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Original Paper

Increasing energy efficiency in classroom lighting at a university in Türkiye

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ABSTRACT

In the study, three objectives were achieved. The first purpose; To ensure minimum energy consumption in lighting a classroom at Afyon Kocatepe University Dazkırı Vocational School. The illumination levels of ten different points in the classroom and the outside environment were measured. The most ideal illumination level for learning in the classroom was set. For this purpose, algorithm design and implementation were carried out in order to benefit from ambient lighting as much as possible. Second purpose; It is a comparison of the energy production of Monocrystalline, Polycrystalline and Thin film solar panels at the location where the work is carried out. It is to determine the most suitable solar panel type. The final purpose: In the energy production system consisting of Monocrystalline, Polycrystalline, Thin-film solar panels, battery and grid, the best use of the produced energy is ensured by providing energy flow control. Different algorithms have been used to control the energy flow. A control card was designed to implement algorithms. With the designed control card, the current, voltage, and power produced by each of three different PV modules were measured. In addition, the current, voltage, and power used by the lighting system were also measured. PIC18F4550 microcontroller was used to provide USB connection to the computer on the control card. Thus, all data in the system is sent to the computer via a USB port. An interface was designed with C# to evaluate and instantly monitor this data. With the designed interface, all data is displayed instantly and saved to the Access database at 10-second intervals. The system can be controlled manually with the designed interface. When the records in the database were examined, 83% of energy savings were achieved with the lighting algorithm and energy flow control algorithms. With the work done, optimal lighting was provided in the classroom. In this way, many effects that would hinder education, especially visual headaches, are prevented. The effect of training is increased by increasing visual comfort.

I. INTRODUCTION

The importance of renewable energy sources is increasing day by day. The most important of these sources is the systems that generate electrical energy from solar energy (photovoltaic). With the development of technology, there has been a decrease in the production costs of photovoltaic systems. Thus, its usage area and variety has increased [1-3]. Major studies on photovoltaic systems; In the study conducted by Park et al., the Powell optimization method was used to obtain high speed and more uniform accuracy of the five parameters of the solar panel in a single diode model. The open circuit current and voltage curve of the solar panel have been extracted [4]. Sadeghi worked on the number of solar panels in his work, environmental, economic, and safety. In this study, he took various solar panels from 150kW to 1500kW as a mathematical analysis. He explained the results of this in detail [5]. Ferrari et al. conducted a simulation to calculate the Maximum Power Point (MPP) point of the solar panel in their study. To achieve this, Fuzzy C-Means, Radial Basis Function Networks, k-nearest Neighbor, and Feed-forward Neural Networks included the current, voltage, and temperature of the solar panel in their calculations [6]. Demenkova et al. worked on solar tracking algorithms and control systems to maximize the production of solar panels. They did these studies on MATLAB. It has been used in the Verilog algorithm in

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studies [7]. Ma et al. made a mathematical model of the solar panel. He worked on the effect of the temperature increase of the solar panels on energy production. Each degree of temperature increase results in a 0.4-0.65% decrease in the energy production of the solar panel [8]. Zhong and his friends tried to get the highest energy from solar panels installed on the roof of a house. They worked on panel layouts to achieve this. They compared the amount of energy produced by placing the panels in different layouts. Energy increased by up to 6% with flexible panel alignment [9]. Gardashov and his friends have worked on increasing the energy production of the solar panels in the plateau. This study is based on simulation. It is aimed to increase energy production by changing the direction of the solar panel. They used different equations for this. As a result of the simulation, it was determined that energy production will increase with the change in the direction of the solar panel [10]. Fiances and his colleagues have studied the efficiency of three different solar panels in Peru. In this study, monocrystalline, polycrystalline, and thin film solar panels are used. Each solar panel has a power of 3.3 kW. As a result of the work done, the monocrystalline solar panel produced the highest energy generation. The polycrystalline solar panel produces an energy close to that of a monocrystalline solar panel. Ibce elephant solar panels produced 50% less energy than other panels [11].

There are studies on the energy production of solar panels from different angles [12-16]. In the study performed by Gaglia et al in Athina, solar panel parameter calculations between 0 and 100 degrees were made. These calculations are only on a single solar panel, and the mathematical equivalent of the solar panel is extracted and made on it [17]. Guenounou et al., On the other hand, produced their annual energy production using four different solar panels. In this study, it was studied at a fixed angle, and energy production in other aspects was not included [18]. In the studies of Elibol et al., Annual energy production at a single angle was calculated using three different solar panels [19]. Fathabadi has used a sensorless dual-axis solar tracking system in photovoltaic systems. He worked experimentally on this system. As a result, it increased between 28.8 and 43 percent [20]. Zhu and her colleagues have worked on the uniaxial solar tracking system. The simulation results show that it has significant advantages over the existing single-axis tracking structures at almost all latitudes [21]. Awasthi has worked on photovoltaic systems and solar tracking systems. They have conducted biaxial solar tracking system design and performance analysis [22]. Jamroen et al. designed a low-cost dual-axis solar tracking system. With this design, there was an increase of 44.89% [23]. Munanga worked on a single-axis solar tracking system. In these studies, they used an LDR sensor for solar medicine. As a result of the study, they achieved a 25% increase in productivity [24-31].

The primary purpose of this study was to make use of the external environment as much as possible in class lighting. For this, 10 different points were identified in the classroom. The algorithm is designed so that the light intensity at these points is not less than 300 lux. While designing the algorithm, light intensities of each point in 20 different brightness intensities were measured. In these measurements, it was determined that at least how many lamps or lamps should be lit if it is below 300 lux. Lux meters were used in these measurements. In the external environment, one light sensor is used. Thus, the lighting algorithm which the lamps or lamps should be lit according to the outdoor light intensity was prepared. Secondly, monocrystalline, polycrystalline, and thin film solar panels with 100Wp power are used to meet the energy required by the system. A control card is designed for these lighting automation and energy flow algorithms. PIC18F4550 microcontroller was preferred for the control card to be computer-connected. The designed control card has achieved optimal illumination based on the data from the outdoor light sensor and the written algorithm. With the control card, current, voltage, power, outdoor, and indoor temperature and light intensities of each solar panel and lighting system were measured. All data from the sensors are sent to the computer via USB. An interface with the C # program has been prepared on the computer. With this interface, all data from the sensors are displayed and recorded in the access database at 10-second intervals. The system can be controlled manually with the interface.

Lighting conditions are not taken into account in classroom lighting. There is high or low lighting. There are negative effects on education due to lighting levels. At the same time, energy consumption is high. The lighting level is adjusted with the work done. In this way, it has a positive effect on education. At the same time, energy efficiency is increased.

II. EXPERIMENTAL METHOD

In the realized system, two objectives were achieved. The first goal is to create an algorithm that will benefit the most from the external environment for classroom lighting. The second goal is the optimal use of the energy produced by controlling energy flow in the hybrid power generation system. For these purposes, the most used monocrystalline, polycrystalline and thin film solar modules are used in the market. Each solar module has a power of 100 Wp. All energies produced in three different solar modules are collected in the battery with a single busbar. Current, and voltage sensors are added to each solar panel to measure the energy generated. In addition, the automation system's current, voltage, and power, as well as indoor and outdoor temperature and light intensities were measured with sensors. In this study, a control board consisting of a PIC18F4550 microcontroller was used. With this card, analog data from the sensors are converted into digital data and sent to the computer. The system realized in Figure 1 is shown. Figure 2 shows the flow chart of the system.

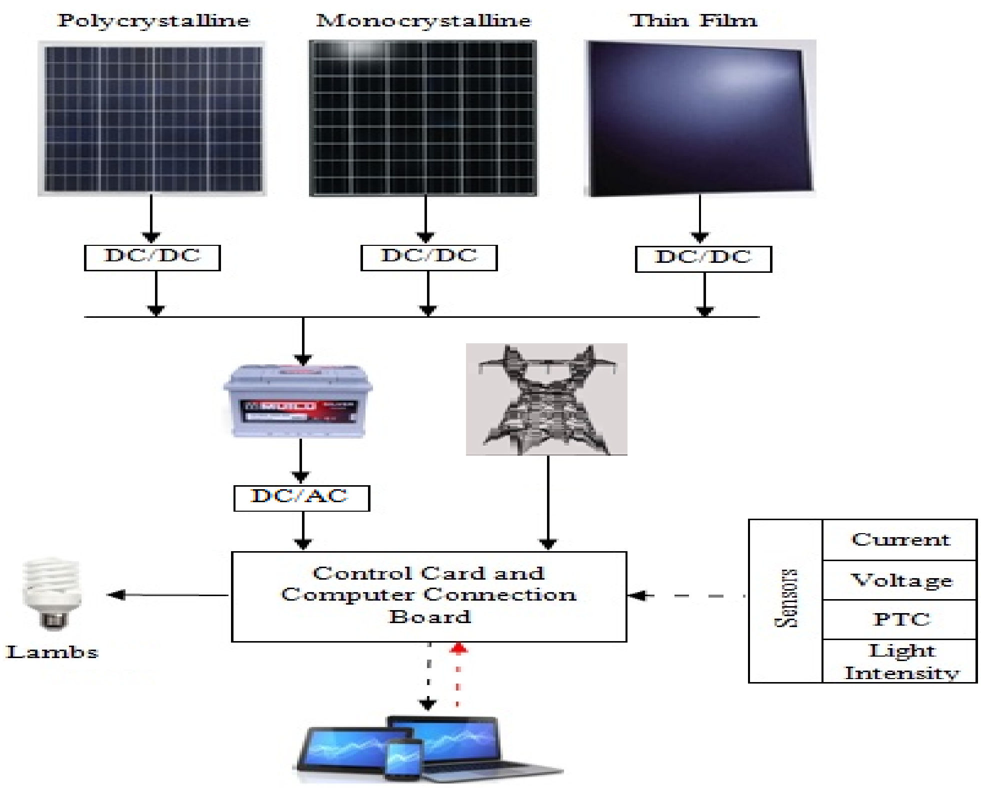


Figure 1. Materials used in the system

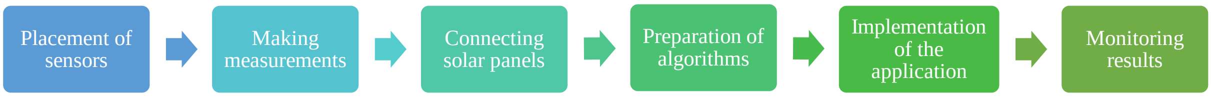


Figure 2. The flow chart of the system

2.1 PV Modules

In this study, monocrystalline, polycrystalline, and thin-film solar panels made of three different materials are used. Technical characteristics belonging to solar panels are shown in Table 1. The installation of monocrystalline, polycrystalline, and thin film solar panels used in the system is shown in Figure 3.

Table 1. Technical properties of solar panels

Technical Specification	Monocrystalline	Polycrystalline)	Thin Film
Maximum Power Voltage	18,06	23,92	45,30
Maximum Power Current (Im)	5,59	4,18	1,16
Open Circuit Voltage (Voc)	22,45	29,50	63
Short Circuit Current (Isc)	5,84	4,52	1,35

Figure 3. Representation of polycrystalline, thin film, and monocrystalline solar modules used in the system

2.2 Contral Cards

In the system, the control card consisting of a PIC18F4550 microcontroller is used to convert analog data from sensors to digital data and send this data to the computer. While selecting the microcontroller to be used in the control card, PIC18F4550 with a USB connectivity is preferred. Thus, the control card converts analog data from the sensors to digital and sends them to the computer with USB connection at the same time.

2.3 Current and Voltage Cards

Current and voltage sensors are added to the output of each solar panel and lighting automation system to measure the forces produced and consumed in the system. AC712-20A is used as the current sensor. To increase the sensitivity of the current sensor, selection was made according to the current produced in the system. The current sensors used for the system are shown in Figure 4.

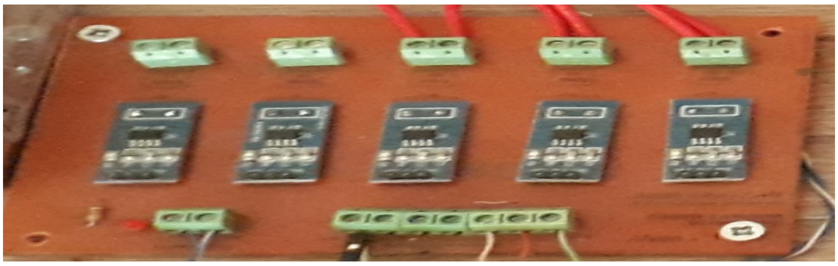


Figure 4. The current sensor card is used in the system.

2.4 Interface Software

An interface prepared in the C # program is used to show the digital data coming from the microcontroller on the computer screen and to save all the data to the access database. The current, voltage, and power produced by three different solar panels are shown with this interface program. The current, voltage and power used by the lighting automation system are shown. In addition, there are outdoor and indoor temperatures, and brightness levels. Manual control is provided with the interface and desired lamp, or lamp groups can be controlled. In addition to the automatic recording of all data at 10-second intervals in the interface, the manual recording feature has also been added. The data recorded in the Access data tab are processed and graphics are drawn. Figure 5 shows the interface designed for the system.

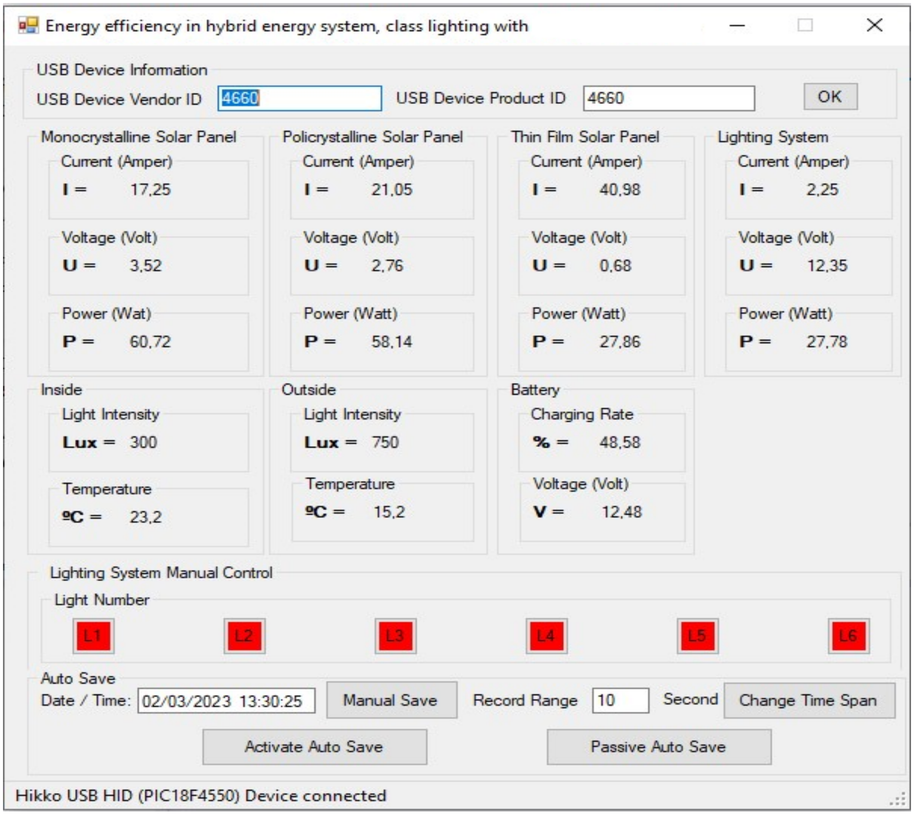


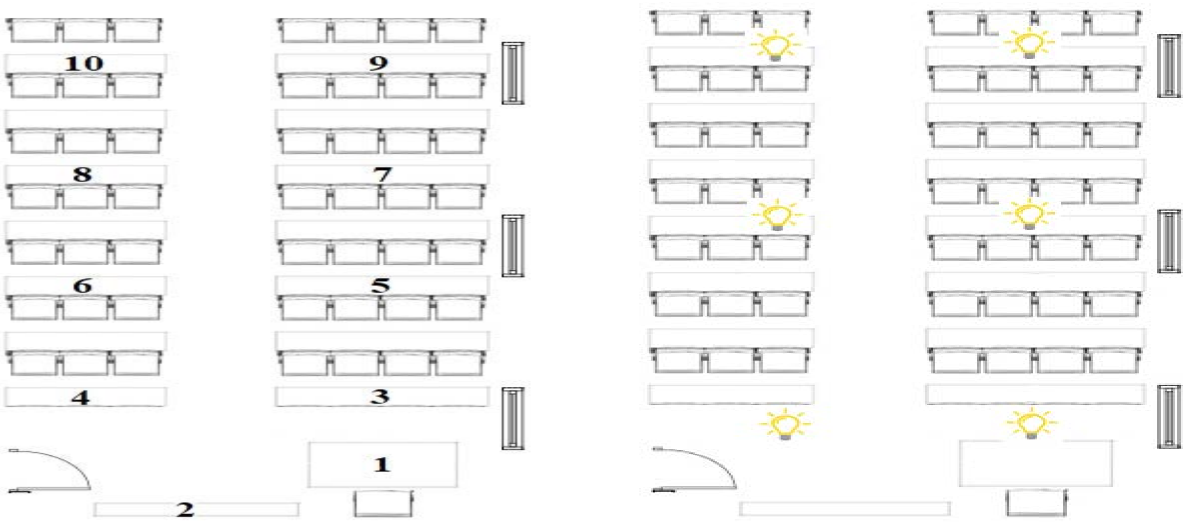
Figure 5. Interface designed for the system

2.4 Lighting Algorithm

In energy efficiency, minimum energy consumption is required besides energy production. Outdoor lighting is optimally utilized to minimize energy consumption. In this, both outdoor and indoor light intensities should be known. MS6610 lux meter was used for outdoor and indoor light level measurements. Figure 6 shows the MS6610 lux meter used for light intensity measurement. MS6610 lux meter accuracy is ± 5%.

Figure 6. Luxmeter

Outdoor lighting intensity and classroom lighting are not sufficient. For this purpose, lighting inside the classroom is required. This lighting is done manually. In this way of lighting, the light level is very high in some places. To determine this, measurements were made from 10 different points in the classroom. In these measurements, it was measured how much illumination that area received. Measurements were made at 10 different points in the classroom environment shown in Figure 7a. 6 groups of lighting are used in classroom lighting. There are 3 groups on the right and 3 on the left. The types of lamps used in lighting are changing. However, the lighting positions in the classroom remain the same. Figure 7b shows the locations of the lighting groups used in the classroom.



a) **b)**

Figure 7a. In-class measurement locations, **b)** Locations of lamp groups used in classroom lighting.

The study was carried out in Dazkırı Vocational School in Dazkırı District of Afyonkarahisar Province. The classroom lighting of the existing classroom on the third floor of the school was adjusted. The classroom is located in the east-west direction. The classroom can receive education for 49 students at the same time. Figure 8a shows the exterior view of the school, Figure 8b shows the interior view of the classroom, and Figure 8c shows the light and temperature sensor used in the study.

a) **b)** **c)**

Figure 8a. The external appearance of the school, **b)** Interior view of the classroom, **c)** Light and temperature sensor

The best lighting in the class is at 300 lux [32, 33]. Outdoor lighting cannot provide this continuously. As a result of the measurements made at 10 different points, the lighting was at a high level near the window, while the other side had a low level of illumination. Light intensities at each point between 8:30 and 17:30 in January are shown in Figure 9a.

There are windows on only one side of the classroom. The area where the window is located naturally receives daylight. Other parties do not benefit from enough daylight. Light intensities were measured from places in the classroom with and without natural light. Since these measurements were made throughout the day, they constantly changed. Light intensity is higher in places with daylight. It is low in places where there is no sunlight. Light intensity measurement results vary depending on the sun condition. It is low at first sunrise and sunset. It reaches its highest level at noon, when the sun is most effective. Lesson times remain between 8:30 and 17:30 while sunrise and sunset change. Therefore, brightness levels change in the classroom. Figure 9b shows the monthly light intensity change at point 1.

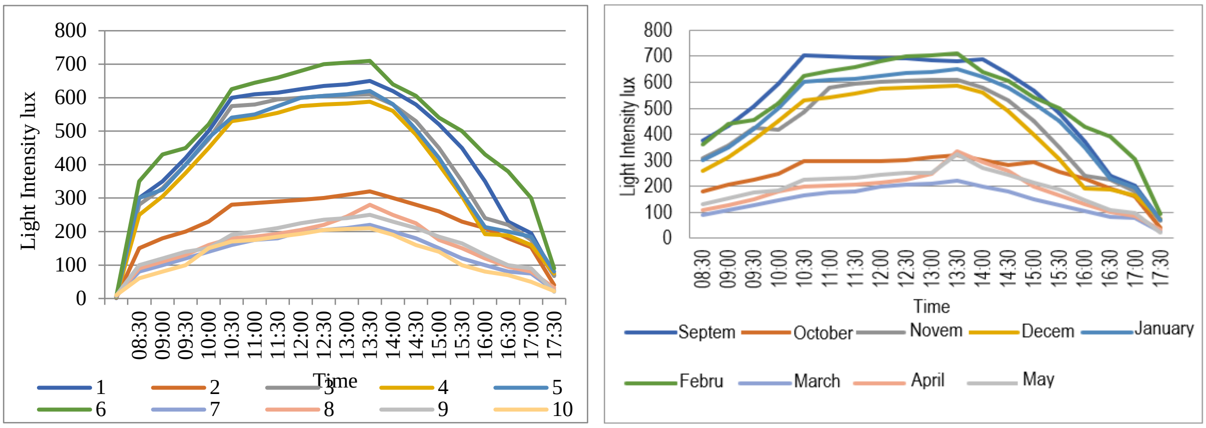


Figure 9a. Light intensities at each measured point, **9b,** Monthly light intensity changes at point 1

2.5 Window Reflection and Refraction

The change in direction of light as it passes from one transparent medium to another is called refraction. The refractive index is a coefficient that shows how much slower light traveling in any material x travels compared to light traveling in a vacuum. Figure 10 shows the refraction of light.

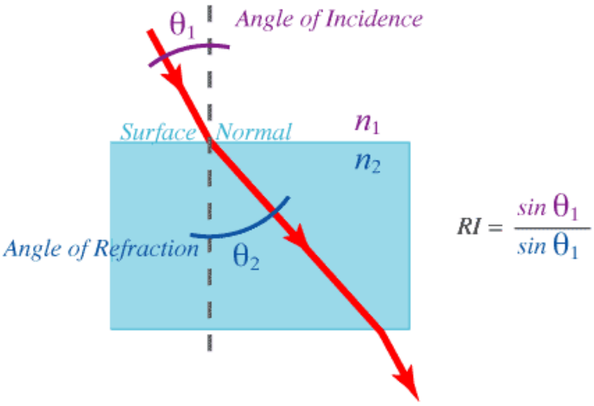


Figure 10. Refraction of light

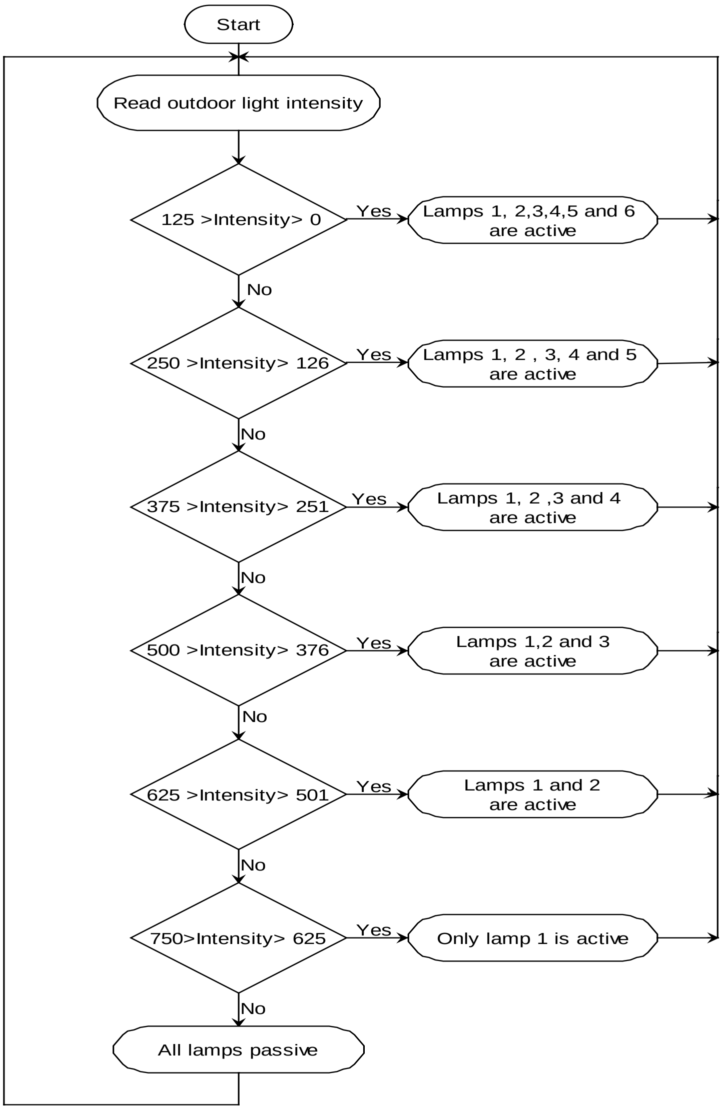


Figure 11. Lighting algorithm

The speed of light in a transparent medium depends on the density of that medium. As the density increases, the speed of light decreases. This means that the smaller of these numbers can be considered as a low-refractive medium, and the larger as a high-refractive medium. If the rays come from a very dense medium to a less dense medium with an angle greater than the boundary angle, they cannot pass to the other medium. In this case, the incident ray is reflected in the same medium with an angle equal to the angle of incidence. This is called total reflection. The refractive coefficient of the glass used in windows has been calculated as 1.51714.

Figure 11 shows the algorithm made in such a way that it makes optimal use of outdoor light intensity. Studying covers an academic period. Sun rays change every month depending on the shape and rotation of the earth. While the classroom receives higher levels of light in some months, it receives lower levels of light in other months. Especially in the summer months, the sun rises early and sets late. For this reason, more daylight is used.

2.6 Energy Requirement

In the system, energy needs are met by solar panels. Energy production of solar panels varies depending on the sun. The energy requirement of the system is independent of the sun. Therefore, the battery was used to store energy. For the capacity selection of the battery, the energy need of the system must be known. Table II shows a one-week lesson program in the classroom.

Table 2. Week lesson

Class Hours	Monday	Tuesday	Wednesday	Thursday	Friday
08:30 – 09:20	X				X
09:30 – 10:20	X				X
10:30 – 11:20	X	X			X
11:30 – 12:20	X	X			X
13:30 – 14:20		X	X	X	
14:30 – 15:20		X	X	X	
15:30 – 16:20		X		X	
16:30 – 17:20		X		X	

Total Power = Total number of lamps x lamp power

Total Power = 12 x 32 = 384 Waat

While calculating the weekly energy consumption, the class hours in the class should be taken into consideration. There are 20 hours of lecture per week in the classroom.

Weekly energy consumption = Weekly lesson hours x hourly energy consumption of lamps

Weekly energy consumption = 20 x 384 = 7680 Waat

2.7 System Overview

The external and internal view of the system realized in Figure 12 is shown. The system can be controlled in three different ways. Firstly, the system can be manually controlled and controlled with the buttons under the tablet. There is a control button for each lamp. Secondly, the system can be automated and used. In automatic control, manual buttons become passive. In automatic control, control is provided according to the most efficient algorithm installed in the system. In automatic control, all data are displayed on the LCD screen and recorded in the Access database. The lamps can also be controlled manually with the control buttons on the bottom of the computer, if desired.

Figure 12. Internal and external view of the system

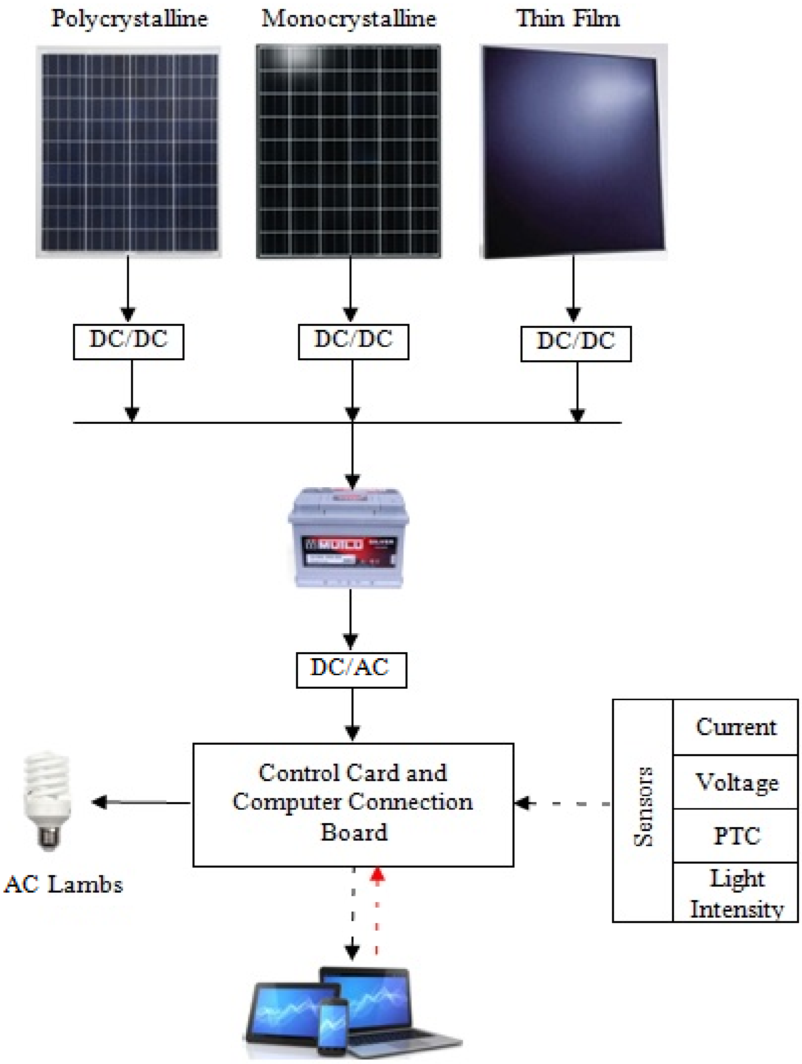


Figure 13. General representation

2.8 *Energy Flow Algorithm I*

In the first algorithm implemented, the AC lamps used in classroom lighting were not changed. Solar panels are used as an energy source. Solar panels also produce DC energy. For the lighting system to work, the DC energy produced must be converted into AC energy. DC/AC inverter was used for this. Table 3 shows the technical specifications of the inverter used in the system.

Table 3. The technical specifications of the inverter used in the system

Name	Explanation
Power	1000 Watt
Input Voltage	12 Volt
Output Voltage	220 Volt
Wave Type	Modified Sine Wave
Productivity	%90
Frequency	50 Hz

In this algorithm, only solar panels are used as energy sources. The electrical energy produced in solar panels is connected to the battery in a single busbar by passing through DC / DC converters. The battery is charged with the electrical energy produced by monocrystalline, polycrystalline, and thin-film solar panels. The electrical energy required by the consumer is also supplied by the battery. The general representation is shown in Figure 13 and the algorithm I is shown in Figure 14.

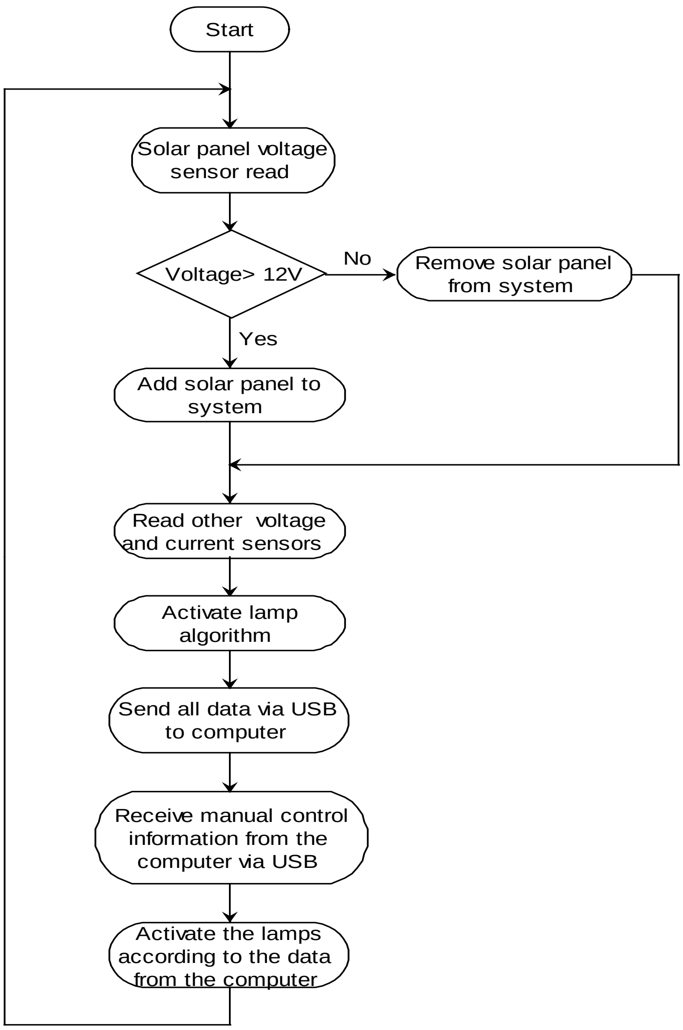


Figure 14. Algorithm I

2.9 Energy Flow Algorithm II

In this algorithm, besides three different solar panels, the network is used as an energy source. While solar panels produce enough energy in summer, they cannot meet the energy required by the system in winter. Since the energy stored in the battery is low in winter, it cannot be used much. The network was used to meet the energy needed by the system. Algorithm II is shown in Figure 15, and the general diagram is shown in Figure 16.

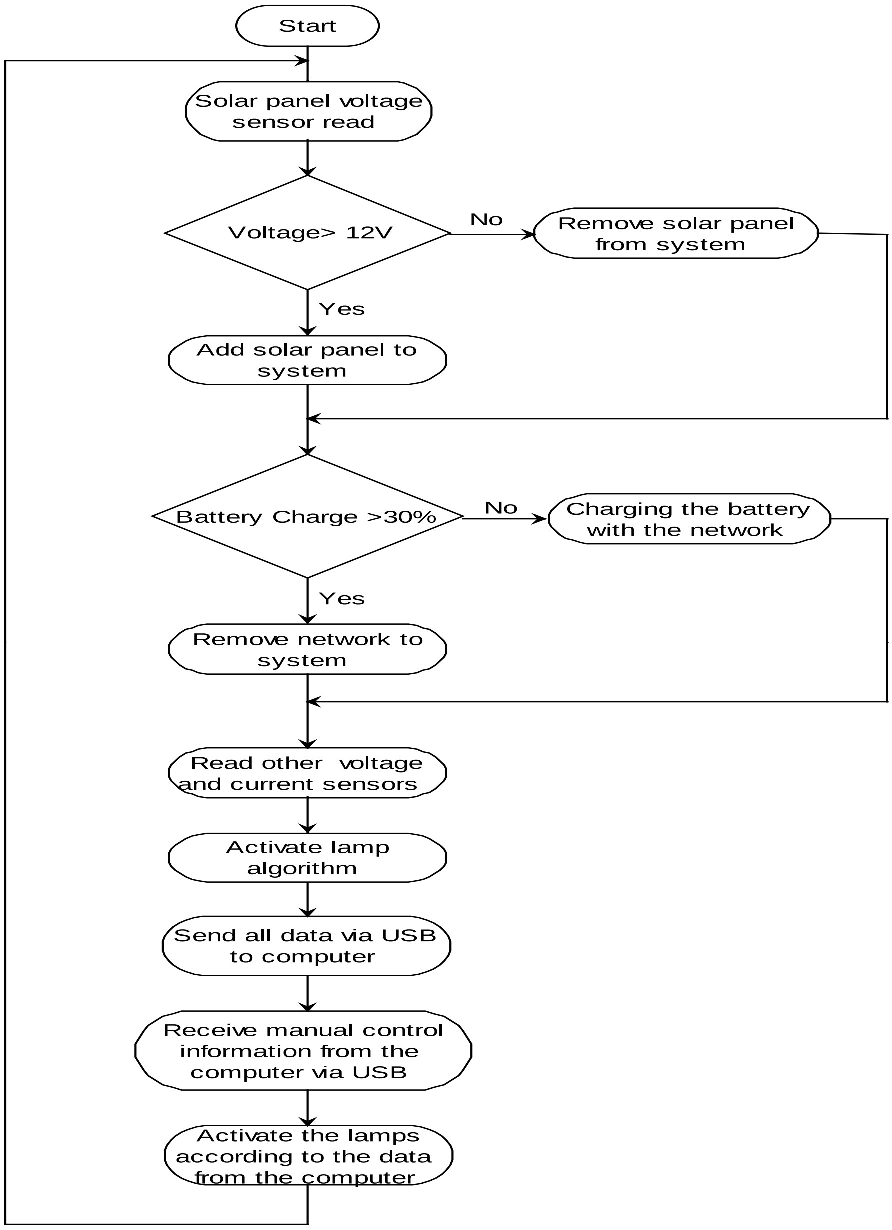


Figure 15. Algorithm II

2.10 Energy Flow Algorithm III

In this algorithm, a DC lamp is used instead of an AC lamp to increase energy saving. An energy saving of 23W per lamp was achieved by using a 9W DC lamp instead of a 32W AC lamp. In addition, the losses in converters have been saved. Figure 17 shows the general form of algorithm III.

2.11 Uncertainty Analysis

A sensitive method called uncertainty analysis is used for error analysis of experimental findings. According to this method, the quantity to be measured in the system is R, and the n independent variables affecting this quantity are shown as x1, x2, x3, ……, xn. The uncertainty analysis formula is shown in Equation 1. In the study, the light sensors are shown as x. Since measurements were made from 11 different points in the study, there are 11 x. The uncertainty analysis calculation of the study is shown in Equation 2.

$$W_R = \left[\left(\frac{\partial R}{\partial X_1} W_1\right)^2 + \left(\frac{\partial R}{\partial X_2} W_2\right)^2 + \left(\frac{\partial R}{\partial X_3} W_3\right)^2 + \left(\frac{\partial R}{\partial X_4} W_4\right)^2 + \cdots + \left(\frac{\partial R}{\partial X_{n11}} W_{n11}\right)^2\right]^{1/2} \quad (1)$$

$$W_R = \left[\left(\frac{0.05}{300}\right)^2 + \left(\frac{0.05}{300}\right)^2 + \left(\frac{0.05}{300}\right)^2 + \left(\frac{0.05}{300}\right)^2 + \cdots + \left(\frac{0.05}{300}\right)^2\right]^{1/2} \quad (2)$$

$$W_R = 5.52 \quad (3)$$

As a result of the calculations, the uncertainty analysis of the system was calculated as 5.52%.

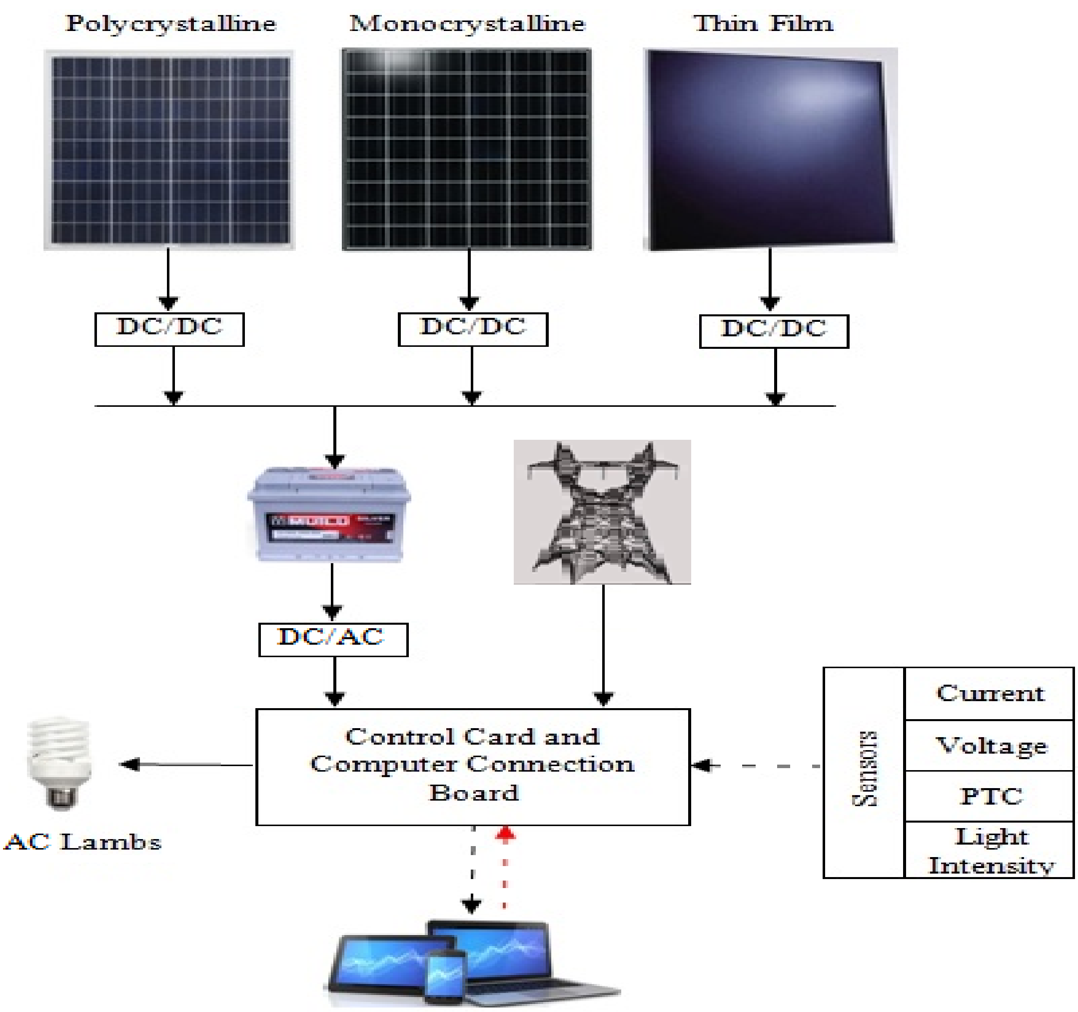


Figure 16. General representation

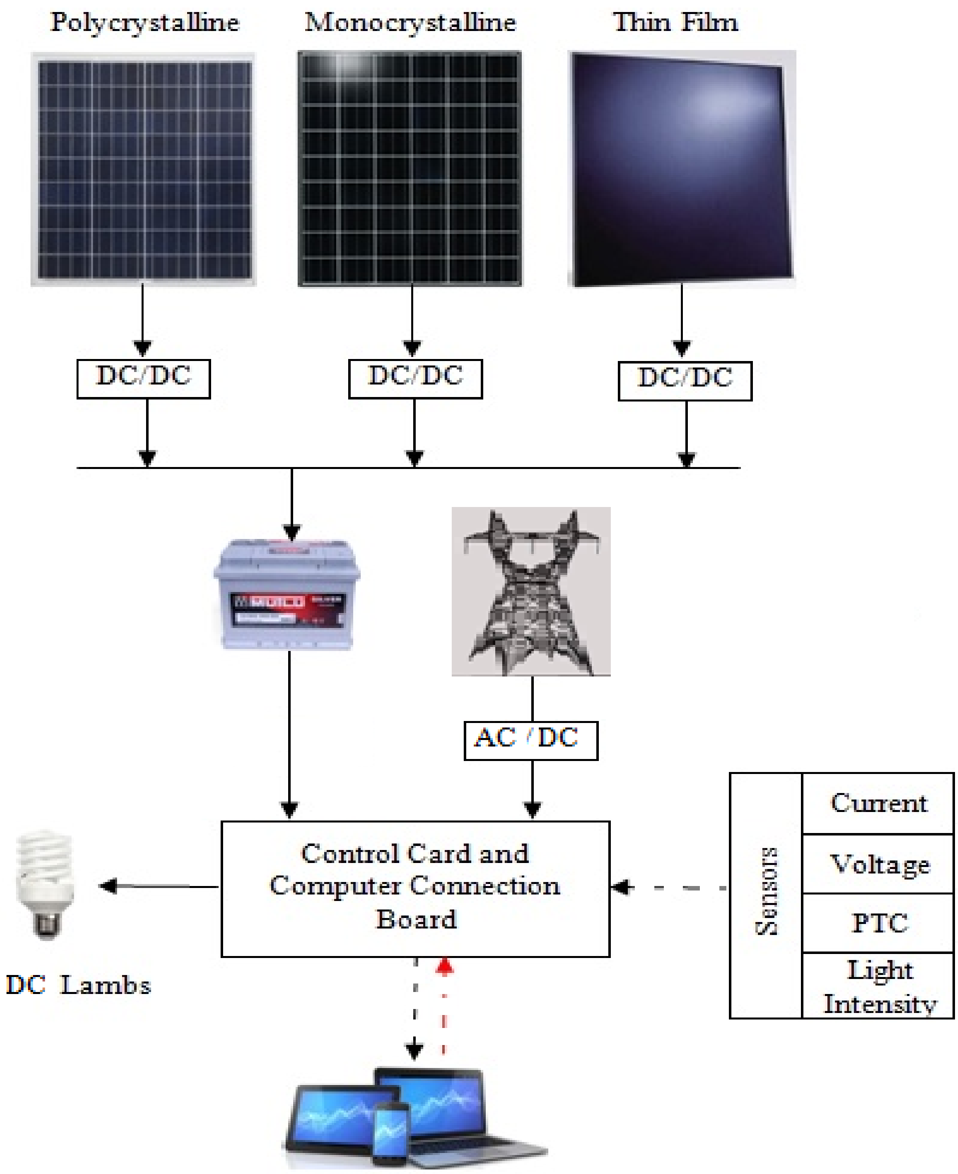


Figure 17. General representation.

III. RESULTS AND DISCUSSIONS

This study achieved three aims. The first goal in classroom lighting is to make the most of outdoor lighting. Second objective: Comparing the energy production of three different solar panel types. The final aim is; It is the best use of the energy produced by controlling the energy flow in the energy production system. To do this, three different algorithms were applied for a single energy flow in classroom interior lighting. Figure 18 compares the energy production of three different solar panels.

When the energy production of monocrystalline, polycrystalline and thin film solar panels is compared, there are differences between the energy productions. The monocrystalline solar panel produces 41% of the total energy. Polycrystalline solar panels produce 40% of the total energy. Thin film solar panels produce 19% of the energy. When looking at the costs of solar panels, the thin film solar panel is the costliest solar panel. Monocrystalline solar panels come second in terms of cost. The cheapest solar panel type is the polycrystalline solar panel. Polycrystalline solar panels are the most suitable type of solar panel when comparing cost and energy production.

In the study carried out, the energy demand is completely independent of the energy produced. While the energy produced in the summer is at the highest level, the energy demand is at the lowest. In winter, energy demand increases while energy production decreases. In the realized system, energy efficiency increase has been realized by using three different algorithms for energy flow. Figure 19 shows three different algorithms and energy demands of normal operation every month.

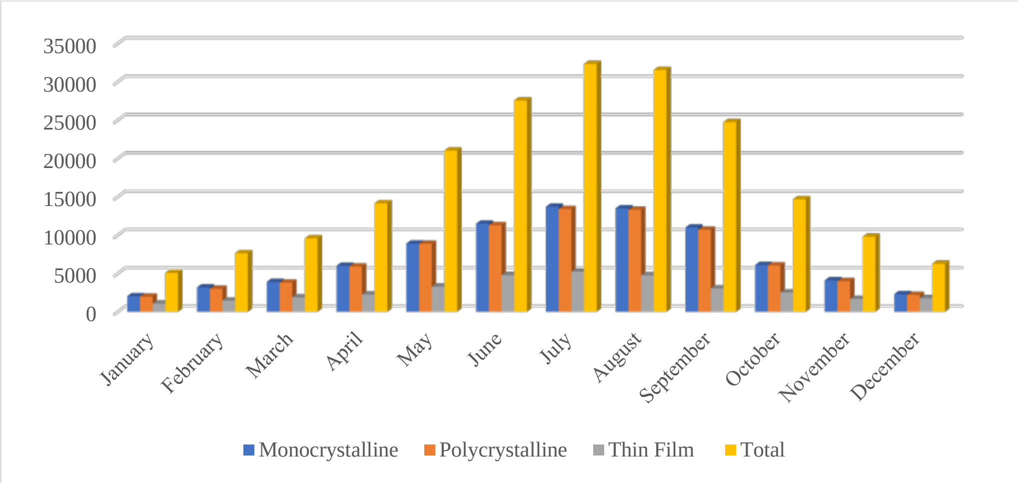


Figure 18. Compare the energy production of three different solar panels

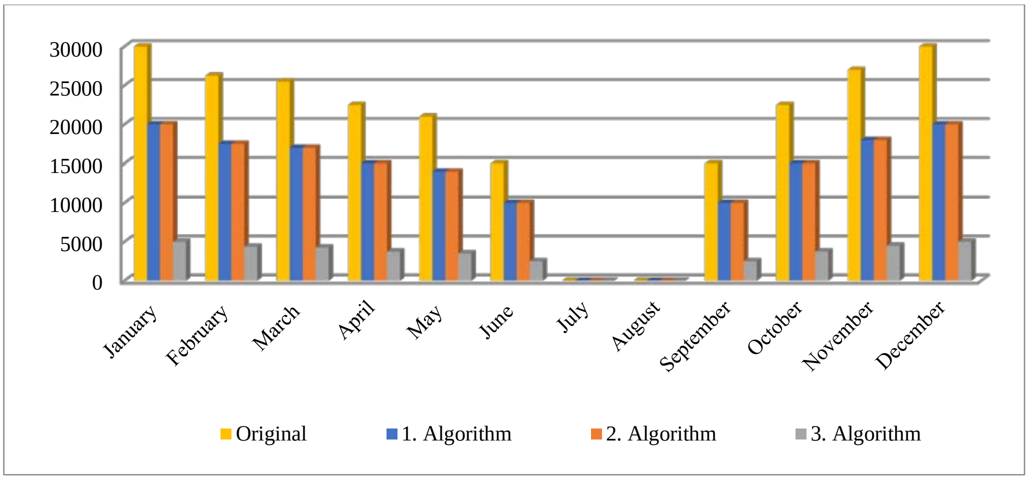


Figure 19. Monthly energy demands

There is a very high energy requirement in normal lighting. The main reason why the energy is so high is that all of its lamps light up at the same time. External lighting is not used in any way. Some areas have very high illumination, while some areas have low illumination. Energy demand appears to be the same for the first and second algorithms. The difference between these algorithms is the amount of energy produced that meets the demand. The difference between the second algorithms from the first algorithm is that the network is added as an energy source. Energy demand cannot be met due to low energy production in winter and no energy production on some days. To meet the energy demand continuously, the network has been added to the second algorithm as an energy source. Thus, the energy demanded by the consumer is constantly met. Figure 20 shows the energy and energy demands generated in each algorithm. The lowest energy demand occurred in the last algorithm. The main reason for this is the use of DC lamps with low energy consumption.

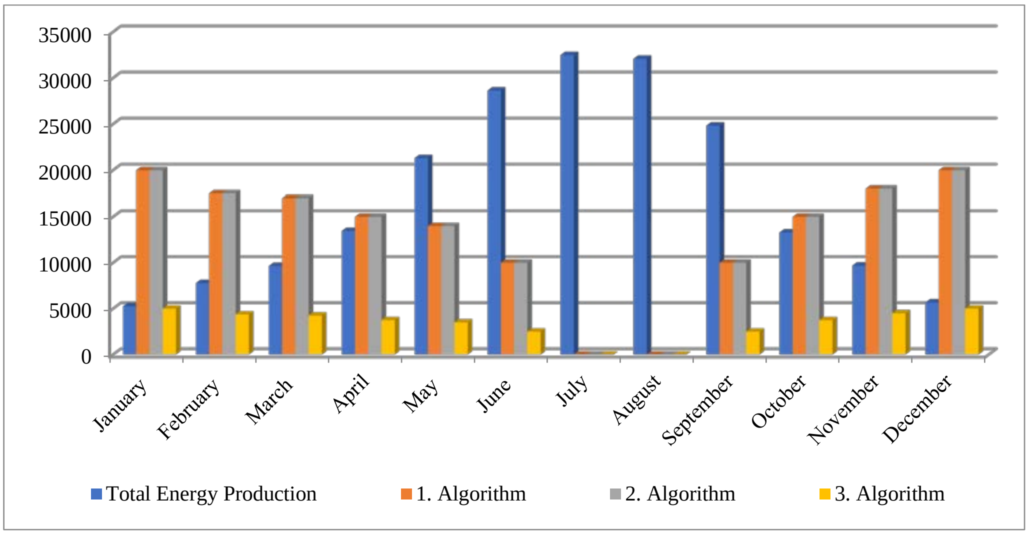


Figure 20. Monthly energy production and demands

Fluorescent lamps used in classroom lighting have many side effects on students. Since fluorescent lamps emit vibrations above 100 Hz, they cause students to experience headaches and poor performance. In a study conducted in England, the average lighting level in classrooms was Due to excessive daylight and artificial lighting sources, 88% of the classrooms are above the recommended lighting level. In 84% of the classrooms, lighting levels are above levels that impair visual comfort [33]. The effect of lighting levels on students is effective not only in primary schools but also in universities [34-36]. In their study, Dang and his colleagues proved that there is a direct relationship between the quality of the classroom lighting environment and visual fatigue. A change in the quality of lighting in the classroom causes visual fatigue in students. Students have difficulty expressing themselves due to visual fatigue [37]. Gentile stated in his study that LED lighting is much more economical than classical lighting. It has been proven that especially the lighting level of 300 lux in the classroom has a positive effect on learning [38]. Castilla conducted a survey for students at the university. The survey asked about the direct benefits of improving the quality of indoor lighting in educational environments in increasing the productivity and alertness of students and teachers. According to the survey results, it was concluded that LED lighting is more efficient instead of fluorescent indoor lighting [39]. Kong conducted a survey of university students about lighting. 333 participants participated in the survey. He examined the effects of different lighting methods used in laboratories. According to the survey results, it is understood that electrically illuminated classrooms offer more homogeneous lighting environments [40]. In order for students to receive a good education even in classrooms, the lighting level must be adjusted very well. In the study, illumination levels between 100 lux and 600 lux were examined. It has been determined that the best lighting level for education is 300 lux. Modeling was done in a kindergarten classroom to make better use of daylight. In modeling, daylight is used at different rates within the classroom on an annual basis. With the simulation, full use of daylight and lighting techniques were used. As a result of the study, a savings of 6.7% was achieved [41]. According to literature studies, it is understood that the best indoor classroom lighting is 300 lux. It has also been determined that daylight illumination is not sufficient and excessive illumination negatively affects education. A real application was made with the study. Maximum benefit was made from daylight. The illumination level of 300 lux required for training was used at the optimum level with the algorithms.It has been calculated how much energy will be saved by using LED lamps instead of fluorescent lamps. A solar energy system was used to save energy. The energy production of solar panel types existing in the solar energy system was compared. The most suitable solar panel type has been determined.

IV. CONCLUSIONS

In the study, energy efficiency in classroom lighting was increased. For this, external lighting was used at the highest level. In addition, classroom lighting was set at 300 lux, which is the best level for education. In this way, energy efficiency was provided and at the same time, a positive effect on education was provided. Three arc solar panels and three different algorithms were used in the study. In the study, firstly, the most effective solar panel type in the application area was determined. In the study, monocrystalline solar panels provided 41% of energy production. The polycrystalline solar panel achieved 40% and the thin film solar panel achieved 19%. The monocrystalline solar panel produced the highest energy. Despite this, when the prices of polycrystalline solar panels are more affordable, they are used more in the field. The energy produced in energy efficiency should be consumed most optimally. In the study, outdoor environment lighting was used at the highest level for classroom lighting. For this, one lighting algorithm, and three energy flow algorithms were used. While normal lighting energy consumption was the highest at 30000kWh, it was 20000 kWh in 1st Algorithm, 19800kWh in 2 Algorithms and 5000kWh in 3rd Algorithm. As a result of the fact that there is no control in normal lighting and all of the lamps are lit together, a very high energy consumption has occurred. Energy consumption was reduced by 33.33% in the first, and second algorithms. With the third algorithm, this consumption decreases by 83.33%. With this algorithm, energy production-consumption is profitable in December and January when the energy production is the lowest and the energy consumption is the highest. In other months, while energy production increases, energy consumption decreases.

It is considered to add deep learning to the work carried out in future studies. By adding deep learning, person detection will be performed in the classroom. Only the area where the people are located will be illuminated. At the same time, when there is no detection in the classroom, the system will turn off all the lights and increase energy efficiency.

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