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Research Article

Evaluation of energy consumption and noise reduction change of a strengthened building: An educational building case

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ABSTRACT

The buildings in various geographical conditions are strengthened due to different reasons, such as earthquakes, fire, or deterioration. One of the important issues is that comfort levels are ensured, and energy consumption is kept at a minimum in educational buildings where renovation and strengthening work is being carried out. In this study, in terms of energy consumption and acoustic comfort, a method is proposed to examine a building damaged in an earthquake and then strengthened. The method has also been created and implemented to provide control and improvement suggestions in terms of thermal and acoustic conditions in strengthening projects of buildings. As a case study, the pre- and post-reinforcement situation of an educational building in a temperate humid climate has been evaluated. In addition, different glazing scenarios that reduce energy consumption while increasing facade noise reduction have been developed and analyzed. The results showed that while sufficient noise reduction is achieved in the building envelope, there is a 15.9% reduction in the total energy consumption of the building. The optimum scenario decreased total energy consumption by 19.4 % in B113 and 26 % in B114 and increased the facade noise reduction levels by 14.2 dB in B113 and 15 dB in B114. The proposed method and the findings will contribute to the design process of newly designed, renovated, and strengthened buildings in terms of energy efficiency and indoor acoustical comfort.

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INTRODUCTION

Buildings protect their occupants from the negative effects of the external environment. In developed countries, people spend 90% of their lives in buildings. For this reason, indoor comfort conditions (heat, sound, and light) which significantly affect the productivity and health of

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occupants in the building, are important in terms of the efficiency of the activity performed [1]. In addition, in recent years, there has been an increase in people's awareness of the effects of indoor comfort conditions on human health and well-being [2].

Indoor comfort conditions in educational buildings affect students' physical and mental health and learning efficiency. For educational activities, the students spend about 30% of their daily lives indoors, therefore it is important to provide appropriate conditions in terms of light, sound, and air in the buildings [3,4]. The educational buildings consist of units such as classrooms, laboratories, conference rooms, and office rooms. The basic units of educational buildings are classrooms. The efficient and healthy progress of the teaching-learning activities depends on ensuring the required environmental conditions in the classroom [5,6]. Ensuring acoustic comfort conditions in educational buildings and classrooms constitute an important design criteria in order to continue educational activities without interruption and under appropriate conditions [7,8]. In addition, the priority of educational buildings is to create quality learning conditions, while minimizing unnecessary energy consumption [9].

Nowadays, energy usage should be kept at a minimum while providing comfort conditions in buildings because of the rapid consumption of energy resources. In many developed countries, buildings account for around 35-40% of total energy consumption [10] 65% of the energy consumed in buildings is used in heating-cooling, ventilation, and hot water systems [11].

Comfort conditions and energy consumption have lost their importance during renovations. The strengthening activities in buildings can be defined as building development, upgrades, and modifications according to user requirements and legal expectations [12]. The renovations of existing buildings are generally related to the age of the building, strengthening of the structural system, changing its function, its adaptation to the current architecture, etc. The strengthening of the structural system is often used in Turkey, which is located in the Alpine-Himalayan active earthquake zone. The educational buildings are one of the building typologies damaged in earthquakes. According to the 2020 data of the Ministry of National Education, Republic of Turkey, the number of schools used by about 21% of the country's population is 68.589 [13]. About 50% of the buildings are over 25 years and were built according to the architectural features, construction standards, and old earthquake regulations [14]. For this reason, many educational buildings may be affected by the earthquake, and it becomes necessary to strengthen them in order to continue education after the earthquake. While strengthening the educational buildings, attention needs to be dedicated to the effects of the units on the physical environmental comfort conditions. Renovation activities due to strengthening works can cause significant changes on building facades that directly and indirectly affect indoor comfort conditions. Indoor environmental quality in buildings is evaluated in terms of thermal comfort, indoor air quality, noise level, and illumination level for users [15].

The design of the building facade, which is one of the important design decisions in buildings, directly affects both energy consumption and acoustic comfort conditions. In a previous study, it was determined that the strengthening carried out in the facade of educational buildings affects the visual comfort of the indoor environments [16]. When the properties of transparent areas change, acoustic and thermal comfort issues can arise in addition to daylighting issues. Therefore, besides daylight, factors related to heat and noise should also be taken into account in transparent space design decisions[14]. In order to provide acoustic comfort conditions in the buildings, some measures are taken against noise in the building envelope. These measures can be exemplified as the use of double walls, using materials with high noise reduction in transparent and opaque areas, and determining transparency ratios [17].

Although design guidelines and technical standards focus separately on a single environmental factor, the changes made to the facade of the building affect the thermal and acoustic comfort conditions with the energy consumption together [9,18]. In the literature, there are many studies on the effect of changing the transparent area properties of buildings' comfort conditions. The windows are considered to be the weakest element of the facade in terms of thermal and acoustical aspects. The effect of transparent areas on both energy consumption and noise control is greater than that of opaque areas [19]. Therefore, the design strategies that focus on improvements in transparent area properties are considered important in terms of thermal and acoustical properties [20,21].

However, few studies have been conducted to investigate energy consumption while providing acceptable thermal and acoustic comfort in relation to the transparent area properties of educational buildings. In studies, the effect of various glass types and different Window to Wall Ratios (WWR) on building energy performance has been investigated [22–24]. The studies investigating the effect of changes in the WWR on noise control in educational buildings are very limited. They are generally aimed at measuring the current situation or determining the acoustical comfort of the occupants [25–27]. There are few research methods or studies on the changes in energy consumption and noise control after strengthening educational buildings. The changing environmental conditions, energy consumption and acoustic comfort conditions should be taken into account in the implementation of strengthening projects of buildings.

Suitable indoor conditions for educational buildings should be provided to improve productivity, reach a healthy environment, etc., while providing energy efficiency. For this reason, even after strengthening, it is important that they protect and/or improve the performance of the buildings in terms of noise control and energy consumption.

This study has investigated the effect of the change in the Window to Wall Ratio (WWR) on noise control and energy consumption after the strengthening in classrooms of a sample building. In addition, the effects of transparent area change have been evaluated by developing suggestions aiming to provide comfort conditions with minimum energy consumption.

METHODOLOGY

In this study, an educational building, that is strengthened, has been determined as a sample building. It is determined by measurements in the previous studies that the current state of the educational building is not at an acceptable level of acoustical, visual, and thermal comfort according to the relevant regulations [16,28]. An educational building was evaluated in terms of facade noise reduction and energy consumption for before and after strengthened situations including different transparent area scenarios. The facade noise reduction evaluations were made for selected classrooms, while the changes of energy consumption amounts were made for both classrooms and the whole building.

The method steps of the study are shown in Figure 1. The proposed method for the study consists of six parts. The first stage is the determination of the strengthened building and its properties. The information was obtained about the environmental, physical, and indoor properties of the building. In order to determine the noise reduction of the building envelope, the opaque and transparent area properties of the facade were defined. Also, the thermal properties of the building envelope were defined to determine total energy consumption. Then, with the information obtained during the determination and identification stages, the analysis was done to determine the effect of the situation before and after the strengthening of the building facade. After this stage, building facade scenarios were suggested for situations where acceptable limit values for the comfort conditions cannot be achieved. The suggested scenarios were developed for transparent areas that have weaker properties in providing comfort conditions on facades.

The scenarios that provided acceptable values in terms of thermal and acoustic performance and had different transparent area properties were evaluated and the most appropriate solution was selected by comparing the energy consumption ratios of the scenarios. The evaluations of

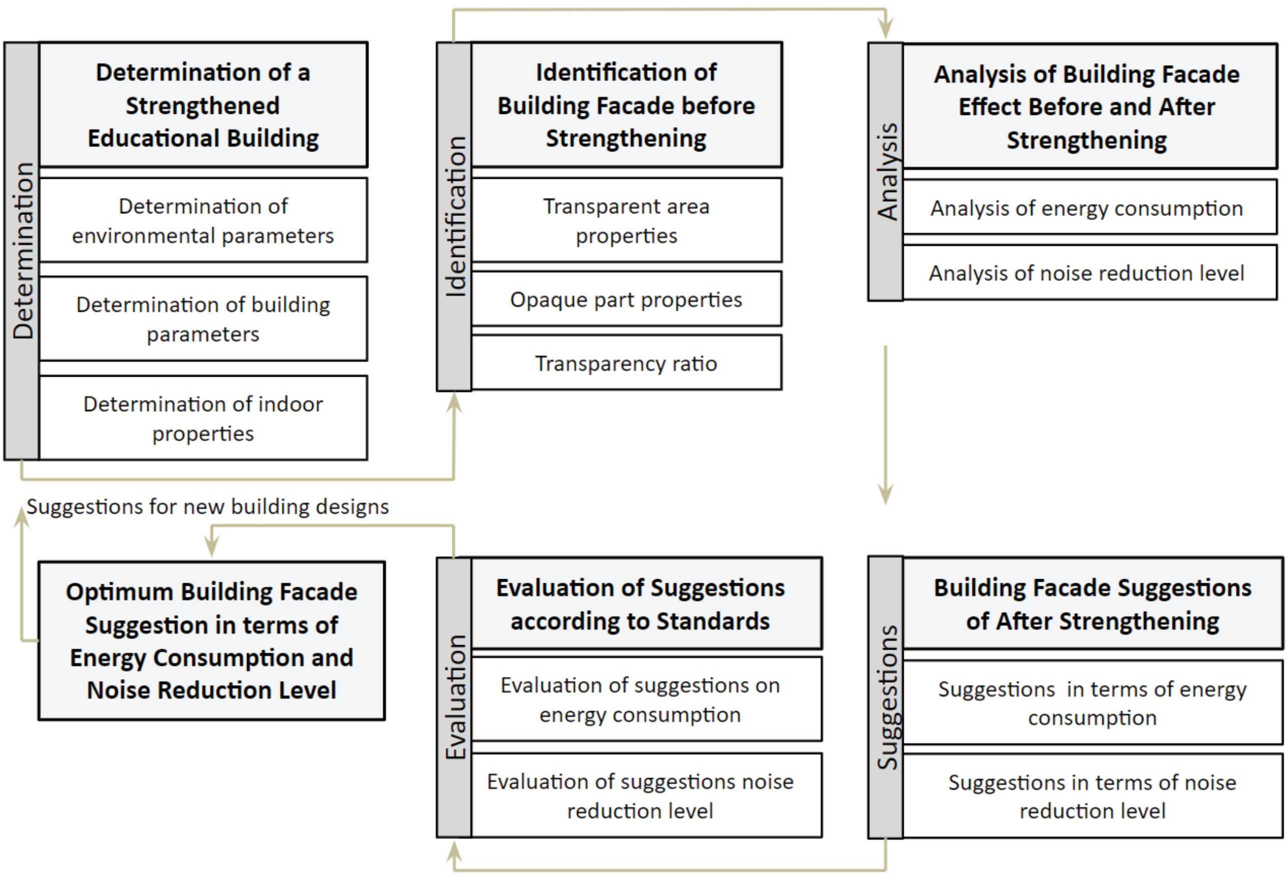


Figure 1. Evaluation stages of the strengthened educational building in terms of energy consumption and noise reduction level.

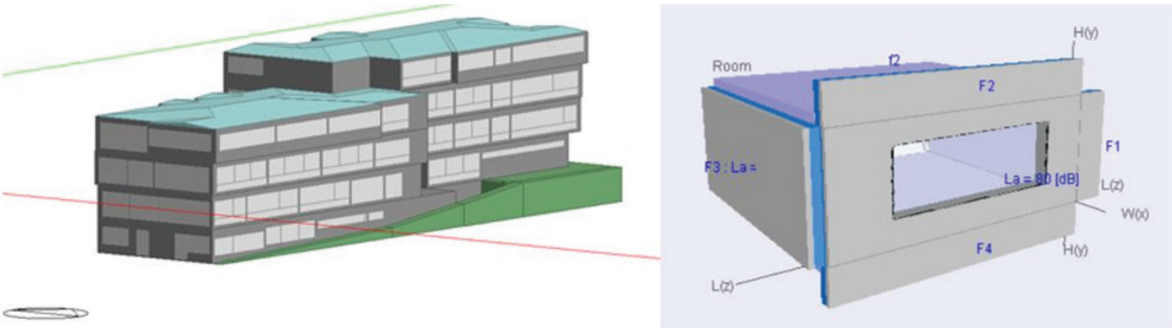


Figure 2. The sample building and classroom visuals designed with Design Builder and Kalksandstein Schallschutzrechner (KS)

acoustical and thermal comfort conditions were made according to international standards, and the results of noise reduction and energy consumption were compared for scenarios that met the conditions. Finally, the optimum facade designs were recommended, providing minimum energy consumption and acceptable noise reduction from the suggested scenarios for transparent areas. The stages of the method mentioned can also be implemented for future studies and different building types.

In the sample building, which was found to have insufficient comfort conditions in previous studies, evaluations were made for the situation before and after strengthening, and scenarios were created to provide appropriate thermal comfort and acoustic comfort. The scenarios for the energy consumption and facade noise reduction were determined through the simulation programs. The energy consumption analyses of the educational building and selected classrooms were made in the Design Builder program. Design Builder is a simulation program that uses the Energy Plus simulation engine to determine thermal and visual comfort conditions and to calculate energy loads [29]. The facade noise reduction analyses of the classrooms were made in the Kalksandstein Schallschutzrechner (KS) program [30]. The KS program calculates in accordance with the 12354-3 ‘’Building acoustics - Estimation of acoustic performance of buildings from the performance of elements” standard [31]. Figure 2 shows the three-dimensional model of the sample building and classroom.

The Properties of Educational Building and Sample Classrooms

The educational building included in the study is on Barbaros Avenue in Beşiktaş, Istanbul, which is exposed to high-level of highway noise. The building is located in an area with temperate humid climate conditions. Figure 3 shows the site plan and view of the educational building. The educational building has five floors including a basement. The building has 26 classrooms, six laboratories, one conference hall, one music workshop, one painting workshop, one dining hall, one archive, and five WC areas. 534 students study between 08:15-15:20 on weekdays [13]. The classrooms chosen for this study are on the east side of the educational building and on the 1st floor. Figure 4 shows the location of the sample classrooms on the floor plan.

The classrooms have capacity of 24 students. They are 7.0 m wide, 8.2 m long and 3.44 m high. The floors in the classrooms are covered with resin-based linoleum. Plastic paint is used on the ceiling and walls. Transparent areas have 6 mm Low-e double glass with a 16 mm air gap, and the parapet height of the windows is 84 cm. An aluminum

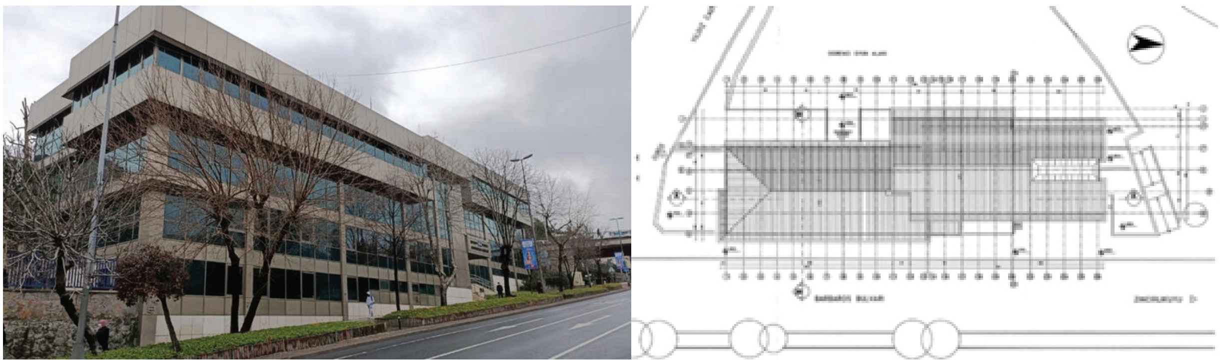


Figure 3. The view of the educational building from Barbaros avenue and site plan.

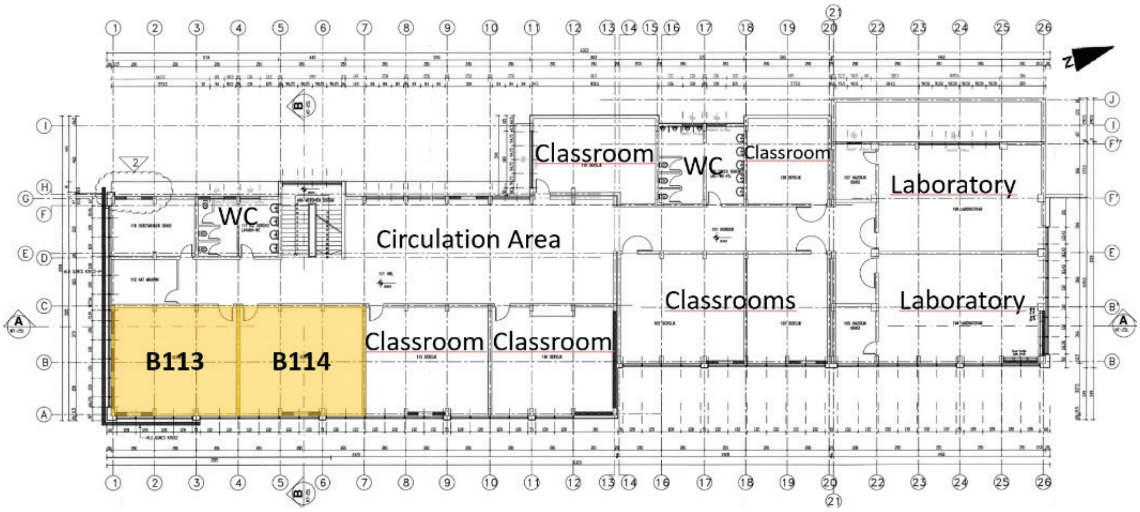


Figure 4. Floor plan and classrooms B113, and B114.

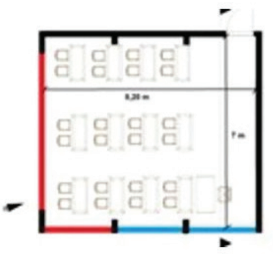
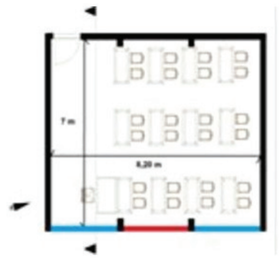
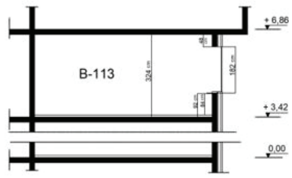
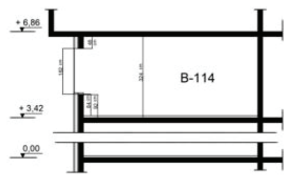
Table 1. The current facade layers properties of the educational building

Building Components	Layers	Thickness (m)	Thermal Conductivity (W/mK)	Overall Heat Transfer Coefficient-OHTC (W/m²K)	Density (kg/m³)
Wall	Aluminum	0.02	160.0	0.423	2800
	Air Gap	0.06	0.30		-
	Thermal Insulation	0.06	0.034		35
	Cement Plaster	0.03	0.72		1760
	R. Concrete	0.2	1.13		2000
	Gypsum Plaster	0.25	0.80		1300
Floor	Linoleum	0.002	0.30	1.684	1000
	Tile	0.03	1.10		2100
	Mortar	0.015	1.40		2100
	Leveling concrete	0.035	0.88		2800
	R. Concrete Floor	0.2	1.13		2000
	Gypsum Plaster	0.025	0.40		1000
Ceiling	Linoleum	0.002	0.30	1.684	1000
	Tile	0.03	1.10		2100
	Mortar	0.015	1.40		2100
	Leveling Concrete	0.035	0.88		2800
	R. Concrete Floor	0.2	1.13		2000
	Gypsum Plaster	0.025	0.40		1000
Indoor wall	Gypsum Plaster	0.02	0.40	1.603	1000
	Brick	0.19	0.72		1920
	Gypsum Plaster	0.02	0.40		1000
Window	Sunguard Low-e Glass	0.006	0.94	OHTC 1.842	-
	Air Gap	0.016	-	SHGC 0.164	
	Green Tinted Low-e Glass	0.006	1.00	LT 0.121	

cladding wall is used in the opaque areas of the building facade. Opaque areas have 5 cm thermal insulation. Table 1 shows layer details of the selected classrooms.

The educational building, which was built in 1992, was strengthened in 2008 and reached its current situation. Table 2 shows the plans and sections of the classrooms in 1992 and 2008. During the strengthening made in 2008, the entire transparent area on the south facade of classroom B113 was covered with a concrete curtain wall. On the eastern facade, the transparent area decreased by triple. There

Table 2. Plan and sections of sample classrooms (The red lines of the transparent areas show the surfaces that were closed during strengthening, and the blue lines of the transparent areas show the current transparent areas - not closed)

<table>
<tr><th colspan="2"></th><th>Classroom B113</th><th>Classroom B114</th><th>Classroom Section</th></tr>
<tr><td colspan="2">1992-2008 WWR Change</td><td></td><td></td><td>
</td></tr>
<tr><td rowspan="2">WWR</td><td>1992</td><td>South-East: 46.90%
South-West: 60.25%</td><td>South-East: 46.90%</td><td rowspan="2">
</td></tr>
<tr><td>2008</td><td>South-East: 31.6%</td><td>South-East: 31.6%</td></tr>
</table>

is a similar situation in classroom B114. The transparent area on the eastern facade of classroom B114 was covered by a concrete curtain wall by ⅓. This situation also exists on other floors and classrooms. The effect of the closed transparent areas of the classrooms on energy consumption and the facade noise reduction was calculated with simulation programs.

Definitions Regarding Analysis Variable

The consumed heating, cooling, and lighting loads and the total energy load were analyzed in order to provide thermal comfort conditions in the educational building and the selected classrooms. In addition, the noise reduction value was analyzed in order to provide the required acoustic comfort conditions in classrooms. While the energy consumption analyses were made for the whole building and selected classrooms, the facade noise reduction evaluations were made for the classrooms only.

In the study, outdoor climate data for Istanbul were taken from the DesignBuilder - Energyplus program [32]. During the education period, the air conditioning systems in the educational building are used between 08:15 and 16:00 on weekdays. They are not used during the summer period. The classrooms are heated by radiators with a boiler heating water system during the heating period. They are cooled with split air conditioners during the cooling period. The indoor temperature was determined as 21 °C during the heating period and 26 °C during the cooling period in the simulation program. The illumination level was set as 300 lux which is specified in the standard for the lighting of the classrooms. The default lighting system recommended for educational buildings was chosen in the program [33].

Outdoor noise levels were taken from the current noise maps created by Istanbul Metropolitan Municipality Environmental Protection Directorate [34]. According to the noise map, the noise level on the classroom facades was accepted as 80 dBA. It is recommended in the Regulation on Protection of Buildings against Noise that existing buildings should meet the minimum D acoustic performance class limit value. The classrooms in educational buildings are determined as 1st-degree sensitive volumes in the regulation. The required limit value is given as "Lden-26" according to the degree of sensitivity and the D acoustic performance class in the regulation [35]. Lden states the day-evening-night noise level. It is a descriptor of noise level based on energy equivalent noise level (Leq) over a whole day. According to the current regulation and the outdoor noise determined as 80 dBA, the minimum noise reduction level that the facade should provide is DnT,A,tr (weighted standardized level difference) 54 dB (80-26 = 54 dB).

RESULTS

Analysis of Energy Consumption and Noise Reduction of the Facade Before and After Strengthening of the Building

The energy consumption and the facade noise reduction were evaluated according to the changes before strengthening the educational building. The building's opaque and transparent component layers and properties of the facade layers remained unchanged during the structural system's strengthening, but WWR of the facades was decreased in the south and west directions. After the strengthening, the transparent area was completely closed on the south facade of classroom B113, and the WWR was reduced by 15.3% on the eastern facade of B113 and B114 classrooms. Figure 5 shows the heating, cooling, lighting, and total energy

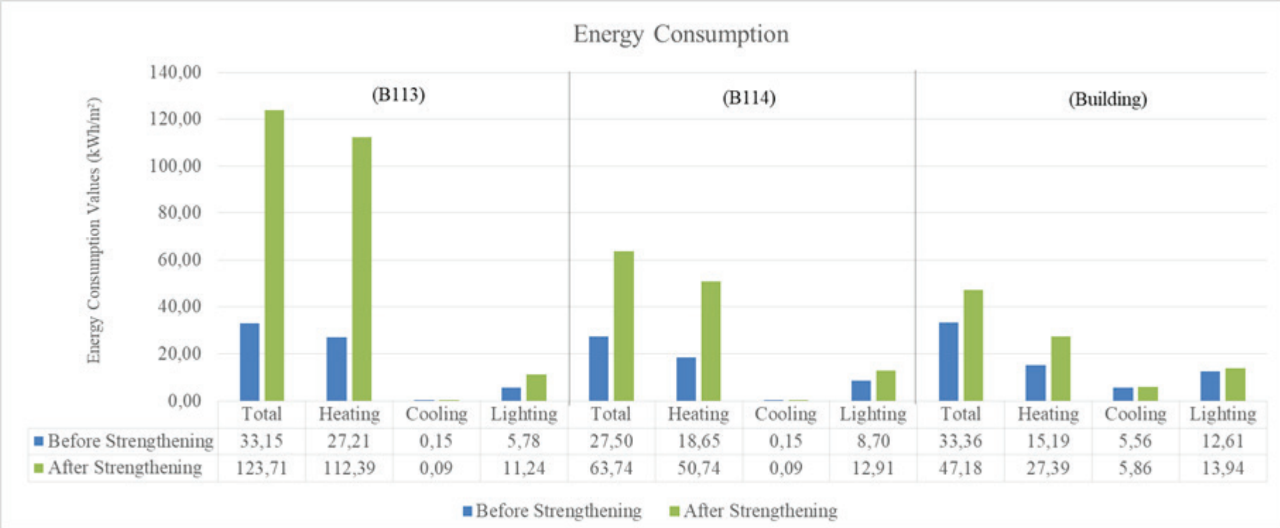


Figure 5. Energy consumption of before and after strengthening of the educational building.

consumption. Figure 6 shows the facade noise reduction levels of B113 and B114 classrooms, and also the whole building before and after strengthening.

As a result of completely closing the transparent areas on the south facade and reducing them on the east facade of the classrooms, solar heat energy gains decreased greatly. For this reason, the heating energy consumption of the classrooms increased by 313% in B113 and by 172% in B114. In addition, the total energy consumption increased by 273% in the B113 and 131% in the B114. Although the WWR change on the east facade was the same in both classrooms, the entire transparent area on the south facade was also covered in B113. Therefore, the proportional increase in heating, lighting, and total energy consumption in B113 was higher than in B114. However, no significant difference was observed in cooling energy consumption.

It was determined that there was an 80% increase in heating energy consumption, a 10% increase in lighting energy consumption, and a 5% increase in cooling energy consumption in the whole building. There was an increase of 41% in the total energy consumption of the building used for heating, cooling and lighting. Accordingly, it was observed that the change in the transparency ratio after strengthening greatly affected the energy consumption ratio and that energy consumption was saved by utilizing solar heat energy before strengthening.

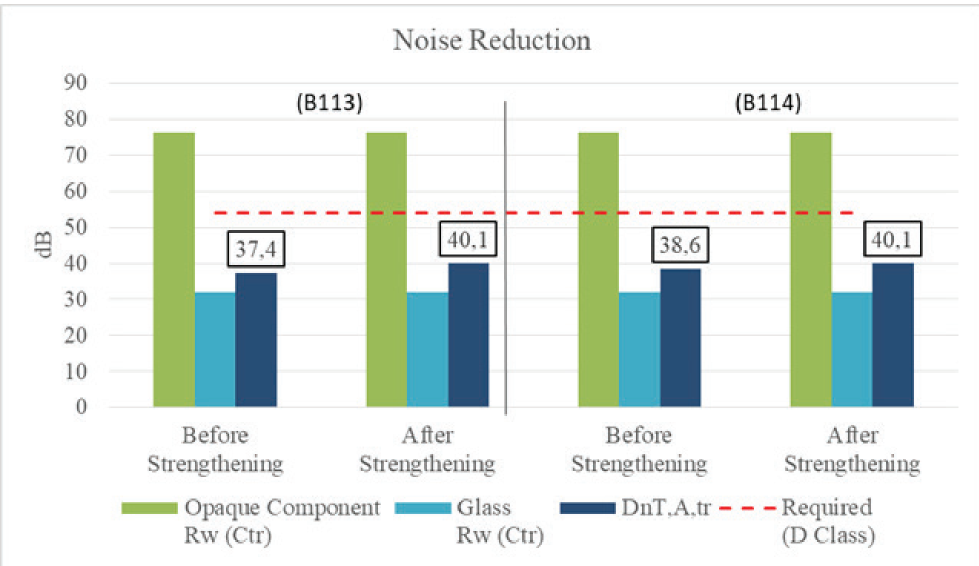


Figure 6. Facade noise reduction levels of classrooms B113 and B114.

As a result of reducing the transparent areas on the facades of the classrooms, the facade noise reduction levels increased in both classrooms with different amounts. There was an increase of 2.7 dB for classroom B113 and 1.5 dB for classroom B114 in facade noise reduction level due to the decrease in WWR, which varies at different ratios depending on the location of the classrooms. After strengthening, facade noise reduction levels increased to 40.1 dB in the B113 and B114 classrooms due to the fact that the transparent area ratios after strengthening were the same. The decrease in the transparency ratio caused the facade noise reduction level to increase. However, this increased ratio could not exceed 1.5-3 dB levels due to the insufficient insulation properties of the transparent area.

The transparency ratio, which has a significant effect on the noise reduction level of the facade, was less effective when the insulation properties of the weak facade element were insufficient. It was observed that the increase in the sound reduction level after the decrease in the transparency ratio will only provide acceptable conditions with the transparent area improvements.

Improvement Scenarios of Transparent Area in Educational Building

In this study, it was determined that the indoor noise level after strengthening did not meet the requirements of the Regulation on Protection of Buildings Against Noise, which is in force in Turkey and determined according to COST Action TU 0901 'Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions' [35,36]. The transparent areas have a greater impact on the facade noise reduction and the thermal load than the opaque areas. Different transparent area scenarios were developed for the current situation, since the noise reduction level of the transparent areas did not meet the requirements given in the regulation and the energy consumption of the building was high after strengthening. The scenarios were created according to the fact that the transparent area sections have different layer properties and layer numbers are selected from the most commonly used glass in the construction market.

In order to provide the required noise reduction level on the building facades consisting of opaque and transparent components, noise control is required through the composite wall. The noise reduction level of the composite wall varies according to the sound insulation of the opaque and transparent components and the transparency ratio. Although the sound insulation level of the opaque component is high and the transparency ratio is low in the educational building, the required noise reduction level cannot be achieved due to the low sound insulation level of the transparent component. Since the noise reaching the facade was far above the acceptable value for a building to be used for educational purposes, scenarios were determined based on the options that meet the acoustic requirement. To limit multiple scenario options, energy consumption data was evaluated for sections where sufficient noise reduction value can be achieved.

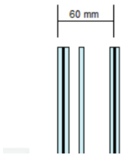
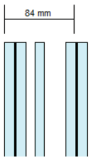
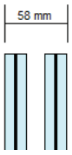
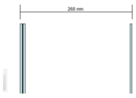
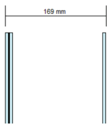
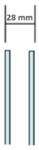
The sample educational building is located in a temperate humid climate type. The energy consumption of the building after strengthening is considerably higher than before strengthening. After strengthening, the WWR of the building facade decreased. This situation reduced the solar energy gain from transparent areas. It also caused an increase in the energy consumed for heating. In addition, the reduction of transparent areas also reduced daylight gain, resulting in an increase in the energy consumed for lighting. When developing the scenarios for energy consumption, the effect of reducing transparent areas, which enable solar energy gain, on heating, lighting, and total load was attached to importance. The scenarios developed for the after strengthening were created by considering these criteria of noise reduction and energy consumption.

The glasses with different heat conduction coefficient properties were chosen among the 2 or 3-layered glasses with high sound insulation properties, which are widely used in the market. Table 3 shows the parameters which are the layering details, weighted sound reduction index (Rw), overall heat transfer coefficients (OHTC), solar heat gain (SHGC), and light transmittance (LT) in the transparent area scenarios. The five scenarios were evaluated in terms of facade noise reduction and energy consumption. In addition, in Scenario 6, only the low-e characteristic of the currently used glass type was changed. Since this situation has no effect on the noise reduction level, only energy consumption assessments were made for Scenario 6.

Evaluation of Improvement Scenarios in terms of Energy Consumption

The total energy consumption reduction was achieved with the proposed building facade sections developed for the current situation (after strengthening) of the educational building. Figure 7 shows the energy consumption values of the whole building for the before and after strengthening, and different glass usage scenarios. Compared to the after strengthening situation, the highest decrease in the heating energy consumption was 20.6% in Scenario 1 (three-layered glass), 19.89% in Scenario 3 (two-layered glass) while in Scenario 6 there was an increase of 8.9% (two-layered glass) only. While the highest increase in cooling energy consumption was in Scenario 3 with 57.4%, there was a decrease in Scenario 6 with 8.27%. The highest decrease in lighting energy consumption was 48.3% in Scenario3. According to the current situation, lighting energy consumption decreased by 45-49 % in Scenario 1, 2, 3, 4 and 5. The maximum decrease in the total energy consumption was 20% in Scenario 1 and 19% in Scenario 3. When only the energy consumption of the building is evaluated, it is seen that the use of Scenario 1 and Scenario 3 is more appropriate than the others.

Table 3. The suggested sections and glass properties for the building envelope

	Glass Section	Glass Layer	Glass Rw (Ctr) dB	OHTC (W/m2K) U value	SHGC	LT
Scenario 1		12.5 mm Lamine Acoustic Glass, 10 mm Air Gap, 6mm Float Glass, 20 mm Air Gap, 10.5 mm Lamine Acoustic Glass	52(-1,-5)	1.34	0.47	0.59
Scenario 2		26.28 mm Laminated Glass, 10 mm Air Gap, 12mm Float Glass, 10 mm Air Gap, 25.14 mm Laminated Glass	49(0,-3)	1.66	0.45	0.66
Scenario 3		20.5 mm Lamine Acoustic, Glass 16 mm Air Gap, 20.5 mm Lamine Acoustic Glass	54(-3,-8)	1.78	0.55	0.65
Scenario 4		12.5 mm Laminated Glass, 250 mm Air Gap, 6mm Float Glass	54(-1,-5)	2.65	0.571	0.65
Scenario 5		12.5 mm Laminated Glass, 150 mm Air Gap, 6mm Float Glass	53(-2,-7)	2.65	0.571	0.65
Scenario 6		6 mm Low-e Glass, 16 mm Air Gap, 5.6 mm Green Glass	37(-2,-5)	2.15	0.175	0.174

Note: Rw: weighed sound reduction index, OHTC: overall heat transfer coefficient, SHGC: Solar Heat Gain Coefficient, LT: Light Transmittance

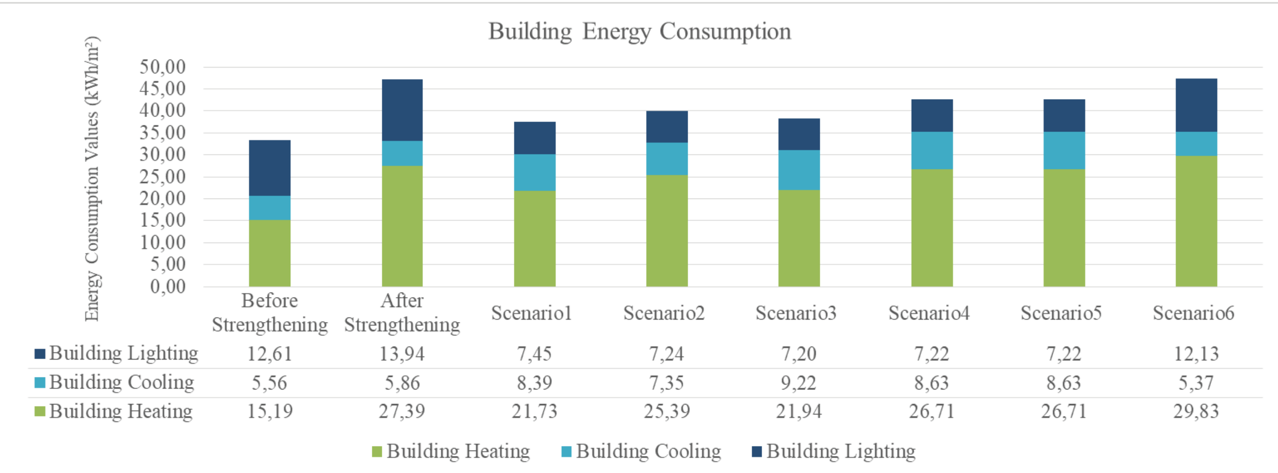


Figure 7. Energy consumption of the whole building for before and after strengthening, and scenarios.

Figures 8 and 9 show the energy consumption amounts of B113 and B114 classrooms for the scenarios developed in the study. There was an increase in energy consumption after strengthening compared to before strengthening in the classrooms. In the B113 classroom, a decrease of 15.1% was achieved in Scenario 1 and 15.9% in Scenario 3, compared to the current situation. On the other hand, cooling energy consumption increased by 56% in Scenario 1 and by 68.5% in Scenario 3, compared to the current situation. In terms of total energy consumption in classroom B 113, it was observed that there was a 19.4% decrease in Scenario 1 and 20.2% in Scenario 3. The decrease in energy consumption is quite similar in Scenario 1 and Scenario 3 according to the current situation. In the B114 classroom, it has achieved a decrease of 16% in Scenario 1 and 3 in terms of heating energy consumption compared to the current situation (Fig 9). In terms of cooling energy consumption, it has been observed that there is an increase of 29% in Scenario 1 and 38% in Scenario 3. In terms of total energy consumption in classroom B114, it has been observed that there is a decrease of 26% in Scenario 1 and 3 compared to the current situation.

Energy consumption evaluations were made for 6 different scenarios that provide acoustic comfort conditions in regions with high noise levels. According to the evaluation results, total energy consumption decreased in all scenarios except Scenario 6. Although it provides a reduction in energy consumption after strengthening, the Scenario 4 and Scenario 5 which have a U value that is not suitable for TS 825, were also not evaluated. Scenario 1 and Scenario 3 were determined as the most appropriate glass selections when the energy consumptions for total, heating, cooling, and lighting loads were examined on all buildings and sample classrooms. The window in Scenario 1 has three layers, and the window in Scenario 3 has two layers and their U values (OHTC) are different from each other and comply

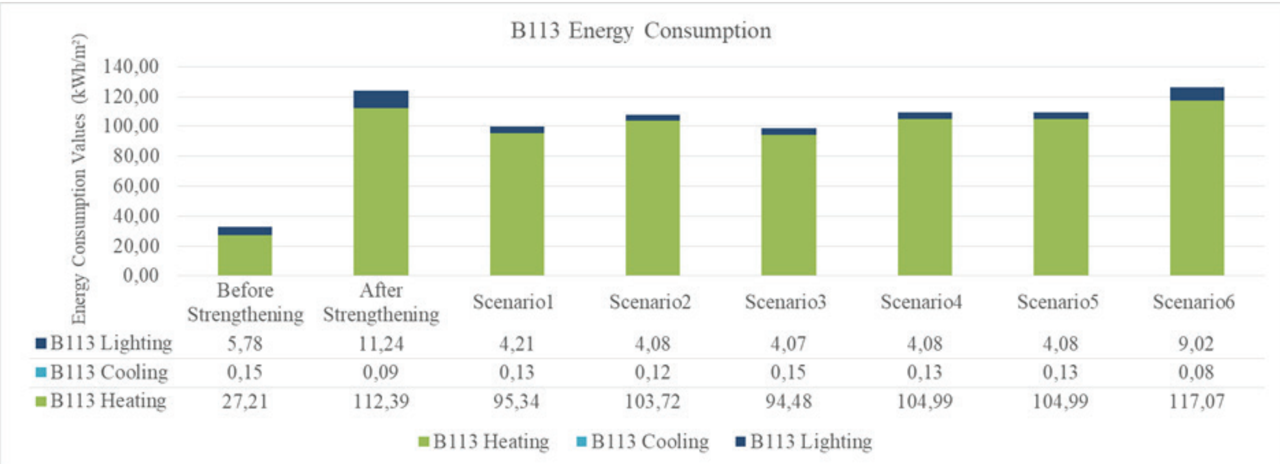


Figure 8. Classroom B 113 energy consumption values for before and after strengthening and scenarios.

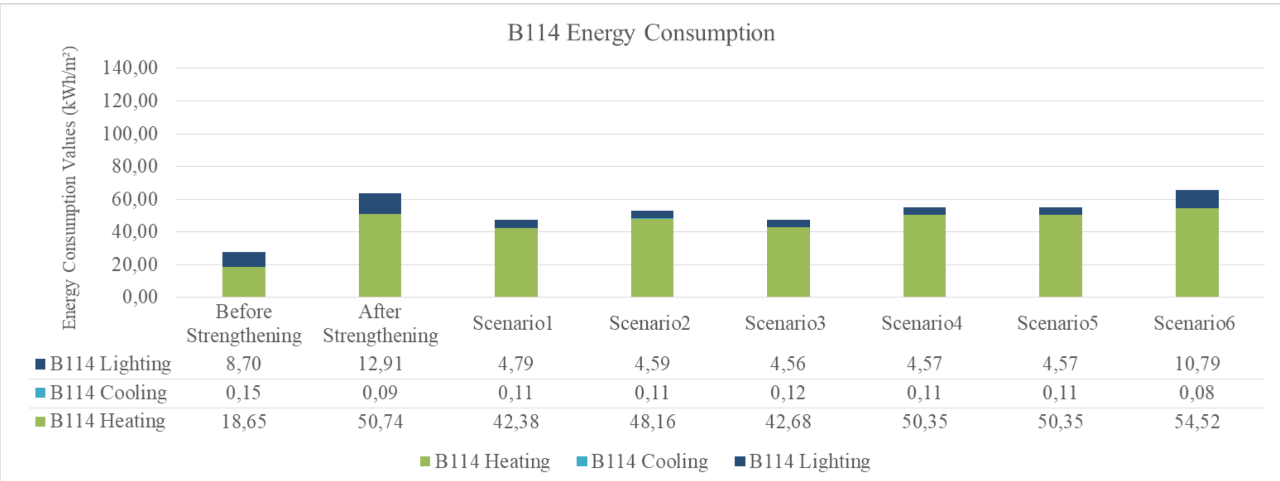


Figure 9. Classroom B114 energy consumption values for before and after strengthening and scenarios.

with TS825. However, the results are similar in terms of total energy consumption due to the difference in layer properties, thicknesses, and air gap ratios. In addition, there is a balance and similarity in total energy consumption because the amount of energy consumed for lighting in Scenario 3 is lower than in Scenario 1.

Evaluation of Improvement Scenarios in terms of Facade Noise Reduction

An increase in facade noise reduction was achieved with the building facade scenarios developed for the educational building. Figure 10 for B113 and Figure 11 for B114 show the noise reduction value of the classrooms for the before and after strengthening, and scenarios. In all scenarios, transparent area alternatives were selected that provide sufficient noise reduction value as required by the regulation.

In the classroom B113, for all scenarios, it was observed that the facade noise reduction levels increased by 14.2 dB, 13.2 dB, 13.2 dB, 16.2 dB, and 13.2 dB, respectively, compared to the current situation. In the classroom B114, for all scenarios, it was observed that the facade noise reduction levels increased by 15 dB, 14 dB, 14 dB, 17 dB, and 14 dB, respectively, compared to the current situation. The noise reduction levels ranged from 1.5 dB to 2.7 dB, depending on how the transparency ratio changed after strengthening. However, it was observed that this level increased to 17 dB with the improvement of the transparent area properties in the scenarios.

Scenario 1 and Scenario 4 have the highest facade noise reduction levels among the scenarios. DnT,A,tr values are provided for Scenario 1 to 54.3 dB and Scenario 4 to 56.3 dB. In Scenario 4 of the double-layered glass section, which is the most suitable option, the sound reduction level increases due to the increase in the air gap between panes of glass. In Scenario 1, it is seen that high noise reduction value is achieved by using 3-layer and laminated sound-reduction glasses. When the scenarios were examined, it was determined that the noise reduction level of the laminated sound-reduction glasses was higher than the laminated glass scenarios for 3-layered glasses (Scenario 1 and Scenario 2). When the results of Scenario 4 and Scenario 5 were compared, it was observed that the level of facade noise reduction improved due to the increase in the air gap between panes of glass.

It was observed that increasing the air gap between panes of glass or using glasses with noise-reducing properties in noise-sensitive volumes such as classrooms will increase the level of facade noise reduction. Therefore, comfort conditions in accordance with the regulations can be provided with appropriate glass selections in spaces with the same transparency ratio and facade properties in areas with high outdoor noise.

Optimum Building Envelope Scenarios in terms of Energy Consumption and Noise Reduction

The total energy consumption and facade noise reduction level have been examined according to the analyses made for the before and after strengthening and the glass scenarios for classrooms B113 and B114. When the situation before strengthening is compared with the current situation, it has been determined that the total energy consumption and facade noise reduction in both classrooms have increased in the current situation due to the decrease in the WWR. When the transparent area scenarios suggested

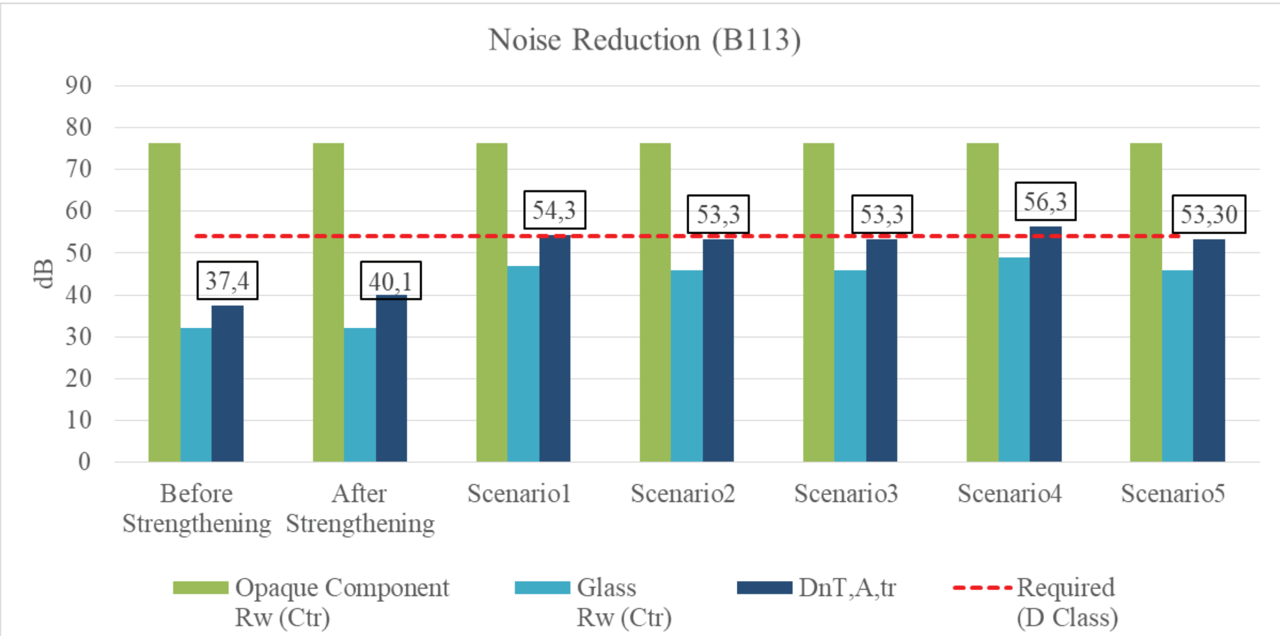


Figure 10. Classroom B 113 noise reduction levels for before strengthening, current situation and scenarios.

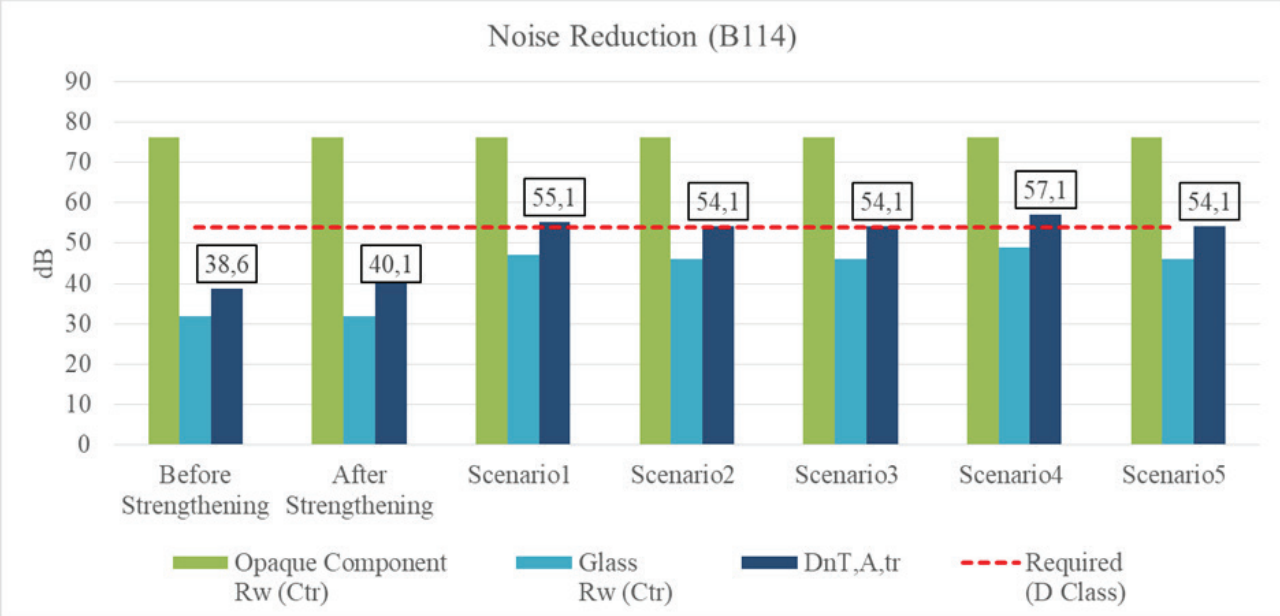


Figure 11. Classroom B 114 noise reduction levels for before strengthening, current situation and scenarios.

for improvement are compared with the current situation, it has been seen that the amount of energy consumption decreases and the sound insulation level increases. Figure 12 shows the total energy consumption and facade noise reduction levels for classrooms B113 and B114 before and after strengthening for 5 scenarios.

The lowest energy consumption was achieved with Scenario 3 in classroom B113 and Scenario 1 in classroom B114. The heat transfer coefficient and solar heat gain coefficient are lower in Scenario 1 than Scenario 3. While this situation reduces the ratio of the heating energy transfer in Scenario 1, it also decreases the solar heat gain from the outdoor environment. Therefore, similar energy consumption was obtained in Scenarios 1 and 3. In addition, the low energy consumption for lighting in Scenario 3 led to results similar to Scenario 1. Since the U value of Scenario 1 is lower, it causes a

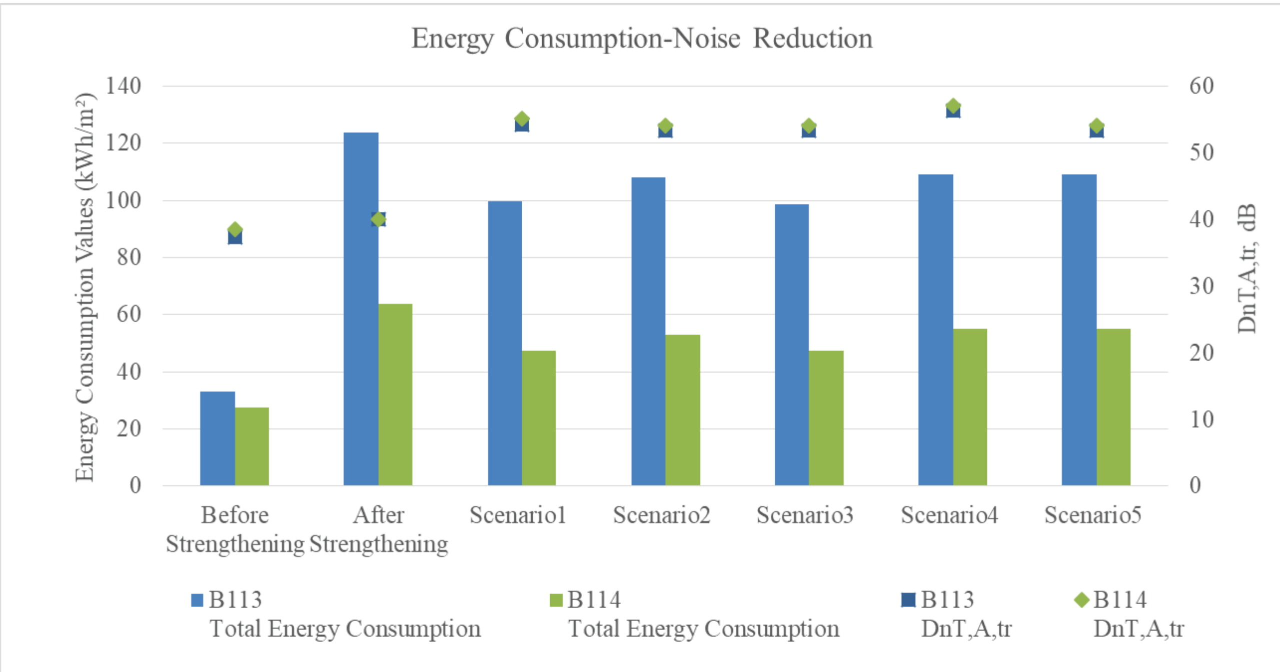


Figure 12. Classrooms B113 and B114 total energy consumption and noise reduction levels.

proportionally smaller increase in cooling loads compared to Scenario 3. Similar results were obtained in heating, lighting, and total energy consumption due to layer properties.

The highest sound insulation level was achieved with Scenario 1 and Scenario 4 in classrooms B113 and B114. The acoustic laminate glass was used in Scenario 1 and laminated glass was used in Scenario 4. In addition to the properties of the glasses, the number of layers and the gaps between the layers are also different. Although the glass thicknesses are less in Scenario 4, the sound insulation level is close to Scenario 1 due to the air gap between the panes of glass. Changes in layer thicknesses, glass properties, and distances between layers have been effective in providing the highest sound insulation level in different scenarios.

In the education building, which is in a location where the outdoor noise is high, transparent area proposals have been created that provide high facade noise reduction value in accordance with the Noise Regulation. When the energy consumption values for these scenarios are evaluated, it is seen that the energy consumption values for all scenarios decrease. In scenarios that provide the required noise reduction value and reduce energy consumption, Scenario 4, Scenario 5, and Scenario 6 , which were scenarios with U-values that do not comply with TS 825, were excluded from the evaluation in terms of noise reduction. According to the noise reduction evaluations, the scenarios that provide the highest reduction are Scenario 1 and Scenario 4. However, since Scenario 4 could not meet the standard requirements of TS 825, it is appropriate to choose Scenario 1 as the optimum scenario.

DISCUSSION

In this study, different scenarios for transparent areas were evaluated in order to provide a high noise reduction level and low energy consumption in a strengthened building located on an area with high outdoor noise. In order to optimize energy consumption and noise reduction, transparent area scenarios that provide heat conservation during the heating period and minimize the heating effect of solar radiation during the cooling period, and provide high sound transmission loss were determined. Among the suggestions, evaluations were made for six different glass scenarios with different glass thicknesses, number of layers and air gaps that meet the minimum values of the regulations.

As a result of the strengthening of the building, the energy consumed for heating, cooling, and lighting increased significantly. This situation shows that the windows should be arranged by considering thermal properties such as heat transfer coefficient and solar heat gain coefficient on facades with reduced transparency. In addition, it was observed that the level of facade noise reduction increased, but that the acoustic performance class requirements specified in the regulation could not be met due to the low insulation properties of the transparent area. This situation shows that even if the noise reduction value increases on the facades with reduced transparency, the insulation properties of the glasses should also be regulated in order to provide an adequate level.

After strengthening, the decrease in the WWR has reduced the benefit from the heating effect of the solar radiation. The observed reduction is evident in the energy consumption data for heating, cooling, and lighting. In the modeled scenarios for the existing conditions, even with identical WWR in the classrooms, the decrease in energy consumption is comparatively smaller in B113, which initially had a south-facing window, than in B114. Furthermore, the scenarios reveal a relatively higher increase in cooling energy consumption for B113 in comparison to B114.

Since the WWR decreased in the current situation compared to the before strengthening, the need for heating and lighting energy in classrooms B113 and B114 increased with the effect of the direction factor, and this situation also increased the total energy consumption. The increase in total energy consumption in classroom B113 was higher than in B114. Yıldız et al., investigated the effects of glass types and WWR on energy performance of a school building located in Izmir. They found that when WWR is increased heating loads decrease and cooling load increase [22]. Although, the objectives and methods of the studies are different, the results show that when WWR is decreased, energy consumption increases. It should be remembered that there are more parameters that affect the results, like climate type. Therefore, this study suggested a usable method for all buildings, which have different characteristics and environmental conditions.

Although the sound insulation of the opaque component is high, a sufficient noise reduction value could not be achieved on the facade due to the low sound insulation of the transparent area. In the current situation, since the WWR decreased after the strengthening, it was observed that the facade noise reduction level increased in the classrooms, but due to the low insulation level of the transparent area, adequate insulation was not provided.

Alonso et al., investigated acoustic retrofit strategies of windows depending on the regulations of certain European countries and other countries [20]. They stated that upgrading strategies focused on windows can be sufficient to comply with national building regulations in European countries and various countries globally. However, Alonso et al. did not consider Turkey in their evaluation of these regulations. Our research expands upon their work by examining an educational facility in compliance with Turkish standards, thereby providing a valuable contribution to their study. We concluded that scenarios 1 and 4 met the standard requirements for Turkey. In addition to proposing a method to evaluate strengthening designs, this study contributes to the literature on this aspect.

Scenario 1 (three-layered glass) is the proposal that provides the most reduction in the total energy consumption of the building compared to the current situation considering the calculation results of the improvement scenarios. When the total energy consumption and noise reduction levels for classrooms B113 and B114 were analyzed, Scenario 1 was determined to be the most suitable alternative. It is seen that when Scenario 1 is applied to the whole building, there is a 15.9 % decrease in total energy consumption, and the facade noise reduction level in the classrooms increases and meets the requirements of the noise regulation valid in Turkey.

The sound insulation levels of the opaque and transparent areas of the facade did not change before and after the strengthening, but the WWR decreased. Although the facade noise reduction increased due to the decrease in the WWR, the limit values given in the regulation could not be achieved. With the scenarios created, the sound insulation values of transparent areas have been increased and all scenarios provided the required facade noise reduction limit values specified in the regulation. Although the scenarios with different layer properties provide similar noise reduction, the highest facade noise reduction level for the classrooms was obtained in Scenarios 1 and 4. Due to its physiological structure, the human ear cannot perceive low sound level differences below a certain value. For this reason, the energy consumption amounts of the scenarios gain importance in the selection of the optimum transparent area. In this study, when the scenarios for transparent areas are considered together with energy consumption and noise reduction, Scenario 1 (three-layered glass), which provides both the high noise reduction level and low energy consumption, is determined as the most suitable option for the transparent area.

CONCLUSION

The buildings need to be renewed or strengthened due to wear during their lifetime and/or damage as a result of natural disasters. After the renewal and strengthening of the structure system, providing indoor comfort conditions is important for health, efficiency and comfort. While providing comfort conditions in the indoor environment, it is necessary to keep energy consumption at a minimum and facade noise reduction at maximum level. The sectional properties of the building envelope should be improved in order to ensure that the indoor environment is minimally affected by external climatic conditions and noise sources.

A method proposal was created to examine the changes made in the envelope of an educational building, whose building's column system was renewed and strengthened against earthquakes. The optimum building envelope scenarios have been developed in terms of energy consumption and noise control. The building envelope was examined for the before and after strengthening conditions, and also six different transparent area scenarios were analyzed. The analyses were evaluated within the scope of the relevant standards and regulations and by comparing them with each other.

The changes in the transparency ratio after strengthening process, directly affect the indoor comfort conditions depending on the direction and the location. In strengthened buildings, the necessary changes should be made in the selection of glass type and the cross-section of the transparent areas, especially considering the change in energy consumption caused by the reduction in the size of the glass areas and depending on the direction of the facade. The reduction in WWR resulted in lower solar heat energy gains. So, the heating energy consumption of the classrooms increased. However, no significant difference was observed in cooling energy consumption. This study found that the total energy consumption increased by 273% in the classroom B113 and 131% in the classroom B114 after strengthening while the facade noise reduction levels (DnT,A,tr) increased by 2.7 dB in B113 and 1.5 dB in B114.

This study revealed the effect of choosing the appropriate transparent area on energy consumption and facade noise reduction of strengthened buildings. The results showed that the optimum scenario (Scenario 1) decreased the total energy consumption by 19.4% in B113 and 26% in B 114 and increased the facade noise reduction levels by 14.2 dB in B113 and 15dB in B 114.

It is expected that other alternative scenarios and the optimum building envelope glass section will contribute to future renovation and/or strengthening studies. Even if the scenarios in the study were able to decrease energy consumption in the current situation, none of the scenarios have not the building physics performance of before strengthening. The designers should consider the performance of after strengthening conditions to be able to build energy efficient buildings. Considering only the issues related to strengthening, it is determined that after the strengthening application, the building's energy consumption is negatively affected and the building does not provide sufficient conditions in terms of sound and light. In strengthening projects, the control is also required in terms of heat, sound and light during the project phase. Therefore, the method proposed in this study is important for future studies as it will lead to the control and improvement of thermal and acoustic conditions in strengthening projects.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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