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# Assessment of the Energy Efficiency of Glass Components in the Improvement of an Existing Office Building with a Double-Skin Façade System in a Temperate-Humid Climate

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**Abstract**

*Industrialisation causes migration from rural to urban areas. This situation increases the consumption of raw materials and energy in building stocks, $CO_2$, greenhouse gases and global warming. The solution is the implementation of sustainable and energy-efficient design strategies. Ensuring physical environmental comfort conditions in buildings - such as thermal, visual, acoustic, and indoor air quality -requires high energy usage. This study assesses the potential for improving the south façade of the Gebze Technical University (GTU) Rectorate Administrative Building in a temperate-humid climate through double-skin façade system. The study aims to evaluate the performance of the glass type and insulating gases used between the glass layers in terms of heating and cooling energy consumption. Rhinoceros/Grasshopper and Honeybee programs were used for the analysis. As a result of the improvements, the system reduced energy consumption for heating and cooling. Low-E glass and argon gas used in the improvement system were key factors.*

***Keywords:*** *Double-skin façade system, energy-efficient improvement, low-e glass, rhinoceros/grasshopper, temperate-humid.*

# Ilıman-Nemli İklimde Mevcut Bir Ofis Binasının Çift Kabuk Cephe Sistemi ile iyileştirmesinde Cam Bileşenlerinin Enerji Etkinliğinin Değerlendirilmesi

**Öz**

*Sanayileşme, kırsal alanlardan kentsel bölgelere göçü tetiklemektedir. Bu durum, bina stoklarında hammadde ve enerji tüketimini arttırarak, $CO_2$, sera gazları ve küresel ısınmayı yükseltmektedir. Çözüm olarak sürdürülebilir ve enerji verimli tasarım stratejilerinin uygulanmasıdır. Binalarda termal, görsel, akustik ve iç hava kalitesi gibi fizik ortam konfor koşullarının sağlanması yüksek enerji kullanımı gerektirmektedir. Bu çalışma, ılıman-nemli iklim bölgesindeki Gebze Teknik Üniversitesi (GTÜ) Rektörlük İdari Binasının güney cephesinin çift kabuk cephe sistemi ile iyileştirilme potansiyelini değerlendirmektedir. Çalışma, cam türünün ve cam katmanları arasında kullanılan yalıtım gazlarının performansını ısıtma ve soğutma enerjisi tüketimi açısından değerlendirmeyi amaçlamaktadır. Analiz için Rhinoceros/Grasshopper ve Honeybee programları kullanılmıştır. Yapılan iyileştirmeler sonucunda, sistem ısıtma ve soğutma enerji tüketimini azaltmıştır. İyileştirme sisteminde kullanılan Low-E cam ve argon gazı kilit faktörler olmuştur.*

***Anahtar kelimeler:*** *Çift kabuk cephe sistemi, enerji etkin iyileştirme, low-e cam, rhinoceros/grasshopper, ılıman-nemli.*

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**1. Introduction**

The global consumption of energy is increasing in line with the expansion of industrialisation, construction and the use of raw materials. In 2021, the total energy resource consumption in Türkiye was distributed by sector as follows; industry (26.1%), housing and services (23.9%), conversion and electricity (22.3%). Transportation accounts for 19.2%, non-energy for 4.8%, and the agriculture and livestock sectors for 3.2% (Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, 2024). The intensive utilisation of non-renewable energy sources gives rise to a plethora of environmental concerns, including pollution, heightened greenhouse gas and $CO_2$ emissions, climate change, global warming and a multitude of other ecological issues. It is therefore imperative to prioritise energy efficiency in the building sector, which is characterised by high energy consumption. This can be achieved through the implementation of energy-efficient design criteria, the enhancement of existing buildings and the incorporation of renewable energy sources (solar, wind, water) throughout the construction and operational phases of the building.

The architectural solution to energy problems experienced from the past to the present is addressed in the principles and strategies of energy-efficient design in new buildings and energy-efficient improvement design in existing buildings. The building envelope, which constitutes the façade system, is the most important element of energy-efficient building design. The advent of innovative technologies have enabled the creation of innovative energy-efficient façade systems that offer superior features and provide energy consumption efficiency in cooling, lighting, and ventilation. Double-skin façade systems represent the future of energy-efficient building envelope design. They control heat loss in winter and solar heat gain in summer due to their innovative design parameters.

The double-skin façade system is the most extensive in the United States and Canada (Alakavuk, 2010). The system provides thermal retention for buildings situated in cold climates, thereby markedly reducing the energy consumption required for heating. In temperate, hot, and humid climates, the utilisation of transparent surfaces that are exposed to solar heat and radiation serves to augment the heat value of the interior environment, thereby increasing the energy consumption required for cooling. Moreover, the high transparency rate of the double-skin façade system permits substantial daylight to penetrate the interior environment, contingent on the design. This situation has yet to be applied, as it creates visual comfort problems (Göksal Özbalta & Yıldız, 2019), (Chong, Somasundaram, Thangavelu & Wei, 2020).

It has been demonstrated that glass components, which constitute the transparent surfaces of the building envelope, are less effective than alternative components in providing thermal and visual comfort conditions within the indoor environment (Cho et al., 2023). However, the performance of glass components is contingent upon the specific technologies employed, the properties of the glass material, and the general design of the building envelope. Modern, high-performance glasses are efficacious in thermal and visual comfort conditions when considering climate, building orientation, shading devices, or other architectural strategies. Furthermore, the optical and thermophysical properties of the glass, the size of the ventilation gap, and the type of gas used between the glass layers are also instrumental in providing energy efficiency.

While studies on the use of double-skin façade systems in energy-efficient façade designs of new buildings constructed in cold climates or façade improvements of existing buildings are relatively common, there is a paucity of studies assessing the design or improvement of double-skin façade systems in hot, temperate and humid climates. It is also very important to consider the design criteria of the glass components used in transparent surfaces that largely cover the double-skin façade system, as this is an essential aspect in ensuring energy efficiency.

In order to assess the functionality of the glass component in a variety of climatic conditions, it is essential to assess and design each of the materials that constitute the component separately. The type of gas employed between the glass layers and the presence of materials utilised as layers on the surfaces of the glass layers on different surfaces are considered significant criteria for assessment in terms of performance. In contrast, some studies assess the performance of Low-E glass, which is layered to reduce heat loss, when used on transparent surfaces in different climate zones.

Nevertheless, there is a paucity of studies that have assessed the impact of Low-E glass on the performance of double-skin façade systems or the optimal location for the Low-E layer on the glass.

In order to address this paucity of knowledge, the present study has proceeded from the perspective of research problems such as "On which surface of the glass does the Low-E layer used in glass elements give the most effective results in improving the energy performance of the transparent elements of the office building in a temperate-humid climate zone and how do the types of gases used between the glass layers affect this?"

Mangan and Koçlar Oral (2014) put forth energy-efficient improvement scenarios for a residential building selected as a reference in Istanbul, categorised according to different climate zones. In these scenarios, a comparison is made between the energy consumption for heating and cooling, and the $CO_2$ emission values originating from energy consumption. The scenarios include improvements to opaque components, the replacement of existing glass systems with coated insulating glass units, the installation of shading devices on the south, east, and west façades, and the integration of renewable energy systems. The changing parameters for improving transparent components are assessed according to climate zones. In addition, the heat transmission coefficient of glass ($U_{glass}$), the heat transmission coefficient of transparent components depending on frame and glass properties ($U_p$), and the solar heat gain coefficient (SHGC) are taken into consideration. The simulation results demonstrate notable discrepancies in heating, cooling, total energy consumption, and $CO_2$ emission values across different climate zones.

Bakkal (2019) proposes the installation of a second skin on the façade of the education building in Samsun province, in accordance with the prevailing climate conditions. The double-skin façade system is selected for installation at the height of the floor. Three distinct proposals were put forth for consideration in conjunction with the existing façade during the course of the improvement works. The aforementioned options are as follows: a double-skin façade, a double-skin façade with the application of PV panels, a double-skin façade with the addition of a panel system, and the implementation of a green façade. In order to ascertain the impact of the proposed solution on energy consumption, calculations have been performed in order to determine the effect on heating, cooling, lighting and annual primary energy consumption. The improvement resulted in the effective determination of heating, cooling, lighting, and annual primary energy loads, as well as the parameters that constitute double-skin façade systems and the type of glass used, the ventilation gap width between glass layers, and the floors where the improvement is applied.

Başarır and Diri (2014) examine the potential for improvement in the double-skin façade system through the addition of a second skin layer to the external or internal surface of the existing façade. The improvement studies demonstrate the efficacy of the double-skin façade system in regulating acoustic environments, facilitating natural ventilation, and reducing energy consumption in both summer and winter.

In their study, Çetiner (2002) constructed scenarios based on the varying positions, material properties, and usage areas of the clear glass, solar control (reflective) glass, and low-emission (Low-E) glass types employed in the single and double-skin façade designs of the existing office building. Energy consumption for heating, cooling, and total was analysed in the scenarios. The results demonstrated that Low-E glass resulted in reduced energy consumption for heating and total, while solar control glass led to decreased energy consumption for cooling.

Cho et al. (2023) stated in his study that windows in newly constructed buildings in Korea are designed with double or triple-layered glass, Low-E coated, and with the presence of gases between the glass layers. Temperature variations between indoor and outdoor environments in cold and hot weather have been shown to induce expansion and contraction of the gas filling between the glass layers, resulting in the formation of leaks. In light of the aforementioned circumstances, the present study has undertaken an examination of argon gas leakage utilised between double-layered glass with respect to its thermal performance. The insulation performance of double-layered glass was calculated using the THERM 7.4 and WINDOW 7.4 simulation programs. This calculation was based on the leakage rates of argon gases, and the deterioration of the U-values of the glass was analysed. The simulation results of the study indicate that, after a period of two years, the filling rate of argon gas between double-layered glass was found to be 65%, accompanied by an insulation loss of approximately 4.3%. In instances where the filling rate of argon gas was less than 35%, a deterioration of approximately 8.6% in the insulation performance was observed. In summary, as the filling rate of argon gas diminishes, a decline in insulation performance is evident.

In their research, Sorooshnia et al. (2023) posited that the implementation of double Low-E glazing in residential buildings situated in temperate climate regions, such as Sydney (Australia) and Tehran (Iran), would enhance the total transmitted radiation energy (TSRE) from the window and the daylight glare factor. However, the study identified shortcomings with regard to spatial daylight autonomy (SDA) and daylight illumination. Consequently, the objective of this study is to ascertain the most efficacious method of leveraging the advantages of double Low-E glazing while circumventing its disadvantages. In this study, a methodological approach was adopted, encompassing the comparison of four factors: window total transmitted radiation energy (TSRE), spatial daylight autonomy (SDA), daylight illumination and daylight glare factor. The investigation involved the utilisation of single clear glass, double clear glass, double argon gas-filled clear glass and double Low-E glazing, with the analysis conducted in both the Tehran and Sydney regions. The study concluded that the implementation of double Low-E glazing resulted in a reduction of total transmitted radiation energy (TSRE) in the Tehran and Sydney regions. When daylight glare factor was evaluated, the level of uncomfortable glare decreased by 66% for Tehran and 63% for Sydney. The spatial daylight autonomy (SDA) factor exhibited a decline of approximately 75% in Tehran and 45% in Sydney. With regard to the parameters of daylight illumination and daylight factor, double Low-E glazing was found to fall short of the requisite performance standards for the cities of Tehran and Sydney.

Urbikain (2020) investigates renovation strategies to improve the energy performance of existing buildings. Utilising a residential building constructed in the 1960s as a case study, an analytical investigation was conducted into the viability of various insulation solutions for enhancing the energy efficiency of buildings in both Berlin, which experiences a cold climate, and Bilbao, which has a temperate climate. The study examined the application of vacuum insulation panels (VIP), a high-performance insulation material designed for façade insulation, rock wool (RW) for utilisation in roof cavities, and advanced double and triple Low-E glazing systems. The aim was to assess their potential in reducing heating and cooling demands, thereby promoting energy conservation and optimising the environmental performance of the buildings. The findings of the analysis indicate that the implementation of VIP facade cladding and argon gas-filled triple Low-E glass has resulted in a 66% reduction in the heating requirement for Berlin, a city characterised by a cold climate. For Bilbao, which enjoys a mild climate, the VIP application reduced the heating requirement by 58% and slightly increased the cooling requirement during the summer period. A comprehensive analysis of the climatic conditions reveals that the implementation of the window solution, characterised by its double Low-E coating, results in a substantial reduction in energy consumption. This reduction, estimated at approximately 35%, is observed in comparison to the pre-retrofit scenario. The findings of this analysis substantiate the conclusion that the window solution exhibits a superior level of energy efficiency in comparison to alternative solutions. However, it is imperative to exercise caution in order to mitigate the risk of overheating, particularly in regions characterised by a mild climate.

The study area was selected as the Gebze Technical University (GTU) Rectorate Administrative Building, which operates as an office building situated in Kocaeli province in the temperate-humid climate region. The rationale for selecting a university building as the case study is that it offers a suitable setting for investigating the potential of new technologies to enhance energy efficiency in academic institutions.

Given that the exist building receives a greater intensity of solar heat and rays from the south façade, the study was conducted on this façade. In this context, a series of scenarios were devised in which a second skin was added to the transparent surface of the existing south façade of the office building. The improvement scenario was based on the use of a double-skin façade. One of the components of the double-skin façade system is the use of Low-E glass, air gas, and argon gas between the glass layers.

The objective is to assess the performance of the location of the Low-E layer used on the façade in the glass layers and the type of gas used between the glass layers in heating and energy consumption for cooling.

It is anticipated that the implementation of a double-skin façade system in an existing building situated in a temperate-humid climate region will result in a decrease in heating and cooling loads. Furthermore, it is anticipated that alterations to the location of the Low-E layer, which is employed as the glass type, and the type of gas utilised between the glass layers will result in fluctuations in energy consumption values during the heating and cooling periods.

The thickness of the glass utilized in the façade is predetermined, with a value of 6 mm selected as a common parameter for all glass types. The interstitial space value between the double-layered glass is fixed at 12 mm. Given that the transparent surfaces of the existing building are designed in accordance with the window system, the box-type double-skin façade system, which represents a specific type of double-skin façade system, was employed in the proposed improvement to the façade. The opaque components constituting the frame system of the glass were selected as insulated aluminium materials.

Ölmez (2013) assesses the ventilation gap values between the skins as 50, 100, 150, and 200 cm in improving the existing building with a double-skin façade system. The assessment demonstrated that the system with a 50 cm air gap exhibited the highest profit rate in annual energy consumption value in comparison to the existing situation. In a similar study, Alakavuk (2010) examined the energy consumption values for heating and cooling by taking the ventilation gap amount of the double-skin façade system applied to the façades as 50, 110, and 200 cm. The assessment yielded effective energy consumption values for heating and cooling when a ventilation gap value of 50 cm was employed.

In light of the findings obtained from the literature review, the scopes of the study was determined in order to address the research problems. In the present study, the ventilation gap width was determined to be 50 cm. While the energy consumption for heating and cooling was assessed in the energy performance assessment, the energy consumption for lighting values was excluded from the analysis. The use of grilles providing natural ventilation in the ventilation gap was not considered, and thus excluded. Furthermore, no shading device was used on the façade to assess the effect of the position of the Low-E layer on the glass layers and the gas types used between the glass layers on the energy consumption for heating and cooling. The energy performance of the building was assessed using Rhinoceros/Grasshopper and the Honeybee, an extension of the Grasshopper.

The objective is to provide designers and researchers with information and guidance regarding the energy consumption performances for heating and cooling of glass components, taking into account the position of the layer to be used in the glass layers and the types of gas used between the glass layers. This will ensure the selection of an appropriate glass component for the prevailing climatic conditions, thereby guaranteeing energy efficiency in façade works.

## 2. Material and Method

In the present era, edifices erected with the aid of innovative technological systems are designed with energy-efficient design parameters in mind. Nevertheless, there are two potential avenues for attaining energy efficiency in existing edifices. First alternative is to demolish the existing structure and construct a new one in accordance with energy-efficient design parameters. Other alternative is to implement improvements that will prevent energy and heat loss while simultaneously providing optimal comfort conditions for users within the existing building. In addition to extending the life span of the building, such improvements are also less costly than rebuilding and result in significant savings in terms of resources, materials, raw materials and energy efficiency (Somasundaram, Thangavelu & Chong, 2020). In light of the considerable waste that will inevitably be generated during the reconstruction process, the issue of disposal, and the damage that such waste causes to the environment due to the extended period it remains in nature, improvement works represent a more environmentally friendly approach. In the process of improving existing buildings, it is essential to concentrate on the areas where deficiencies and issues have been identified and to conduct analyses at a level that will meet the required specifications. This approach is solution-oriented and ensures that the necessary improvements are made.

The data required to conduct the study was approached in three distinct categories: The first is the collection and classification of data on the existing structure and climate data on its location. One of the internationally accepted studies in climate classification is the Köppen-Geiger climate classification. The TS 825 standard, which has been adopted in Türkiye under the title "Thermal Insulation Rules in Buildings," establishes a standardized calculation method by imposing limitations on the energy utilized for building heating in our nation, thereby reducing energy consumption and determining the requisite energy usage levels (Atmaca, 2016). Accordingly, the values stipulated in the TS 825 standard were considered in this study. The application project drawings of the building, construction manufacturing data and information on the exposure numbers of the materials were obtained from the GTU Department of Construction and Technical Affairs. Secondly, energy-efficient improvement methods in existing buildings and data were obtained from national and international articles, master's theses, doctoral theses, papers, journals, books and accepted standards. Consequently, the examination results have led to the formulation of enhancement scenarios that are predicated on the implementation of a double-skin facade system, which involves the integration of an additional skin onto the extant facade system. Thirdly, Rhinoceros/Grasshopper for energy performance analysis program and Honeybee program, which is an extension of Grasshopper, were used.

### 2.1. Collecting Building Data

The exist building, which was selected as a case study, is situated within the Gebze district of Kocaeli. The climate is classified as Type II according to the TS 825 standard, exhibiting characteristics associated with a temperate climate (Atmaca, 2016). The northern parts of Türkiye are characterised by a maritime humid climate, which is reflected in the climate of the Gebze district, which is classified as "temperate-humid". The average temperature values of Kocaeli province are presented in Table 1, which is taken from the official statistics of the General Directorate of Meteorology and covers the period from 1991 to 2020 (Turkish State Meteorological Service, 2024).

**Table 1.** Average temperature values of Kocaeli province (Turkish State Meteorological Service, 2024)

| Kocaeli | January | February | March | April | May | June | July | August | September | October | November | December | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Temperature (°C) | 6,2 | 6,7 | 8,5 | 13,0 | 17,6 | 21,7 | 23,8 | 24,0 | 20,5 | 16,2 | 12,2 | 8,4 | 14,9 |
| Average Highest Temperature (°C) | 9,7 | 10,6 | 13,2 | 18,5 | 23,3 | 27,5 | 29,6 | 29,8 | 26,2 | 21,1 | 16,5 | 12,0 | 19,8 |
| Average Lowest Temperature (°C) | 3,2 | 3,4 | 4,8 | 8,5 | 12,8 | 16,6 | 19,0 | 19,3 | 16,1 | 12,5 | 8,8 | 5,5 | 10,9 |
| Average Sunshine Time (Hour) | 2,5 | 3,1 | 4,0 | 5,7 | 7,3 | 8,8 | 9,5 | 9,0 | 7,0 | 4,7 | 3,6 | 2,6 | 5,6 |
| Average Number of Days with Rain | 16,93 | 14,92 | 14,01 | 11,29 | 9,82 | 8,38 | 5,78 | 5,08 | 7,26 | 11,39 | 12,40 | 16,20 | 133,5 |
| Average Monthly Total Rainfall (mm) | 92,7 | 76,3 | 71,8 | 51,5 | 48,4 | 56,2 | 45,1 | 42,8 | 58,8 | 85,7 | 79,0 | 108,1 | 816,4 |

The mean annual temperature in Kocaeli is between 6,1°C and 23,9°C, with fluctuations throughout the year. The highest average temperature values are observed in June, July, and August, with an annual mean of 19,8°C based on data from 1929 to 2020. The lowest average temperature values are observed in January, February, and March, with an annual value of 10,8°C (Turkish State Meteorological Service, 2024).

The primary factors influencing the energy consumption of buildings are location, orientation, climatic conditions, architectural design, intended use, user load, decisions regarding the building envelope, material selection, lighting, heating, cooling, and air conditioning systems. Figure 1 illustrates the floor plan of the exist building. Table 2 presents climate data, general information, building envelope data, and mechanical data (Kavak, 2022).

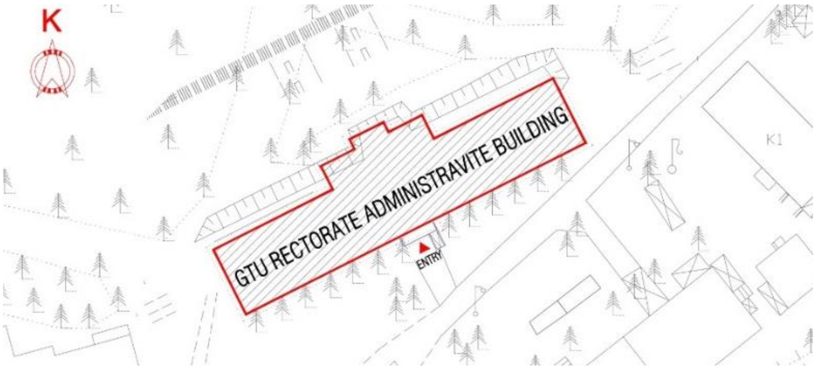


**Figure 1.** Site plan (Kavak, 2022)

**Table 2.** Climate data, general information, building envelope data, and mechanical data of the building (Kavak, 2022)

| Data Types | About Building | Data Values |
|---|---|---|
| Climate Data | Building Location (Latitude, Longitude) | Kocaeli, Gebze (40.81158, 29.35907) |
| | Climate Type of Building | Temperate-Humid (2nd Region According to TS 825) |
| General Information About The Building | Function of The Building | Office |
| | Direction of The Building | North-East-South-West Direction |
| | Form of The Building | Rectangle |
| | Number of Floors in The Building | Ground Floor + 1st Floor |
| | Floor Height of The Building | Ground Floor: 4.30 m<br>1st Floor : 4.30 m |
| Building Façade Data | Opaque Components | 190 mm Thick Horizontal Perforated Brick (190 x 190 x 135 mm) |
| | Transparent Components | Aluminium Joinery Profile<br>6+16+6 mm Argon-Filled Double-Glazed Window Unit |
| Mechanical Data | Heating Energy Type | Natural Gas (Boiler system) |
| | Cooling Energy Type | Electricity<br>(Split Air Conditioner / Compact 4-Way Cassette Type) |

### 2.2. Energy-Efficient Improvement Scenarios

The energy-efficient improvement results in reduced energy consumption, achieved through the utilisation of minimal energy for the heating, cooling, lighting and interior comfort conditions of the existing building. It is recommended that passive systems be employed wherever feasible during the course of energy-efficient improvement, with active systems being utilized as a supplementary measure when necessary. Studies that adopt a solution-oriented approach to existing buildings are focused on the façade systems that are directly related to the external environment and directly exposed to external environmental conditions. Energy-efficient improvement studies have been conducted on building façade systems are listed as follows (Tıkır, 2009);

- Façade demolition and rebuilding,
- Improvement of opaque and transparent components,
- Use of solar control elements,
- Integration of renewable energy panel systems,
- Façade system design improvement.

There are numerous methodologies for achieving energy efficiency in building façades. The objective of this study is to analyse the energy efficiency performance of double-skin façade systems when applied to a university building. This enhancement is accomplished by incorporating a supplementary transparent surface, establishing an air gap in front of the existing transparent surface. The improvement is contingent upon the utilisation of the double-skin façade system, with the parameters varying accordingly;

- Glass type and thickness,
- Width of the space between the glass layers and type of gas used in the space,
- Width of the air gap between the skins,
- Use and location of shading elements,
- Direction and floor spacing in which the façade system is used.

Double-skin façade systems are categorised according to the configuration of the ventilation gap (Naddaf & Baper, 2023) and the systems are visualized in Figure 2 (Çakır Kıasıf, 2015).

- Building-Height Double - Skin Façade (DSF) System,
- Storey-Height Double - Skin Façade (DSF) System,
- Box-Window Double - Skin Façade (DSF) System,
- Shaft-Box Double - Skin Façade (DSF) System.

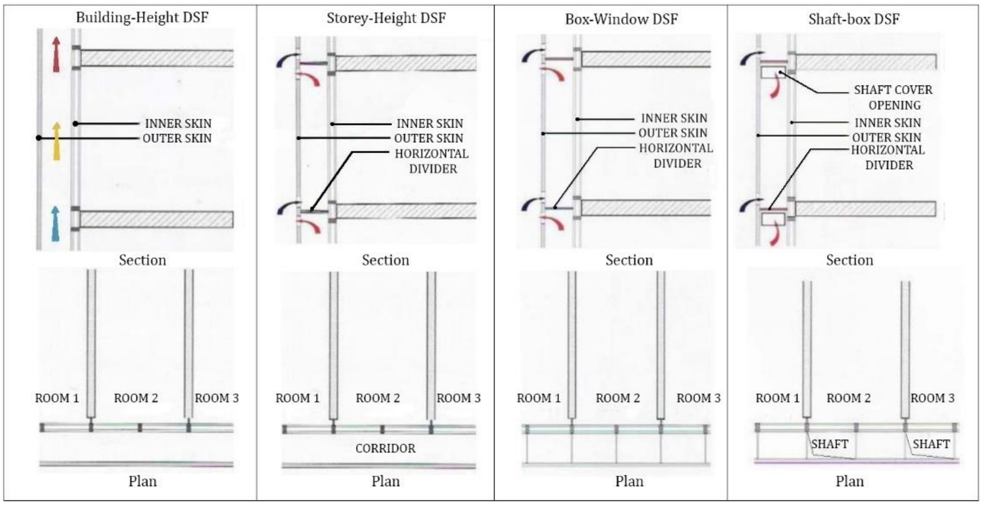


**Figure 2.** Double-skin façade system according to the design of the ventilation gap (Çakır Kıasıf, 2015)

In this study, a double-skin façade system was employed at the box-window. A double-skin façade at a box-window is a system design comprising two skins separated by a ventilation gap, which is divided horizontally along each floor. The distance between the two skins is 20 - 150 cm. An air inlet and outlet are situated at the bottom and top of the outer skin on each floor, respectively. Consequently, each floor is ventilated independently, thereby providing insulation against sound and fire. However, given that sound propagates readily within the same floor space, this can give rise to a detrimental situation (Çakır Kıasıf, 2015).

The assessment of climatic conditions is a crucial element in the process of optimising energy loads, which is a fundamental objective of any improvement project.

It is desirable to achieve optimal energy efficiency in the glass components that comprise the building envelope. The design stage is the appropriate time to consider the solar heat and radiation control provided by glass components, the heating/cooling balance of the interior environment and the visual comfort of the interior environment. The aforementioned criteria are provided by solar control, thermal control and daylight control parameters. The sunlight reflected from the glass surface is absorbed into the interior environment as heat and radiation, resulting in an increase in temperature and illumination. The solar control of glass types is assessed based on their Solar Heat Gain Coefficient (SHGC) and Solar Control Coefficient (SC). The thermal loads experienced within a building are a function of solar heat gain, thermal conduction, ventilation and internal loads. In addition to internal loads, the building envelope is responsible for regulating external factors (Karaca, 2011).

The optical and thermophysical properties of glass types permit the regulation of daylight according to climatic zones. The low thermal transmittance (U) and Solar Heat Gain Coefficient (SHGC) values facilitate more effective control of the heat and light entering the building.

Improvement proposals regarding the double-skin façade system were developed by the addition of a second skin to the existing south façade of the exist building. In consideration of the temperate-humid climate conditions, a series of scenarios were devised, delineating the positioning of the Low-E layer on the glass, the type of air and argon gas employed between the glass layers, and an energy efficiency assessment was conducted. The characteristics of the fixed and variable components, which were taken into account in the study, are presented in Table 3 (Kavak, 2022).

**Table 3.** Properties of fixed and variable compounds (Kavak, 2022)

| Components | Component Types | Values / Features of Components |
|---|---|---|
| Fixed Components | Frame Type | Insulated Aluminium |
| | Glass Thickness and Gap Width | 6 mm - 12 mm - 6 mm |
| | Double-Skin Ventilation Gap Width | Fixed - 50 cm |
| | Layer of Glass | Double Layers |
| | Glass Type | Low Emission (Low-E) Glass |
| Variable Components | The Position of The Low-E Layer in The Glass | 2nd Surface<br>3rd Surface |
| | The Type of Gas Used Between The Glass Layers | Air and Argon |

In the first scenario, designated Scenario 1 (S1), the existing inner glass is fixed in place. The additional outer glass layers are separated by argon gas. The presence of the Low-E layer on the third surface of the used glass is visualized in Figure 3 (Kavak, 2022).

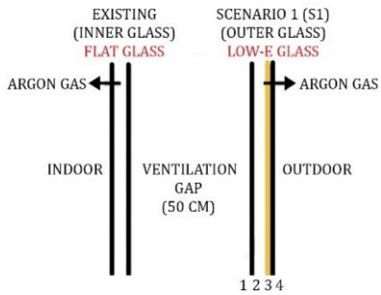


**Figure 3.** Image of Scenario 1 (S1) (Kavak, 2022)

In the Scenario 2 (S2), the existing inner glass is fixed in place. The additional outer glass layers are separated by air gas. The presence of a the Low-E layer on the third surface of the used glass is illustrated in Figure 4 (Kavak, 2022).

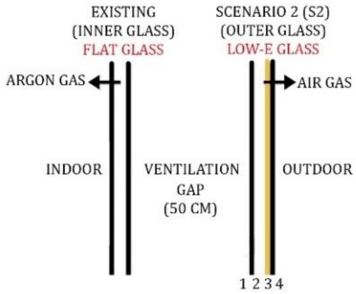


**Figure 4.** Image of Scenario 2 (S2) (Kavak, 2022)

In the Scenario 3 (S3), the existing inner glass is fixed in place. The additional outer glass layers are separated by argon gas. The presence of a the Low-E layer on the second surface of the used glass is illustrated in Figure 5 (Kavak, 2022).

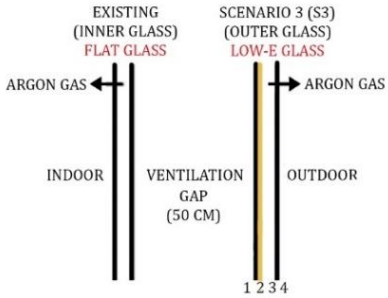


**Figure 5.** Image of Scenario 3 (S3) (Kavak, 2022)

In the Scenario 4 (S4), the existing inner glass is fixed in place. The additional outer glass layers are separated by air gas. The presence of a the Low-E layer on the second surface of the used glass is illustrated in Figure 6 (Kavak, 2022).

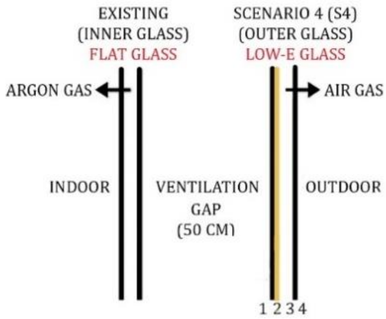


**Figure 6.** Image of Scenario 4 (S4) (Kavak, 2022)

### 2.3. Rhinoceros/Grasshopper for Energy Performance Analysis

Building energy simulation tools provide data on the energy loads and energy consumption profiles of buildings, thereby enabling designers to compare alternative solutions and define the optimal option or combination of options in line with the data obtained.

The Grasshopper, which is employed in the study to assessment building energy performance, constitutes an extension of the Rhinoceros program. The Honeybee program is an extension of the Grasshopper that performs energy performance analysis (Rhinoceros, 2024). In the Grasshopper, the visual representation of the algorithmic parameters is created, and 3D images are simultaneously transferred to the Rhinoceros screen as shown in Figure 7 (Parametrichouse, 2024).

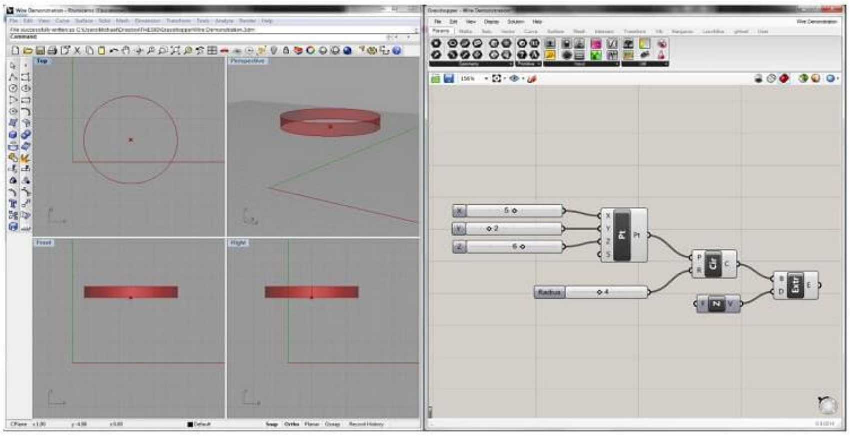

**Figure 7.** Principle of simultaneous operation of the Grasshopper and Rhinoceros programs (Parametrichouse, 2024)

The modification of the algorithmic parameters enables the real-time parametric design of experiments and the incorporation of feedback. The data pertaining to the edifice in question was defined parametrically in the Grasshopper program in four discrete stages. The mentioned steps are as follows (Kavak, 2022):

In the initial phase of the process, the parametric algorithm was defined in the Grasshopper program with regard to the general information pertaining to the building as illustrated in Figure 8 (Kavak, 2022).

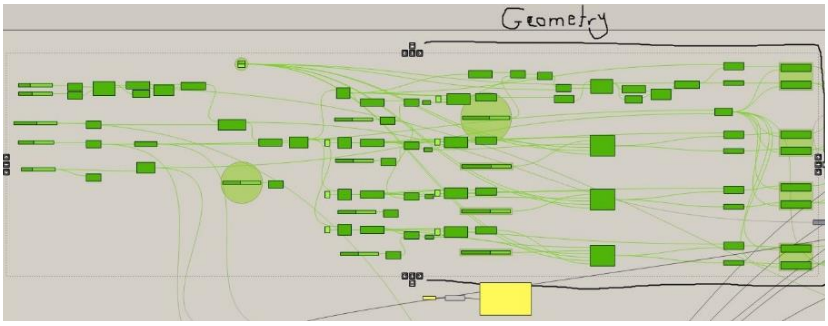


**Figure 8.** Parametric coding of general information about the building in the Grasshopper program (Kavak, 2022)

The 3D modelling was transferred in a simultaneous process to the Rhinoceros program and visualized as shown in Figure 9 (Kavak, 2022).

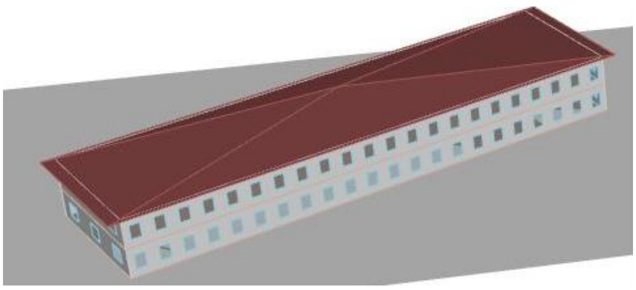

**Figure 9.** 3D visual of the exist building in the Rhinoceros program (Kavak, 2022)

In the second step, the climate data for the Kocaeli province, where the building is situated, was defined in the Grasshopper program as a file with the extension ".epw", as illustrated in Figure 10 (Kavak, 2022).

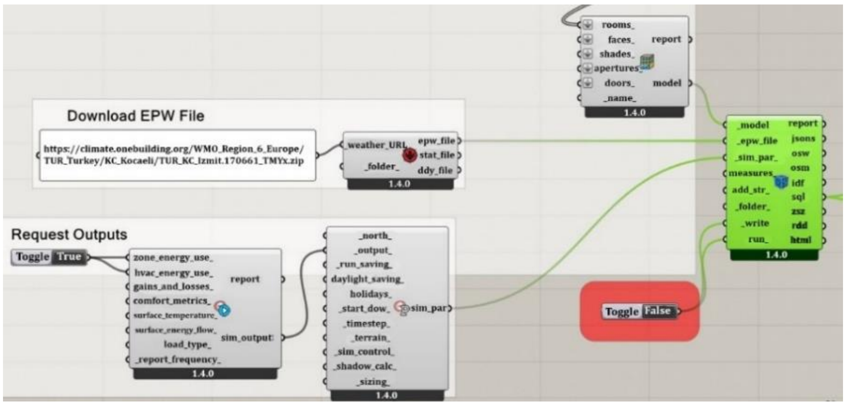


**Figure 10.** Uploading the climate information of the existing building to the Grasshopper as .epw (Kavak, 2022)

In the third step, the façade areas of the building and the transparent areas on the façades (m²) were determined, and the transparency ratios of the façades were calculated using the formula (Transparent Area x 100) / (Façade Area). The resulting ratios are presented in Table 4 (Kavak, 2022).

**Table 4.** Four distinct façades of the existing building, transparent façade area, and transparency ratios (Kavak, 2022)

| Façades | Façade Area (m²) | Transparent Surface Area (m²) | Transparency Rate (%) |
|---|---|---|---|
| South Façade | 629,30 | 120,00 | 20% |
| North Façade | 629,30 | 105,30 | 17% |
| East Façade | 120,00 | 19,20 | 16% |
| West Façade | 120,00 | 19,20 | 16% |

The data pertaining to the façade, roof, and floor covering, which comprise the transparent and opaque elements of the existing building envelope, as delineated in the Grasshopper program, is illustrated in Figure 11 (Kavak, 2022).

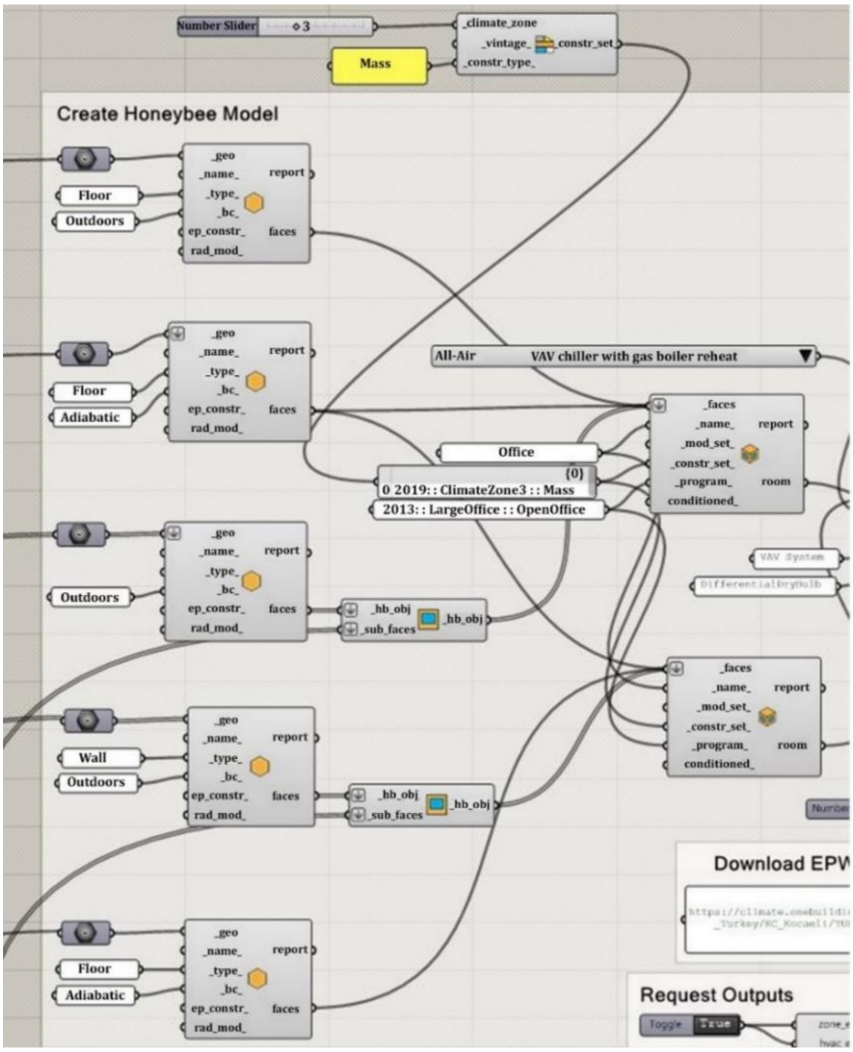


**Figure 11.** Defining the data about the façade, roof, and ground floor of the existing building in the Grasshopper (Kavak, 2022)

In the fourth step, the visual algorithm of the data belonging to the systems of heating and cooling that constitute the mechanical data of the building was defined in the Grasshopper program, as illustrated in Figure 12 (Kavak, 2022). The heating energy type was defined as natural gas (boiler system), while the cooling energy type was defined as electricity (split air conditioner/compact 4-way blowing cassette type). The mean value for the indoor temperature comfort level was established at 21°C (Kavak, 2022).

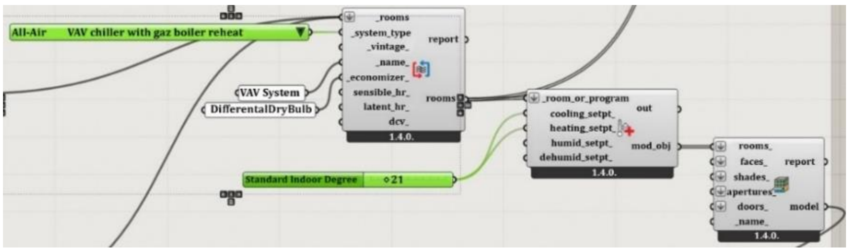


**Figure 12.** Defining heating and cooling systems in the Grasshopper (Kavak, 2022)

## 3. Findings and Discussion

In the study, recommendations for enhancements were formulated based on the box-window double-skin façade system, which entailed the retention of a 50 cm ventilation gap in front of the windows on the south side of the existing building. In this system, four distinct scenarios were devised, varying the presence of the Low-E layer on the second or third surface of the glass and the gas employed between the glass layers, either air or argon. The energy consumption values for heating and cooling of the aforementioned scenarios, as they relate to temperate-humid climate conditions, were obtained as an output from the Honeybee plugin of the Grasshopper program. In accordance with the obtained results, the existing building's energy consumption values for heating and cooling and scenarios were assessed comparatively.

### 3.1. Calculation Annual Energy Consumption for Heating and Cooling of Existing Building

The existing building envelope comprises both opaque and transparent components. The opaque surface of the wall was formed using horizontal perforated brick (190 x 190 x 135 mm) material with a thickness of 19 cm. The external walls were selected using a program that was appropriate for the characteristics of the existing building, which was situated in the second region according to TS 825. The U-value of the selected wall type was accepted as 0.52 (Çiçek, 2019). A window unit comprising 6+16+6 mm argon-filled double glazing is employed on transparent surfaces. The thermophysical properties of the glass component forming the transparent surface were calculated using the Şişecam Performance Calculator and are presented in Table 5 (Şişecam, 2022). The "Performance Calculator" program is a calculation engine developed by Şişecam. The program presents a range of options with respect to thickness, colour, distance between layers, and the type of gas used for the desired glass, encompassing single, double, and triple glazing.

**Table 5.** Calculating the thermophysical properties of the glass component of the existing building in the "Performance Calculator" program (Şişecam, 2022)

| Thermophysical Properties | Daylight Transmittance | Total Transmittance of Solar Energy (Solar Factor) | Shading Coefficient (SC) | U Value w/(m²K) |
|---|---|---|---|---|
| Flat Glass (6 mm) + Argon (16 mm) + Flat Glass (6 mm) | 81% | 75% | 0,86 | 2,6 |

The thermophysical, opaque and transparent properties of the existing glass components on the façade are defined in the visual algorithm of the Grasshopper program, as illustrated in Figure 13 (Kavak, 2022).


**Figure 13.** Defining the thermophysical properties of existing glass components in the Grasshopper (Kavak, 2022)

Once the data had been defined in the Grasshopper, the annual energy consumption values for heating and cooling per m$^2$ of the existing building, as obtained in Honeybee, are shown in Figure 14 (Kavak, 2022). The annual energy consumption for heating per m$^2$ by the building was measured as 44.486 kWh/m², while the energy consumption for cooling was measured as 12.862 kWh/m² (Kavak, 2022).

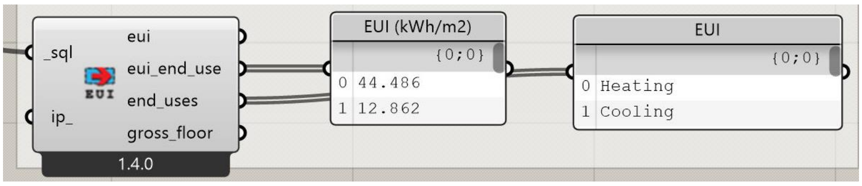


**Figure 14.** Annual energy consumption for heating and cooling per m$^2$ of the existing building (Kavak, 2022)

The energy consumption for heating per area of the existing building was the highest in January and the energy consumption value reached 1844852,87 kWh, as illustrated in Figure 15 (Kavak, 2022). The energy consumption for cooling was the highest in August and the energy consumption value reached 560139,16 kWh, as illustrated in Figure 16 (Kavak, 2022).

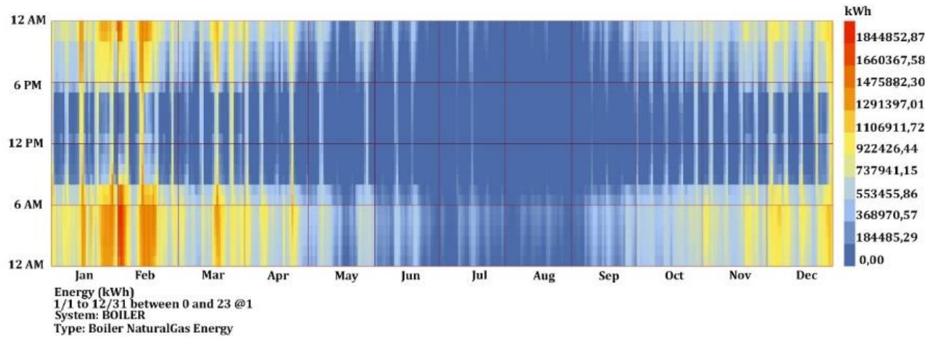


**Figure 15.** Annual energy consumption for heating per entire area of the existing building (Kavak, 2022)

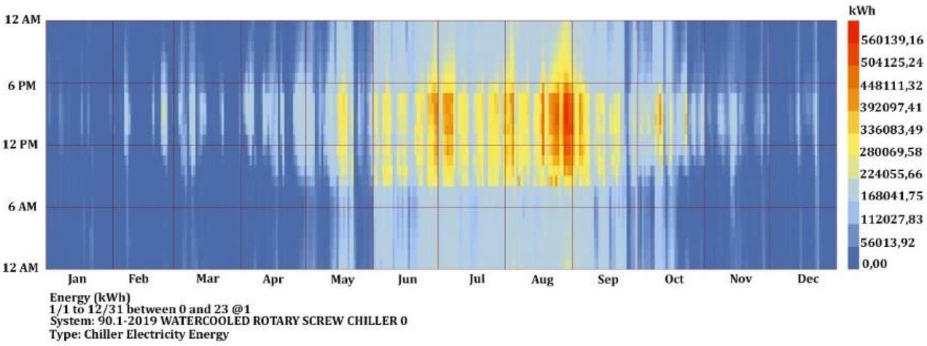


**Figure 16.** Annual energy consumption for cooling per entire area of the existing building (Kavak, 2022)

### 3.2. Calculation of Annual Energy Consumption for Heating and Cooling of Scenarios

The system parameters suitable for the definition of Scenario 1 (S1) are defined in the Grasshopper program as illustrated in Figure 17 (Kavak, 2022).

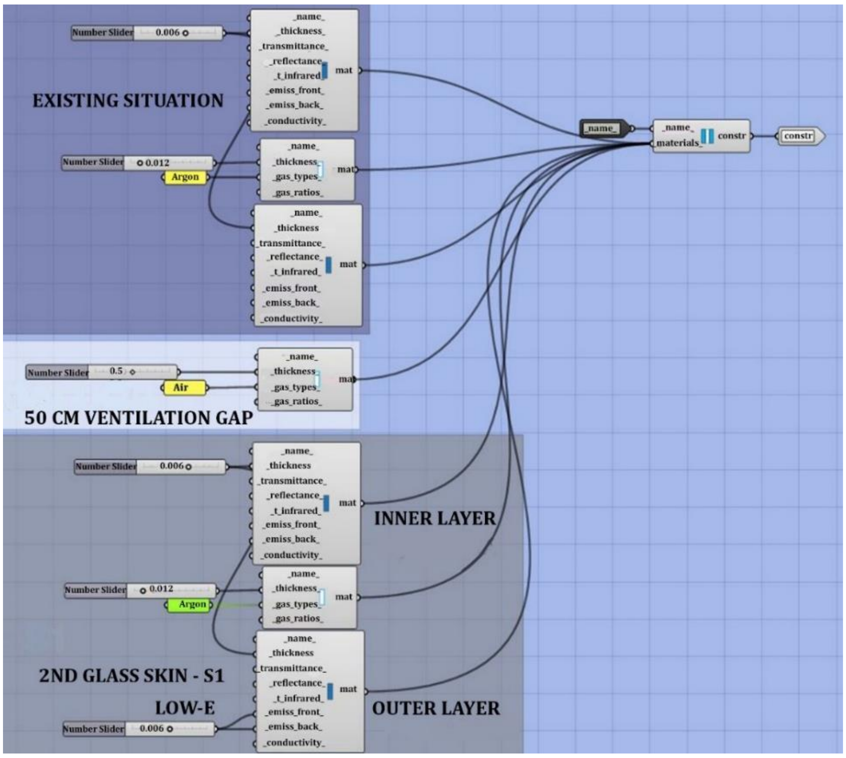


**Figure 17.** Visual algorithm of system parameters created for S1 (Kavak, 2022)

Once the data had been defined in the Grasshopper, the annual energy consumption values for heating and cooling per m² of the Scenario 1 (S1), obtained in Honeybee, are presented in Figure 18 (Kavak, 2022). Following the proposed system's implementation in Scenario 1 (S1), the annual energy consumption for heating per m² of the building was measured to be 34.967 kWh/m², while the energy consumption for cooling was recorded at 12.637 kWh/m² (Kavak, 2022).

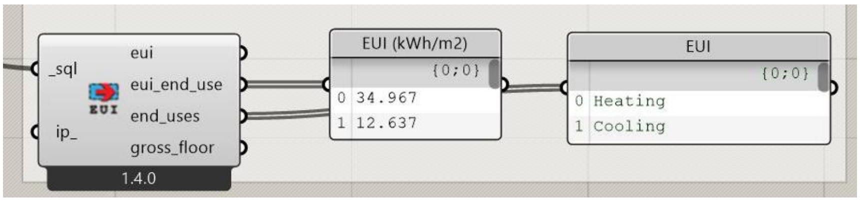


**Figure 18.** Annual energy consumption for heating and cooling per m$^2$ of the building in S1 (Kavak, 2022)

The conclusion of the improvement observed in Scenario 1 (S1) resulted in the highest energy consumption for heating per area of the building being recorded in January, as illustrated in Figure 19 (Kavak, 2022). This reached a total of 1634688,43 kWh. The greatest demand for cooling energy was observed in August, as illustrated in Figure 20, reaching a total of 552903.04 kWh (Kavak, 2022).

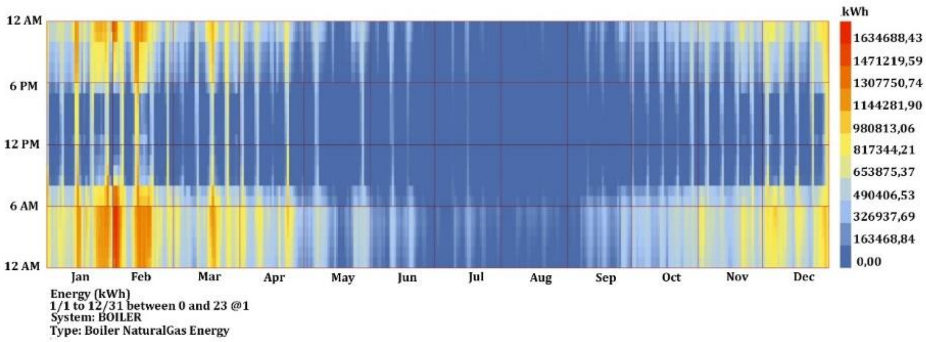


**Figure 19.** Annual energy consumption for heating as a result of the improvement with S1 (Kavak, 2022)

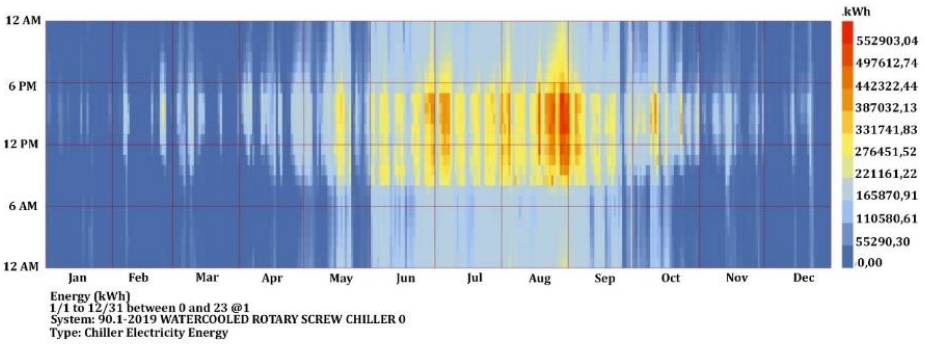


**Figure 20.** Annual energy consumption for cooling as a result of the improvement with S1 (Kavak, 2022)

The system parameters appropriate to the definition of Scenario 2 (S2) are defined in the Grasshopper program as illustrated in Figure 21 (Kavak, 2022).

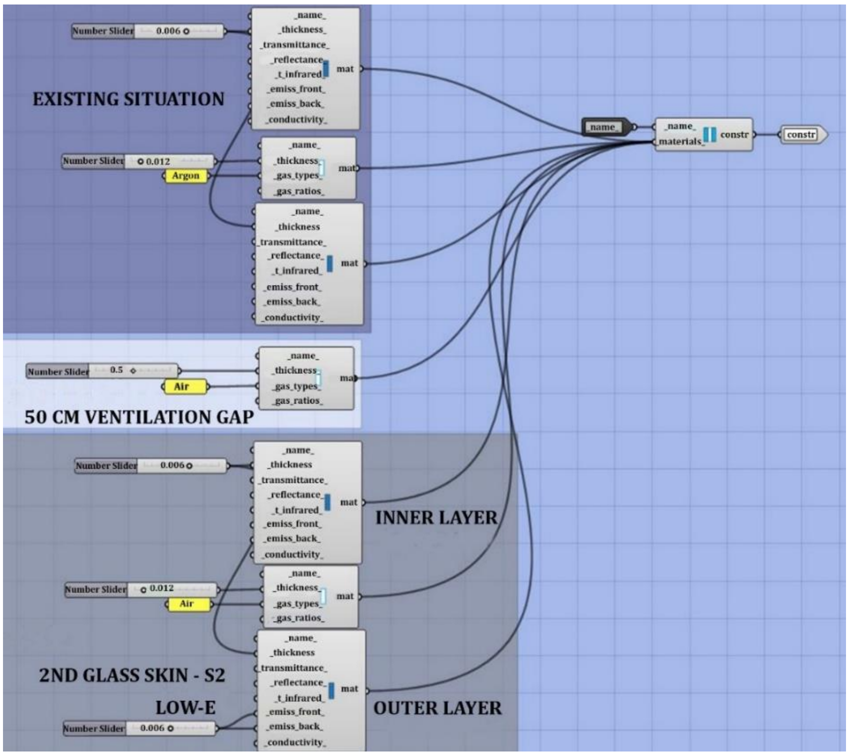


**Figure 21.** Visual algorithm of system parameters created for S2 (Kavak, 2022)

Once the data had been defined in the Grasshopper, the annual energy consumption values for heating and cooling per m² of the Scenario 2 (S2) were obtained in the Honeybee and are presented in Figure 22 (Kavak, 2022). Following the proposed system's implementation in Scenario 2 (S2) to enhance the existing building, the annual energy consumption for heating per m² of the building was measured to be 35.255 kWh/m², while the energy consumption for cooling was found to be 12.65 kWh/m² (Kavak, 2022).

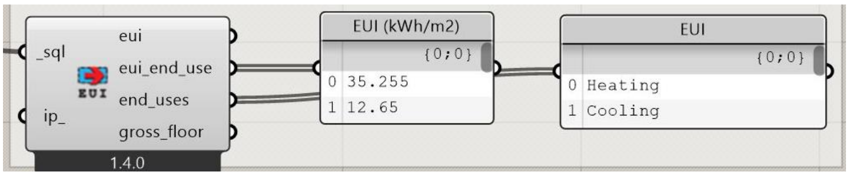


**Figure 22.** Annual energy consumption for heating and cooling per m$^2$ of the building in S2 (Kavak, 2022)

The conclusion of the improvement observed in Scenario 2 (S2) resulted in the highest energy consumption for heating per area of the building being recorded in January, as illustrated in Figure 23 (Kavak, 2022). This reached 1641112,76 kWh. The highest level of energy consumption for cooling was observed in August, as illustrated in Figure 24, reaching a total of 558545.68 kWh (Kavak, 2022).

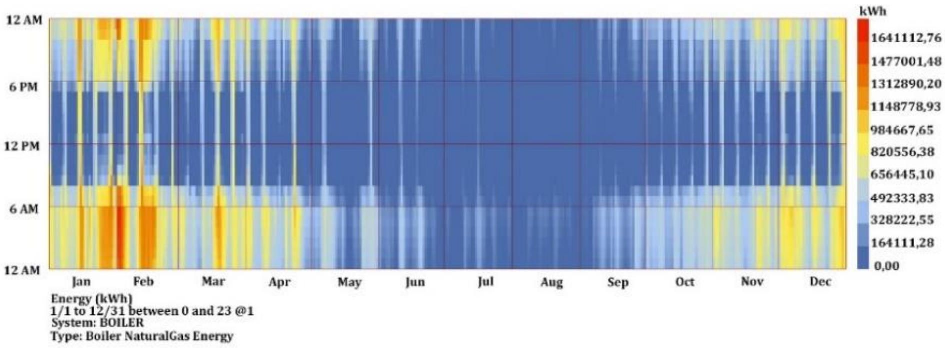


**Figure 23.** Annual energy consumption for heating as a result of the improvement with S2 (Kavak, 2022)

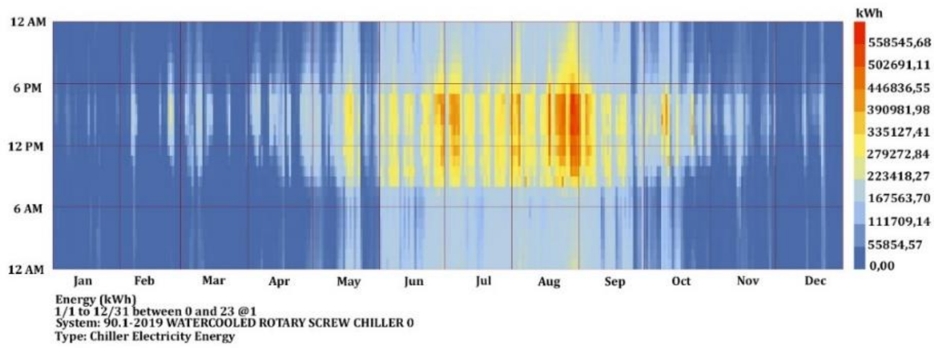


**Figure 24.** Annual energy consumption for cooling as a result of the improvement with S2 (Kavak, 2022)

The system parameters appropriate to the definition of Scenario 3 (S3) are defined in the Grasshopper program as illustrated in Figure 25 (Kavak, 2022).

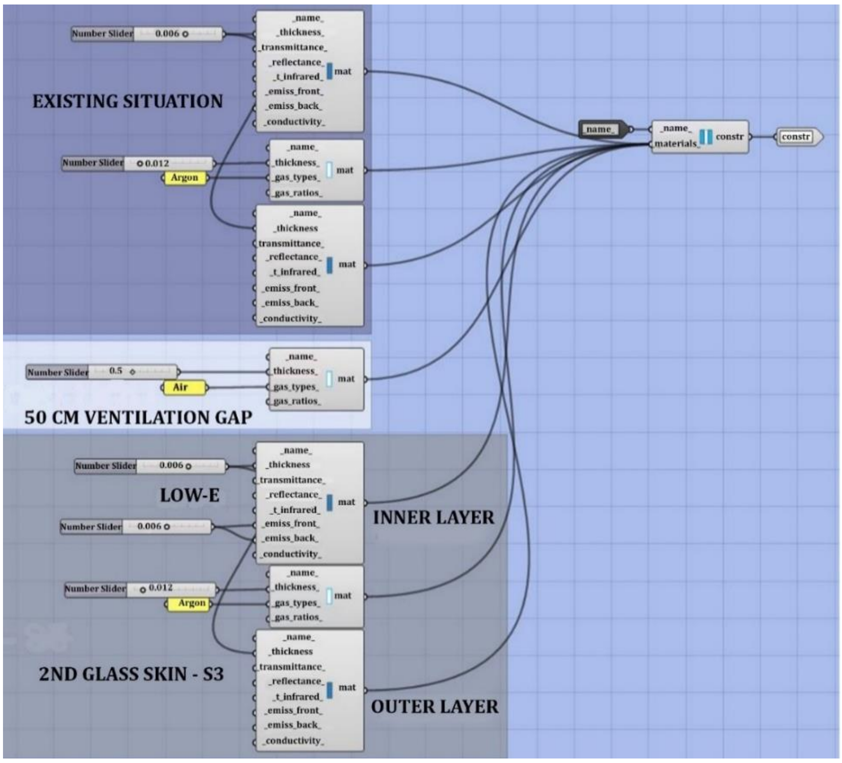


**Figure 25**. Visual algorithm of system parameters created for S3 (Kavak, 2022)

Once the information had been defined in the Grasshopper, the annual energy consumption for heating and cooling values per m² of the Scenario 3 (S3) obtained in the Honeybee were displayed in Figure 26 (Kavak, 2022). Following the proposed system's implementation in Scenario 3 (S3) to enhance the existing building, the annual energy consumption for heating per m² of the building was found to be 35,027 kWh/m², while the energy consumption for cooling was recorded at 12,75 kWh/m² (Kavak, 2022).

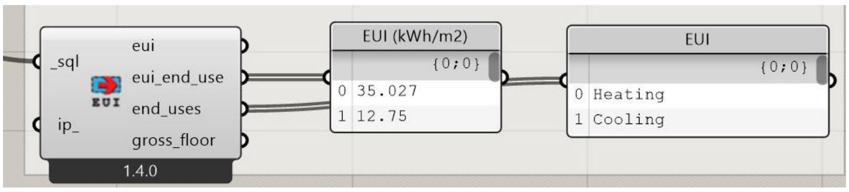


**Figure 26**. Annual energy consumption for heating and cooling per m$^2$ of the building in S3 (Kavak, 2022)

The conclusion of the improvement observed in Scenario 3 (S3) resulted in the highest energy consumption for heating per area of the building being recorded in January, as illustrated in Figure 27 (Kavak, 2022). This reached a value of 1636568,64 kWh. The highest level of energy consumption for cooling was observed in August, as illustrated in Figure 28, reaching a total of 545459,86 kWh (Kavak, 2022).

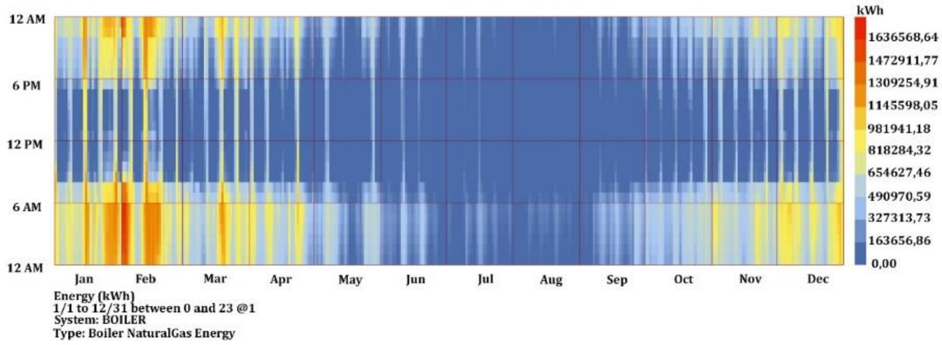


**Figure 27**. Annual energy consumption for heating as a result of the improvement with S3 (Kavak, 2022)

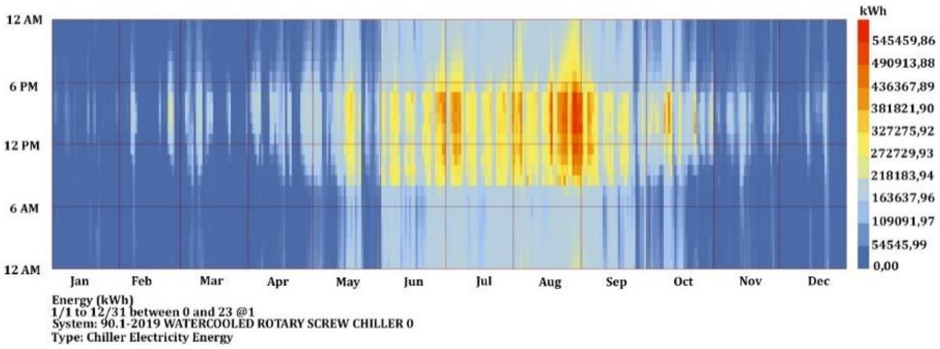


**Figure 28**. Annual energy consumption for cooling as a result of the improvement with S3 (Kavak, 2022)

The system parameters appropriate to the definition of Scenario 4 (S4) are defined in the Grasshopper program, as illustrated in Figure 29 (Kavak, 2022).

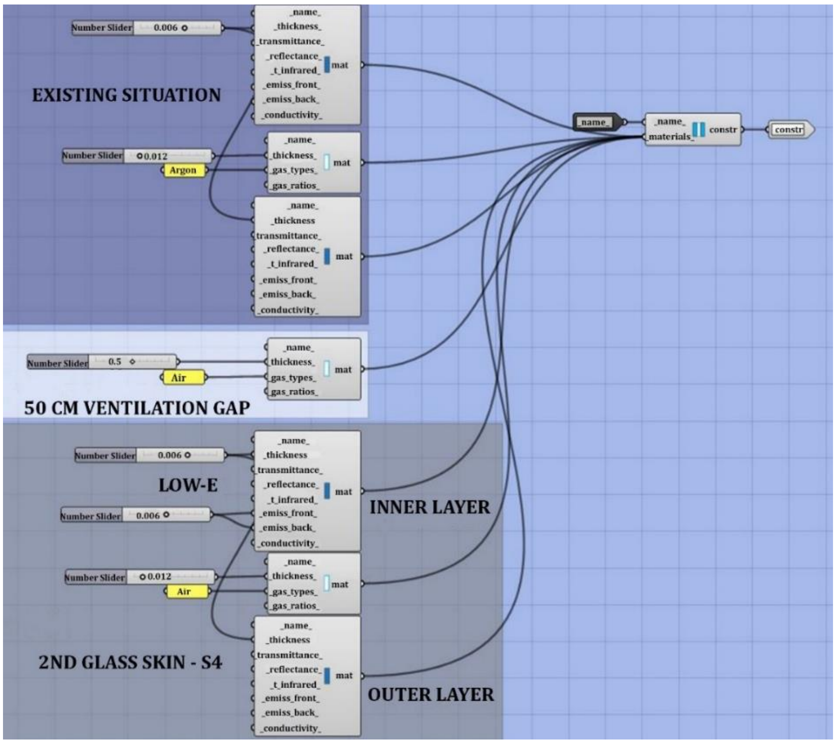


**Figure 29**. Visual algorithm of system parameters created for S4 (Kavak, 2022)

Once the data had been defined in the Grasshopper, the annual energy consumption values for heating and cooling per m² of the Scenario 4 (S4) building were obtained in Honeybee and are presented in Figure 30 (Kavak, 2022). Following the proposed system's implementation in Scenario 4 (S4) to enhance the existing building, the annual energy consumption for heating per m² of the building was found to be 35.321 kWh/m², while the energy consumption for cooling was recorded at 12.762 kWh/m² (Kavak, 2022).

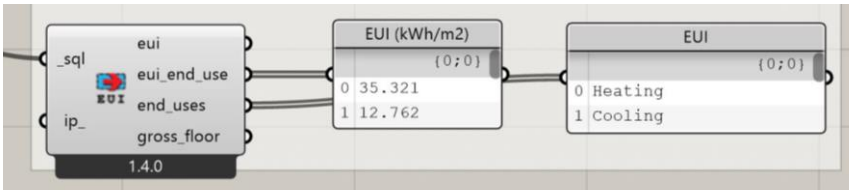


**Figure 30**. Annual energy consumption for heating and cooling per m$^2$ of the building in S4 (Kavak, 2022)

The conclusion of the improvement observed in Scenario 4 (S4) resulted in the highest energy consumption for heating per area of the building being recorded in January, as illustrated in Figure 31 (Kavak, 2022). This reached 1643618,53 kWh. In contrast, the highest energy consumption for cooling was recorded in August, as shown in Figure 32. This reached 566110,37 kWh (Kavak, 2022).

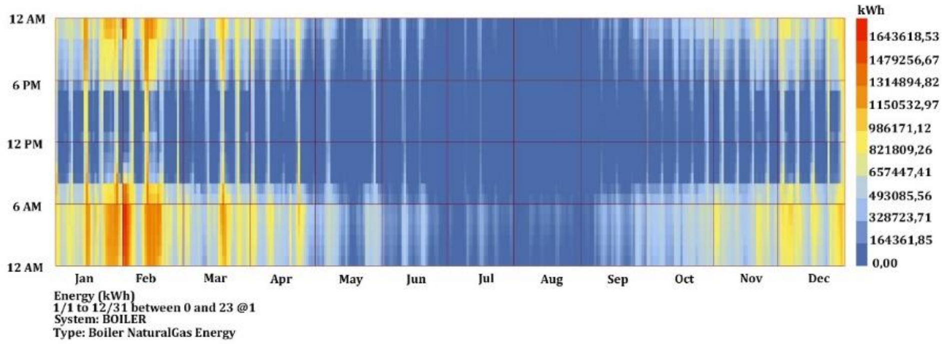


**Figure 31**. Annual energy consumption for heating as a result of the improvement with S4 (Kavak, 2022)

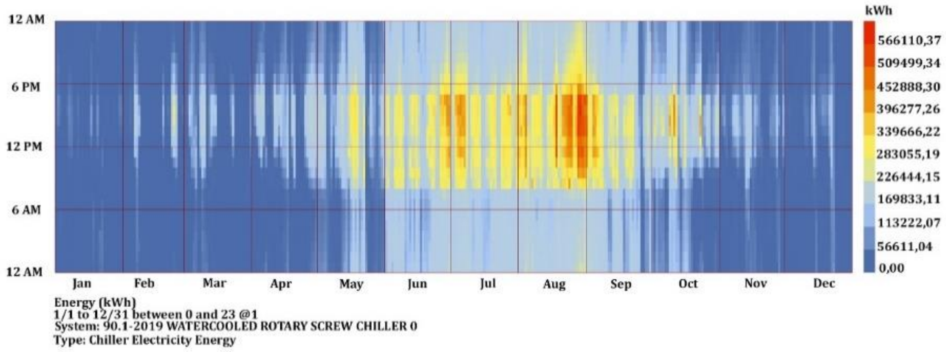


**Figure 32**. Annual energy consumption for cooling as a result of the improvement with S4 (Kavak, 2022)

### 3.3. Comparison of Analysis Results and Performance Assessment

Table 6 illustrates the annual energy consumption values for heating and cooling per m$^2$ of the existing situation and improvement scenarios analyzed in the study (Kavak, 2022).

**Table 6.** Annual energy consumption values for heating and cooling per m$^2$ for the existing situation and improvement scenarios (Kavak, 2022)

| Scenarios | Annual Energy Consumption for Heating Per m$^2$ of Building (kWh/m$^2$) | Annual Energy Consumption for Cooling Per m$^2$ of Building (kWh/m$^2$) |
|---|---|---|
| Existing Situation | 44,486 | 12,862 |
| Scenario 1 – (S1) | 34,967 | 12,637 |
| Scenario 2 – (S2) | 35,255 | 12,650 |
| Scenario 3 – (S3) | 35,027 | 12,750 |
| Scenario 4 – (S4) | 35,321 | 12,762 |

The improvement values of the annual energy consumption for heating and cooling of the scenarios in comparison to the existing situation are expressed in Table 7 as ratios (Kavak, 2022).

**Table 7.** Improvement rates in annual energy consumption values for heating and cooling of the scenarios compared to the existing situation (Kavak, 2022)

| Scenarios | Rate of Improvement in Annual Energy Consumption for Heating Compared to Existing Situation | Rate of Improvement in Annual Energy Consumption for Cooling Compared to Existing Situation |
|---|---|---|
| Scenario 1 – (S1) | 21,40% | 1,75% |
| Scenario 2 – (S2) | 20,75% | 1,65% |
| Scenario 3 – (S3) | 21,26% | 0,87% |
| Scenario 4 – (S4) | 20,60% | 0,78% |

A decrease in the annual energy consumption for heating and cooling per $m^2$ was observed across all scenarios. However, while there was a notable decrease in energy consumption for heating, the change in energy consumption values for cooling was less pronounced. In this instance, the transparent surfaces on the south façade act as opaque surfaces against long-wavelength radiation while transmitting short-wavelength radiation, thereby creating a greenhouse effect and providing heat gain in the interior environment. Furthermore, the utilisation of argon gas between the existing glass layers and the additional glass layers resulted in the preservation of heat within the interior environment. The positioning of the Low-E layer within the glass components of the building, situated within a temperate-humid climate region, resulted in a notable decrease in energy consumption for cooling. In comparison to the existing situation, Scenario 1 (S1) demonstrated a 1.75% improvement in energy consumption for cooling, while Scenario 2 (S2) exhibited a 1.65% improvement, Scenario 3 (S3) a 0.87% improvement, and Scenario 4 (S4) a 0.78% improvement. Upon assessment of the results, it becomes evident that the utilisation of the Low-E layer on the third surface of the glass represents the most important factor in the effective performance of Scenario 1 (S1) and Scenario 2 (S2) in comparison to Scenario 3 (S3) and Scenario 4 (S4).

An assessment of the energy consumption for heating in the proposed improvement scenarios developed for the building situated in the temperate-humid climate zone, in relation to the existing situation, reveals the following performance improvements: 21.40% for Scenario 1 (S1), 20.75% for Scenario 2 (S2), 21.26% for Scenario 3 (S3) and 20.60% for Scenario 4 (S4). Upon assessment of the results, it becomes evident that the effective performance of Scenario 1 (S1) and Scenario 3 (S3) in comparison to Scenario 2 (S2) and Scenario 4 (S4) is largely attributed to the utilisation of argon gas between the glass layers.

In general, the utilisation of Low-E glass on the south façade of the exist building situated within a temperate-humid climate zone, has resulted in a notable decrease in energy consumption for heating and cooling. Furthermore, the data indicates that the location of the Low-E layer on the glass has been a significant factor in determining the performance of the energy consumption for cooling. The type of gas used between the glass layers is also an important determinant of the performance of the energy consumption for heating.

## 4. Conclusion and Suggestions

According to the results of the literature reviewed in this study, Mangan & Koçlar Oral (2014) showed that the technical performance parameters of glass, including the inclusion of opaque elements, replacement of glazing systems with insulated coated glass, the addition of shading elements and the integration of renewable energy systems, are effective in reducing heating-cooling loads and CO2 emissions. Bakkal (2019) utilised the double-skin façade system, addressing energy efficiency at the façade system level, to evaluate the efficiency of heating, cooling, lighting and annual primary energy consumption in buildings. In contrast, Başarır & Diri (2014) evaluated sound control, natural ventilation and energy efficiency. The conclusion drawn from this analysis was that double-skin façade systems are advantageous in reducing heat loss, especially during the winter months. Çetiner's (2002) research yielded findings that Low-E glass, when incorporated into single and double-skin façade systems, exhibited superior performance in terms of heating and total energy consumption. In contrast, solar control glass demonstrated efficacy in reducing cooling consumption. Urbikain (2020) asserted that the renovation of existing buildings with VIP (vacuum insulating panel) and Low-E glass resulted in a reduction in energy consumption. Cho et al. (2023) posited that the utilisation of argon gas between glass layers engenders an insulating effect within the glass. Sorooshnia et al. (2023) posited that the utilisation of Low-E glass in architectural structures has the capacity to curtail energy consumption while concomitantly exerting a deleterious effect on daylight comfort.

In this study, improvements to the south façade of an existing building are proposed using a double-skin façade system. Four scenarios are developed for the analysis, the annual energy consumption values for heating and cooling of the existing situation are compared and evaluated in terms of efficiency per $m^2$..

In consideration of the extant situation, the most substantial decrease in energy consumption for heating was observed to be 21.40%. The configuration is attributable to the positioning of the Low-E layer within the double-skin façade system on the glass layer and the utilisation of argon gas between the glass plates. The utilisation of the Low-E layer on the third surface of the glass resulted in enhanced energy performance. The use of argon gas in place of air gas results in greater heat preservation, thereby increasing energy efficiency in heating. In the existing situation, the highest saving in energy consumption for cooling was 1.75%. This configuration is attributable to the positioning of the Low-E layer within the double-skin façade system on the glass layer and the utilisation of argon gas between the glass plates. The utilisation of the Low-E layer on the third surface of the glass layer prevented overheating of the interior by reducing the solar heat permeability on the transparent surface. Furthermore, the use of argon gas between the glass layers provided savings in energy consumption for cooling by maintaining thermal comfort in the interior.

In consequence, in the temperate-humid climate region (Kısa Ovalı, 2019), where the heating requirement is higher, the utilisation of argon gas between the glass layers has been demonstrated to provide a more effective performance in saving energy consumption for heating. It was observed that the position of the Low-E layer on the glass layer was relatively less important. In light of these findings, the use of argon gas between glass layers is recommended as a means of reducing energy consumption for heating in temperate-humid climate regions. Furthermore, the utilisation of a Low-E layer on the third surface of the glass is recommended as it offers enhanced efficiency.

A comparison of the findings from the extant literature with those of the present study reveals both parallel and divergent results, which are discussed in turn. The utilisation of Low-E glass in façade retrofit applications has demonstrated favourable outcomes with respect to heating and cooling energy consumption. The utilisation of argon gas between the glass layers enhanced the heating efficiency by facilitating the retention of heat within the interior environment. The double-skin façade system has been demonstrated to engender a substantial reduction in heating consumption during the winter months, whilst exhibiting a more modest impact on cooling consumption. The study emphasises the effect of the surface on which the Low-E layer is used on the glass on energy efficiency. The absence of emphasis on surface position in extant literature contributes to the study's originality.

The following suggestions for future research are presented for those interested in enhancing the energy efficiency of existing office buildings utilising double-skin façade systems;

1. The energy efficiency performance of the building can be assessed by modifying the parameter values of the variables deemed constant.

2. The potential for opening the vents in the double-skin façade system, which are currently assumed to be closed, can be investigated, as can the impact this may have on energy consumption for cooling.

3. In this study, data pertaining to temperate-humid climates were taken into account. It would be beneficial to examine the energy consumption performances for heating and cooling of locations where Low-E layered glass is utilised in other climate regions within Türkiye.

As a consequence of the enhancements made to the double-skin façade system, it is now possible to calculate and assess the increased internal energy load resulting from the additional material incorporated into the façade.

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**Author Contribution and Conflict of Interest Declaration Information**

All authors contributed equally to the article. There is no conflict of interest.

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