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Energy performance retrofits targeting national strategy development for typical Turkish school building

Hazal Kızıldağ [1], *Gökçe* Tomrukçu [2], *Gizem* Avgan [3], *Ayşe Özlem* Dal [4], *Neşe* Ganiç Sağlam [5], *Ece* Kalaycıoğlu Özdemir [6], *Touraj* Ashrafian [7]

[1] Graduate School of Engineering and Science, Department of Architecture, Ozyegin University, Istanbul, Turkey, hazal.kizildag@ozu.edu.tr

[2] Graduate School of Engineering and Science, Department of Architecture, Ozyegin University, Istanbul, Turkey, gokce.tomrukcu@ozu.edu.tr

[3] Graduate School of Engineering and Science, Department of Architecture, Ozyegin University, Istanbul, Turkey, gizem.avgan@ozu.edu.tr

[4] Graduate School of Engineering and Science, Department of Architecture, Ozyegin University, Istanbul, Turkey, ozlem.dal@ozu.edu.tr

[5] Faculty of Architecture and Design, Department of Architecture, Ozyegin University, Istanbul, Turkey, nese.saglam@ozyegin.edu.tr

[6] Faculty of Architecture and Design, Department of Architecture, Ozyegin University, Istanbul, Turkey, ece.kalaycioglu@ozyegin.edu.tr

[7] Faculty of Architecture and Design, Department of Architecture, Ozyegin University, Istanbul, Turkey, touraj.ashrafian@ozyegin.edu.tr

Abstract. Today, most existing buildings should be retrofitted to reduce the negative impact on the environment. According to the EPBD, Member States should prepare national action plans to increase nZEB. Therefore existing buildings must go under deep refurbishment. Educational facilities are a critical segment of the public sector, and a frequently used building type with high energy needs. In Turkey, more than 17 million students spend the majority of their time in school buildings, hence increasing energy efficiency in existing educational buildings not only contributes to the environment and can create healthy and comfortable indoor conditions for the students, but also creates an awareness of the youth and increases their learning performance. This study focuses on analyzing the effects of various retrofitting applications of the building envelope and HVAC systems on the energy performance of a school building to improve existing energy consumptions. Analysis of the building envelope is an important primary step towards achieving a low energy level, as other energy efficiency measures such as buildings' HVAC systems' efficiencies. The aim is to reduce the heating and cooling demand of the selected building and to increase its energy performance. The analysis of the case study showed that there is no insulation layer on the outer wall as a result of the measurements. Therefore, the first step is to observe how the appropriate insulation layer affects the energy performance of the building. The methodology consists of energy modeling of the case study building in DesignBuilder and obtaining energy performance results by EnergyPlus software. Various retrofit scenarios were prepared into packages which include alternatives of thermal characteristics of the opaque elements such as external walls and roof, application of different glazing units, and implementation of solar control elements. These variables were combined and compared in terms of their effects on total primary energy consumption, heating and cooling demand. Based on the results, technical suggestions were given according to the best performing scenarios. It is expected that the research outcomes will contribute to the studies to improve the energy performance in educational buildings.

Keywords. energy consumption, educational buildings, energy performance, energy retrofit
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1. Introduction

Global energy use is rapidly increasing day by day. This demand for energy causes a lack of resources, pollution to our environment, and worldwide catastrophes such as global warming and climate change that we can sense the consequences even today. The construction sector consumes an unignorable high amount of energy. Therefore the energy efficiency analysis of the present buildings and retrofitting strategies is vital to take precautions against energy overconsumption. This issue has affected the national protocols and legislations. In order to meet their aims, the European Union (EU) has established several laws under the Kyoto Protocol to improve energy efficiency, reduce energy consumption, and eliminate waste. In 2002, the Energy Performance of Buildings Directive (2002/91/EC, EPBD) was introduced [1]. One of the requirements is the implementation of minimum standards in new and some renovated structures.

The monitoring of the existing buildings' energy efficiency is an important strategy for preventing energy overconsumption in the construction sector. It is one of the fundamental challenges in moving towards sustainable buildings. Demolition of existing structures to construct new ones is not a reasonable method in terms of high budget, effort, or pollution to the environment, and it also consumes more energy [2]. To ensure adequate performance, the initial option is to lower the energy demand of buildings through passive solutions, followed by the retrofitting of building envelope layers. Preventing heat transmittance between outside and interior spaces is crucial for achieving the energy efficiency goal of sustainable buildings. The envelope of a building is like the skin of a human body, is the boundary between the inside and outside spaces that determine heat gain and heat loss. To provide optimum indoor comfort for the occupants as well as preventing over consumption of energy, heat loss prevention must be ensured with possible envelope alternative solutions with the assistance of efficient HVAC systems. Identifying the most significant material and insulation thickness requirements in the early design stages is vital. Presently, the majority of building thermal parameters' efficiency is computed using simple energy models of building envelope dynamics [3]. The thermal permeability is the most important parameter in these computations in case of comparing characteristics of thermal performance given by Turkish national standards and to evaluate thermal performance of educational buildings' envelopes suited for thermal insulating purposes. In the literature, various building parameters are analyzed on the retrofitting of educational buildings towards NZEB with cost efficiency in the process of refurbishment design [2,4,5,6]. The building envelope features, insulation thickness, HVAC system's effectiveness and role of solar shadings are analyzed in studies to evaluate building energy performance [7,8,9]. The occupancy schedules, parameters related to occupant behaviors input in computational programs affect the energy efficiency analysis results [4].

This study is a part of an ongoing project funded by Scientific and Technological Research Council of Turkey (TUBITAK) that focuses on analyzing the energy performance of a school building located in İstanbul, Turkey to determine the effects of envelope design elements and highlight key HVAC features' impacts.

2. Methodology

At the first step of the research, the building geometry is modeled in DesignBuilder [10] with all structural features including the materials, envelope details and HVAC systems to perform a dynamic energy simulation. The energy performance of the case study building is validated for the whole year of 2019 through the obtained electricity and natural gas bills. After calibrating the energy model by conducting simulations using DesignBuilder and Energyplus [11], the next step presented in this paper focuses on retrofit measurements on the building envelope and HVAC system to reduce the energy consumption of the building. Initially, the current energy use is observed in terms of annual heating and cooling consumption (kWh/m2a) and primary energy use (kWh/m2a). The energy usage is analyzed from both the bills and validated simulation results obtained from EnergyPlus. Then the variables that affect the energy demand are identified, such as material properties of walls, roof and glazing. Secondly, several alterations on building envelope components such as changing the thickness of insulation materials and also enhancing the mechanical system made within the simulation packages. Then the best performing individual packages are combined to analyze an overall effect.

2.1 Case Study Building

The case study building (Fig 1,2) is an elementary school located in Bakırkoy, Istanbul. The climate of Istanbul is classified as Csa according to Köppen [12], which has a mild Mediterranean climate. The selected building consists of four typical floors and a basement with a gross area of approximately 4435.78 m^2. Since the case study building is a typical school building commonly constructed in Turkey, the retrofitting strategy can be generalized and suitable for other school buildings. Hence, it may be a guideline for future constructions in Turkey. The construction of the building was completed in 2008 and opened for use. The school building is used between 09:00-14:40 on Friday and 09:00-16:20 for the rest of the weekdays. The geometry, thermophysical features, mechanical systems, internal gains, and user schedules were modelled and calibrated using electricity and natural gas bills obtained from the school administration.

Fig. 1 - Exterior view of the case study building.

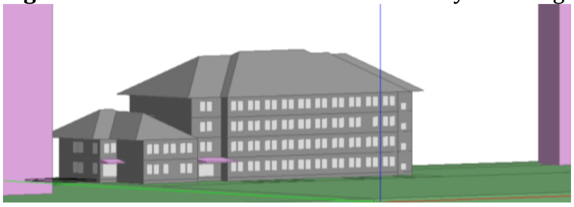

Fig. 2 - DesignBuilder 3D model.

2.2 Existing Building Properties

The external walls of the building are entirely cast concrete as it is located in one of the earthquake zones. The U-value of the external wall was measured on the field, and the rest of the material information was obtained from the school municipality and technical drawings. However, it has been observed that the thermal transmittance of the wall does not meet the permitted value by the national standard for Istanbul [13] which is 0.6 W/m2-K, while the existing U-value of the wall is 1.663 W/m2-K. Other construction details with material specifications are given in Table 1.

Tab. 1 Construction materials of the case building.

	Material	**Conductivity (W/mK)**	**Specific Heat Capacity (J/kgK)**	**Density (kg/m3)**	**Thickness (m)**	**U value (W/m2-K)**
External Wall	gypsum plaster	0,42	840	1200	0,03	1,663
	cast concrete	1,13	1000	2000	0,35	
	gypsum plaster	0,42	840	1200	0,03	
Floor	ceramic floor tile	0,8	850	1700	0,03	1,815
	floor screed	0,41	840	1200	0,07	
	cast concrete	1,13	1000	2000	0,35	
Roof	roofing tile	0,84	800	1900	0,01	0,507
	polyester resin	0,19	1200	1400	0,02	
	oriented strand board	0,13	1700	650	0,02	
	air gap	n.a	n.a	n.a	0,5	
	MW stone wool	0,038	840	40	0,05	
	reinforced concrete	2,3	1000	2300	0,12	
	cement plaster	0,72	840	1760	0,03	
Internal Wall	plaster	0,16	1000	600	0,03	1,184
	brick	0,62	800	1700	0,13	
	plaster	0,16	1000	600	0,03	

The glazing consists of air-filled double glazed windows (4+12+4) with a light-grey colour covering on the interior glass (Table 2). Additionally, there is no external shading; only the internal blinds are used for shading purposes.

Tab. 2 -Glazing materials of the case building.

Material	Thickness (mm)	Visible Transmittance (Tvis)	Solar Heat Gain Coefficient (SHGC)	U value (W/m2-K)
clear glass	4	70%	50%	2,7
air	12			
light grey-coloured glass	4			

The mechanical system information was gathered during the field observations, and it was determined that the heating system consists of a non-condensing hot water boiler with radiators.The single boiler has a 300 kW capacity. However, according to the latest regulation released in 2018 [14] it is forbidden to use non-condensing boilers that have a capacity under 400 kW. In terms of cooling, there are split air conditioners in several rooms such as the principal's room, teachers' room, kindergarten classrooms and elementary classrooms facing the south façade. Using air conditioners in classrooms is not common among public elementary schools. Since there is no use of an active cooling system in the building, there is an overheating problem affecting occupancy thermal comfort in the southern part of the building.

2.3 Existing Building Energy Performance

According to the U value measurement on the wall, the U value of the case study building is very high as stated above. It is clear that this situation directly affects the energy performance of the building. Annual heating demand is calculated as 42,931.54 kWh/m^{2}a, cooling demand is 0.4183 kWh/m^{2}a, and the primary energy consumption is calculated as 83,134.71 kWh/m^{2}a. The lack of insulation material in the building envelope and the lack of maintenance of the boiler caused an increase in the energy consumption of the building.

3. Results

3.1 Retrofit Strategies of External Wall

To ensure the energy performance improvements of the building, the current U value was measured during a site visit on 24th of May 2021. The measured U-value was recorded as 1.663 W/m^2-K. It has been observed that the building has a high U value according to the climate type and strategies have been developed for energy improvements. The selection of the materials for enhancing the building envelope was conducted according to the best performing materials available in TS 825 [13]**.** According to the measurements and information obtained from the technical personnel of the school, it is determined that there was no insulation layer on the outer walls. At the first step, expanded polystyrene (EPS) material is added to the outer walls (W1), and the resulting U-value is 0.685 W/m^2-

K which is appropriate for the Istanbul region. Secondly, the U-value is decreased to 0.432 W/m^2-K by increasing the thickness of this insulation material (W2). The improvement scenarios are shown in Table 3.

Tab. 3 Retrofit scenarios of the exterior wall.

Wall	Material	Thickness	Conductivity	Specific Heat	Density	U Value
		M	W/mK	J/ Kg-K	Kg/m3	W/m2-K
WO (Existing)	Cement Plaster	0.03	0, 42	840	1200	1,663
	Cast Concrete	0.35	1,13	1000	2000	
	Cement Plaster	0.02	0, 42	840	1200	
W1	Cement Plaster	0.03	0, 42	840	1200	0,685
	Cast Concrete	0.35	1,13	1000	2000	
	EPS Expanded Polystrene (Heavyweight)	0.03	0, 035	1400	25	
	Cement Plaster	0.02	0, 42	840	1200	
W3	Cement Plaster	0.03	0, 42	840	1200	0,432
	Cast Concrete	0.35	1,13	1000	2000	
	EPS Expanded Polystrene (Heavyweight)	0.06	0, 035	1400	25	
	Cement Plaster	0.02	0, 42	840	1200	

Results showed that (Fig. 3) the building's need for heating energy is decreased. Currently, the building has a heating demand of 42.93 kWh/m^{2}a, but with the addition of the insulation layer, this demand is lowered to 33.97 kWh/m^{2}a. Finally, if the thickness of the insulation material is increased, the heating requirement becomes 31.72 kWh/m^{2}a. A reduction of 11.21 kWh/m^{2}a is achieved according to the heating needs of the existing building. On the other hand, while the cooling load is 0.41 kWh/m^{2}a at the beginning, it has decreased to 0.35 kWh/m^{2}a in the W2 scenario. This situation also affected the primary energy consumption of the building. In the current situation, the primary energy consumption of the building is 83.13 kWh/m^{2}a per year. In comparison, the primary energy consumption obtained in the W1 scenario is 74.12 kWh/m^{2}a and in the W2 scenario is 71.85 kWh/m^{2}a. Therefore, in general, both the primary energy consumption and the need for heating and cooling have decreased, especially when the insulation layer is added to the building.

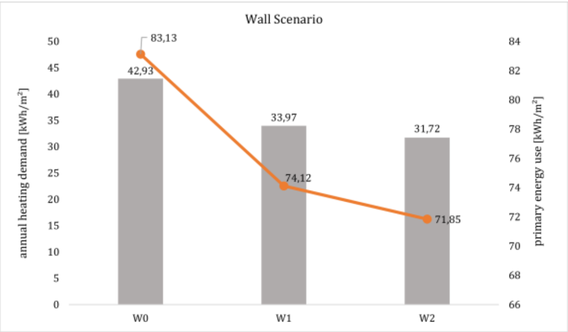

Fig. 3 - Comparison of wall scenarios

3.2 Retrofit Strategies of Roofing System

In order to reduce the energy consumption of the building, an improvement proposal is also developed on the roofing system (Table 4). Currently, the U-value of the roof is 0.503 W/m^{2}K. The insulation layer of the roof, which was 0.05 m, is changed to 0.07 m by increasing the thickness of the MW stone wool layer. The revised U-value of the roof is calculated as 0.398 W/m^{2}K.

Tab. 4 Retrofit scenarios of the roof.

Roof	Material	Thickness	Conductivity	Specific Heat	Density	U Value
		M	W/mK	J/ Kg-K	Kg/m3	W/m2-K
RO (Existing)	Roof Tile	0.025	0,84	800	1900	0, 503
	Polyester Resin	0,02	0, 19	1200	1400	
	Oriented Strand Board	0.02	0, 13	1700	650	
	Air Gap	0.5	N.A	N.A	N.A	
	Mw Stone Wool	0.05	0, 038	840	40	
	Concrete Reinforced with %1 steel	0.12	2, 3	1000	2300	
	Cement Plaster	0.03	0, 72	840	1760	
R1	Roof Tile	0.025	0,84	800	1900	0, 398
	Polyester Resin	0,02	0, 19	1200	1400	
	Oriented Strand Board	0.02	0, 13	1700	650	
	Air Gap	0.5	N.A	N.A	N.A	
	Mw Stone Wool	0.07	0, 038	840	40	
	Concrete Reinforced with %1 steel	0.12	2, 3	1000	2300	
	Cement Plaster	0.03	0, 72	840	1760	

The results obtained in the comparison of the roof scenario showed that the difference between primary energy consumption and yearly heating and cooling demand is not so apparent as in the wall scenarios (Fig. 4).The primary energy consumption, which is currently 83.13 kWh/m^{2}a, has been analyzed as 83.09 kWh/m^{2}a after the roof improvement. On the other hand, the heating demand was initially 42.92 kWh/m^{2}a, and it is 42.89 kWh/m^{2}a in the R1 scenario. As the results did not meet the expected outcomes, it is evident that retrofit measurements on the roof system require different strategies.

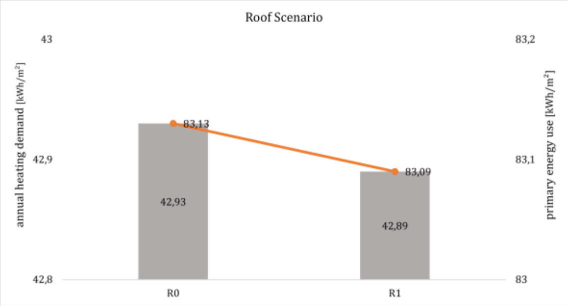

Fig. 4 - Comparison of roof scenarios

3.3 Retrofit Strategies of Glazing System

Another analysis to improve the energy performance of the selected building is conducted on glazing systems. Currently, it is double glazing, and the interior glass is grey coated. The existing U-value is

2.665 W/m²K. The first recommended glazing system (G1) is double Low-E glazing filled with air. The U-value of this glass is 1.5 W/m²K. The second scenario (G2) contains double solar Low-E glazing on outer glass and the system's cavity filled with argon gas with a U-value of 1.1 W/m²K (Tab. 5).

Tab. 5 -Retrofit scenarios of the glazing system.

Glazing	Material	U Value	Total Solar Transmittance	Visible Transmittance
		W/m2-K	SHGC	Tvis
G0 (Existing)	Dbl Clr 6mm/13mm Air (Grey)	2,665	0, 47	0, 38
G1	Dbl LoE 6mm/13mm Air	1,5	0, 54	0, 78
G2	Dbl Solar LoE 6mm/18mm Argon	1,1	0, 42	0, 71

According to the results (Fig. 5), low-E glass has reduced primary energy use and annual heating and cooling demand. The primary energy consumption, which was 83.13 kWh/m²a at the beginning, decreased to 78.27 kWh/m²a with Low-E and 78.22 kWh/m²a as a result of filling the space inside with argon instead of air in the G2 scenario. While the heating demand is 42.92 kWh/m²a at the existing state, the value reached in the second scenario (G2) is 40.26 kWh/m²a. While the cooling demand is 0.41 kWh/m²a in its existing situation, it decreased to 0.39 kWh/m²a.

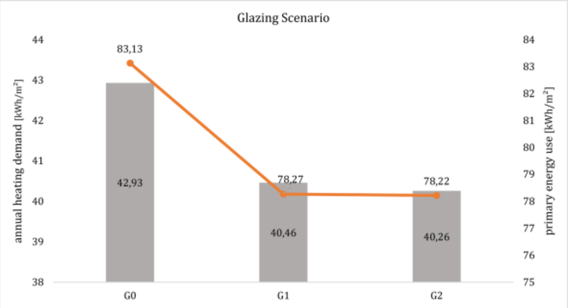

Fig. 5 - Comparison of glazing scenarios

3.4 Retrofit Strategies of HVAC System

Apart from the building envelope, enhancement of the mechanical heating system is proposed. Accordingly, there is a non-condensing single hot water boiler with a 300 kW capacity that has 75% efficiency at the current state (H0) . Replacing the existing boiler with a 300 kW capacity condensing boiler that has 95% efficiency (H1) has drastically reduced annual heating demand by 25.3%. Also, primary energy use is decreased from 83,13 kWh/m²a to 72,25 kWh/m²a (Fig. 6). It is evident that boiler efficiency has a considerable impact on energy consumption mainly in heating demand.

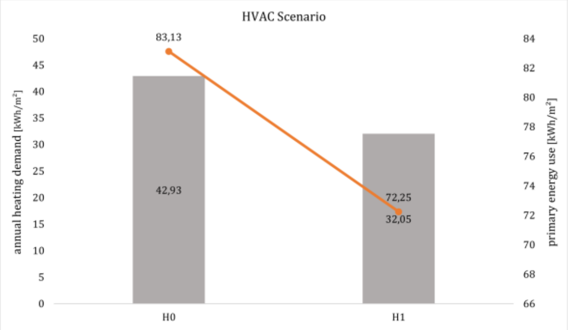

Fig. 6 - Comparison of HVAC scenarios

3.5 Combination of Retrofit Scenarios

At this stage of the research, the best performing retrofit scenarios (W2, R1, G2, H1) are selected to measure their combination's outcome. Among the analyzed scenarios, W2-R2-G2 scenarios with high insulation and low U values are selected for the wall, roof, and glass system. The HVAC system aims to increase the efficiency with the condensing option of the existing boiler. As a result of combining these scenarios, the heating demand, which was initially 42.93 kWh/m²a, is reduced to 19.93 kWh/m²a; hence the building will need less energy for heating. Considering the primary energy consumption, it is decreased by 25.31 kWh/m²a from 83.13 kWh/m²a. While the cooling requirement was 0.41 kWh/m²a at the initial state, it is dropped to 0.32 kWh/m²a.

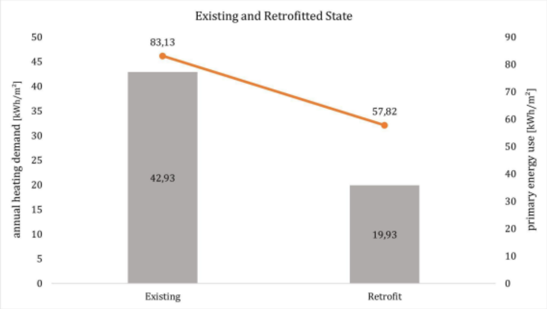

Fig. 7 - Comparison of existing and retrofitted state

3.6 Combination of Retrofit Scenarios with Exterior Shading

Another strategy to reduce the energy performance of the building requires that the shade elements are designed and applied in accordance with the climate and the structure. It is essential for students' performance, especially in educational buildings. As a result of the observations made in the case study building, there is an overheating problem, especially in south-facing spaces in summer. For this reason, indoor air temperature is controlled by air conditioning in these places. However, this situation increases the energy consumption of the building. Therefore, wooden overhang elements are included in the simulation scenarios. Adding shading elements to the south-facing spaces of the best-combined package has increased the need for overall heating and lighting. However, since it reduces the need for cooling, especially in summer, the overall reduction in energy consumption has been analyzed. While the primary energy consumption was 57.82 kWh/m^{2}a in the combined scenario, it is decreased to 55.31 kWh/m^{2}a with the addition of shadow elements.

4. Discussion & Conclusion

In this paper, energy performance analysis and retrofit strategies were analyzed in order to decrease energy consumption. For this purpose, a school building selected as a case study is modeled in DesignBuilder, and energy performance analysis is conducted in EnergyPlus. Firstly the effect of external walls and roof on energy performance is observed by adding and increasing insulation layers. The lack of insulation layer in exterior walls in the building caused the building's energy consumption to be high. Secondly, different glazing systems are implemented with lower U-values as the glass systems must not leak the ambient air. In addition, the HVAC system's increased efficiency by high capacity hot water boilers has a significant impact on fuel consumption for heating energy. After that, the combinations of individual retrofit packages are simulated. Results showed that adding 0.6 m EPS insulation in external walls, 0.07 m stone wool insulation in the roof, installing argon filled double solar Low-E glazing system, and enhancing the boiler with an efficiency of 95% have a dramatic effect on both annual heating, cooling demand, and primary energy consumption. The outcomes showed that the primary consumption was significantly reduced from 83.13 kWh/m^{2}a to 57.82 kWh/m^{2}a. Lastly, the effect of exterior shading on energy performance is analyzed by adding overhangs on the south façade. Overall, the combination of retrofit scenarios and shading elements decrease the primary energy use by 33.4%.

5. Acknowledgements

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