Araştırma Makalesi

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Yalova Üniversitesi Mühendislik Fakültesi Binasının Yeşil Perde ile Gölgelendirilmesi ve Sağlanacak Soğutma Tasarrufunun Değerlendirilmesi

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Anahtar Kelimeler

Yeşil kalkan, Pasif tasarım, Gölgeleme, Soğutma yükü, Yeşil bina

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Amaç

Bu çalışmada Yalova Üniversitesi Mühendislik Fakültesi binasında enerji tasarrufu sağlayacak, yenilikçi ve doğa ile bütünleşik yeşil kalkan tasarımı değerlendirilmiştir. Bu tasarım ile binanın gölgelenmesi simüle edilmiş ve sağlanabilecek soğutma yüküne bağlı enerji tasarrufu ortaya koyulmuştur.

Metot

Yeşil kalkan, binanın güney ve doğu cephelerini ısı kazançlarından koruyan sarmaşıktan bir perdedir. Yaz sezonunda yaprakları yeşeren bu bitkisel yapının, güneşten gelen ısı kazançlarını soğurması; kış döneminde ise yaprak döküp ısı kazancına engel olmaması amaçlanmıştır. Çalışma kapsamında binanın Design Builder programı üzerinde modellemesi oluşturulmuş ve soğutma yükü simüle edilmiştir. Simülasyondan bağımsız olarak MMO Klima Tesisatı Kitabı'nda yer alan ısı kazançları hesap metodu ile soğutma yükü hesaplanmıştır. Elde edilen simülasyon sonucu ve hesaplama sonuçları birbiriyle kıyaslanıp, doğrulanmıştır. Akabinde Design Builder üzerindeki yapı modeline yeşil kalkan tasarımı eklenmiş ve soğutma yükü tekrar simüle edilmiştir.

Sonuçlar

Sonuç olarak, soğutmaya bağlı yıllık enerji tüketiminde %22'lik azalma ve buna bağlı yıllık 26.6 tonCO_2e salımının önlenmesini sağlayan doğal bir tasarım modeli sunulmuştur. Uygulamayla gerçekleşebilecek bu tasarruf; ülke ekonomisine, enerji güvenliğine ve çevre sağlığına katkıda bulunmayı hedefler. Bu ve benzeri doğa dostu tasarımların yaygınlaşması; sağlıklı ve sürdürülebilir bir geleceğin inşası için önem taşır.

Research Article

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Shading of Yalova University Faculty of Engineering Building with Green Shield and Evaluation of Savings on Cooling Load

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ABSTRACT

Buildings are a major part of human life, as well as global energy consumption and carbon emissions. In today's world, passive strategies like green shield, which is a plant curtain that protects the facades of a building from heat gain, are of great importance for energy efficiency and conservation in buildings. In this study, the shading of the Yalova University Faculty of Engineering Building with the green shield was simulated and the potential savings from cooling consumption were evaluated. The green shield is a plant curtain that protects the southern and eastern facades of the building from heat gain. The simulation of the green shield was created in the Design-builder software, and the results were compared with the current energy consumption. As a result, within this study, a natural design model has been presented which provides 22% annual reduction in energy consumption from cooling and prevent 26.6 tons of CO_2e emissions.

Keywords: Green shield, Passive design, Shading, Cooling load, Green building

NOMENCLATURE

ABBREVIATION	DESCRIPTION	UNIT
CO_2e	Carbon Dioxide Equal Emission	(kg or tonne)
COP	Coefficient of Performance	(kW / kW)
Q	Cooling Load	(W)
U	Heat Transfer Coefficient	(W / m^2.K)
R	Thermal Resistance Coefficient	(m^2.K / W)
A	Area	(m^2)
CLTD	Cooling Load Temperature Difference	(K)
SC	Shading Coefficient	Dimensionless
SCL	Solar Cooling Load	(W / m^2)

1. INTRODUCTION

Today, environmental problems and climate crisis are on the agenda of all countries of the world [1, 2]. Many countries are actively working on initiatives and policies to address these issues and have made commitments to implement solution-oriented practices [3, 4]. The main reason for the environmental crises is greenhouse gas emissions due to fossil fuels consumptions [5, 6]. Global warming is thought to be at the level of 1.1 °C compared to the period before the industrial revolution and this warming is becoming increasingly dangerous for the future of the planet [3, 7]. The development of technology increases the amount of energy demand we need every day and this increment causes another increase in fossil fuel consumption [8-10]. Currently, all countries and stakeholders of these problems are searching for a solution.

1.1.The Importance of Energy Efficiency

For 2021, approximately 50.7 billion dollars' worth of energy imports were realized in Turkey and approximately 40% of this energy is consumed in buildings [11, 12]. It is claimed that approximately 80% of the buildings in Turkey consume energy in a low efficient way, which results in energy waste equivalent to 10 billion dollars in 2021 due to inefficient usage [13]. For Turkey, which is in the position of an energy-importing country, saving on this high cost through proper consumption methods is of great importance for the national economy [14].

The production of the energy that is being wasted leads to greenhouse gas emissions, which is currently recognized as one of the main causes of the climate crisis [15]. The emission reduction that will be achieved through efficient energy usage provides a great step forward in ensuring the carbon neutrality policies that countries have made commitments to, while displaying an environmentally friendly attitude [16]. In addition, energy efficiency in buildings is also included in the scope of the Climate Action target within the Sustainable Development Goals published by the United Nations [17].

1.2.Net Zero Energy Buildings

Approximately 87% of the average human life is spent in buildings [18]. Buildings are responsible for 36% of global energy consumption and 37% of CO_2 emissions [19]. In many countries around the world, practices for effective energy use in buildings are developed and encouraged, and there are various organizations that serve this purpose [20]. These structures, which can be located in all kinds of geography and climate conditions, provide energy savings thanks to the correct planning to be conducted especially at the design stage. Energy savings reduces carbon emissions and provide a great reduction in energy bills. This economic advantage is a great opportunity both for the building users and for the countries that are dependent on outsourced energy [20].

Today, net-zero energy buildings are shown as the solution to this problem. These buildings have high energy efficiency performance and provide 70% to 90% less energy consumption than a standard building [12]. Zero-energy buildings generate as much energy as they consume. This is a very effective solution to reduce carbon emissions and contribute to decrease environmental problems [21].

1.3.Purpose and Scope of the Study

In this study, a green shield for Yalova University Engineering Faculty Building is modeled. The purpose of the green shield is to make a summer shield from the leaves of the plants which prevent solar radiation during summer. In the wintertime, the shield allows solar radiation, thanks to defoliation. The shield decreases the energy consumption of the building and ensuring a vital precondition for becoming a net zero energy building. In the study, the east and south facades of the building are covered with ivy vegetation and provide shading, while the roof is covered with green roof concept to provide insulation. This completely natural structure can maintain its own operation with no automation or heavy maintenance and repair, and it has the quality of an ecological and original design.

Figure 1 – Yalova University Engineering Faculty Building

2. MATERIAL and METHOD

2.1.Climatic Conditions

Yalova is in the Marmara Region–Turkey and has an average annual temperature of 14.6 °C. The summer seasons are dry and hot, while the winter seasons are warm and abundant rain. However, the average temperature of the coldest month is 6.6 °C, while the average temperature of the hottest month is 23.7 °C [22].

The climate type in the city, according to the Köppen Climate Classification method, is CSA. This classification indicates a climate characterized by mild winters, hot and dry summers (Mediterranean Climate) [23].

2.2.Engineering Faculty Building

Yalova University Engineering Faculty Building, photographed in Figure 1, comprises 5 floors. Its dimensions are 53 meters width, 53 meters length and 27.8 meters height and a total indoor area of 11176 m^2 [24, 25].

2.2.1. Building Simulation

Design-builder–EnergyPlus program was used for the cooling load simulation of the building. The program provides three-dimensional modeling of the building in computer aided design (CAD) file type, various technical data entries on a single platform, and provides various analysis results and technical reports because of these inputs [26].

In the building modeling phase, the building's architectural drawings and floor plans which provided by Yalova University Rectorate Department of

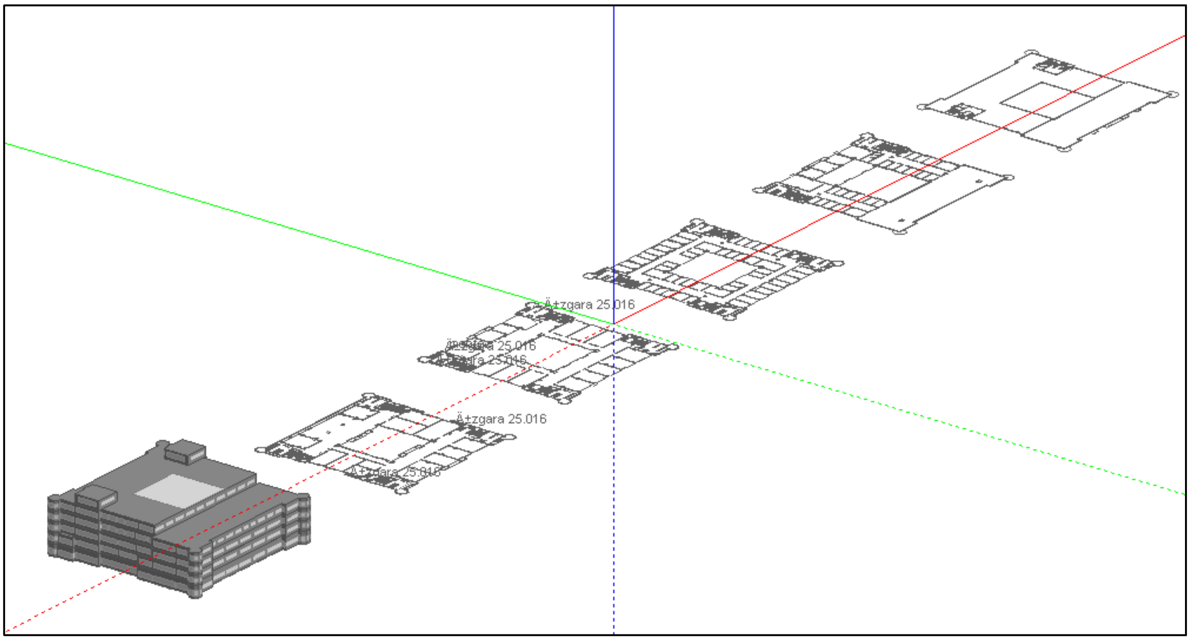

Figure 2 – Architectural Drawings Imported into Design-Builder

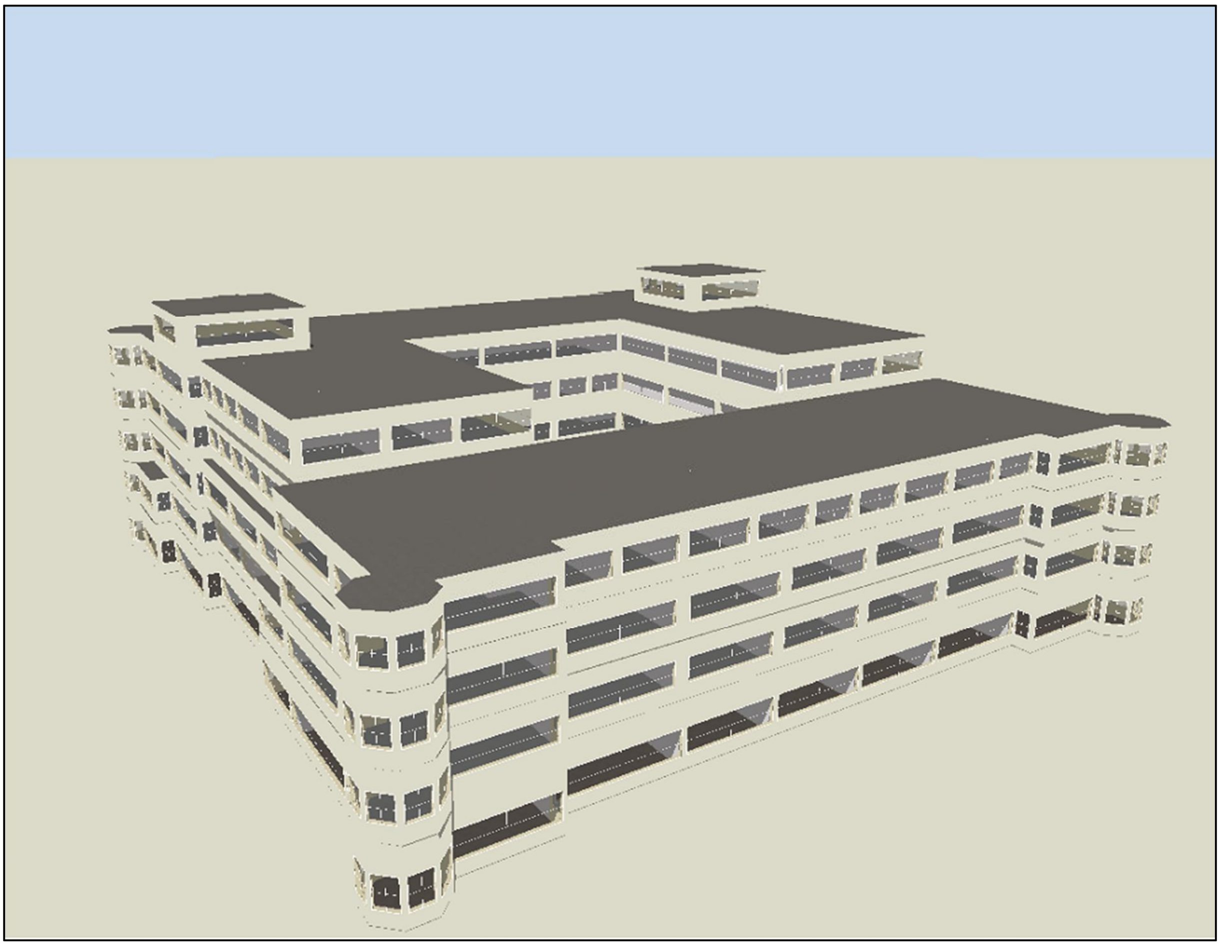

Figure 3 – Faculty of Engineering Three-Dimensional Model Image

Construction Affairs were used to model the faculty building. The plan files of all the floors were transferred to the program and three-dimensional block models were drawn (Figure 2). Then, the floor blocks were combined to get a general three-dimensional model of the building (Figure 3). The wall thickness and material information of the building can be inputted into the program, and the total heat transfer coefficient (U-value) of the walls can be calculated based on the obtained model. However, since information for the external wall material could not be obtained, the U-value of the wall was directly entered as a separate data, and the simulation calculations were conducted accordingly.

In building modeling, data such as the location of the building, activity information, and seasonal periods were also input. The coordinates, altitude and time zone of Yalova have been input for location definition. The building activities were selected as the study offices template and the university building. Metabolic activities were defined as the light office work, standing and walking activities. In addition, internal heat gains from air conditioning systems, office equipment and computers were selected as program defaults. Since the cooling load affect is considered in this paper, only the details of the cooling system of the air conditioning system are processed. The coefficient of performance (COP) of the cooling system was inputs as 2.5. Using grid electricity and operating conditions of the cooling system were entered specific to the university building.

2.2.2.Cooling Load Modeling of the Structure

Cooling load report was obtained from Design-Builder program. All the information such as reinforcement, location, climate, facades of the building are provided; the program calculates heat gains and cooling load. The cooling simulation covers the summer months that are between July and September.

According to the simulation results, the current cooling load of the building is 405.6 kW, and the seasonal electricity consumption due to cooling is obtained as 217 MWh.

2.2.3.Calculation of the Cooling Load of the Structure

The cooling load of the building is also calculated analytically by using the method given in the publication of Chamber of Mechanical Engineers Book of Air Conditioning Installations [27]. The heat gain from roofs, glass surfaces and external walls, as well as solar radiation from glass surfaces were calculated, and the total cooling load was obtained by including the internal heat gains in these calculations.

Equation 1 was used for calculating the heat gains from exterior walls, windows, and roof.

$$\dot{Q} = U\,A\,(CLTD) \qquad (1)$$

In this equation, "$\dot{Q}$" is cooling load (W) and "U" is total heat transfer coefficient (W/m^2. K), "A" represents the surface area (m^2), and "CLTD" represents the cooling load temperature difference (K).

Equation 1 was used for calculating heat gain by conduction from external walls. Here; the total wall area is taken from the architectural drawings of the structure, the U value for the walls is taken from the structural works and technical department of the university and from the academic studies previously done for the faculty building [25] [28].

The basic material code of the wall is designated as C9. Secondary wall material is rough or thin plaster, wall R value is determined between 1.59 – 1.89. Since the equivalent of C9 wall type could not be found in these values, C8 wall type with close values was accepted and it was reached that the wall number was 11. In line with these results, the CLTD of wall 11 for the North, South, East and West facades was read for 13:00.

The calculated parameters and the heat gains of the structure from the external walls are given in Table 1. The heat gains were calculated from the walls in the middle opening and outer side of the building and found to be about 21.67 kW.

Table 1 - Heat Gains by Exterior Wall Conduction

Exterior Walls				
Direction	North	South	West	East
Total Wall Area (m^2)	509.1	686.9	870.8	790.8
CLDT value (K)	6.0	7.0	7.0	16.0
U value for walls			0.617	
Q heat gain (W)	1884.6	2966.6	3761.0	7806.8
			Total Heat Gain (kW)	**16.42**
Middle Opening Walls				
Direction	South	North	East	West
Total Wall Area (m^2)	315.6	138.6	238.1	238.1
CLDT value (K)	7.0	6.0	16.0	7.0
Q heat gain (W)	1363.1	513.1	2350.5	1028.4
			Total Heat Gain (kW)	**5.26**
			TOTAL (kW)	**21.67**

Table 2 – Heat Gains from Glass Surfaces by Conduction

Exterior Glass Surfaces				
Direction	North	South	West	East
Total Glass Area (m^2)	380.5	490.4	254.2	254.2
CLDT value (K)			7.0	
U value for glass			2.78	
Q heat gain (W)	7404.5	9543.6	4946.7	4946.7
			Total Heat Gain (kW)	**26.84**
Middle Opening Glass Surfaces				
Direction	South	North	East	West
Total Glass Area (m^2)	219.4	122.0	235.8	235.8
Q heat gain (W)	4269.5	2374.1	4588.7	4588.7
			Total Heat Gain (kW)	**15.82**
			TOTAL (kW)	**42.66**

Table 3 - Heat Gain from the Roof by Conduction

Roof	
Total Roof Area (m^2)	2100.0
CLDT value (K)	23.0
U value for the roof	1.894
Q Total heat gain (kW)	91.48

The total glass area is taken from the architectural drawings of the building, the U for the glass surfaces is taken from the previous studies for the same faculty building [25] [28]. The CLTD corresponding to the time of 13:00 was read from the relevant table.

The heat gains of the building by conduction from glass surfaces are shown in Table 2. The heat gains from the windows by conduction in the middle opening and outer side of the building were calculated to be approximately 42.66 kW.

The U for the roof is taken from academic studies previously conducted for the faculty building [28]. The CLTD was determined according to the insulation was in the outer shell of the building, the suspended ceiling existed, the R was between 0 and 0.9. The main building material was reinforced concrete and the corresponding roof number was obtained as 5 in the tables. This roof number and the CLTD corresponding to 13:00 hours were read.

The determined parameters and the heat gain from the roof are shown in Table 3. The heat gains of the building by conduction from the roof were calculated and found to be 91.48 kW.

It is necessary to determine the choice of the time, the facade of the wall for which the calculation is made and the wall number, when calculating the heat gains generated by the conduction from the walls. Here, in order to determine the wall number, it is necessary to know the material of the wall, the thermal resistance (R).

In order to determine the CLTD for the heat gain from glass surfaces, it is necessary to determine the time the surface is exposed to the sun. In order to determine the CLTD for the heat gain calculations from flat roof surfaces, the time and roof type must be determined. In order to determine the roof type, it is necessary to know the layout of the ceiling, the existence of a suspended ceiling, the thermal resistance (R-value) of the surface and the type of building material.

Equation 2 is used to calculate the heat gained by radiation from the window and glass surfaces.

$$\dot{Q} = A\ (SC)\ (SCL) \tag{2}$$

In this equation, "A" is surface area (m^2), "SC" is the dimensionless shading coefficient, and "SCL" is the solar cooling load (W/m^2).

In order to obtain the SC to be used when calculating the radiation heat gain from windows, the single or double glazing status, thickness and permeability of the glass must be known. In order to obtain the SCL, the direction of the window, the solar time and the region type must be known. The window zone type is determined by the window/wall ratio, the floor covering, the separator wall type, and the interior shading condition.

The glass type was chosen as the outer heat sink and the inner transparent since the green-colored glasses are used in buildings and the classification of these colored glasses is in the heat sink category [27]. The thickness of each of the double glasses was accepted as 6 mm and the corresponding SC was 0.565. Since the windows in the middle opening of the building (Figure 1) are excessively shaded, a value of 0.36 was used.

Table 4 – Glass Surface Radiation Heat Gains

Exterior Glass Surfaces				
Direction	North	South	West	East
Total Glass Area (m^2)	380.5	490.4	254.2	254.2
SCL value (W/m^2)	101.0	217.0	167.0	189.0
SC value	0.565			
Q heat gain (W)	21713.2	60127.9	23985.0	27144.7
			Total Heat Gain (kW)	**132.97**
Middle Opening Glass Surfaces				
Direction	South	North	East	West
Total Glass Area (m^2)	219.4	122.0	235.8	235.8
SCL value (W/m^2)	217.0	101.0	189.0	167.0
SC value	0.36			
Q heat gain (W)	17139.5	4435.9	16043.8	14176.3
			Total Heat Gain (kW)	**51.80**
			TOTAL (kW)	**184.77**

In the spaces, the number of glass-fronted walls is 1-2, the floor covering is vinyl, the separator type concrete block and the interior shading is half or none. The zone type corresponding to these values was determined as D and different SCL values were read for the North, South, East and West facades of the windows at 13:00 in the D zone. The determined parameters and the radiation heat gains of the building from the glass surfaces are given in Table 4. The heat gains by radiation from the windows in the middle opening and exterior of the building, and the total were calculated to be 184.77 kW.

In the indoor heat gain calculations, the indoor heat gains were evaluated under five categories: human metabolism, lighting, computers, electrical appliances and heat input from hot masses.

The following parameters were considered in the internal heat gain calculations. Since the canteen and cafeteria in the building did not serve, it was accepted that there was no hot food and hot mass entrance. Heat gain by metabolic activities was chosen according to the literatures [24] [29]. There are 905 people in the faculty building, including 116 academic staff, 769 students and approximately 20 administrative staff. The heat dissipation capacity of a person is accepted as 70 W for school [30]. There are 4 different fluorescent lighting in the building: (18W×4), (36W×2), (20W×2) and (40W). The heat dissipation factor of the lighting type was accepted as 0.42 [31]. There are approximately 120 rooms in the building. It is used for different purposes, such as offices, classrooms, laboratories, warehouses, archives. It is assumed that there is at least 1 computer in each room, with 120 desktop computers. The average heat dissipation capacity per computer is considered being 116 W. [30]. It is assumed that there is approximately 1 electrical appliance in active use in each of the 120 rooms. These electrical appliances can be of different types, such as projectors in classrooms and printers in administration. The power consumption of these electrical devices is about 200 W and the heat dissipation factor is accepted as

0.4 [32]. The results of all heat gain calculations are given in Table 5. The internal heat gains of the building were calculated and found to be about 120 kW.

As a result, the total heat gains and cooling load of the structure are given in Table 6. The total of all heat gains of the building were calculated to be 461 kW.

2.3.The Green Shield

The green shield ecologically enriches the environment where the building is located. For this, the environment is afforested or various green plants are used. Thanks to shading, coolness, sound insulation, air pollution, filtration and a natural design are provided. In addition, an increase in oxygen concentration is expected [33]. In

Table 5 – Internal Heat Gains

Heat Source	**Power (W)**	**Heat Dissipation Factor**	**Piece**	**Total (W)**
Human Metabolism	70	1.0	*116 academic personnel + 769 student + 20 administrative staff = 905*	63350.0
Lighting	72 72 40 40	0.42	651 71 230 468	33559.7
Computer	116		120	13920.0
Electrical Appliances (Office equipment, water heaters, etc.)	200	0.4	120	9600.0
Hot Mass	0	-	0	0
			Total Internal Heat Gain (kW)	**120.43**

Table 6 – Total Heat Gain and Cooling Load (kW)

Heat Gains by Conduction Through Walls	21.7
Heat Gain by Conduction from Windows and Glass	42.7
Heat Gain from the Roof by Conduction	91.5
Heat Gain by Radiation from Windows and Glasses	184.8
Internal Heat Gains	120.4
Total Heat Gain (kW)	**461.0**

Figure 4 – The Green Shield Modeling

the Design-builder program, the south and east facades of the building were modeled as covered with ivy vegetation and shaded, and a green roof applied to the model.

Figure 4 illustrates the green shield modeled besides the building. As seen in the figure, the east and south facades of the building are shaded by planting. In the northern hemisphere, buildings are mainly exposed to the sun's rays from the south during the day, because of this; the green-shield design applies to the east and south facades [34]. Besides this, shading is provided to the eastern facade during the morning hours. The application is not preferred on the Western facade. Because the structure is a school building and was accepted as not using air conditioning intensively during evening sunset hours.

The structure of the block type of the green shield was defined as adiabatic in Design-builder. This block type is selected since it includes all shading effects in the calculations of reflection effects [35].

The permeability calendar was defined as the model that will show active features on summer days in the Northern Hemisphere. The reason for this choice is the applied green ivy provides shading with its leaves in the summer, while it does not cause any effect by shedding leaves in winter. The value of block material is specifically defined for this simulation.

The thermal-solar absorption coefficient and a visible absorption coefficient of the surfaces were selected as 0.7 and 0.2 respectively.

While determining these values, we aimed for the green shield to meet the following conditions;

i. The solar radiation gains of the building should be prevented by at least 70%,

ii. Block the light by no more than 20%

iii. Get maximum benefit from sunlight.

In addition, the rough and green surface details were input, the remaining data were accepted as program defaults, and were selected to be active only on summer days in the Northern Hemisphere. The reason for this preference is that, while the green ivy applied provides shading with its leaves in summer, and it does not create any shading effect by defoliation in the fall and winter season.

In addition, Green Roof tab is activated, and the simple calculation method was selected, 10 cm plant length and 3.5 leaf area index values were entered, all remaining values were left as the program defaults. At this stage, it was assumed that the plants would be kept at a length of 10 cm. The leaf area index of 3.5 was used because it was the leaf area index of the plant known as “American Ivy” and called “Boston Ivy” in the literature [36]. This value is a dimensionless indicator that represents the ratio of the leaf area to the ground surface [37]. This plant can also be used in green shield facade application.

In order to measure the effect of the added green shield and green roof models, the simulation performed in the section “2.2.2.Cooling Load Modeling of the Structure” was repeated. According to the simulation results, with the implementation of the green shield, the cooling load of the building is obtained as 247.16 kW, and the seasonal electricity consumption due to cooling is 169 MWh.

3. RESULTS and DISCUSSION

The current cooling load of the building in Design Builder is 406.6 kW, while the cooling load obtained in the green shield simulation is 247.16 kW. The difference of 158.4 kW indicates a prevention of 39% heat gain. According to the Design-Builder simulation result report, the annual cooling energy consumption of the building is 542 514.6 kWh. Since the seasonal COP of the air conditioning system is accepted as 2.5, electricity consumption is calculated as 217 MWh. In the Design-builder simulation, which includes the green shield application, the annual cooling energy consumption of the building is calculated as 422742.5 kWh. For the case where the seasonal COP of the air conditioning system is 2.5, electricity consumption is calculated as 169 MWh.

An electric energy consumption difference of 48 MWh is observed between the two scenarios that correspond to an annual cooling electricity savings of 22%.

The CO2e emission reduction achieved through the savings obtained from green shield modeling is calculated using Equation 3.

$$\text{tonCO2e} = \frac{\text{kWh Electric Savings} \times (0.555)}{1000} \quad (3)$$

In this equation, “tonsCO_2e” the amount of CO_2e emissions prevented (ton), “0.555” is electricity emission factor (kgCO_2e / kWh) [38].

This electrical savings will indirectly prevent 26.6 tons of CO2e emissions.

As seen in the results, the heat gain from the south direction is higher compared to other directions. This indicates that the correct direction choice was made for the green shield application considered for the south facade.

Also a Design-builder simulation was created for the current cooling load of the faculty building. There is a difference of approximately 55.4 kW between the Design-Builder simulation result and the analytical calculation result presented in Table 6. The difference between the two results obtained is approximately 12%. There is not a perfect agreement between the results, but the calculation results are similar to the Design-Builder simulation results, and the comparison was made using the Design Builder simulation results as the reference. According to the Design-builder simulation, it has been determined that about 48 MWh of energy can be saved and 26.6 tons of CO_2e can be prevented annually during the cooling season.

The application is expected to save energy and have social impacts, besides its technical benefits. Green facades covered with plants provide comforting, promising and satisfying effects to users [39]. Photosynthetic green plants increase the amount of oxygen in the environment and reduce the carbon dioxide. Increased oxygen concentration provides an open mind for building users and students. This ecological structure fills the vegetation gap on campus and throughout the building and provides a pleasant visualization to the occupants. Air cleanliness and quality are very important in industrial cities and metropolises. Green shield acts as a filter, reduces air pollution and particulate concentration in and around the building [40]. Increasing air quality is also a precaution for Sick Building Syndrome [41], one of the global health problems. The vegetation also prevents the noise in the environment, prevents the sound pollution in the building and prevents distraction in the lessons [40].

4. CONCLUSION

In this paper, energy saving opportunity was investigated by reducing the cooling load of the building with the green shield and green roof models. 48 MWh energy savings and the associated emission reduction have been observed. However, the amount of energy consumed for cooling, meter information and invoice price could not be confirmed. That means this study should be confirmed with field or experimental studies. The analysis in this paper reflects the results of a simulation and requires validation with experimental data. Various assumptions made can cause deviation in the application. The error margins of the simulation methods can also cause deviations in the results. However, this study aims to provide a preliminary idea and guidance for practical applications.

Achieving 22% electricity savings due to cooling is a very important benefit in terms of both economy and environmental awareness. It is preferred that such investments are made by a non-profit public institution as exemplary applications. Within this study, an innovative application that will guide other institutions was proposed by Yalova University.

In order to build sustainable built environments and cities, it is necessary to implement various designs, including passive building approaches that yield effective ecological, economic, and socio-cultural outputs. It is important that these designs, which aim to create healthy and sustainable environments, apply to all buildings.

5.ACKNOWLEDGEMENT

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