



Journal of Materials and Engineering Structures

Research Paper

The Energy Performance of Shading Element and Double Skin Facade System Integration into Office Buildings in Turkey

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ARTICLE INFO

Article history :

Received : 20 December 2022

Revised : 21 February 2023

Accepted : 21 April 2023

Keywords:

Energy Efficiency

Double skin facades

Shading System

Shaded double skin façade

ABSTRACT

Energy efficiency in building design tends to be important in reducing the share of construction sector in energy consumption and environmental problems caused by it. In this study, energy performance of an existing office structure was evaluated by integrating shading elements and double skin facade systems within the scope of energy efficiency in buildings. Initially, current energy performance of the building was examined by design builder program and then, the shading element alternatives and the double skin facade system alternatives were separately integrated into the structure and simulated by solar tool and design builder program. Alternatives with the highest energy performances were determined in both building components. Later in the study, the shading element and the double skin facade system alternatives, which gave the most successful results, were integrated into the building model simultaneously and the energy performance thus evaluated was compared with the energy performance of the existing building. According to results, the Shaded Double Skin Facade scenario indicated a drop in heating load of around 2% and a decrease in cooling load of about 45% compared to the present building model.

1 Introduction

Energy consumption and consequently energy need are increasing day by day due to rapid progress in industrialization, development in technology and exponential growth of population in the world. Increasing energy needs are mostly met by fossil-based energy resources, and since these energy resources are not renewable and environmentally friendly, they are likely to be depleted in the near future and cause irreversible damage to the natural environment.

Construction sector uses a large part of the total energy in Turkey as in the whole world[1]. An important part of the energy consumed in the construction sector is used for heating, cooling and ventilation purposes in order to provide user comfort in buildings. In the world, the share of energy used in buildings considering the total energy consumption has reached up to 45-50%, whereas in Turkey, this rate is found to be around 37%[2-4]. The fact that the energy used in buildings has such an important share in total energy consumption shows how important energy efficiency is in buildings.

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One of the most important design parameters affecting energy efficiency in buildings is the facades that form the building envelope. In architectural structures, indoor conditions are directly related to outdoor conditions. Energy losses in buildings are related to the climatic conditions and adaptation to these conditions. Most of these energy losses in buildings are caused by the facade elements that separate the building from the external environment [5-9]. Building facades are known to be the most important variable under designer's control in providing energy conservation and climatic comfort for the user. In order to provide user comfort in buildings, there is a need for heating and cooling at certain times of the year according to the climate change [10]. Building facades are important in determining the amount of heat energy gained and lost. According to climatic and environmental conditions, building facades reduce heating and cooling loads and ensure efficient use of energy [11]. As a result of implementation of building facades, which have the largest area in buildings and are in direct contact with renewable energy resources (such as solar energy and wind energy) along with the opportunities provided by technology, energy can be used efficiently. Facades have many functions such as lighting, ventilation, insulation against humidity and hot/cold weather, protection against glare, energy gain and energy production. The facade systems fulfill these energy-requiring functions. Despite having a certain share in the energy consumed throughout the life cycle of the building, facade systems are the most effective building systems that determine the energy consumed especially in providing thermal comfort during the use of the building [12]. In this context, designing facades that consume minimum energy and contribute to the energy production needed in the building has taken its place as one of the most important factors in building design [12]. Within the scope of this study, shading elements and double skin facade systems were studied which are energy efficient facade systems.

The use of shading elements is known to have a direct effect on heating, cooling and lighting performance of the building. These elements are used in solar control for internal and external shading of structures by preventing overheating, reflection and glare [13]. Apart from physical properties of the glass material used against overheating and light problems caused by the sun, these elements play a vital role in design strategies by providing direct solar control. Shading elements are commonly used building envelope elements that are known to improve the energy performance of structures [14-16]. Therefore, fixed, manual, indoor and outdoor movable shading elements have been developed.

Double skin facade systems are building facade systems that can be designed and produced by adding energy efficient features with the development of technology. These facade systems provide heat, light, acoustic control and effective natural ventilation of the building and consist of an outer layer, an intermediate space and an inner layer [17, 18]. The outer layer provides protection against noise and atmospheric effects and has openings and covers necessary for fresh air to enter the space in between [19, 20], whereas in the inner layer, there are windows that provide fresh air passage from the space in between to the inner area [21].

In the literature review, studies conducted on energy efficient designs of new buildings and energy efficient improvements brought to existing structures were examined. The studies performed on the integration of energy efficient facade systems such as shading systems and double skin facade systems into buildings in order to improve them in terms of energy efficiency, were emphasized. Prior research has mostly focused on improving cavity airflow and controlling solar heat to address overheating issues [22-30]. Some of them are about glazing material types [31-33], interior Venetian blinds [27-30, 32, 34-38], interior or exterior slat blinds [39], and vertical greenery integrated systems [40-44]. According to Kim et.al. [39], while an interior blind model exhibits increases in thermal load when compared to the baseline, an external blind model exhibits a significant reduction in building thermal loads and lighting consumption in double skin facade case. So the exterior shading system was considered for this research.

The aim of this study was to compare and evaluate the energy performances of the existing office building in Gemlik, Bursa, and the improved office building within the scope of energy efficient building design. In this context, first of all, the energy performance of the existing building was examined. Afterwards, exterior shading element alternatives and double skin facade system alternatives were integrated into the building in order to increase its energy performance.

Initially, the building was simulated by integrating different shading element alternatives into the building in order to reduce the cooling load and to provide sunlight control, especially due to the climatic condition and the location of building facades. As a result of the simulations, the shading element alternative with the highest energy performance was determined. Afterwards, in order to reduce the cooling load and the heating load of the building in the hot and the cold months, respectively, the double skin facade system alternatives were integrated into the building, the building was simulated and the alternative with the highest energy performance was determined. The energy performance of the building was also examined by integrating the shading element and the double skin facade system alternatives with the highest energy performances into

the building, simultaneously. Firstly, shading elements and double skin facade systems were integrated into the building separately. After determining the two alternatives that contributed the most to the energy performance of the building in both building components, these two alternatives were integrated into the building together. Then, the energy performance was investigated by simulating the integrated state of the building. With these improvements, the aim was to increase the energy performance of the building by reducing the heating load, cooling load and primary energy demand, and to make it a comfortable building with high energy efficiency.

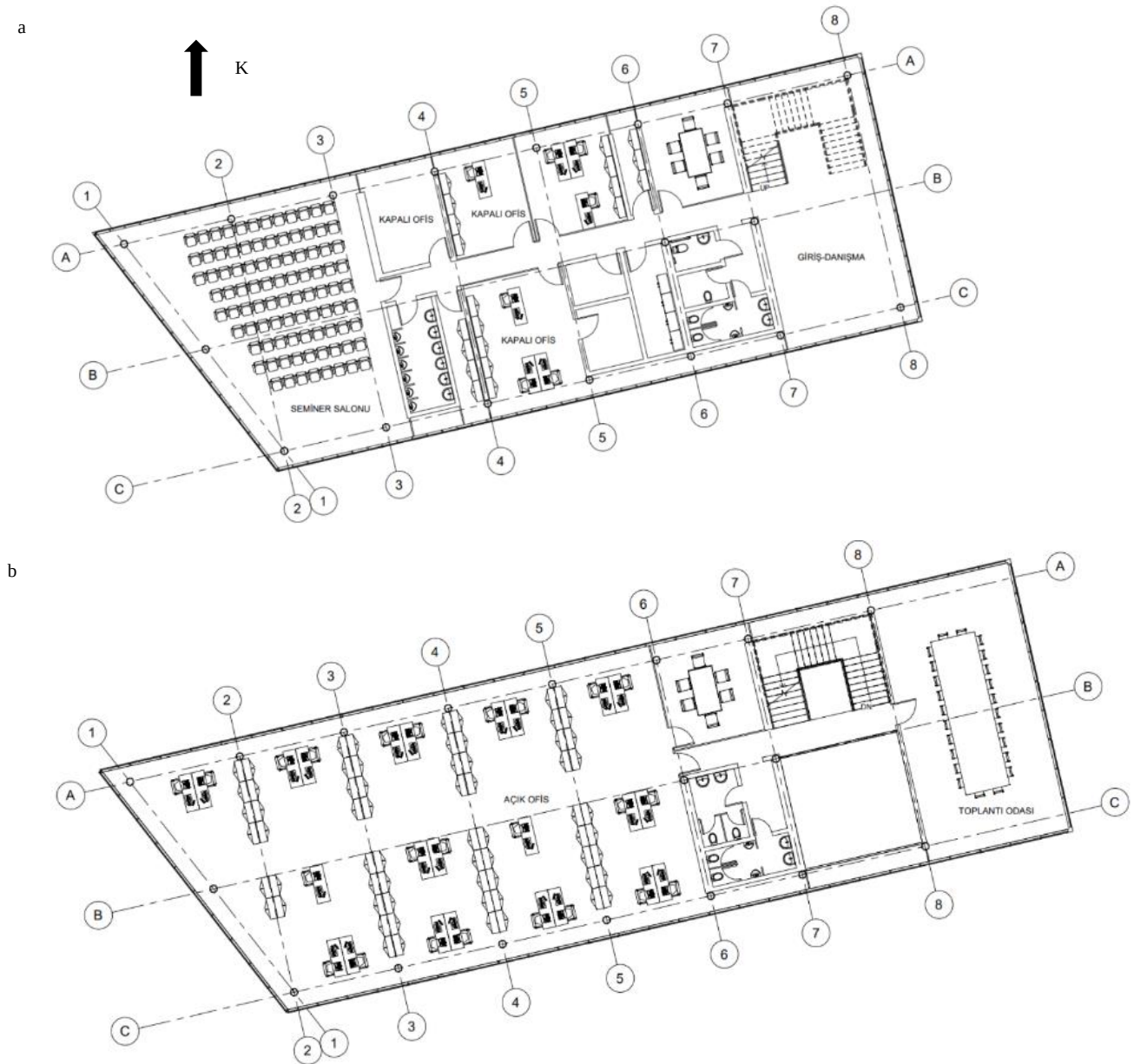


Fig. 1 – a) Ground Floor Plan b) Building First Floor Plan of Bursa/Gemlik Office Building (Adopted from Arkiv[45])

Considering the previously mentioned research gaps, the present study investigates the integrated shading device and double skin facade system to answer the following questions:

1. To what extent can the double skin facade system with proper placement help to reduce the energy of the existing office building in Turkey?
2. If the shading system is added, how much will the cooling load of the building be reduced with appropriate specifications?

- How much can the method of integrating the fixed external shading system on the double skin facade improve in reducing the primary energy demand of the building?

The results of this study can thus serve as a reference for the initial design of a double skin facade (DSF) system used in the rehabilitation of existing constructions as well as serve as supporting information for further simulation studies of exterior shaded Double Skin Facades (SDSFs).

2 Material and Method

2.1 Material

In this study, the office building located in Gemlik district of Bursa province was chosen for improvement purposes because the energy performance of the building needed to be improved. In the office building; heating loads, cooling loads and primary energy demand were observed to be very high due to the following problems: all facades involved full-length curtain walls but there were no shading elements to provide solar control on the curtain walls that form the outer envelope of the building, and the building was located on the side of the main road in the industrial production facilities and was exposed to noise and air pollution all the time.

The building is situated in the Gemlik district of Bursa, within the industrial production facilities by the main road. As shown in Figure 1, the building deviates 13° from the East-West axis to the Southwest-Northeast axis and has a Southwest and Northeast orientation[45].

The four-story building was constructed for the management of the industrial production facility and was built with steel structure. The floor area of the building is approximately 500 m² and the total construction area is 2000 m². When the building floor plans are examined, it can be seen that it consists of units such as open and closed office areas, meeting rooms, seminar hall and kitchen. The main entrance of the building is on the northeast facade. The ground floor and first floor plans of the building are shown in Figure1. The total height of the building is 18.5 meters with a floor height of 4.5 meters. All facades of the building involve aluminum glass curtain walls and double glazing is used. There is no shading system on the building facades. The total wall-opening ratio of the building facades is 99.5%. The roof of the building is designed as a flat terrace roof.

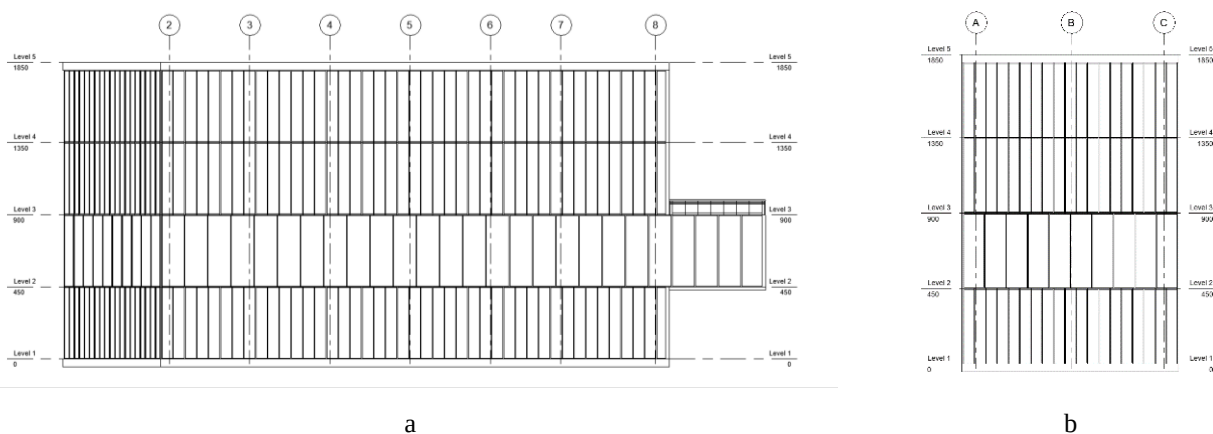


Fig. 2 – a) South-East Elevation b) South-West Elevation of Bursa/Gemlik Office Building (Adopted from Arkiv[45])

The building is used between 08:00-18:00 hours and on weekdays only. There is a fan coil system as heating and cooling system in the building. There are no opening windows on the facade of the building and the building is ventilated by mechanical ventilation.

Climate data

The climate data for the Gemlik district of Bursa, where the building is located, is shown in Figure 3 below.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	4 °C (39.2) °F	5 °C (41) °F	7.8 °C (46) °F	11.8 °C (53.2) °F	16.7 °C (62) °F	20.9 °C (69.6) °F	23.5 °C (74.3) °F	23.7 °C (74.6) °F	20.1 °C (68.2) °F	15.3 °C (59.6) °F	10.7 °C (51.3) °F	5.9 °C (42.7) °F
Min. Temperature °C (°F)	0.9 °C (33.7) °F	1.4 °C (34.5) °F	3.3 °C (38) °F	7.1 °C (44.7) °F	12.1 °C (53.7) °F	16.5 °C (61.7) °F	18.8 °C (65.9) °F	19.2 °C (66.6) °F	16.3 °C (61.3) °F	12.2 °C (53.9) °F	7.5 °C (45.4) °F	3.1 °C (37.5) °F
Max. Temperature °C (°F)	7.4 °C (45.4) °F	9 °C (48.1) °F	12.3 °C (54.1) °F	16.4 °C (61.4) °F	20.9 °C (69.7) °F	25 °C (77) °F	28.1 °C (82.5) °F	28.5 °C (83.3) °F	24.3 °C (75.8) °F	18.9 °C (66) °F	14.4 °C (57.9) °F	9.3 °C (48.7) °F
Precipitation / Rainfall mm (in)	93 (3)	83 (3)	88 (3)	69 (2)	57 (2)	52 (2)	29 (1)	32 (1)	59 (2)	80 (3)	79 (3)	104 (4)
Humidity(%)	81%	78%	74%	73%	70%	66%	63%	63%	67%	75%	77%	80%
Rainy days (d)	10	9	9	8	6	6	4	4	6	7	7	10
avg. Sun hours (hours)	5.0	5.7	7.2	8.9	10.3	11.2	11.4	10.4	8.8	6.7	6.3	5.2

Fig. 3 – Climate Data for Bursa/Gemlik[46]

- A warm and temperate climate prevails in Bursa/Gemlik.
- The annual average temperature of Gemlik district is 13.8°C.
- The annual average rainfall in Gemlik district is 825mm.
- With 29mm of precipitation, July is the driest month of the year, whereas with an average of 104mm of precipitation, the highest precipitation is seen in December.
- With a temperature of 23.7°C, August is the hottest month of the year. The average temperature in January is 4.0°C, which is the lowest average of the year.
- The average temperature varies around 19.7°C throughout the year.
- Table 1 – Settings Entered in the Optimization Menu

GENERAL SETTINGS	
DEGREE OF LATITUDE: 40°	
DEGREE OF LONGITUDE: 29°	
GRAPH TYPE: STEREOGRAPHIC	
SOUTH-EAST FACADE	SOUTH-WEST FACADE
ORIENTATION ANGLE: 167°	ORIENTATION ANGLE: 233°
DATE: JUNE 21	DATE: JUNE 21
TIME RANGE: 09:00-14:00	TIME RANGE: 11:00-16:00

2.2 Method

The plans, sections and views of the office building whose energy performance was aimed to be increased were drawn in the Autodesk Revit Architecture program (2022 version, Academic User License). In order to determine the current energy performance of the building, the building was modeled and simulated in the Design Builder simulation program (6.1.0.006 version, Single User License). Improvement scenarios were created for integration of the shading element and the double skin facade system over the current state of the building. Using Design Builder simulation program, the scenarios thus created were integrated into the building and a simulation was carried out. Then, the energy performances of the existing building

and the improvement results were compared and evaluated accordingly. The Solar Tool program (2.0 version, Single User License) was used to determine the optimum dimensions of the shading elements integrated into the building.

The shading element was integrated to the South-East and South-West facades, which were found to be most exposed to sunlight and needed the shading element the most. The orientation angles of these two facades were entered in the optimization menu. The hours when the sun was most effective on these two facades were determined and the optimum shading element size for these hours was calculated by the program.

Table 2 – Numbers and Widths of Shading Element Pieces

SOUTH-EAST FACADE	SOUTH-WEST FACADE
Single-Piece Shading Element Width: 150cm	Three-Piece Shading Element Width: 150cm
Three-Piece Shading Element Width: 50cm	Nine-Piece Shading Element Width: 50cm
Ten-Piece Shading Element Width: 15cm	Thirty-Piece Shading Element Width: 15cm

The main directions in The Solar Tool program are: North 0°, South 180°, East 90°, West 270°.

The general settings entered in The Solar Tool program and the data entered in the optimization menu for South-East and South-West facades are shown in Table 1 below.

As a result of the optimization of the South-East and South-West facades, the optimum shading element width was found for these facades. The optimum widths for the South-East and South-West facades were determined to be 150 cm and 450 cm, respectively. The three-fold difference between the optimum shading element widths of the two facades were thought to adversely affect the aesthetic of the building facades. Also, statically integrating the 450cm wide shading element into the building was considered to be difficult. For this reason, shading elements of the same width were decided to be used on both facades.

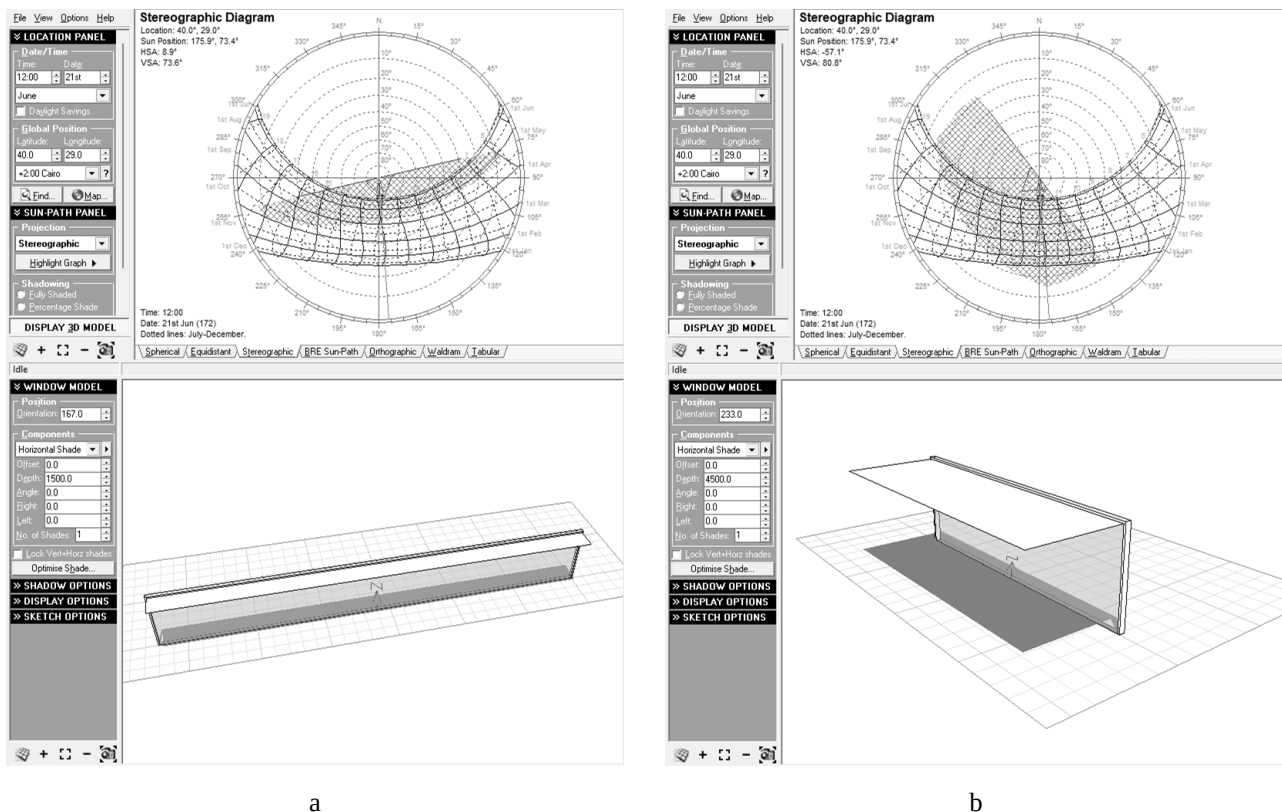


Fig.4 – a) The Solar Tool Model of South-East, b) South-West Facades

The program first calculated the optimum shading element size in one piece. Since shading elements of the same width were to be used on both facades, the shading elements were supposed to be divided into several pieces. Therefore, by entering the number of pieces in the optimization menu, optimum shading element dimensions were obtained according to the number of pieces. The number of shading element pieces and the widths depending on the numbers obtained as a result of the data entered into the program are given in Table 2 below.

2.3 Scenarios

The most effective control to protect buildings from the effects of sun rays can be achieved by blocking and capturing the rays outside the building envelope prior to controlling them inside the skin. The reflection of the captured sun rays and the flexibility and mobility of the shading elements according to the annual movement and angles of the sun may increase the performance. Shading elements applied outside the building can reduce the cooling load in buildings by half as compared to glass facade systems in which no shading is applied. Especially in buildings with high glass ratio, solar control should be performed against overheating [47].

As all facades of the selected building involved curtain walls and the wall-glass ratio was determined to be 99.5%, especially on the South-East and South-West facades, it was difficult to control the sun rays coming into the building. The sun rays incident on these facades could not be controlled, especially in summer. Therefore, the cooling load was found to be increased and accordingly the energy performance of the building decreased.

Scenarios were created according to the optimum shading element sizes and numbers obtained from The Solar Tool program, and the most successful scenario was determined by comparing the changes in the heating load, cooling load and primary energy demand of the building. Shading elements were designed using the Design Builder program and were integrated into the building model. Wood was selected as the shading element material. Shading elements were designed in such a way to be open during the warmer months and closed during the colder months. The closed design for colder months was designed in the form of a thin strip folding and pleating along the facade as in an accordion. According to the optimum shading element widths obtained from The Solar Tool program, the folding dimensions were determined for the closed design which was designed in the Design Builder program. Then, the closed design was integrated into the building. Optimization of the shading elements, whether open or closed according to months, was conducted manually in the Design Builder program.

The shading elements were designed to be open in the months of April, May, June, July, August, September and October, when the cooling load was high in the building, whereas the shading elements were arranged to be folded and closed like an accordion in November, December, January, February and March when the cooling load decreased and the heating load increased.

According to the data obtained from The Solar Tool program, six different scenarios were created based on the width of the shading elements and the number of pieces. The shading element scenarios thus created are given as follows:

S1 Scenario: In this scenario, 150 cm long shading elements with one piece on the South-East facade and three pieces on the South-West facade, were designed.

S2 Scenario: In this scenario, shading elements having length of 150 cm and a slope of 30° with one piece on the South-East facade and three pieces on the South-West facade, were designed.

S3 Scenario: In this scenario, 50cm long shading elements with three pieces on the South-East facade and nine pieces on the South-West facade, were designed.

S4 Scenario: In this scenario, shading elements having length of 50 cm and a slope of 30° with three pieces on the South-East facade and nine pieces on the South-West facade, were designed.

S5 Scenario: In this scenario, 15 cm long shading elements with ten pieces on the South-East facade and thirty pieces on the South-West facade, were designed.

S6 Scenario: In this scenario, shading elements having length of 15 cm and a slope of 30° with ten pieces on the South-East facade and thirty pieces on the South-West facade, were designed.

Three-dimensional models of scenarios (S1, S2, S3, S4, S5, S6) created on the basis of shading elements are shown in Figure 5 below.

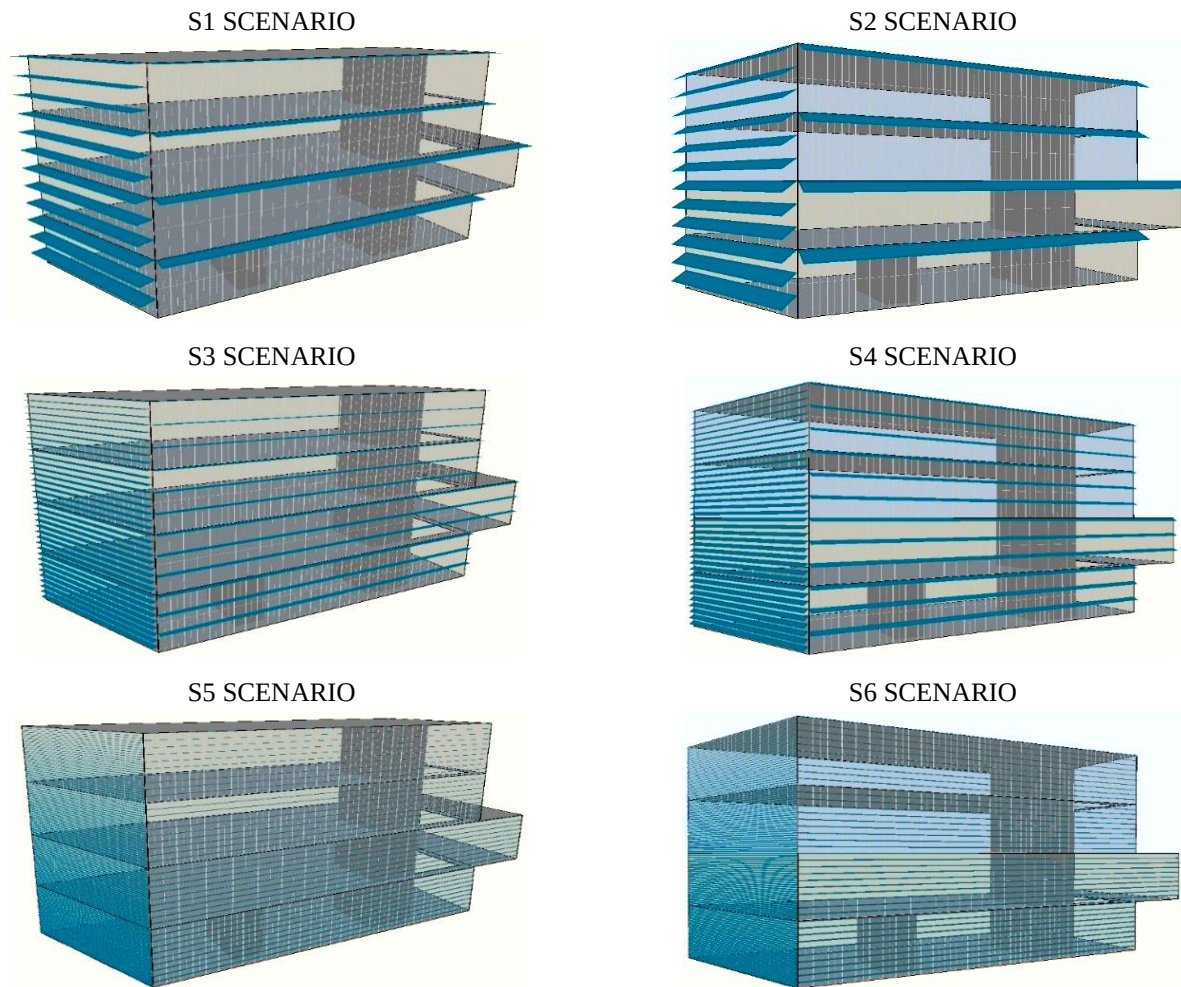


Fig. 5 – Shading Element Scenario Models of Office Building

Double skin facade systems can be defined as systems created to prevent noise and heat gain and loss as well as to benefit from natural lighting and ventilation. With these facade systems, a sustainable approach can be exhibited as energy is passively obtained and the need for mechanical systems is reduced [48, 49].

Double skin facade systems consist of an outer layer, an intermediate space and an inner layer. Intermediate space varies between 20cm and 200cm and acts as a buffer zone. The outer layer protects the building from environmental conditions and also provides air flow to the intermediate space using the outlet. The natural and clean air coming from the outer layer to the intermediate space is taken into the interior spaces through the windows in the inner layer and thus natural ventilation can be provided. In cases with unfavorable external weather conditions, the exterior vents can be closed automatically[50].

In this study, as all facades of the building involved curtain walls and had high glass ratio causing direct exposure to sunlight in summer, the cooling load was increased thus creating a greenhouse effect in the building. In winter, the heating load of the building increased due to the fact that the glass forming the curtain wall was made up of material with low thermal mass.

Scenarios were created based on the integration of double skin facade systems, which increased energy efficiency by preventing unwanted heat gains and losses in buildings, on the South-East and South-West facades, which were most exposed to the sun. Double skin facades were integrated into the building model and simulated according to the scenarios. In all scenarios, the space width between the outer and inner layers of the double skin facade was designed as 1m. As a result of

the simulations, the changes in the heating load, cooling load and primary energy demand of the building were compared. The scenarios that were created based on double skin facade systems are given below.

DSF1 Scenario: Corridor-type double skin facade was integrated into the South-East facade of the building.

DSF2 Scenario: A full-length double skin facade was integrated into the South-East facade of the building.

DSF3 Scenario: Corridor-type double skin facade was integrated into the South-West facade of the building.

DSF4 Scenario: A full-length double skin facade was integrated into the South-West facade of the building.

DSF5 Scenario: The integration of DSF1 and DSF3 scenarios, which yielded the most successful results on the South-East and South-West facades, into the building. In this scenario, a corridor-type double skin facade was integrated into South-East and South-West facades.

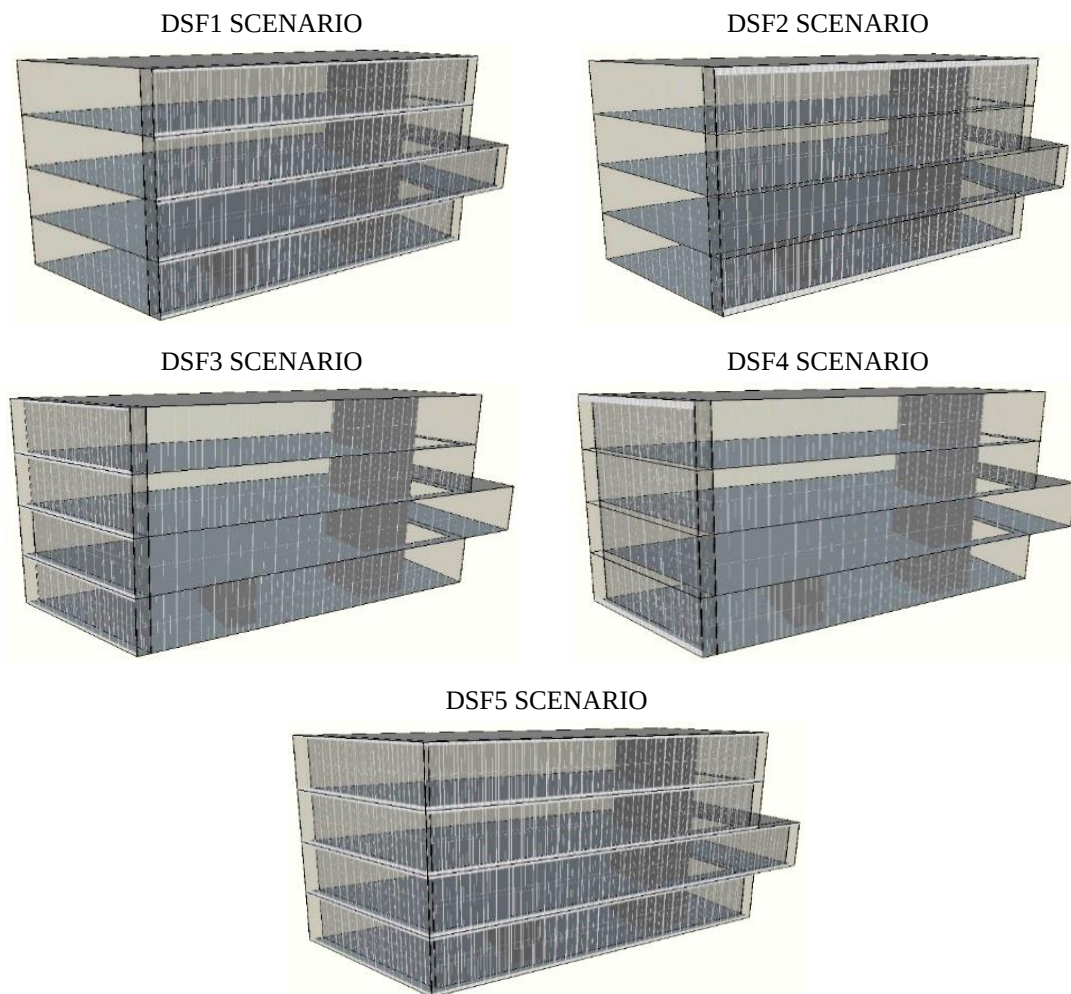


Fig. 6 – Double Skin Facade System Scenario Models of Office Building

As a result of integrating scenarios based on shading elements and double skin facade systems together into the existing office building, the energy efficiency of the building was thought to increase more than the models integrated separately. Therefore, the scenario involving integration of shading element and double skin facade together was created.

Shading elements and double skin facade systems were integrated into the building separately, and two scenarios that gave the most successful results in terms of energy performance in both building components were determined. These two scenarios were integrated together and simulated with the building facade and the changes in the heating load, cooling load and primary energy demand of the building were evaluated.

SDSF Scenario: This scenario involves the integration of the S2 scenario, which gave the most successful result among S1, S2, S3, S4, S5 and S6 scenarios, and the DSF5 scenario, which gave the most successful result among DSF1, DSF2, DSF3, DSF4 and DSF5 scenarios, into the building model. In this scenario, a corridor-type double skin facade was integrated into South-East and South-West facades. Shading elements having a length of 150 cm and a slope of 30° with one piece on the South-East facade and three pieces on the South-West facade were integrated into the exterior of the corridor-type double skin facade.

The three-dimensional model of the scenario created based on the combined use of shading element and the double skin facade is shown in Figure 7 below.

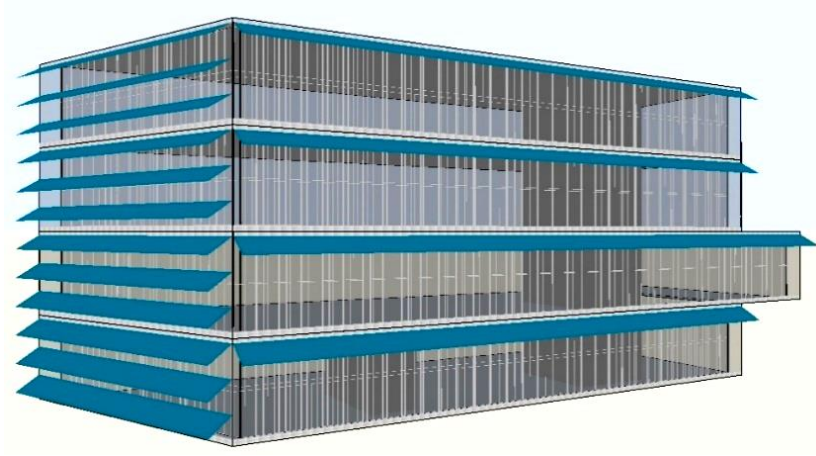


Fig. 7 – Model of Shading Element and Double Skin Facade Scenario

3 Results

The findings regarding lighting, heating load, cooling load and primary energy demand reached as a result of the simulation of the existing building model created to determine the energy performance of the existing office building located in Gemlik district of Bursa province is shown in Figure 8 below.

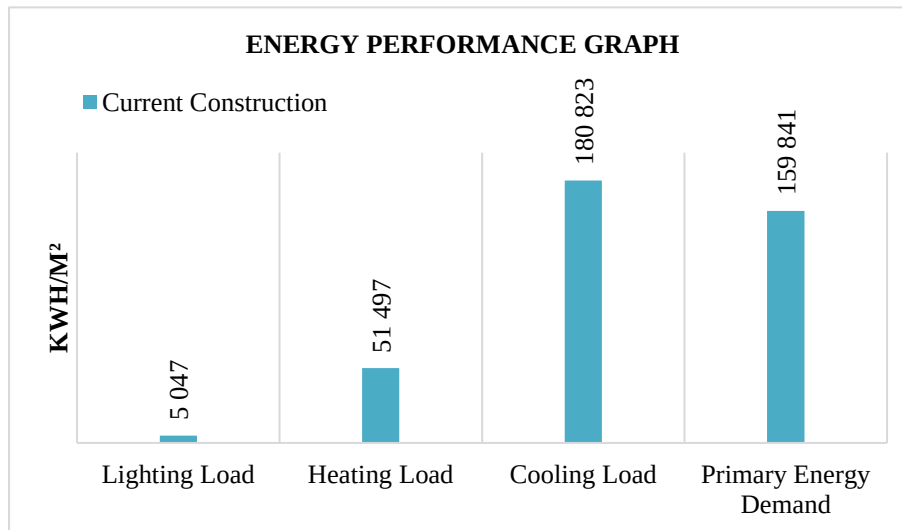


Fig. 8 – Energy Performance Graph of the existing Office Building

Lighting, heating load, cooling load and primary energy demand findings of the existing office building model were compared with lighting, heating load, cooling load and primary energy demand findings of the shading element scenarios and double skin facade scenarios integrated into the building separately and together in order to improve the energy performance of the building, and the obtained results were evaluated accordingly.

3.1 Energy Performance of Scenarios Created Based on Shading Elements

The findings regarding lighting, heating and cooling load obtained as a result of the simulation of the scenarios created based on shading elements for the existing office building are shown in Figure 9 below.

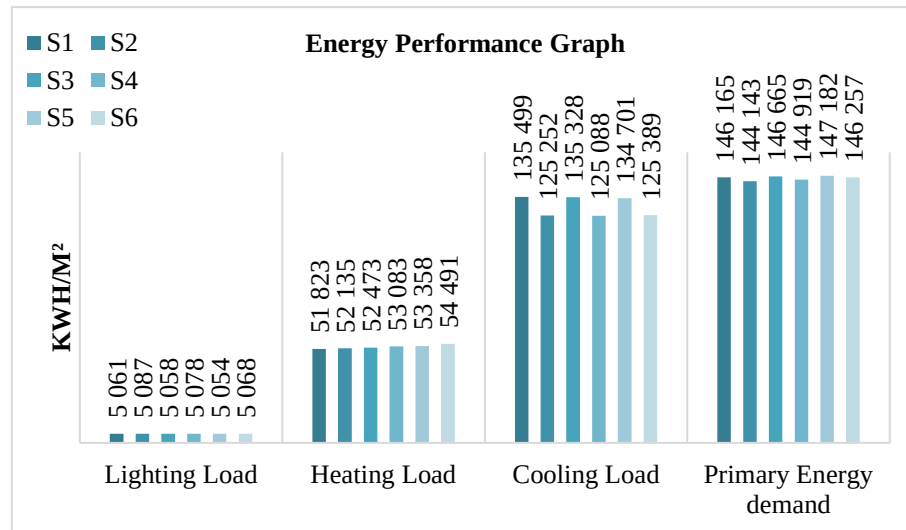


Fig. 9 – Lighting, Heating and Cooling Load, and Primary Energy Demand Graph for Shading Element Scenarios

According to results, the lighting, heating and cooling load found to be respectively 5.047, 51.497, 180.823kWh/m² in the existing building model was determined to be;

- S1 (150cm wide shading element integrated) scenario; lighting energy consumption increasing by 0.27%, heating load increasing by 0.63%, and cooling load decreasing by 25.06%.
- S2 (150cm wide and 30° inclined shading element integrated) scenario; lighting energy consumption increasing by 0.79%, heating load increasing by 1.23%, and cooling load decreasing by 30.73%.
- S3 (50cm wide shading element integrated) scenario; lighting energy consumption increasing by 0.21%, heating load increasing by 1.89%, and cooling load decreasing by 25.15%.
- S4 (50cm wide and 30° inclined shading element integrated) scenario; lighting energy consumption increasing by 0.61%, heating load increasing by 3.07%, and cooling load decreasing by 30.82%.
- S5 (15cm wide shading element integrated) scenario; lighting energy consumption increasing by 0.13%, heating load increasing by 3.61%, and cooling load decreasing by 25.50%.
- S6 (15cm wide and 30° inclined shading element integrated) scenario; lighting energy consumption increasing by 0.41%, heating load increasing by 5.81%, and cooling load decreasing by 30.65% respectively.

According to the results of the shading element scenarios, S2 scenario was observed to have the highest energy performance with the lowest primary energy demand.

3.2 Energy Performance of Scenarios Created Based on Double Skin Facades

The findings regarding heating load, cooling load and primary energy demand obtained as a result of the simulation of scenarios created based on double skin facade systems for the existing office building are shown in Figure 10 below.

According to results, compared to the existing model can be seen;

- DSF1 (corridor-type double skin facade integrated to the South-East facade) scenario; heating load decreasing by 2.75%, cooling load decreasing by 21.59%, and primary energy demand decreasing by 10.16%.
- DSF2 (Full-length double skin facade integrated to the South-East facade) scenario; heating load decreasing by 8.69%, cooling load decreasing by 7.28%, and primary energy demand decreasing by 6.09%.

- DSF3 (corridor-type double skin facade integrated to the South-West facade) scenario; heating load decreasing by 5.23%, cooling load decreasing by 9.01%, and primary energy demand decreasing by 6.44%,
- DSF4 (Full-length double skin facade integrated to South-West facade) scenario; heating load decreasing by 7.66%, cooling load decreasing by 1.80%, and primary energy demand decreasing by 4.29% respectively.

When the general evaluation of the scenario results of the double skin facade systems was carried out according to the South-East and South-West facades, it was observed that;

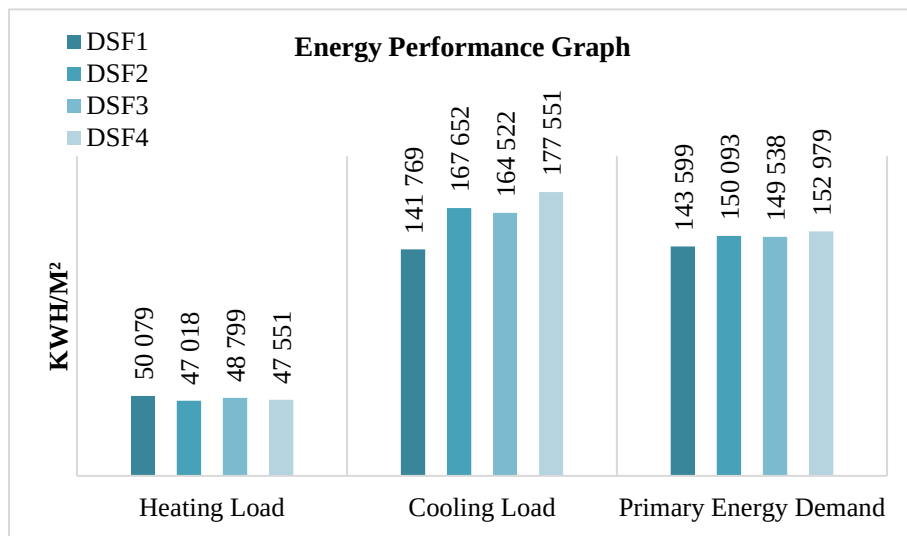


Fig. 10 – Energy Performance Graph of Double Skin Facade Scenarios

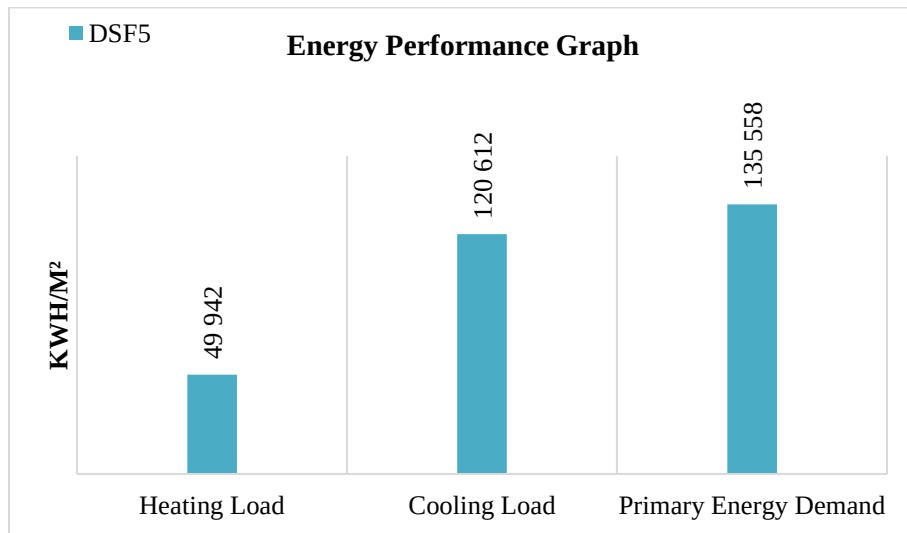


Fig. 11 – Energy Performance Graph of DSF5 Scenario

- DSF1 (corridor-type double skin facade integrated) scenario on the South-East facade,
- and DSF3 (corridor-type double skin facade integrated) scenario on the South-West facade were the scenarios with the highest energy performance with the lowest primary energy demand. A new scenario was created by integrating these two scenarios having the highest energy performance on the South-East and South-West facades, into the existing building model.

DSF5 (corridor-type double skin facade integrated on the South-East and South-West facades) scenario was created by integrating DSF1 and DSF3 scenarios, which were determined to have the best energy performance in the South-East and South-West, into existing building model.

The findings regarding heating load, cooling load and primary energy demand obtained as a result of the simulation of DSF5 scenario created based on double skin facade systems are shown in Figure 11 below.

When the heating load, cooling load and primary energy demand findings of the scenario were examined;

- heating load found to be 51.497 kWh/m² in the existing building model was observed to be 49.942 kWh/m² in DSF5 scenario decreasing by 3.01%,
- cooling load found to be 180.823 kWh/m² in the existing building model was observed to be 120.612 kWh/m² in DSF5 scenario decreasing by 33.29%,
- and primary energy demand found to be 159.841 kWh/m² in the existing building model was observed to be 135.558 kWh/m² in DSF5 scenario decreasing by 15.19%.

When the general evaluation of DSF1, DSF2, DSF3, DSF4 and DSF5 scenarios created based on double skin facade systems was carried out, it was found that DSF5 scenario, which was created by integrating DSF1 and DSF3 scenarios into the existing building model, had the highest energy performance and had reduced the primary energy demand the most.

3.3 Energy Performance of Scenarios Created Based on Double Skin Facades

The SDSF (integration of 150cm wide 30° inclined shading element and corridor-type double skin facade to the South-East and South-West facades together) scenario was created by integrating S2 and DSF5 scenarios, which had the best energy performances based on shading element and double skin facade system, respectively.

The findings regarding heating load, cooling load and primary energy demand obtained as a result of the simulation of SDSF (150cm wide 30° inclined shading element and the integration of the corridor-type double skin on the South-East and South-West facades) are shown in Figure 12 below.

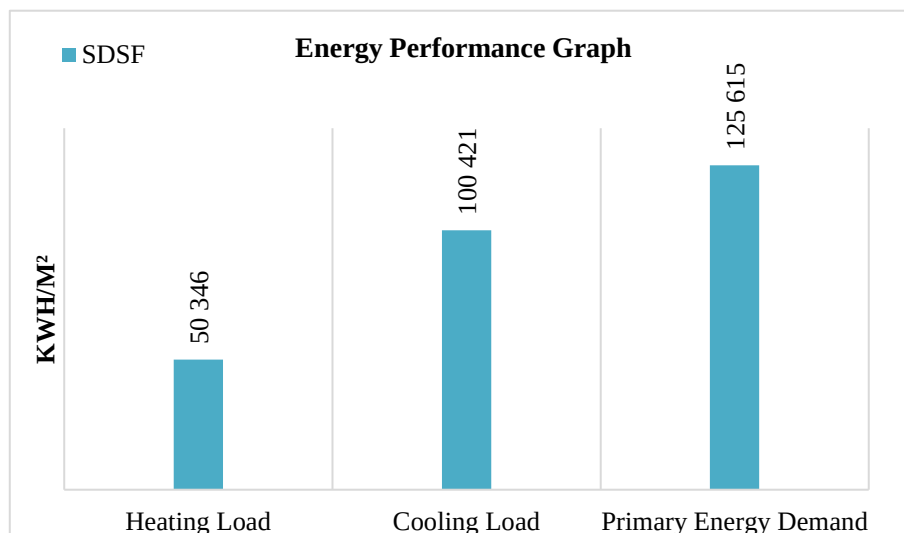


Fig. 12 – Energy Performance Graph of SDSF Scenario

When the heating load, cooling load and primary energy demand results of the scenario were examined,

- heating load found to be 51.497 kWh/m² in the existing building model was determined to be 50.346 kWh/m² in SDSF scenario decreasing by 2.23%,

- cooling load found to be 180.823 kWh/m² in the existing building model was determined to be 100.421 kWh/m² in the SDSF scenario decreasing by 44.46%,
- and primary energy demand found to be 159.841 kWh/m² in the existing building model was determined to be 125.615 kWh/m² in SDSF scenario decreasing by 21.41%, respectively.

3.4 General Evaluation

In this section of the study, the scenarios with the highest energy performances were evaluated. Heating loads, cooling loads and primary energy demand of S2 scenario based on shading elements, DSF5 scenario based on double skin facade system and SDSF scenario integrating two systems together were compared.

The energy performance graph of the existing building model and S2, DSF5 and SDSF scenarios with the highest energy performances in their categories are shown in Figure 13 below.

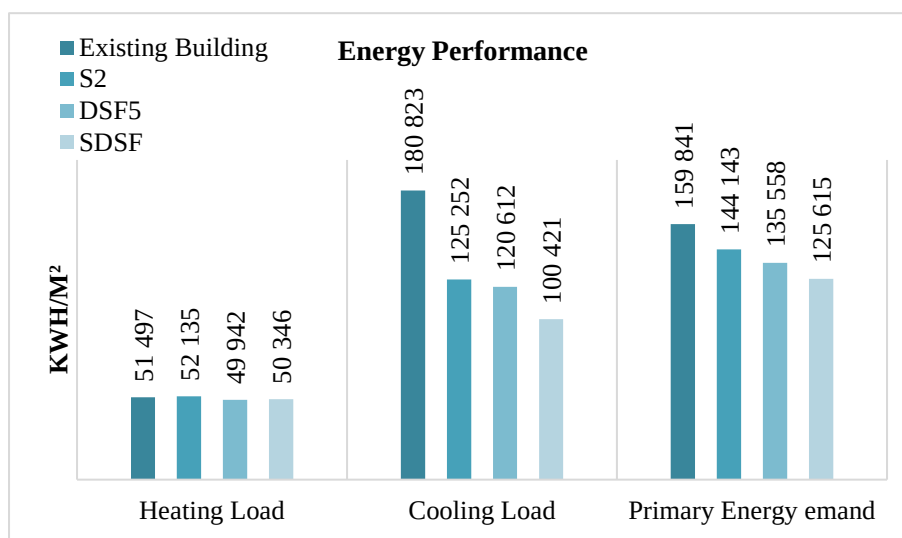


Fig. 13 – Energy Performance Graph of Existing Building Model and S2, DSF5 and SDSF Scenarios

According to results,

- Primary energy demand was found to be decreased by approximately 10% in S2 scenario, which included 150cm wide and 30° inclined shading element integrated into the building.
- Primary energy demand was observed to be decreased by approximately 15% in DSF5 scenario, which included the corridor-type double skin facade integration to the South-East and South-West facades of the building,
- and primary energy demand was decreased by approximately 21% in SDSF scenario and this scenario including a 150cm wide 30° inclined shading element and the integration of the corridor type double skin on the South-East and South-West facades, exhibited the best performance in terms of primary energy demand.

4 Conclusion

The study was conducted to increase the energy efficiency of the office building located in the Gemlik district of Bursa province. In this study, various improvement scenarios were created in the building envelope, these scenarios were tested using simulation program and the energy performances were evaluated. Scenarios were created in 3 categories as the integration of shading elements into the existing office building facade, the integration of double skin facade systems and the integration of these two building components together. Scenarios were modeled and simulated, and in order to evaluate their energy performances, the simulation results were examined over lighting energy consumption, heating load, cooling load and primary energy demand. In each of the 3 categories, the scenarios with the highest energy performances were determined

and these scenarios were compared under general evaluation section. As a result, the scenario having the highest energy performance was determined among all scenarios.

According to the results, annual lighting energy consumption, annual heating load, annual cooling load and annual primary energy demand of the existing office building was found to be 5.047 kWh/m², 51.497 kWh/m², 180.823 kWh/m² and 159.841 kWh/m², respectively. In 6 scenarios involving integration of a shading element into the existing building model, the lighting energy consumptions were increased because the shading elements prevented the natural light to pass into the interior spaces to a certain extent. Even though the shading elements were kept closed during winter, heating loads were increased since they occupied a certain area on the facade and prevented the passage of sunlight to the interior in cold winter months.

Cooling loads and primary energy demands were reduced in all shading scenarios.

The scenarios consisting of 30° inclined shading elements gave much more successful results in terms of cooling load and primary energy demand as compared to those with flat shading elements. When a general evaluation was made for shading element scenarios, the scenario having the highest energy performance was S2 (150cm wide and 30° inclined shading element integrated) scenario with a 10% decrease in primary energy demand. Heating loads, cooling loads and primary energy demands were observed to be decreased in all 5 scenarios involving the integration of double skin facade systems into the existing building model.

According to this study, in double skin facade scenarios, while the scenarios integrating full-length double skin facades on the South-East and South-West facades gave more successful results in terms of heating loads, the scenarios integrating corridor-type double skin facade on South-East and South-West facades gave much more successful results in terms of cooling loads and primary energy demands. The full-length double skin facade system was more effective in reducing the heating loads, whereas the corridor-type double skin facade system was more effective in reducing the cooling loads. When a general evaluation was made for double skin facade system scenarios, the scenario with the highest energy performance was DSF5 (corridor-type double skin integration to the South-East and South-West facades) scenario with a 15% decrease in primary energy demand.

Heating load, cooling load and primary energy demand was observed to be decreased in SDSF scenario, which included the integration of the shading element and the double skin facade system together in the existing building model. SDSF scenario showed the highest decrease in terms of cooling load and primary energy demand, thus making it the scenario with the highest energy performance among all scenarios.

In the SDSF scenario, even though the shading elements were considered to be kept closed during winter, there was less decrease in the heating loads since shading elements occupied a certain area on the facade and prevented the passage of sunlight to the interior in cold winter months.

When all scenarios were examined and a general evaluation was made, the scenario with the highest energy performance in this study was the SDSF scenario, which included a 150cm wide 30° inclined shading element integrated along with the corridor-type double skin on the South-East and South-West facades of the building.

Compared to the existing building model, the SDSF scenario showed a decrease of approximately 2% in heating load, approximately 45% in cooling load, and approximately 20% in primary energy demand.

In the study, adding shading elements to the facades of the building decreased the cooling load and primary energy demand of the building. However, it caused a slight increase in the lighting and heating loads of the building. Accordingly, energy performance and energy efficiency of the shading element scenarios also decreased.

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