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A Comparison of Energy and Daylighting Performances of Different Window Glazing Types Used in the Traditional Harput House

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Abstract
A review of the history of glass that dates back to the mid-2000 BC pursuant to the archaeological data suggests that the effects of the thermophysical properties of window glass on building energy performance could have been understood only over time. Today, the optimum combinations of thermophysical parameters help significantly reduce the energy demand of the buildings. Furthermore, the energy sustainability is also achieved by increasing building energy efficiency during the early design phase, using building simulation tools. The present study was aimed to comprehensively review the improvements in glazing technologies from past to present. Furthermore, the energy and daylighting performances of the retrofitted traditional Harput house in Turkey were analyzed using a building simulation tool. The results indicated that the use of retrofit measure, i.e., the triple-glazed window with low-e coating filled with Argon gas combined with daylighting control system improved the annual primary energy performance of the building in question located in a cold climatic region of Turkey by %8.20. In addition, it was found that the illuminance of indoors increased by means of higher visible transmittance ensured by the retrofit measure.
Keywords: Building Energy Performance; Daylighting; Energy Performance Simulation; Energy Retrofit; Energy Sustainability; Traditional Building; Window Glazing.

1. Introduction

The current archeological data suggests that the use of glass in architecture began with the mid-2000's BC. Using the mosaic technique, the glass pieces were applied as a coating on the columns or walls of palatial or significant structures alike throughout the said period. Functional uses of glass in architecture, however, started with the mounting of glazing onto the windows. The earliest use of the window panes dates back to Caerleon (in Wales) [1]. In Anatolia, many finds of window glass in the forms of glass panes and stained-glass fragments were unearthed from the structures belonging to the Roman and Byzantine period. Those data will surely be expanded by future research and studies. This paper is limited to a brief introduction on window glazing in the Ottoman structures.

Natural lighting of the earliest Turkish buildings in Anatolia were provided by means of slit windows or small-scaled oculi (pl. oculus) with the roofs hosting either oculus or lanterns [2]. There were traces of oculus in the early 13th century single-floor Seljuk buildings, however it was not clear whether the façades included windows [3]. Only after the mid-13th century the windows became prominent on the façades, which prevailed thereafter with lower story windows having been provided direct access to the exteriors [4]. As the windows needed temporary covers due to the climatic conditions, upper windows were incorporated to the buildings with an aim to provide natural light and reduce the load of the upper walls. Called as skylights, those windows was manufactured in tandem form with inner and outer windows since they were fixed and placed at high levels. Covering the windows on the exterior, the lattices with or without transparent glass were called "dışlık" (the exterior), while wooden or gypsum windows with glass, thin hide, waxed paper, or parchments that stretched between the frames were called "içlik" (the interior). Those windows with gypsum frames with colored glass panes attached thereto were called as "revzen-i menkuş", or stained glass [5]. Today, the authenticity of extant Ottoman ornamental glasses is subject to ongoing debate. However, revzens from the tombs of Sultan Mustafa and Cem in Bursa were suggested to have received "little restoration" that they were authentic, and thus proved the existence of interior windows during the 15th century [6].

There was a significant development and increase in production of Turkish glass crafts during the 15th century. This may be associated with the institutionalization of glass-making under the patronage of the Ottoman state, where the "camgeran" (glass makers) of the glassmakers' guild were considered "Ehl-i Hiref", i.e., artisans (Figure 1a).

Surnâme-i Hümayun, an illustrated manuscript from Topkapı Palace Library, prepared in commemoration of the circumcision ceremony held for Şehzade Mehmed, son of Sultan Murad III (Inv. No. TSH Hazine 1344), depicted the procession of entertainers and guilds of craftsmen and tradesmen held at Atmeydanı/Hippodrome, which also included the miniatures of glassmakers. One of the miniatures represents the glassmakers in a cart, while another one shows their procession with workshops (Figure 1b). Most likely drawn in 1582-84, the miniatures present gypsum frames similar to those we see on contemporary Ottoman buildings today, indicating their importance as a source for future restorations. From 17th century onwards, the utilization of revzen became popular for the purposes of civic architecture. By late 17th century, however, the Western large glass pane products made an impact on Ottoman architecture, the examples of which can be seen on Baghdad Kiosk and Revan Kiosk along with their depictions in the miniatures of the period. Due to changes in the traditional architecture, the ornamented upper floor windows started to disappear following the mid-19th century.

(a) (b)

Figure 1: *Surnâme-i Hümayun* (circumcision ceremony from the reign of Murad III), glassmakers and traders as a part of the parade walking through in front of Ibrahim Pasha Palace [7].

The designers should consider a number of design possibilities during the early stages of building design and have to make the majority of relevant decisions for the entire process. Choosing the appropriate window area and materials is a part of early design stage decisions, which are hard to change later. For example, large windows will allow more daylight into the room and improve the indoor visual comfort, but they may be associated with excessive heat gain or loss as well, which would affect the indoor thermal environment and energy consumption. Furthermore, window design involves multiple parameters, including the window to wall ratio (WWR), glazing, and filling gas of the window material. Changing one parameter could potentially lead to the fact that important interactive effects may be unnoticed. Window design is therefore typically a multi-factor and multi objective optimization problem. It is important to simultaneously optimize the window parameters during the early stages of building design and find a balance between the energy consumption, indoor thermal environment, and visual performance.

Thalfeldt et al. [8] optimized the facade parameters, including the window type, wall insulation, WWR, and shading devices for the best energy performance. Su and Zhang [9] focused on the environmental impact of a typical office building to determine a suited limited value for the WWR for different orientations and window materials. Ma et al. [10, 11] studied the relationship in thermally autonomous buildings between maximum WWRs and the ambient temperature amplitudes with different thermal envelope resistances. Lee et al. [12] optimized the annual heating, cooling, and lighting energy consumption in five typical climatic zones in Asian regions upon an analysis of the window properties, including the WWR, U-value, solar heat gain coefficient (SHGC), and visible transmittance. Hiyama and Wen [13] proposed a rapid response surface creation method to optimize the window geometry using dynamic daylighting and energy simulations. There has been certain focus on the daylighting performance and potential energy savings. Most studies focused on performance assessment and prediction. The optimization of the daylighting performance and energy savings were implemented separately. Yu et al. [14] presented the metrics and methods for indoor daylight availability assessment and the estimation methods used for predicting potential energy savings from daylight. Ghisi [15] presented a method to predict the potential energy savings for lighting using an ideal window area concept for effective daylight integration with an artificial lighting system. Mangkuto et al. [16] investigated the influence of the WWR, wall reflectance, and window orientation on various daylight metrics and the lighting energy demand in simple buildings located in the tropical climate. Krarti et al. [17] proposed a simplified method to estimate the energy savings of artificial lighting by investigating several combinations of building geometries, window opening sizes, and glazing types for four geographical locations. A generalized window energy rating system (WERS) for typical office buildings was presented by Tian et al. [18] and the energy effects of window parameters were analyzed and indicated using the localized WERS. Recently, several studies focused on the window design with simultaneous optimization of the energy and daylighting performance [19]. However, the research is far from being deemed as adequate [20] and the optimization process is very complex without consideration of the interaction of the window parameters. Ochoa et al. [21] used a graphical optimization method to determine the window size, when simultaneously optimizing the low-energy consumption and high visual comfort. Vanhoutteghem et al. [22] determined the appropriate window solution by evaluating the effect of the window design parameters on the heating demand, daylighting, and thermal environment using a contour plot.

2. Material and Methods

The present study aimed is to investigate the energy and daylighting performance of the traditional Turkish houses, which were designed as compatible with the climatic conditions, using a building energy simulation tool. It was also aimed upon an analysis of the existing performance of house to improve both the energy, and daylighting performance using window glazing designed by contemporary glazing technologies replacing the existing glazing.

For the purposes of the study, the Şefik Gül House located in Harput within the Elazığ Provincial borders in Turkey was chosen as the case-study building and the energy performance of this building was modelled using the DesignBuilder simulation tool, featuring a detailed dynamic calculation methodology. Accordingly, different kinds of window glazing were tested for Şefik Gül House considering the thermophysical properties of the selected glazing materials with an aim to decrease the annual primary energy demand and increase the level illuminance (light level) on the spaces in the house.

The numerical values of energy demand of the building are multiplied by the energy conversion factors specified for each country in order to calculate the primary energy demand of a building. The energy conversion factors as specified by the Turkish Ministry of Environment and Urbanization were used for the purposes of the present study; where, the energy conversion factors were provided by the BEST (Ecological and Sustainable Design in Buildings) Residential Certification Guide [23]. The foregoing guide specified the energy conversion factors for electricity and natural gas for Turkey as 2.36 and 1, respectively. The relevant equations for the calculation of primary energy demand are as follows, where;

PED_e is primary energy demand for electricity (kWh/m^2y),

T_e is conversion factor for electricity,

PED_n is primary energy demand for natural gas (kWh/m^2y),

T_n is conversion factor for natural gas,

PED_t is total PE consumption (kWh/m^2y).

$$PED_e = T_e \times 2.36 \quad (1)$$

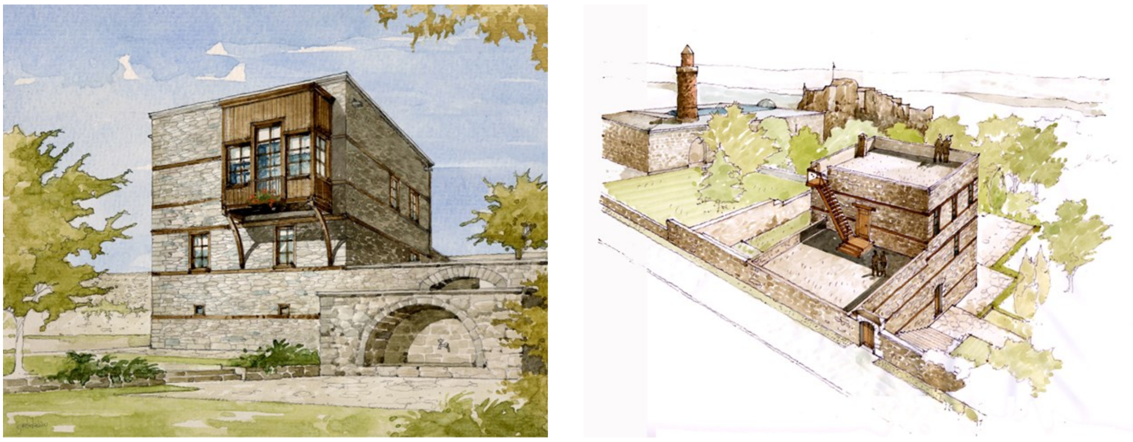
$$PED_n = T_n \times 1 \quad (2)$$

$$PED_t = PED_e + PED_n \quad (3)$$

The DesignBuilder building simulation tool was used to analyze the energy and daylighting performance of the window glazing. The DesignBuilder software is a building simulation tool by a United Kingdom (UK) based developer that can be used with a user-friendly interface to model all kinds of buildings, which performs the energy and daylighting analyzes using the EnergyPlus and Radiance infrastructure, respectively. All these simulation tools were tested by a number of other research studies, which confirmed their accuracy. Furthermore, their calculation methodology is based on a detailed-dynamic methodology stated in EN 13790 [24].

3. Definition of the Case Study Building

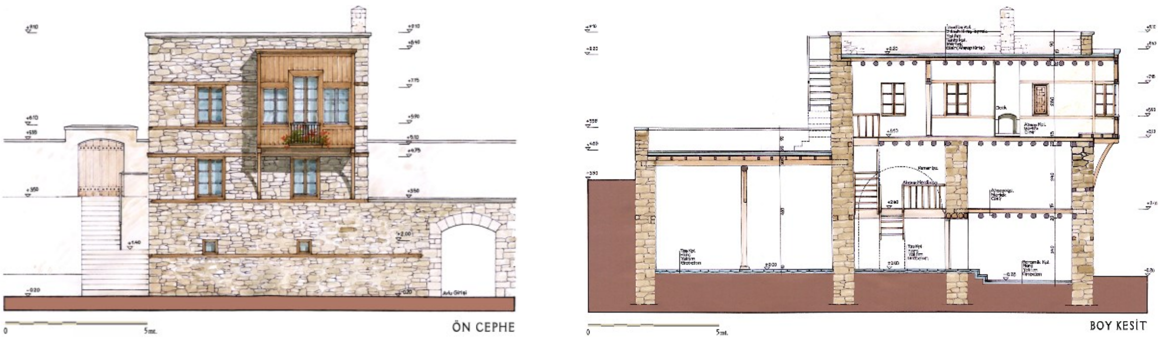
The Elazığ province, which hosts the Şefik Gül House, is located in the cold climatic region of Turkey. The views of the south and north façades of the Şefik Gül House are given in Figure 2. One of the important parameters of designing a building compatible with climate is the windows. In the said region, the windows are designed in a smaller form in order to minimize heat loss, because of a prolonged and colder winter season and a shorter, but hotter summer season.



(a) (b)

Figure 2: The view of the south (a) and north (b) façade of the Şefik Gül House (case study building) [25].

The mean dry bulb temperatures of Elazığ for winter and summer seasons are -12°C and 38°C, respectively. Accordingly, the impact of the window glazing to the energy efficiency and daylighting performance of traditional Harput houses were considered in this study. As such, different glazing types utilizing contemporary glazing technologies were tested and the optimum glazing type was specified for the cold climate region of Turkey.
The Şefik Gül House was bought by GÜLSAN AŞ in 2004 and put into service in 2005 as the Harput Şefik Gül House of Culture. Since there is no inscription on the building, the construction date isn't known clearly but it's construction is considered to have started in the first quarter of the XX. century based on a comparison with other existing traditional buildings around Harput [26]. The Şefik Gül House has the characteristics of architectural design features of the traditional Harput houses, and it was built using traditional and organic construction materials. The building, oriented towards the south on the inclined terrain, was built with a flat roof and in three floors as seen in Figure 3.



(a) (b)

Figure 3: The front (a) and sectional (b) view of case study building [25].

Upon a review of the floor plans provided in Figure 4, the thickness of external walls is remarkable. The Elazığ province is located in the cold climatic region of Turkey, so the envelope of traditional building was designed to minimize the heat transfer to provide indoors energy conservation.

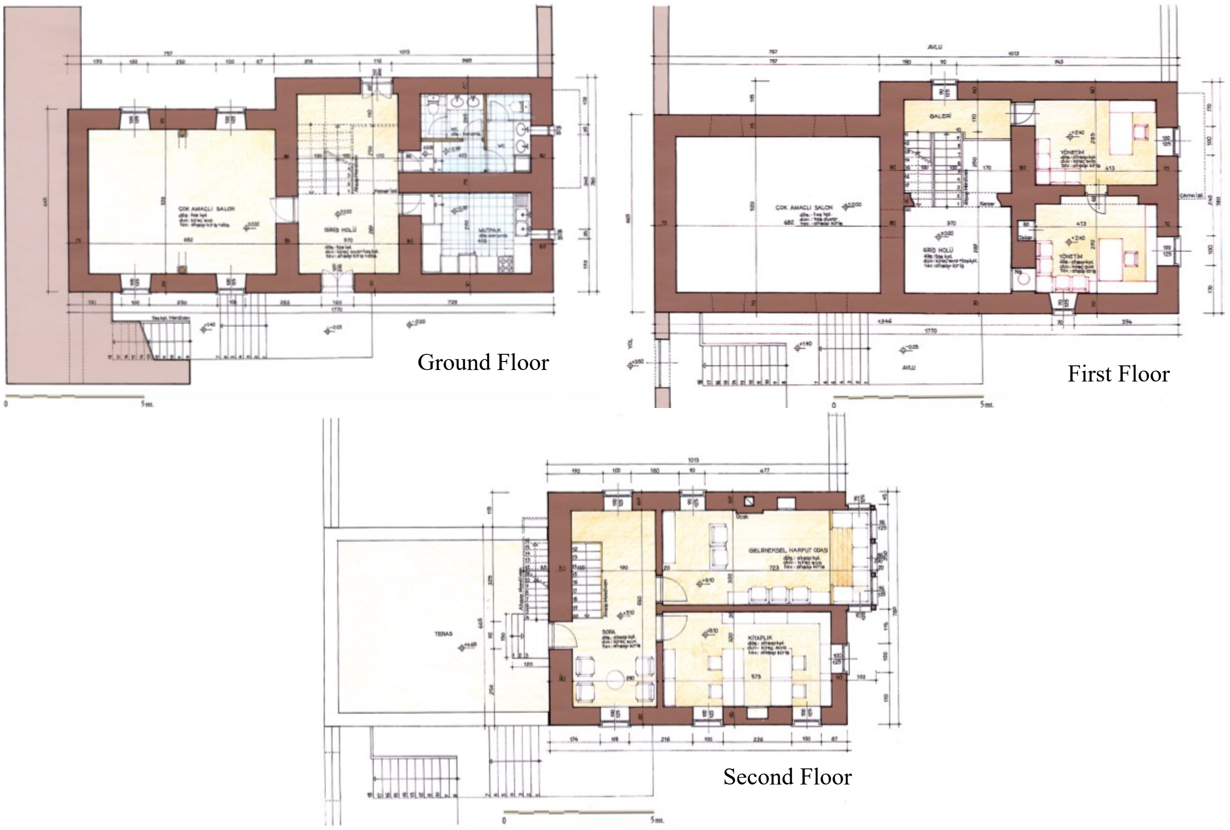


Figure 4: The Floor plans of case study building [25].

The construction materials of case study building with the thermophysical properties of the opaque and transparent materials are given in Table 1. The U–value (or factor) is the overall heat transfer coefficient for a wall, floor, ceiling, door, and glazing system. It is defined as the rate at which heat is transmitted through it, per unit surface area per unit temperature difference between its two sides. It is measured in watts per m^2 per degree Kelvin (W/m^2K) [27]. The lower the U-value, the lower the amount of the heat transferred by the construction material. The solar heat gain coefficient (SHGC) is given as a number between 0 and 1. It represents the portion of heat addition due to the solar radiation transmitted directly by fenestration, added to the portion that is absorbed and re-emitted to the inside of the building by the fenestration itself [28]. The lower the SHGC, the more effective the glass in blocking solar heat gains. Visible light, called the visible spectrum, is that portion of the electromagnetic spectrum having wavelengths from about 380 nm (nanometers or billionths of a meter) to 780 nm. Light of different wavelengths is perceived as having different colors [29]. The visible light transmission (T-vis) is given as a number between 0 and 1. The higher the T-vis, the higher the proportion of visible light transmitted to indoor. The U-value of the window glazing is quite high compared to the opaque materials generally, upon a review of the thermophysical properties of the Şefik Gül House given in Table 1. The U-value of construction materials should comply with the reference values prescribed in the Turkish Heat Insulation Requirements (TS 825). However, it was concluded that the U-value of window glazing in the Şefik Gül House was higher than 2.4 W/m^2K, which was specified for window glazing in TS825.

Table 1: The thermophysical properties of building construction materials in case study building [26].

Building Envelope	**Thickness (m)**	**U-value (W/m^2K)**	**SHGC (%)**	**T-vis (%)**
Exterior Wall	0.070	1.26	-	-
Ground Floor (Stone Coating)	0.042	2.143	-	-
Ground Floor (Ceramic Coating)	0.025	3.057	-	-
Ground Floor (Timber Coating)	0.015	0.538	-	-
Ceiling	0.020	0.01	-	-
Window	-	4.975	0.321	0.201
Door	-	2,381	-	-

4. Energy Performance and Daylight Modelling of the Case Study Building

The energy performance of the Şefik Gül House was modelled using the DesignBuilder simulation tool. Typical Meteorological Year (TMY) data, ie., the weather data source for the Elazığ province, were included in building performance calculation to analyze the building's response to outdoor conditions during the year. The passive system model views of Şefik Gül House are provided in Figure 5.

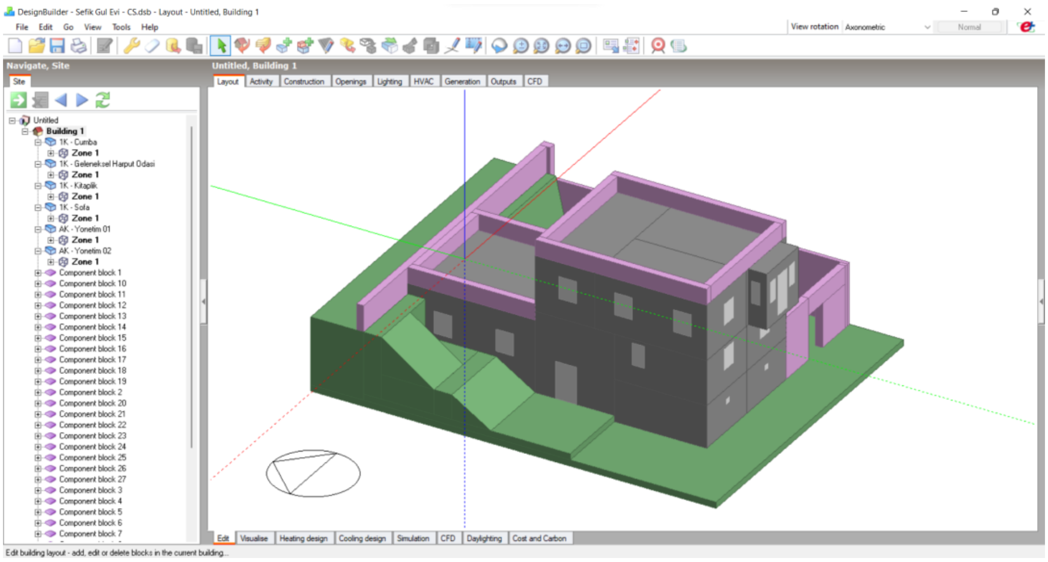


Figure 5: The energy model view of architectural system for the Şefik Gül House captured by DesignBuilder

In the present study, the Şefik Gül House was considered as a residence building, so the building energy model was constituted on the basis of the heat loads and setpoint temperatures of residence buildings stated in ASHRAE 90.1 standardization. To perform the energy analyzes, the heating, cooling and ventilation design features of the building should be entered to the simulation tool. The design features of the case study building are seen in Table 2, below. The heat given off by people, lighting systems, and household equipment represent the internal heat gain of a building. The internal gain significantly impacts the energy demand of the building. In order to calculate the annual heating and cooling energy demand of a building by including the internal gains, the setpoint temperatures of building zones are required. All these building parameters were met considering the data stated in ASHRAE 90.1 standardization.

Table 2: The design features of the case study building.

	Zone	Area (m^2)	People (m^2/person)	Lighting (W/m^2)	Equipment (W/m^2)	Heating Setpoint Temperature (°C)	Cooling Setpoint Temperature (°C)	Orientation	Ventilation
Ground Floor	Saloon	31.43	59.11	3.75	3.06	21	24	West-East	Natural
	Corridor	23.52	64.50	2.50	1.57	21	24	West-East	Natural
	Kitchen	11.42	42.19	7.50	30.28	21	24	South	Natural
	WC	11.22	41.12	2.50	1.61	21	24	South	Natural
First Floor	Bedroom 01	11.87	43.59	2.50	3.58	21	24	South	Natural
	Bedroom 02	11.67	43.59	2.50	3.58	21	24	South	Natural
Second Floor	Saloon 01	15.75	59.11	3.75	3.06	21	24	South	Natural
	Saloon + Bay Window	21.52	59.11	3.75	3.06	21	24	South	Natural
	Saloon 02	16.50	59.11	3.75	3.06	21	24	West-East	Natural
Total Zone Area		**154.89**							

5. Energy Retrofits

In the present study, certain energy retrofit measures were applied considering the thermophysical features of the window glazing with an aim to reduce the lighting energy consumption of the building and increase the illuminance of spaces. Each window glazing type, which was tested for its impact on the building energy performance, was called a single measure for the purposes of the study. The thermophysical features of the glazing type of the case study building (CS) and the single measures (SM) are shown in Table 3, below.

Table 3: The single measures applied to the case study building.

Single Measures	Glazing Type*	U-value (W/m^2K)	SHGC (%)	T-vis (%)
CS	3 mm Clear Glass	4.975	0.321	0.201
SM 01	Vertical Glazing**	2.27	0.45	0.56
SM 02	Double Clear 3/6/3 mm Air	3.159	0.762	0.812
SM 03	Double Clear 5/13/5 mm Arg	2.526	0.818	0.834
SM 04	Double Clear 5/13/5 mm Air	2.682	0.818	0.834
SM 05	Double Elec Ref Bleached 6/13/6 mm Arg	1.493	0.643	0.727
SM 06	Double LoE Elec Ref Bleached 6/13/6 mm Arg	1.323	0.428	0.634
SM 07	Quadruple LoE Films (88) 3/8/3/8/3 mm Krypton	0.781	0.466	0.624
SM 08	Triple LoE (e2=e5=.1) Clr 3/13/3/13/3 mm Arg	0.780	0.474	0.661

* All the glazing types are designed using wooden window frames compatible with traditional Harput houses.
** Compatible with the reference U-value for the windows as prescribed in the TS825 Standardization

In the present study, the energy retrofit packages were applied by combining each single measure with daylighting control systems as seen in Table 4. Thus, it was aimed to reduce the annual lighting energy consumption of the building, when there were adequate light levels in the house spaces during the year. The daylight-controlled lighting systems were preferred to avoid lighting overuse. The artificial lighting systems were dimmed or switched off, when sufficient light levels were achieved on the working plane or the space was unoccupied, using an integrated lighting system (daylight and artificial lighting system). Benefits of daylighting control systems:

- Save money spent on electrical energy
- Automated control of lights
- Health benefits of correct lighting

Table 4: The packages applied to the case study building.

Packages	
P 01	CS + Daylighting Control System
P 02	SM 01 + Daylighting Control System
P 03	SM 02 + Daylighting Control System
P 04	SM 03 + Daylighting Control System
P 05	SM 04 + Daylighting Control System
P 06	SM 05 + Daylighting Control System
P 07	SM 06 + Daylighting Control System
P 08	SM 07 + Daylighting Control System
P 09	SM 08 + Daylighting Control System

6. Results

Upon the energy efficiency analysis, the annual primary energy demands of the existing building and the retrofitted buildings were obtained. Figure 6 indicates the energy performance results by total annual primary energy demand of the case study building and upon building retrofits.

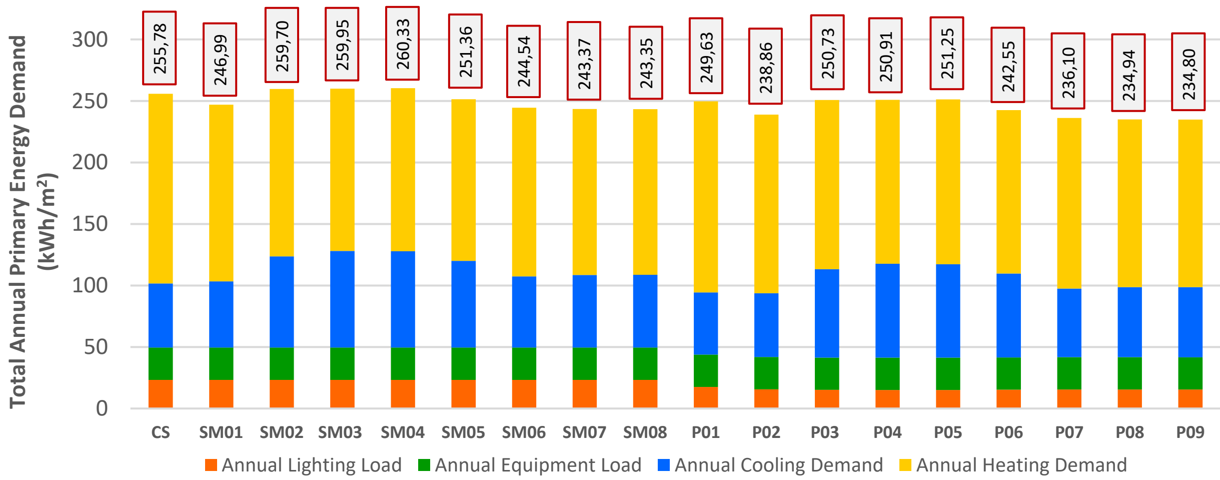


Figure 6: The total annual primary energy demand of the case study building and retrofitted building.

As regards the daylighting performances, the light levels of the saloons and the kitchen in the building at 12 pm as of 21th June and 21th December which are longest day and longest night respectively, were measured.

Figure 7: The daylighting performance of the case study building at 12 pm in 21th June and 12 pm in 21th December.

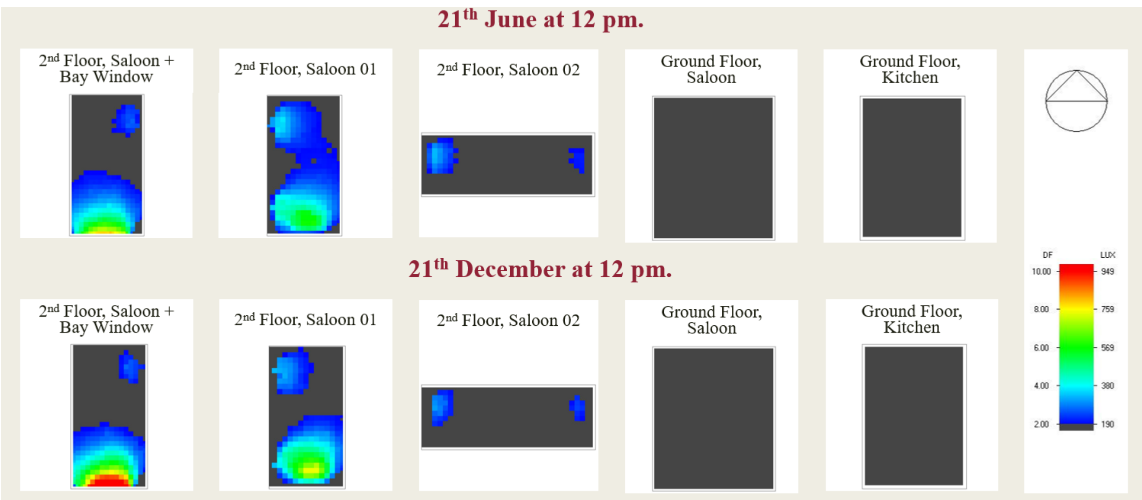


Figure 8: The daylighting performance of the SM 01 at 12 pm in 21th June and 12 pm in 21th December.

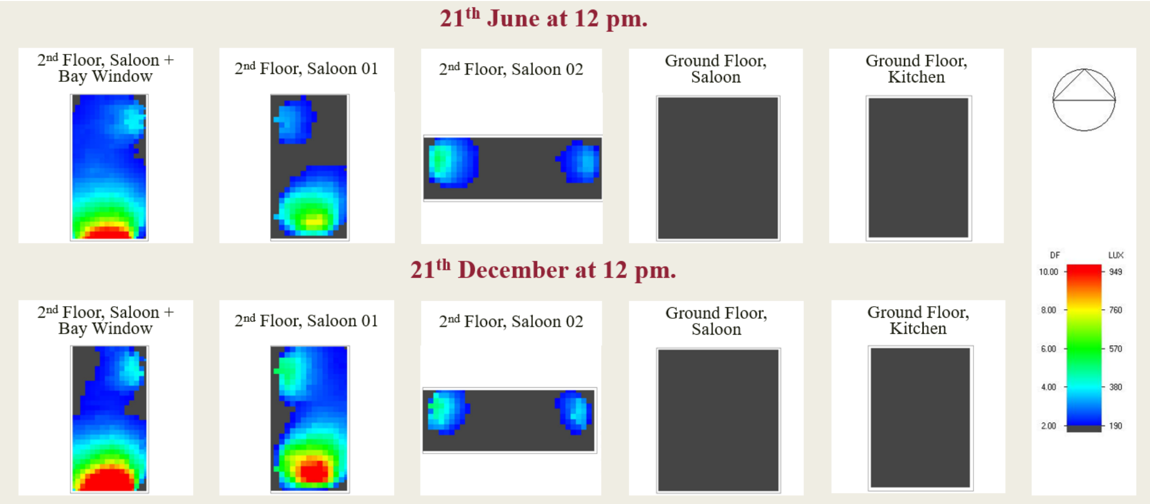


Figure 9: The daylighting performance of the SM 02 at 12 pm in 21th June and 12 pm in 21th December.

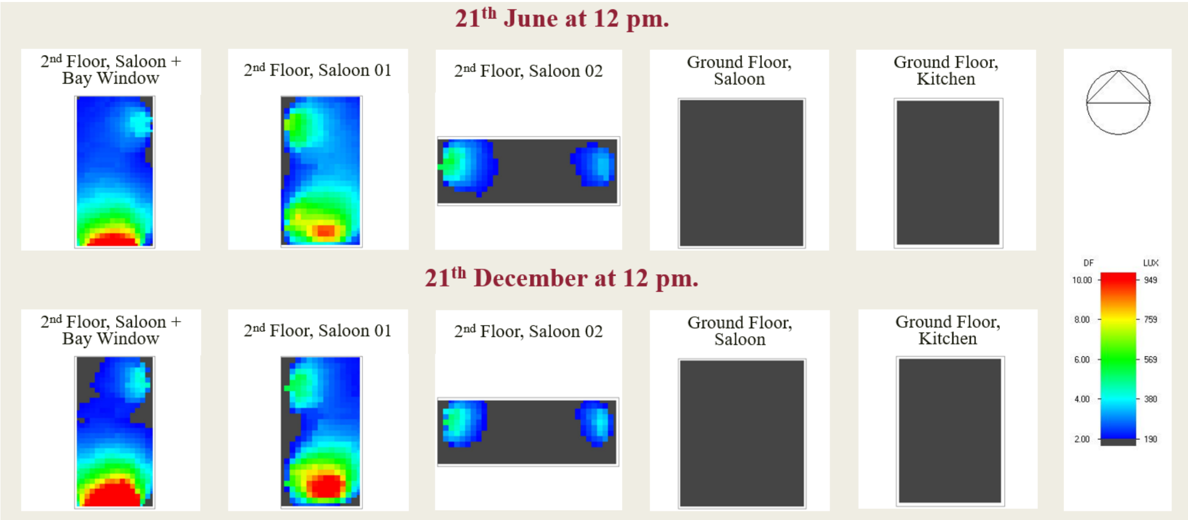


Figure 10: The daylighting performance of the SM 03 at 12 pm in 21th June and 12 pm in 21th December.

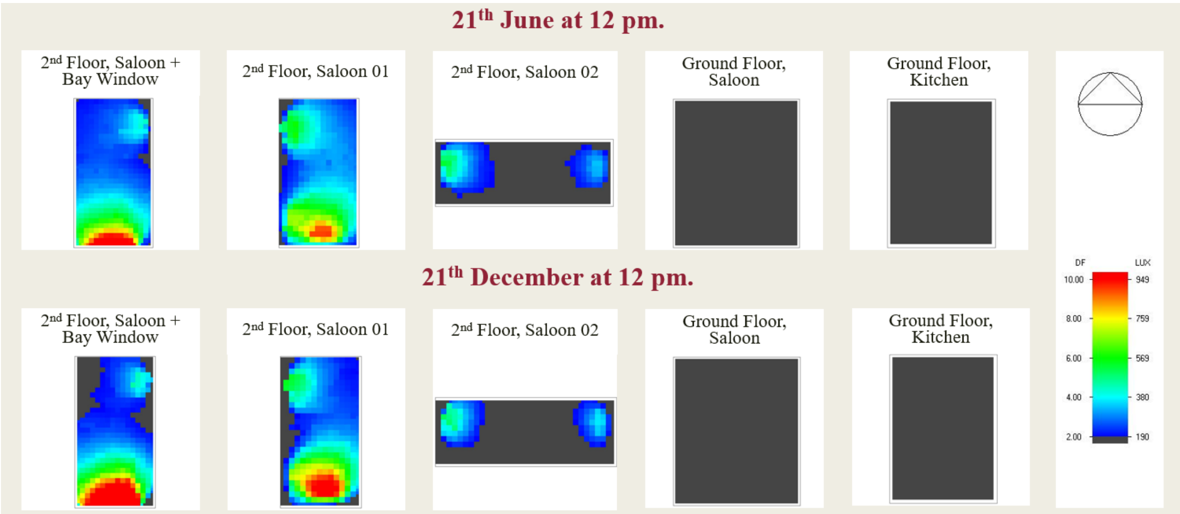


Figure 11: The daylighting performance of the SM 04 at 12 pm in 21th June and 12 pm in 21th December.

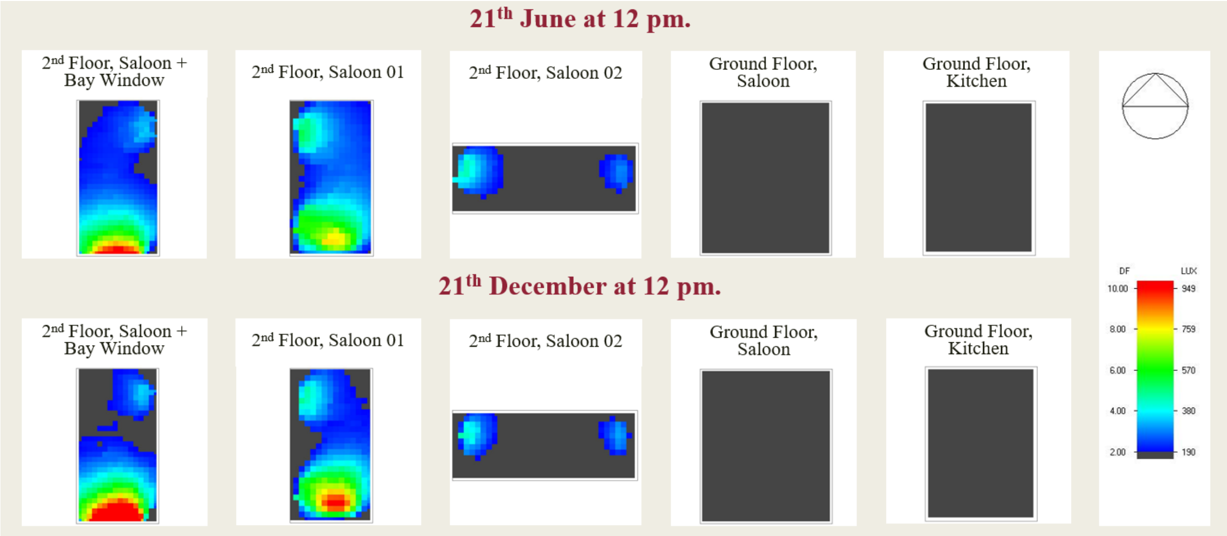


Figure 12: The daylighting performance of the SM 05 at 12 pm in 21th June and 12 pm in 21th December.

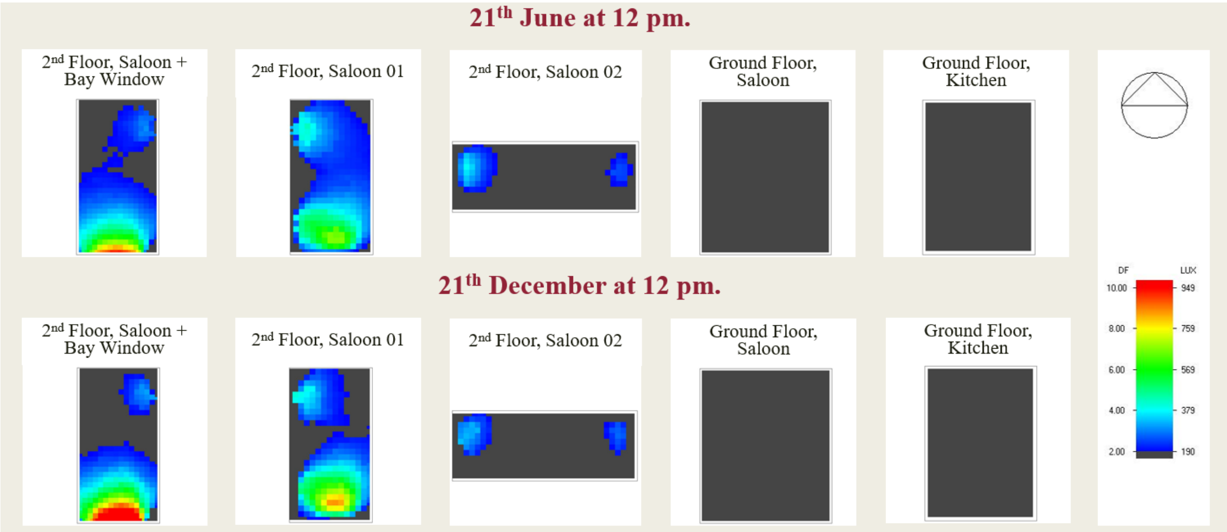


Figure 13: The daylighting performance of the SM 06 at 12 pm in 21th June and 12 pm in 21th December.

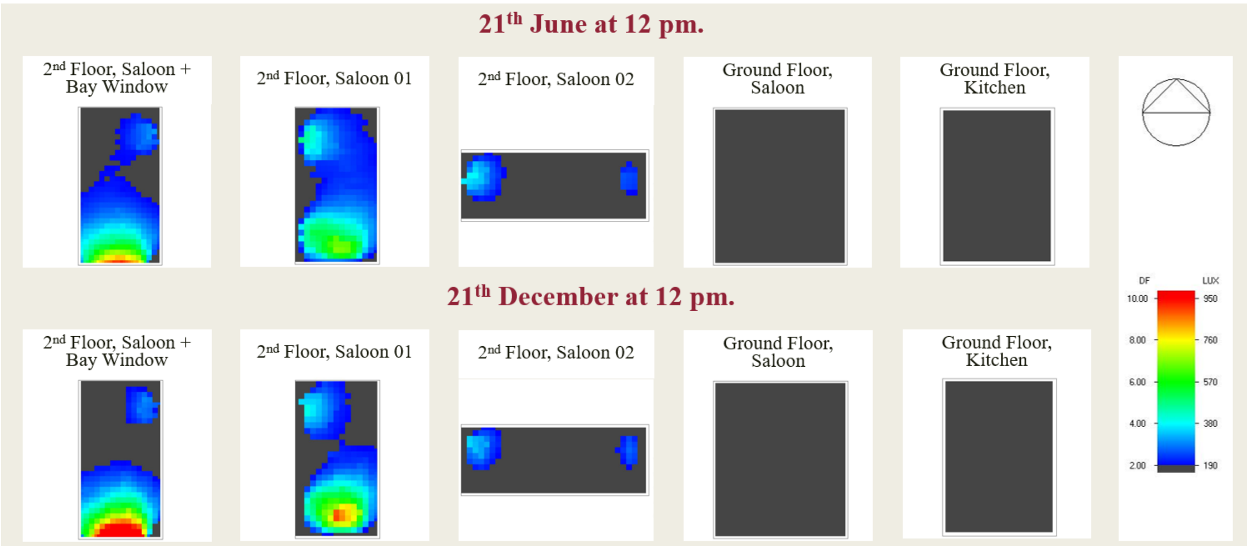


Figure 14: The daylighting performance of the SM 07 at 12 pm in 21th June and 12 pm in 21th December.

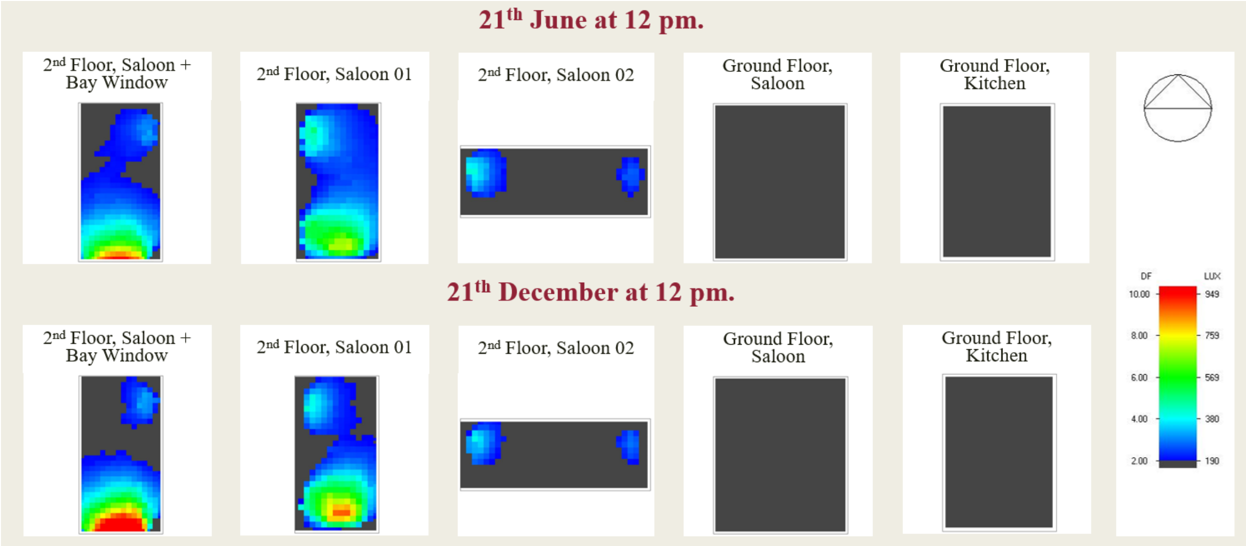


Figure 15: The daylighting performance of the SM 08 at 12 pm in 21th June and 12 pm in 21th December.

7. Conclusions

The existing window glazing (3mm clear glass) was not adequate to ensure a decrease in the annual heating demand and an increase in the light level of spaces of the Şefik Gül House. Therefore, it was decided to apply energy efficiency measures for the building considering contemporary glazing types with an aim to improve the energy and daylighting performance of the building.

A review of the building energy performance results indicated that the annual primary energy demand of the building was reduced in direct proportion to the reduced U-value of the glazing type. However, it was concluded that even if the U-value was lower compared to the existing case, the total annual primary energy demand increased due to higher SHGC (solar heat gain coefficient) in the SM 02, SM 03, and SM 04 measures.

As regards the retrofit packages, it is concluded that the daylighting control system ensured a significant amount of energy efficiency in the annual lighting energy consumption of the building. Furthermore, the annual cooling demand was reduced due to the reduced internal gain given off by artificial lighting systems.

The visible light transmittance (T-vis) of the glazing type was a highly important thermophysical feature to ensure the minimum illuminance in spaces as specified in the lighting standards, including the CIBSE, EN, and TS standards. For the purposes of the present study, the daylighting simulations were performed for the saloons, dining areas, and the kitchen, where people spent longer time and needed to clearly see the objects, colors, and patterns. In those indoor areas, the working plane was considered 0.75m above the ground to perform the illuminance (lux) calculation.

A review of the daylighting performance of each single measure suggested that the higher the increase in T-vis the lower the light level increase in the spaces at the second floor. However, it was notable that the illuminance of the living room and kitchen on the ground floor did not change, despite the glazing type was changed. This might be associated with the fact that window sizes of those areas were not large enough to achieve the required light level. Besides, the windows of the saloon were west- and east-oriented, and the garden walls around the house created a shading effect lessening the exposure to the sunlight.

It is restricted to amend the architectural form of traditional buildings and it isn't permitted to use methods other than the traditional construction methodology in cases when the building needs repairs pursuant to the Law on the Conservation of Cultural and Natural Property as introduced by the Republic of Turkey.

In conclusion, a review of all the study results suggested that the optimum retrofit measure, which allowed an improvement in the energy and daylighting performance of the Şefik Gül House was the Package 08.

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Conflict of Interests

The authors declare no conflict of interest.

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