Passive Steel House Designed with Usage of Solar Energy Sources and Building Materials

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Abstract- This study focuses on the passive steel house design using photovoltaic power systems and examines building materials. The concept of a passive house assumes that the energy consumption of other potentially energy-consuming sources in the building is kept to a minimum. Firstly, suitable building materials for passive steel house are examined. Since rock wool is a non-combustible material and provides very good sound and heat insulation, it can be preferred. Due to the high compressive strength and moisture resistance, extruded polystyrene plate is preferred on under the ground flooring. Fibercement boards are easily used as interior and exterior cladding in passive steel house. The designed passive steel house has an area of approximately 150 m2. The use of renewable energy sources is one of the most important factors that determine the energy efficiency of buildings. In this study, solar energy has been examined. Monocrystalline photovoltaic panels are sufficient to meet the energy needs of the passive house. Passive steel house is located in Istanbul and the global radiation value is approximately 1400 kWh/m2-year. Annual energy production of the monocrystallian panel is calculated as 18,893.5 kWh. The required installed power is calculated approximately 4 kW for connected to the grid and 5 kW for independent from the grid. 22 monocrystalline panels are used to meet the energy needs of the house. In new buildings designed due to the increase in energy costs today, it is important and necessary to save energy and to spread the houses that produce its own energy.

Keywords Passive steel house, building materials, photovoltaic power system, cost analysis, energy calculations.

1. Introduction

In proportion to population growth, energy consumption is increasing day by day in the world and especially in developing countries. Although fossil fuels meet a large part of the world's energy needs, the reserves of fossil fuels are being depleted rapidly. It is estimated that the reserves of some fossil fuels such as natural gas and oil are approaching in the second half of the 21st century, so the efficient use of all energy resources is of great importance. While the need for energy is increasing, there are many applications for efficient consumption of energy in the world where limited resources are depleted. Consumption according to the energy resources in the world is given in Fig. 1. Due to the gradual decrease in energy resources and the increase in energy demand, awareness around the world has led people to work on concepts such as sustainability, energy conservation and environmental awareness. With the 1973 oil crisis, it became increasingly difficult to reach energy. The events of 1973 exceeded the attempts to contain them as a matter of market forces. New doubts about the supply problem and the possible limits of oil reserves, the increasing difficulty of predicting future demand and prices, the inability to prevent catastrophic oil spills and environmental protection have been triggered [1].

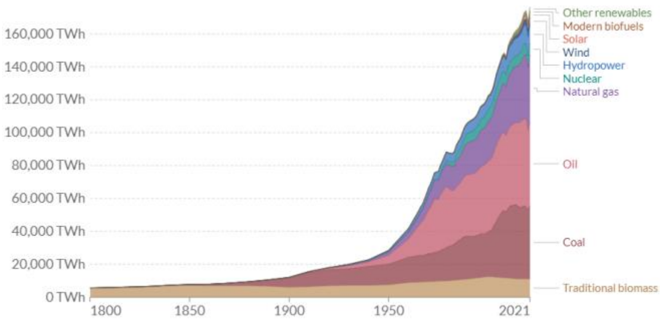

Fig. 1. Global primary energy consumption by source [2]

For this reason, the concepts of sustainability, ecology and energy have started to be discussed. While housing, industry and transportation are the most important factors, energy use also comes to the fore. On the other hand, fuel prices increase simultaneously with the increase in energy demand. Gases that pose a danger to the atmosphere and the natural environment are released for the fuel used, and global warming becomes inevitable. In today's century, it has led to the emergence of building designs that include environmental awareness and energy saving in order to minimize environmental problems and leave a livable world to future generations.

Industry, building, transportation and electrical facilities sectors are among the sectors that consume the most energy worldwide [3]. The share of the building sector in final energy consumption is constantly increasing. Energy consumption of a building accounts for nearly 40% of the total energy generation in a developed country [4], with traditional houses containing a higher number of inefficient energy systems. Systems such as heating, ventilation, cooling and lighting provide comfort conditions in buildings. Hence, increased efforts are being exerted toward passive and net-zero building concepts. While energy efficiency is an important criterion for buildings, it is also important to save energy without sacrificing comfort conditions and to reduce the energy costs consumed. For this reason, the fuel used in the buildings and the energy to be consumed should be at the lowest level, but this requires a cost. When buildings are taken as a basis, efforts to increase energy efficiency in buildings have a significant share in total consumption. The use of renewable energy sources is one of the most important factors that determine the energy efficiency of buildings [5]. The use of renewable energy sources in buildings does not bring any other cost other than initial investment and maintenance costs. With these systems, it is aimed to minimize fossil energy consumption by meeting some or all of the building's electricity, hot water and heating needs. In this context, the term passive is defined as the heat emitted by the residents' own household appliances, where the main source of heating is the sun, and the heat passively consumed by the house without the need for special heating systems [6]. Furthermore, the concept of a passive house assumes that the energy consumption of other potentially energy-consuming sources in the building is kept to a minimum. The target of a passive dwelling is to reduce its ecological footprint. This concept is not only framed in residential dwellings but is also widely used in office buildings, schools, and other types of buildings. The passive concept is not a retrofit or a supplement for the architectural design of an existing building [4]. It is integrated with the architectural design of the building. Furthermore, constructing a passive house brings much more benefits than operating as a low-energy building. A house designed according to passive concepts could be helpful to provide higher comfort levels to its residents [7]. The maximum annual heating requirement for the passive house is defined as 15 kWh/m^2 [8]. The standard was first developed by Wolfgang Feist, and is now regulated by the "passive hause" German Institute for passive houses [9]. The five basic principles at the center of the passive house design and construction are high-performance glazing, airtight construction, superinsulated envelopes, heat recovery ventilation and thermal-bridge-free detailing [10].

The introduction of renewable energy sources to cater to the energy requirement introduces a novel concept: net-zero building [11]. A net-zero energy building showcases characteristics such as having equal electricity generation for its usage in operation, net-zero greenhouse gas emissions, and significant reductions in energy demand [12]. Today, energy efficient buildings are designed by using mostly solar and wind energy from renewable energy sources. On the other hand, as a case study especially in Istanbul, published information on the use of solar energy sources and building materials for passive steel house is still limited. In this study, photovoltaic power systems and suitable building materials have been examined, and the residential sector, which is one of the important areas where energy can be used more efficiently in the design of passive house, is taken as a basis. A cost study was conducted to meet the annual energy need of the passive house. In addition, the power capacity of the photovoltaic system that will meet the energy need has been calculated. In this way, it is aimed to increase awareness by giving the necessary importance to this issue in the context of energy saving philosophy.

2. Materials and Methods

In this section, building materials and passive house desisgn methods are examined.

2.1. Building Materials

Before the industrial revolution, natural materials such as stone, wood and adobe were used in the buildings [13]. These materials did not contain any additives and were used in their pure form in nature. Wood and stone were only used by cutting and grinding, and adobe, which was turned into mortar, could be obtained in desired dimensions. The materials used in the construction field have gained diversity after the industrial revolution. Artificial materials, which have undergone some processes in the industry, have created an alternative to natural materials in the construction of buildings [14]. By adding some additives to natural materials, artificial materials can be obtained in desired standards and sizes, with desired properties.

When a general evaluation of the building materials that can be preferred in the passive house system is made, in addition to its important physical properties, rock wool can be preferred in the passive steel house system because it is a non-combustible material and provides very good heat and sound insulation. Itewi [15] suggested the use of rock wool as a good insulation material to insulate exterior walls in green building construction. It has been stated that rock wool has a wide product collection due to its extraordinary capacity to prevent sound and heat. Extruded polystyrene (XPS) sheets have high compressive strength and moisture resistance. XPS had been identified as an attractive thermal insulation material due to its availability, low cost, low thermal conductivity, and significant creep resistance at room temperature [16]. It can be applied under the floor and on the floors sitting on the ground, at the same time it protects the building envelope from condensation and corrosion. Therefore, the passive steel house system can be used for underfloor flooring. Fibercement boards are not an insulation material on their own. However, they have very good heat and sound insulation values. It is used with materials with high insulation value and is fully resistant to fire. They can be preferred in passive steel house system as they are easily used as interior and exterior cladding in all kinds of buildings and in every detail of the building.

2.1.1. Steel Construction Systems and Its Usage in Architecture

With the industrialization and development of the modern world, the demand for large-span structures has increased, so it has become common for steel to be consumed in structural system applications of materials. In addition, steel, which is a 90% recyclable material, does not lose its properties no matter how much recycling is applied, it is an environmentally friendly material that does not harm the environment. With the production of iron and steel, the inclusion of these materials in construction techniques has been one of the most important steps in the development of architecture. With the transition to mass production, steel has established its place as the indispensable structure of modern buildings. In the study carried out by Marchwinski [17], the architectural importance of steel used as a construction material was also examined. Due to its advantages such as high tensile strength and lightness, it is extremely suitable for large span coverings in terms of construction. Thus, it is a preferred material for production buildings, warehouses, public buildings and sports halls. Architecturally, these applications have a strong impact, as a steel structure also creates the visual aesthetics of the building. The impact and contribution of steel on modern architecture has also increased and steel has removed the borders in the process of bringing original structures to life. For this reason, steel has become indispensable for creative designs.

Within the framework of today's architectural understanding, steel structures are one of the most important elements in the enrichment of the building and the formation of a different architectural language. At the same time, the steel structure offers endless options. The steel structure combined with controlled production, accurate planning and project management makes it easy to build the most challenging projects. The reason why it is preferred in terms of application and construction is that it reduces the construction period, the weight of the structure is low, the main cost is reduced, it can be disassembled, easily adapted to changes, it is more resistant to earthquakes, and it provides convenience and flexibility in the distribution of mechanical and electrical installations [18].

2.2. Passive House

Among different sectors, the building sector is a significant consumer of energy and natural resources, and it potentially damages the environment [19]. For instance, in Europe, the impact on the buildings' life cycle is around 50% of all energy use, 33% of all water use, 50% of all raw material extraction, and 40% of all greenhouse gas emissions [20]. From this perspective, any effort towards increasing sustainability and cleaner construction must include this sector as a critical element in decreasing the total energy usage and greenhouse gases. Concerning the desire to reduce building energy use and greenhouse gases, the operational stage of a building is critically important as it typically contributes to 60–90% of the total building environmental impacts [21, 22]. Several strategies may help to achieve a significant reduction of energy use in the building operation phase: (i) minimizing the need for energy inputs; (ii) adopting buildings with energy-efficient and low-carbon technologies; (iii) decarbonize of the electricity mix production and use on-site electricity production; and (iv) variation of occupant behaviors [23, 24]. The Passive House Institute was established in Darmstadt in 1996 to promote and control passive house standards. According to the targets set by the Passive House Institute by using standard construction materials and technologies, the annual heating load should be kept below 15 kW/m2 and the total primary energy consumption (heating, hot water and domestic electricity) should be kept below 120 kW/m2 [25]. Buildings based on the passive house concept are ultra-low energy buildings that reduce their ecological footprint, have a voluntary standard for energy efficiency, and require low energy for space cooling or heating. Passive design is not an add-on or complement to architectural design, it is a design process that integrates with architectural design.

Worldwide, the number of houses built according to the passive house standard is over 50,000 [26]. In 2017, there are approximately 10 projects in Turkey, three of which are certified and the implementation has been completed. The basic idea of the passive house is to reduce heat losses to the point where the internal sources and solar gains compensate for the heat loss and there is no need for a separate heating system. A very good thermal insulation coating should be done on the building envelope. The heat transfer coefficient values of the building exterior wall are generally in the range of 0.10-0.15 W/(m2K) [27]. In passive houses, since the electricity need of the house is the largest element of the total energy demand of the house, having high-efficiency electrical devices in the house can be presented as a solution proposal [28].

According to the passive house standard, the passive house should have high energy efficiency, be economical and at the same time be environmentally friendly. High heat preservation, air tightness and high efficiency heat recovery from the exhausted air are the main considerations in the design. The provision of comfort conditions is achieved with minimum energy consumption, without the need for a traditional heating system, by using the internal heat gain and the gain obtained from the sun. In the passive house system, preheating or cooling the fresh air is important and necessary. Passive houses are a fundamental concept and apply to all climates. The building envelope, consisting of special windows, highly insulated exterior walls, and roof and floor, is used to reach the desired interior temperature.

Shading is done to keep heat and energy losses to a minimum. Balanced and continuous clean air is provided in the indoor environment, and the efficient heat recovery unit ensures that the heat contained in the polluted air is reused. With the passive house standard, the living comfort of the building occupants increases. It offers the user a cost-effective way to keep the energy demand of new buildings to a minimum. Thus, the basis of the use of renewable resources is formed in order to meet the energy needs. The passive house standard can be applied to all kinds of structures, including commercial, industrial, residential and public buildings built with steel, wood, masonry, brick, reinforced concrete, prefabricated systems [29].

In the design of a passive house standard, the windows should be oriented towards the south. Since windows facing north will increase energy consumption, windows should not be opened on the north facade if possible, or places that require a large number of windows during design should not be located on the north facade. By insulating the building shell with appropriate materials and using appropriate window glazes, the heat can be controlled and captured inside the house in winter and released outside in the summer [30]. Special windows used for passive house design vary from climate to climate, but three-layer glazing with low-glazing, argon gas and insulated frames is commonly used [29]. Passive houses save 90% of energy compared to traditional houses. In today's conditions, where energy is of vital importance, independent living spaces gain importance in terms of energy needs. The advantages of passive house are [25];

- By reducing CO_2 emissions in passive houses, 90% savings are achieved. Thanks to thermal insulation and energy efficiency, the results obtained in terms of natural environment and economy reach very good levels.
- Thermal insulation made according to passive house standards ensures a balanced temperature distribution in the interior of the building envelope and provides comfort.
- Good thermal insulation, reduction of thermal bridges, air tightness and reinforced ventilation are extremely beneficial in preventing structural damage.
- The ventilation system takes the outside air and provides clean and filtered air to the inside, allowing for continuous clean air and thus creating a healthy environment inside.
- Passive houses use surrounding energy sources such as natural lighting, natural ventilation and solar energy instead of purchased energy such as electricity or natural gas, while active houses use purchased energy to keep the building comfortable.

2.2.1. *Passive House Design*

In the passive house design phase, the basic rule is to ensure that the form designed for the building makes maximum use of the sun. The main purpose is to keep the building standard and to minimize the energy inputs. The production, operation, use, maintenance and air-conditioning systems of all materials and components selected for the building are important factors in achieving this goal. Central ventilation should be installed in passive houses. Ventilation is not possible by opening the window. Regenerative heat system is installed. Furthermore, natural environment, solar radiation, air temperature, humidity and wind are important parameters. Wind is an important factor for ecological design. The direction of the land, its slope, location, building height, facade slope and roof type (gable, terrace, hipped roof) are parameters related to the building. In passive houses, it is necessary to provide very good insulation, air tightness, elimination of thermal bridges and a compact building envelope [31].

For passive houses, at the project design stage, designing a compact body (building shell) is the most important factor in terms of energy efficiency. Apart from electricity companies, this system can be applied in residences as well as in all administrative buildings and public institutions. A healthy and ecological, compact building shell is designed in the structure created. The housing, designed with simple, neat forms and materials, energy efficient and low maintenance cost, was created with light steel construction technology. Small windows were used in the north and large windows in the south. Since it is important to benefit more from the sun, there is also a winter garden in the project. Thus, in winter, heat energy is taken from sunlight and stored. The house has mechanical ventilation with heat recovery. The designed passive house has an area of approximately 150 m2. There are high, large windows on the south façade, thus allowing the passive house to benefit more from daylight. The entrance to the passive house is on the north side. Passive house modeling was carried out with the Revit architectural program [32], which allows not only to build geometrically correct structures, but also to attach real elements with specific dimensions to abstract geometry. The ground floor and the first floor plans of the designed passive house are shown in Figs. 2 and 3, respectively.

Fig. 2. Ground floor plan

In a part of the terrace area on the first floor, there is a light-filled (glass partition) winter garden. The winter garden has an area of 22 m^2.

Fig. 3. First floor plan

The south and north facade plans of the designed passive house are shown in Figs. 4 and 5, respectively. There are high windows on the south facade of the ground floor. The facade of the first floor, where the winter garden is located, is designed with a glass partition that receives light. It is advantageous to use high windows to get maximum energy on the south facade. Since the winter garden on the first floor is designed as a glass partition, the passive house benefits from daylight more.

Fig. 4. South facade

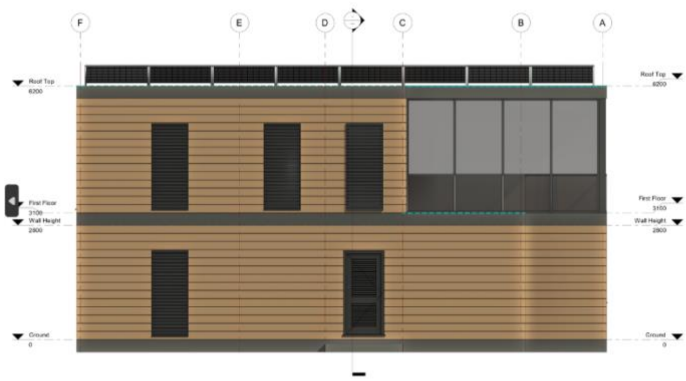

Fig. 5. North façade

There is an entrance to the passive steel house on the north facade. On the first floor, there are three windows. The windows are smaller than those on the south facade to avoid heat losses.

After the floor plans were created, the model was created by choosing the materials used for the designed passive house. Two models are included in this study. Models 1 and 2 are shown in Figs. 6 and 7, respectively. In model 1, the south and east facades come to the fore, while in model 2, the north facade and the winter garden come to the fore. While modeling, the images of the photovoltaic panel application in the terrace roof area are also specified. In the calculations carried out, it is seen that the photovoltaic panels are sufficient to meet the energy needs of the passive house.

Fig. 6. Model 1

Model 2, has two balconies that can be seen in the terrace area. The entrance and windows on the north facade are visible. A winter garden is designed in a part of the terrace area.

Fig. 7. Model 2

3. Results and Discussion

In this section, passive steel house cost analysis, using solar energy systems in passive steel house system and energy calculations for photovoltaic power systems are studied.

3.1. Passive Steel House Cost

Energy saving in the passive house is a very important concept. The passive house, built with good design and ready-to-use components, is an economically attractive option. However, costs can generally remain somewhat high due to better quality products and the need for more detailed planning at the design stage. The authors highlight an additional investment needed for the implementation of passive house standard, however the environmental benefits are perhaps far more important in respect to thermal comfort conditions and excellent indoor air quality, leading to an overall better health conditions of residents. Passive home insulation levels are always higher than required by regulations. With the use of efficient windows, the required insulation level is lower. If the airtight building shell design is carried out appropriately, it does not bring additional costs. Also, an airtight shell helps prevent potential repair costs. At the design stage, small and medium-sized passive houses should be designed to be thermal bridge-free. Thus, this design requires almost no additional costs. In general, the cost-benefit ratio is sufficient to reduce the thermal bridge. With good planning, it offsets most of the other extra investments required to reach the passive house standard. As a result of the researches and the analysis of the implemented projects, the building cost increase per m² for Turkey is in the range of 20% to 40% [33].

An average of 10 tons of steel is needed in the designed steel house. In order to minimize heat losses, heat-insulated aluminum joinery is used on windows and exterior doors. Stone wool was preferred as the heat and sound insulation material on the interior wall, mezzanine and roof. A1 class fireproof, climate-resistant and environmentally friendly fibercement coating material is used for the exterior walls. The items that make up the cost including assembly are given in Table 1.

Table 1. Steel house cost [34]

Steel house components	**Cost**
Steel	37400 $
Interior doors	945 $
Exterior doors (thermal insulation aluminum joinery)	6580 $
Windows (thermal insulation aluminum joinery)	13260 $
Medium floor chassis (rock wool partition board)	2500 $
Exterior wall covering (fibercement coating)	9200 $
Interior wall covering (rock wool insulation)	5360 $
Ceiling coatings	1510 $
Roof coatings (rock wool insulation)	2600 $
Drain-gutter-rain down pipes	775 $
Jamb (window-door-corner)	100 $
Exterior paint	1770 $
Interior paint	1450 $
Railing	4300 $
Stairs / coating	235 $
Electrical installations	1670 $
Mechanical installations	800 $
Electric- luminaire	515 $
Mechanical- vitrified	880 $
Total	**91850 $**

As seen in the Table 1, the steel house cost is 91,850$.

3.2. Passive Steel House Cost

Once the energy-saving measures are incorporated, the renewable technologies fulfil the remaining energy requirement [11]. During specific periods of the year, the installed renewable energy technologies may generate excess electricity. The excess power can be supplied to the national grid, and electricity from the grid can be consumed where the generation is lower than the demand of the house. As electricity consumption continuously grows with time, the demand for renewable energy has increased with decreasing costs [35]. In this section, studies on solar energy, one of the renewable energy sources, are included. In passive solar building technologies, the windows, walls, and floors are made in a way to collect, store, reflect, and distribute solar energy in the building without using mechanical and electrical devices. Energy calculations of monocrystalline panels within the scope of photovoltaic power systems and panel layouts and cost analyzes in passive house system were carried out. The sun, which forms the basis of all energy sources in the world, provides 170 billion MW of energy to the world thanks to the rays it emits. This value is 15,000-16,000 times the total energy used by human beings in the world today. The sun is an inexhaustible source of energy. It does not harm the environment as it does not need fuel and is a natural and clean energy source. Its usage areas are also quite wide. Compared to other power plants, solar power plants are easier and less costly to maintain. In addition, plant installation can be carried out anywhere. Although the installation of the system is fast and simple, the capacity of the system can be adjusted according to the needs. Even if one of the system modules fails, the others can continue to produce energy. It is long-lasting due to its minimum 20 year usage period. Although solar energy has many advantages, it also has disadvantages. It is more difficult to use than liquid and gaseous fuels. Solar energy is diffuse, which is one of the barriers to utilizing solar energy. Therefore, large surfaces are required for the collection of energy. In addition, since solar energy cannot be produced on cloudy days and nights, it is an intermittent energy source. For this reason, the situation of storing the solar energy obtained also arises. There are two ways to evaluate solar energy, converting it to heat and electrical energy. Concentrators are used to convert solar energy into heat energy, and solar cells are used to convert it directly to electricity. Solar energy is directly converted into electrical energy by photovoltaic power systems.

3.2.1. Photovoltaic Power Systems

Photovoltaic technology converts solar energy into electric current. Photovoltaic power systems contain different components according to their design and usage purposes. All photovoltaic power systems have photovoltaic panels, inverters and connection cables. Different elements are used to store the electricity produced and to ensure system safety.

Photovoltaic power systems are installed with different system structures such as grid-connected and disconnected, and energy storage and non-storage. Therefore, the components in the systems vary such as photovoltaic panels, inverters, battery packs, cables, charging units and generators. In addition to the electricity produced by photovoltaic power systems, grid-connected systems are used by using grid electricity. Off-grid systems are generally preferred in areas where there is no electricity grid. It is essential to store the electricity produced in these systems in batteries and to use this electricity when needed. This would pave the way for net-zero energy constructions, whose potential in terms of energy consumption and reduction of global warming is commonly recognized [36].

Photovoltaic cells have semiconductor properties and convert solar radiation directly into electrical energy. Depending on the photovoltaic principle, when light falls on them, electrical voltage is formed at their ends. Cells absorb photons and convert their energy into electrons, and these electrons are collected in the front and rear parts of the cells. An electric current occurs with the voltage created here. In order to increase the power output, a large number of solar cells are connected in parallel or in series and installed on a surface. This structure is called a photovoltaic module. Depending on the power demand, the modules are connected to each other in series or parallel, thus providing a system from a few watts to megawatts [37]. The general layout of the photovoltaic power system is shown in Fig. 8.

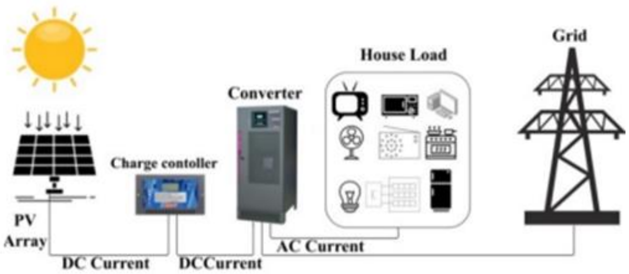

Fig. 8. General layout of the photovoltaic power system [38]

Since the 1950s, polycrystalline or monocrystalline silicon solar cells have attracted attention with their efficiency and stability. With the technologies developed in recent years, photovoltaic conversion efficiencies are increased. Monocrystalline solar panels were the first commercial solar cells to make up a sizable portion of the market. Its efficiency is quite high and it is ideal for long-term investments. In laboratory conditions, 24% efficiency is provided in monocrystalline solar panels. In commercial modules, it varies between 15% and 18%. Polycrystalline solar panels are less costly to manufacture than monocrystalline solar panels. In laboratory conditions, 18% efficiency is obtained in polycrystalline solar panels and 14% in commercial modules. Electrical, optical and structural properties are the same with monocrystalline panels.

3.2.2. Energy Calculation for Photovoltaic Power Systems

In this part, first of all, standard efficiency calculations of selected monocrystalline panels at 25 °C and 45 °C were made. It is also known that the efficiency of photovoltaic panels is highly affected by temperatures [39]. Annual energy production, losses, on-grid and off-grid system requirements and annual energy need calculations of the building that can be obtained from 80 m^2 roof area are made.

First of all, it is necessary to know the sunshine duration and global radiation values of the region considered in the installation of photovoltaic power systems. In this context, Turkey Solar Energy Potential Atlas has been examined, in Fig. 9. Provinces of Turkey that benefit more from solar radiation are indicated with light and dark red colors. In these provinces, the solar energy global radiation values vary as 1600-1800 kWh/m2-year. In this study, the province of Istanbul is considered and the global radiation value is approximately 1400 kWh/m^2-year. The region with the highest solar energy potential is Southeastern Anatolia, while the region with the lowest potential is the Black Sea.

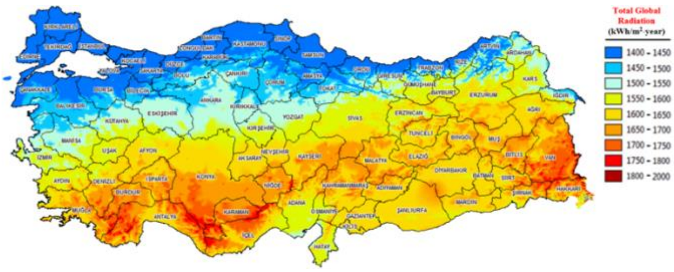

Fig. 9. Solar energy potential atlas [40]

Total global radiation and sunshine durations in Istanbul are calculated by taking the values in Fig. 10 as reference. When the global radiation values are examined, it is seen that the highest global radiation values are in June and July. When the sunshine durations are examined, it is seen that the highest sunshine duration is in July.

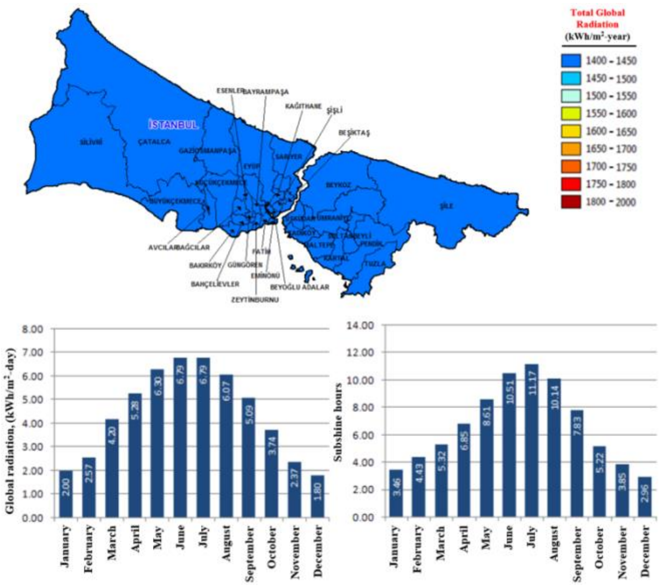

Fig. 10. Global radiation value and sunshine hours in Istanbul [40]

The monocrystalline panel used in this study is 1.56 m long and 0.8 m wide. The appropriate angles of the fixed panels with the ground for Istanbul have been determined as an annual average of 30°. In determining this value, Istanbul's latitude and angle of Earth's tilted axis values were taken into consideration. The minimum distance between the panel arrays to avoid shadow losses is approximately 1.6 m depending on panel length, panel tilt angle and latitude. The dust and pollution accumulated on the top glass layer reduces the solar rays reaching the semiconductor layer and therefore the panel efficiency decreases. Therefore, the soil structure of the land where the system will be established is also effective on the yield. The energy efficiency of the power plants to be established in highly polluted areas will decrease over time. If the panel surfaces are not cleaned, the decrease in efficiency will increase over time. Depending on the panel tilt angle, the rate of dust accumulation on the surfaces will also change. As the dust size increases, the cleaning period (number of days) decreases, and as the panel inclination angle increases, the cleaning period increases [41]. It is stated that the optimum cleaning period for photovoltaic systems is between 12 and 14 days [42]. In addition, the detailed specifications of the monocrystalline panel are given in the Table 2.

Table 2. Monocrystalline panel specifications [43]

Standard operating conditions (1000 W/m^2, 25 °C panel temperature, AM 1.5)	
P_{max}	230 W
V_{mp}	41 V
I_{mp}	5,61 A
V_{oc}	48,7 V
I_{sc}	5,99 A
Temperature Coefficients	
P_{max} %/ºC	-0.38 %
V_{oc} %/ºC	-132,5 mV
I_{sc} %/ºC	3,5 mA

Here, the module area (A_m) of the monocrystalline panel is 1.25 m^2. The power value (P_m) of the panel at 25 °C is 230 W. The power density of the panel can be calculated by Eq. (1) [44, 45].

$$P_{m,d} = \frac{P_m}{A_m} \tag{1}$$

According to Eq. (1), the power density of the panel at 25 °C is calculated as 184 W/m2. The standard efficiency of the panel can be calculated Equation 2 [44, 45]. Here, P_d^s represents the power value produced in 1 m^2 area.

$$\eta_{STC} = \frac{P_m}{P_d^s xA} \tag{2}$$

According to Eq.(2), the standard efficiency of the panel at 25 °C is calculated as 18.4%. The power calculation of the panel at a temperature of 45 °C is calculated by Eq. (3) [44, 45].

$$P_m^T = P_m^{STC}[1 + (T - 25)\alpha_P] \tag{3}$$

T value is taken as 45 °C. α_P is the temperature coefficient for power calculation. According to Eq. (3), the power of the panel at 45 °C is 212 W. The power density of the panel at 45 °C is equal to the ratio of the panel's power at 45 °C to the module area of the panel. It can be calculated by Eq. (4) [44, 45].

$$P_{m,d}^T = \frac{P_m^T}{A_m} \tag{4}$$

According to Eq. (4), the power density of the panel at 45 °C is calculated as 170 W/m^2. Despite the ambient temperature of 25 °C in the panels, the temperature in the cells can reach 45 °C. For this reason, it is very important to calculate the efficiency value at 45 °C in order to provide real conditions. Panels with a low temperature coefficient have higher performance in hot ambient temperatures than panels with a higher temperature coefficient. In addition, with increasing temperature, the decrease in voltage becomes greater. This causes lower efficiency at 45 °C. The efficiency of the panel at 45 ° C is calculated by Eq. (5) [44, 45].

$$\eta_T = \frac{P_m^T}{P_d^s xA} \tag{5}$$

According to Eq. (5), the efficiency of the panel at 45 °C is calculated as 17%. Annual energy production of the monocrystallian panel on an area of 80 m^2 is calculated as 18893.5 kWh. In this study, the average monthly electricity consumption of a 100 m^2 house was accepted as 250 kWh. When an average house of 150 m^2 is based on the calculations, the electricity consumption of the designed building is 375 kWh. Accordingly, the average annual electricity consumption of the designed passive house is calculated as 4500 kWh. In the passive steel house, electricity consumption from devices such as refrigerator, electric furnace, laundry, dishwasher, ironing, television, vacuum cleaner, computer and interior and exterior lighting are realized. The equivalent continuous power factor (E_m) can be calculated by Eq. (6) [44, 45].

$$E_m = \eta\, E_d^s A_m = \frac{P_m}{P_d^s A_m} E_d^s A_m = P_m \frac{E_d^s}{P_d^s} \tag{6}$$

Here, $\mathrm{E_d^s} = 1400 \frac{\mathrm{kWh}}{\mathrm{m^2 year}}$ and $\mathrm{P_d^s} = 1 \frac{\mathrm{kW}}{\mathrm{m^2}}$. Therefore, it bocemes $\frac{\mathrm{E_d^s}}{\mathrm{P_d^s}} = 1400 \frac{\mathrm{h}}{\mathrm{year}}$.

$$P_m = \frac{E_m}{E_d^s / P_d^s} \tag{7}$$

According to Eq. (7), the equivalent continuous power factor (P_m) is calculated as 3.21 kW. Here, the losses are 0.90 for the panels due to temperature correction, the battery charge-discharge efficiency is 0.90 (lifetime average), the inverter efficiency is 0.95, and the cable losses are 0.95. Therefore, the loss rate in the on-grid system is taken as 0.81. Accordingly, the required installed power is 3.96 kW. For the off-grid system, the loss rate is calculated as 0.65. Accordingly, the required installed power is calculated as 4.94 kW. The power of the monocrystalline panel discussed in the study is 230 W. The number of panels sufficient for the required installed power of approximately 5 kW is calculated as 22. Accordingly, 22 monocrystalline panels are sufficient to meet the needs of the passive house. The total roof area of the designed passive steel house is 108 m^2. Monocrystalline panels were installed on a roof area of 80 m^2. Monocrystalline panel roof layout is shown in Figs. 11 and 12. The panels are designed to face south. Thus, this system will be sufficient for the passive steel house to produce its own energy.

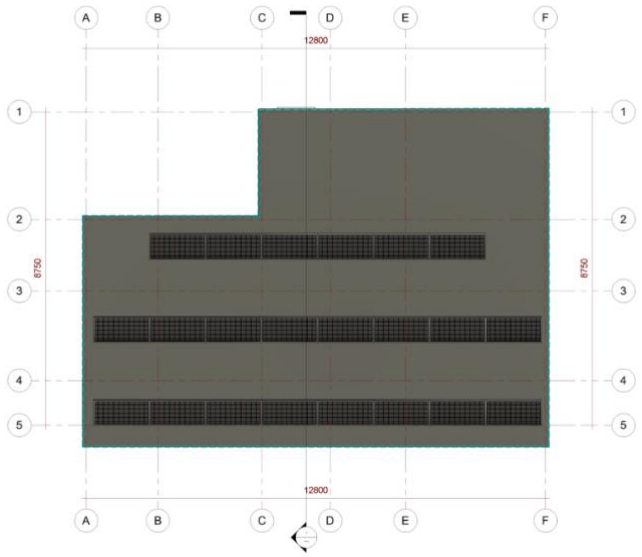

Fig. 11. Photovoltaic panel roof layout plan

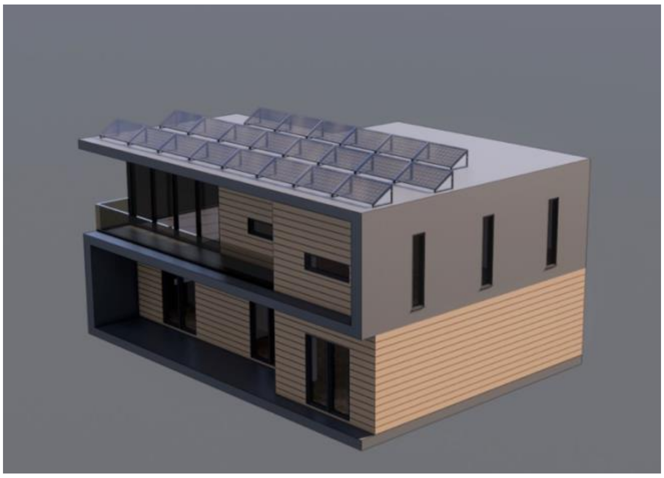

Fig. 12. Photovoltaic panel layout

Table 3. Passive steel house photovoltaic system cost- 5 kW [46]

Items that make cost	Amount	Unit	Price
Solimpeks solar panel	22	Piece	3,256 $
Growatt 5 kWe inverter	1	Piece	1,000 $
Solar cable	100	Meter	85 $
Flat roof aluminum panel construction	15	Piece	650 $
Growatt 3.3 kW Lithium battery + kit	1	Piece	1,750 $
Electrical and mechanical institution AC panel + grounding operations Hybrid system additional contactor materials	1	Set	1,895 $
Total			**8,636 $**

While the photovoltaic system cost was created in Table 3, the prices of solar panels, inverter, solar cable, flat roof aluminum panel construction, lithium battery, electrical and mechanical institution were calculated. In the calculations, it has been seen that 22 monocrystalline panels can produce approximately 5 kW of power.

As seen in Table 3, the total cost of photovoltaic system for 5 kW installed power is 8,636$.

4. Conclusion

The concept of passive house has emerged in order to make the energy efficient due to the high energy usage of the houses. With this concept, it is planned to further develop the home idea that needs low energy. The largest energy consumption in the house is the energies spent for heating and cooling. This energy spent in passive houses is much lower. The most important issue in passive home systems is heating effective ventilation systems. With this system, heating and cooling costs fall to the minimum level. In addition, renewable energy systems contribute to the electrical energy and heating systems.

In this study, the design procedures of the passive home system, which is suitable for energy efficiency, were carried out. Rock wool, fibercement and extruded polystyrene plate were examined as a building material suitable for passive steel home design. Rock wool provides the heat and sound insulation of the passive steel house. The extruded polystyrene plate is used on under the ground flooring. With the modeling of the passive steel house, the cost information of the system is also included. The passive steel house, which is designed with the use of nature-friendly, environmentalist, building materials and solar energy resources, is aimed to produce the energy it needs. Within the scope of the study, solar energy from renewable energy sources is elaborated and the energy required by the passive home system is aimed to meet these systems. In this context, the necessary energy calculations of the solar energy system were realized and the installed power of this system was determined. For the passive steel house system designed as a result of the calculations, the monocrystalline photovoltaic power system with approximately 4 kW and 5 kW installed power will be sufficient for connected to the grid and independent from the grid situations, respectively. 22 monocrystalline panels will be suitable to meet the needs of passive steel house. Necessary cost calculations for the photovoltaic power system were also carried out. Accordingly, the cost of passive steel house was calculated as 91,850$ and the cost of monocrystalline photovoltaic power system was calculated as 8,636$.

In new buildings designed due to the increase in energy costs today, it is important and necessary to save energy and to spread the houses that produce its own energy. This study aims to develop evidence-based guidelines for researchers and practitioners to make well-informed model and method choices in meeting the energy needs of passive steel houses with solar energy systems.

Nomenclature

A_m	Module Area
P_m	Power Value
P_d^s	Power Value Per Square Meter Area
η_{STC}	Standard Efficiency of the Panel
α_P	Temperature Coefficient
P_m^T	Power of the Panel
η_T	Efficiency of the Panel at 45 °C
E_m	Equivalent Continuous Power Factor
AM	Air Mass

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