupants' clothing insulation	0.5-1.0 clo
Airspeed	0.2 m/s
Natural ventilation settings:	Minimum and maximum outdoor temperatures: 10°C and 33.5°C. Minimum and maximum indoor temperatures: 22°C and 24°C
Air tightness value	0.7 W/m^2K

The building had nine floors. It was assumed that the thermal performance of the opaque and transparent components did not comply with TS 825. In this context, it was assumed that there was no thermal insulation in the opaque components, and the thermal performance of the windows was insufficient. The transparency rate of the analyzed building is 17%, the floor area is 580 m^2, and the total heated area is 4370 m^2. Table III shows the thermal conductivity coefficients of the opaque and transparent components of the analyzed building. Table IV shows the optical and thermophysical properties of the glasses used in the calculations of the building.

TABLE III. THERMAL CONDUCTIVITY COEFFICIENTS OF EXISTING BUILDING

Heat Lost Surface	**Thermal conductivity coefficient U (W/m²K)**
Existing walls	$U_D = 1.25$ (W/m²K)
Existing ground contact	$U_t = 2.70$ (W/m²K)
Existing ceiling tile	$U_T = 3.45$ (W/m²K)
Existing window	$U = 5.1$ (W/m²K)

TABLE IV. OPTICAL AND THERMOPHYSICAL PROPERTIES OF GLASSES OF EXISTING BUILDING

Glass No	**Glass type**	**Thermal transmittance (W/m²K)**	**Solar heat gain coefficient (W/m²)**	**Visible transmittance (%)**
1	6 mm Solar Low-E + 12 mm argon + 6 mm + 12 mm argon + 6 mm	1.008	0.386	0.607
2	6 mm Low-E + 12 mm argon + 6 mm + 12 mm argon + 6 mm	1.102	0.515	0.664

Within the scope of this study, many glass types and sun shades were calculated for each region, and the best performers were evaluated. Glass type 1 was used in the calculations made in climate zones I and II, while glass type 2 was used in zones III and IV. Glass types with three layers and argon gas between the layers were selected to achieve maximum savings. Sun shading type 1 is proposed for climate zones I and II, which is a sun shading system in the form of movable blinds placed at 15° angles with a size of 20 cm. Sun shading will be activated in the period when solar gain is desired. It is positioned on the existing building's south, east, and west facades. Sun shading type 2 reduces heat losses at night in climate zones III and IV. Insulated blinds applied from the outside were added only to the windows on the north facade in winter.

IV. FINDINGS

Table V shows the savings in total energy consumption by region with the retrofit of opaque, transparent, and opaque-transparent components. With the proposed retrofits, the highest savings in total energy consumption were achieved in the Ankara and Erzurum provinces. When comparing the renovation proposals for opaque and transparent components, the total energy consumption decreased the most with the renovation of opaque components. Total energy consumption decreased by 35.6% in Erzurum, 32.2% in Ankara, 27.3% in Istanbul, and 19.3% in Antalya.

In Turkey's hottest zone, known as day zone degree I, discussions focused on strategies to minimize cooling loads during building renovations. Accordingly, the opaque components of the building were insulated according to TS 825, transparent components were replaced with double- or triple-layer selectively permeable windows, and movable sun shading was added. With the renewal of opaque and transparent components, the heating load was reduced by a maximum of 29.8%, the cooling load by 23.5%, the electricity consumption by 12.7%, the natural gas consumption by 29.2%, and the total energy consumption by 19.3%.

TABLE V. ENERGY-EFFICIENT RENOVATION STRATEGIES FOR THE BUILDING ENVELOPE AND SAVINGS IN TOTAL ENERGY CONSUMPTION

Renovation of components		**I. Zone (Antalya)**	**II. Zone (İstanbul)**	**III. Zone (Ankara)**	**IV. Zone (Erzurum)**
Opaque	Insulation of walls	13%	20.1%	24.4%	33.4%
	Insulation of earth contact slab				
	Insulating the ceiling slab				
Transparent	Renovation of windows	3.1%	5.4%	6.4%	6.4%
	Addition of sunshades	2.9%	0.5%	1.1%	1.4%
Renovation of opaque and transparent components		19.3%	27.3%	32.2%	35.7%

In day zone II, where heating and cooling times are equal, renewal strategies to prevent unwanted heat gains in summer and suggestions to reduce heat losses in winter were discussed. Accordingly, the opaque components were insulated according to TS 825. Transparent components were replaced with double- or triple-layer selectively permeable windows and movable sun shading was added. With the renewal of opaque and transparent components, the heating load was reduced by 33.3% at most, the cooling load by 41.3%, the electricity consumption by 9.7%, the natural gas consumption by 33.3%, and the total energy consumption by 27.3%.

Renovation strategies in day zone III, where the heating time is longer than the cooling time, involved suggestions to reduce heat losses in winter. Accordingly, the opaque components of the building were insulated according to TS 825, the transparent components were replaced with heat-controlled double- or three-layer Low-E coated windows, and heat-insulated shutters were added. With the renewal of opaque and transparent components, a maximum reduction in heating load, 37.8% in cooling load, 23.8% in electricity consumption, 2.2% in natural gas consumption, and 37.7% in total energy consumption by 32.2% were observed.

Renovation strategies in day zone IV, which has cold climate characteristics, especially in winter, involved building insulation according to TS 825, and transparent components with temperature-controlled double- or three-layer Low-E coated windows, and heat-insulated shutters. With the renewal of opaque and transparent components, a maximum reduction of 40.7% was observed in heating load, 27.8% in cooling load, 1.3% in electricity consumption, 40.7% in natural gas consumption, and 35.7% in total energy consumption.

According to the renovation results, the savings potential was greater in cold climates. When comparing the savings in total energy consumption by zone, the lowest savings were achieved by renewing sunshades and windows, and the highest savings were achieved by applying thermal insulation. The effect of renovation strategies on the performance of an existing building is less in hot climates than in cold climates. Instead of improving a finished building, the basic principles of energy-efficient design, such as orientation, building form, and transparency rate, should be considered during construction. In the improvements to be made in residential buildings in the climatic zones of Turkey, it is essential to increase the insulation thickness at an appropriate rate to reduce the heat loss of the opaque components, increase the thermal performance of transparent components, and control the sun when necessary.

V. RESULTS AND CONCLUSION

The increasing need for energy and limited energy resources has led countries to reduce energy consumption and use renewable energy sources. Reducing the energy consumption of buildings, which have a significant share in total energy consumption, will reduce the need for energy. In addition to the energy-efficient design of new buildings, it is also essential to reduce the energy consumption of existing buildings. Considering that a large part of the existing housing stock in Turkey needs to be improved in terms of heat conservation, energy-efficient renovation has become even more critical.

In the context of these vital requirements, this study investigated a mass housing project that has the characteristics of the existing housing stock in Turkey and is insufficient in terms of heat preservation, located in the four day zones. The TS 825 standard provides energy-efficient renovation alternatives, and the climatic characteristics and thermal performance of the building were analyzed. The suggestions for opaque and transparent components were analyzed in the Design-Builder simulation program. As a result of the recommendations made according to the zones, the changes in heating and cooling loads, the electricity and natural gas consumption, and the total energy consumption were determined in the four zones. The best-performing examples, according to the zones, were presented as suitable renewal alternatives for that zone, and comparisons were made according to the day zones of Turkey. According to the results, the savings in energy-efficient renovation works of projects that do not meet the climatic characteristics and energy-efficient building design criteria vary according to the climatic factors. In this context, it is seen that energy-efficient building design can be achieved by first designing the building according to the environmental, physical, and climatic requirements of the location where it is going to be built. Furthermore, savings can be increased by reducing the heat conductivity coefficient in TS 825 in cold climate zones. For this reason, it is necessary to review the recommendations for cold climate zones in the standard to introduce legislation for the energy-efficient renovation of existing buildings and to encourage renovation.

In summary, this study investigated energy-efficient renovation strategies for existing dwellings in different climatic regions of Turkey and analyzed their impact on heating-cooling loads and energy consumption. Similarly, in [15, 32-35], it was emphasized that increasing the thermal resistance of building envelopes is essential to reduce the energy consumption required to achieve indoor thermal comfort by minimizing heat loss or gain. Furthermore, increasing the thermal resistance of transparent elements will minimize heat transfer, thus reducing energy demands for heating and cooling [16, 17, 35, 43, 51]. In addition, the positive impact of solar control elements on heating and cooling loads and comfort has been emphasized [18, 50]. Unlike similar studies, this study deals in detail with the four different climate zones in Turkey and presents glazing and shading element alternatives in various configurations for each climate zone. In addition, it has also developed feasible solutions for existing buildings.

As a result, energy-efficient renovation of existing multi-story residential buildings, which occupy an essential portion of the building stock, is vital in energy consumption, environmental protection, and use of energy resources. This study determined the extent to which savings can be made with proper renewal strategies according to the day zones. Future studies should involve energy-efficient renovation of existing buildings, using the results of different building forms by zone and the effect of opaque components on regional performance by improving U-values and using renewable resources. Furthermore, the relationship in the performance-cost axis of the recommendations should be examined, by calculating the performance change caused by the renewal results and the life cycle cost of the recommendations. This approach enabled the development of recommendations specific to each climate zone, considering regional differences in energy-efficient renovation strategies.

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