Scientific Research Communications
Research Article
Sci. Res. Comm. (2023)
Volume 3, Issue 2
doi: 10.52460/src.2023.010

A Case Study on PV-Aided Net Zero-Energy Building: the Daycare in IKCU

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Received: 18.07.2023 Accepted: 08.08.2023

Abstract

At the core of our growing societies, energy supply stands as one of the major concerns today, and it will be an inevitable challenge for our near future. As the nations are looking to find solutions for the transition from fossil fuels – depleting at a high rate – to alternative energy sources, solar energy through PV cells is getting attention as an affordable and easily implemented option especially for power supply in commercial and residential buildings. This work consists in analyzing the possibility to cover the entire energy needs of a building via PV solar cells for the case of a constructed daycare. In this case study, HVAC energy requirement has been calculated by the TS825 standard. The standard specifies a method for calculating the net heating/ventilation energy need and provides the rules for calculating the maximum allowable temperature in buildings. First, dimensions of the investigated building are taken and characteristics affecting the thermal insulation are assessed. Then, other energy needs, mainly lighting and electrical devices, are computed in the analysis as internal electricity needs. The scope of this work extends to the assessment of indoor air quality for occupants of building, which is an important aspect in our case study where the occupants are children. ASHRAE standards 62.1 is utilized for this purpose. The standard specifies minimum ventilation rates and other measures intended to provide acceptable indoor air quality to human occupants and that minimizes adverse health effects. The results are obtained for monthly varying solar exposition in the specified area where the building is located to provide supply for the determined energy demand via solar energy. Finally, monocrystalline PV panel system has been proposed with proper orientation and adequate power potential. Based on the obtained results, as well as the economical aspect, inferences and suggestions are made for improvements.

Keywords: Photovoltaic panels; power generation; zero-energy building

1. Introduction

As the world population continues growing, energy demand due to industrial and human-based activities increases in parallel (Kaviraj and Robi, 2018). Usage of renewable energy sources has become an attractive alternative to conventional energy sources to meet the growing energy demand while reducing greenhouse gas emissions (Ardehali et al., 2017). One of the most promising renewable energy sources is solar or radiant energy which can be harvested via photovoltaic (PV) panels (Fumo et al., 2021). Recent progress in efficiency of PV panels has allowed the rise of concepts like zero and net-zero energy buildings.

A zero-energy building is a construction that generates adequate energy for annual energy consumption. Such buildings are designed to reduce energy consumption to a minimum and produce the remaining energy using renewable sources (Zhang et al., 2018). The concept of zero energy buildings has gained increasing popularity due to the growing concerns on sustainable environment and energy-efficient buildings. PV panel systems are commonly used in zero energy buildings to generate renewable energy-based electricity. PV panels convert sunlight into electricity without any harmful emissions. The size and capacity of the PV systems depend on the building's energy demand and the available solar irradiation. PV-aided zero energy buildings have been researched extensively in recent years (Tonui, 2016).

In western countries, the main factor affecting the total energy demand in buildings is the heating, ventilation, air conditioning and refrigeration (HVAC-R) units. A review of energy consumption in buildings across developed countries by Firth et al. in 2016 documented that space heating accounted for the largest proportion of energy consumption in both residential and commercial buildings (Firth et al., 2016). The authors note that this is due to a combination of factors, including the climate conditions and building design. This fact is better illustrated in Fig. 1 by a pie chart for the US (National Academies of Sciences, Engineering and Medicine, 2010).

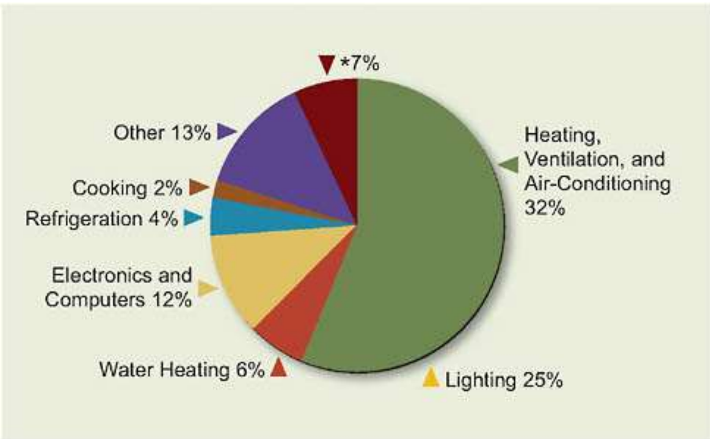

Figure 1. Energy use in U.S. commercial buildings (National Academies of Sciences, Engineering and Medicine, 2010)

At this point Turkish Standard TS825, that is a technical norm developed by the Turkish Standards Institution (TSE), provides a guideline for the calculation of energy requirement in the residential/commercial buildings. The title of the standard is "Energy Performance of Buildings - Calculation of Energy Use for Heating and Cooling" (Turkish Standards Institution, 2018). In Turkiye, it is estimated that buildings that obey the TS825 regulations for insulation can save up to 60% of the energy used for heating purpose. As energy represents a major issue today in the world and especially in the country, TS825 has become a mandatory norm for all new buildings as of June, 2000. The purpose of TS825 is to provide a standardized method for assessing the energy performance of buildings, particularly with respect to heating, heat gains and heat losses. The standard allows engineers and designers to determine the energy performance of buildings using a range of parameters, including the building placement, wall specifications, ceiling layers, floor type and layers, window types and area, door type, indoor and outdoor temperature level for each month, heating and cooling systems, ventilation system and type, and solar heat gains. We mainly utilized from this standard and the methodology within it to determine the monthly and annual heating energy requirement for the building considered in our case study, i.e., the daycare (nursery) at Izmir Katip Celebi University. In that calculation method, TS825 mainly takes into consideration: building properties such as construction materials, insulation, heat losses through conduction convection and ventilation; as well as heat gains from internal sources and solar radiation, to determine the heating energy need for the building. Other factors considered when calculating the energy need in our work are the energy needs for cooking, lighting, refrigeration, electronic devices, and water heating. Their values are relatively constant, and they are taken as monthly and yearly average. The calculation provides an accurate estimation of the total energy demand of the building. The procedure is detailed in section 2. Our assumption is that under TS825 specified conditions, PV-panels will provide 100% of the energy needs for the daycare in our case study, making it a net zero-energy building.

Next, indoor air quality and personal comfort conditions have been considered while calculating the total energy consumption of the investigated domain. ASHRAE 62.1 standard (ASHRAE, 2022) is used for ventilation rates and indoor air quality requirements. This standard provides guidelines for the assessment of indoor air quality of occupants in various spaces. In a daycare, where the occupants are kids/children, this standard is crucial in achieving a viable zero energy building and ensuring the health and safety of kids. Furthermore, ASHRAE 55 is utilized for the determination of personal comfort conditions especially for the ventilation speed point of view (ASHRAE, 2017).

In this case study, we investigate usage of PV panels for the daycare building at Izmir Katip Çelebi University to cover all the energy requirement in an annual period. First, the monthly and annual heating energy loads of the selected nursery are calculated via TS825 standard. Next, energy consumption due to the electronic appliances, lighting and specific devices are determined to obtain total energy requirement of the investigated building. PV panel type and total number of PV panels have been determined according to the maximum energy requirement case experienced in January. Furthermore, a detailed cost analysis has been performed to compare the investment cost of possible PV solutions.

2. Methodology

The first step in our work is to measure the building properties needed at all calculation stages of the TS825. They include mainly: measurements of dimensions, heat losing surfaces, area of each component considered in calculations, and total window and door areas in each direction. The data are presented in Table 1.

The heating energy need for the building, as stated in the previous sections, is the main factor affecting the total energy demand. That value was calculated according to the systematic calculation method using the TS825 with the data listed in Table 1. The calculation steps contain: calculation of heat loss of the building (through conduction, convection), calculation of heat gain of the building (internal and solar gains), and lastly, calculation of the heating energy need using the obtained data. In order to determine the specific heat loss of the building, we initially focused on the heat loss through conduction and convection. Then we calculate the heat loss through ventilation, and we add the two values to get the total heat loss value as shown in Eq. (1).

$$H = H_T + H_V \tag{1}$$

Table 1. Main dimensions and specifications of the investigated building

Building dimensions (m)		Layer/wall areas (m^2)		Gross volume (m^3)	Window area (m^2)		Door area (m^2)		Internal Temp. (°C)
Length	18.9	Reinforced Concrete	53.4	1791	North	20.6	North	0	20
Width	25.5	External Wall	202.5		East	16.3	East	5.9	
Height	3.7	Ceiling	484.1		West	13.0	West	0	
Floor Height	3	Floor	484.2		South	15.6	South	1.9	
		Total Area	1297.6		Total	65.5	Total	7.9	
		Net Usage	573.3						

where, H is the total specific heat loss, HT is the heat loss through conduction and convection heat transfer mechanisms, and HV denotes the heat loss through ventilation. First, we calculate the thermal permeability resistance (R) values of each building components via Eq. (2) to determine the HT.

$$R = \frac{d}{\lambda} \tag{2}$$

where, R corresponds to the thermal permeability resistance (m2K/W), d is the thickness of the building component, and λ is the thermal conductivity of the components (W/mK). Note that the thermal conductivity values are provided in Annex E of the TS825 (Turkish Standards Institution, 2018). R-value calculation for multi-layered building components is made by simply adding the R-values of each structural element (layer) of the component. Utilizing the R-values previously calculated, we derive the total thermal performance coefficient (U), from the inverse function of total thermal permeability resistance (1/U) formula, for each component, as shown Eqs. (3) and (4).

$$\frac{1}{U} = R_i + R + R_e \tag{3}$$

$$U = \frac{1}{R_i + R + R_e} \tag{4}$$

In equations (3) and (4), R_i and R_e are the surface thermal transmission resistance of the inner and outer surfaces, respectively. R_i and R_e values are provided in TS825 standard for various building scenarios. The heat loss by conduction and convection (HT) value is then calculated by summing up the products of each component's total thermal performance coefficient (U) by its specific area (A), and adding to it the heat loss transmitted through the thermal bridges, as shown in equation (5):

$$H_T = \sum AU + \sum Ul \tag{5}$$

In the case of our building that doesn't contain thermal bridges, the term (∑Ul) is ignored from equation (5) which can then be developed for each component, giving us Equation (6):

$$\sum \mathrm{AU} = U_D A_D + U_p A_p + U_k A_k + 0.8\, U_T A_T + 0.5\, U_t A_t + U_d A_d + 0.5 U_{ds} A_{ds} \quad (6)$$

where:

U_D = Thermal permeability coefficient of the outer wall (W/m²K),

U_P = The thermal transmittance coefficient of the window (W/m²K),

U_k = Thermal permeability coefficient of the outer door (W/m²K),

U_T = Thermal permeability coefficient of the ceiling (W/m²K),

U_t = Thermal permeability coefficient of the base/floor on the ground (W/m²K),

U_d = Thermal permeability coefficient of the sole in contact with the outside air (W/m²K),

U_{ds} = The coefficient of thermal permeability of the building elements in contact with the indoor environments at low temperatures (W/m²K),

A_D = Area of the outer wall (m²),

A_P = Area of the window (m²),

A_k = The area of the outer door (m²),

A_T = Ceiling area (m²),

A_t = Floor-to-floor/floor area (m²),

A_d = Area of floor/floor in contact with outside air (m²),

A_{ds} = Area of building elements in contact with indoor environments at low temperatures (m²).

The calculation of heat loss by ventilation, Hv includes both natural and mechanical ventilations affecting to the building. In the case of the daycare building of our study, since there is no mechanical ventilation, only natural ventilation is considered and calculated as follows:

$$H_V = \rho.c.V^1 = \rho.c.n_h\, V_h = 0.33\, n_h.V_h \quad (7)$$

where, ρ is the unit volume mass of air, c is the specific heat capacity, V^1 corresponds to air exchange rate by volume, n_h is the air exchange rate, and V_h denotes the ventilated volume. As density and specific heat capacity of the air slightly change (depending on temperature and pressure), their variations are neglected in the equation, and values are taken at 20 °C and 100 kPa. The enthalpy increase between the incoming and outgoing air is also neglected.

Heat gains need to be calculated to determine the monthly and annual energy demand of the building. Heat gain term refers to the amount of heat that enters the building through various sources such as solar radiation, appliances, lighting, and occupants. In this study, we calculate total heat gains as the sum of internal and solar gains. Average monthly internal heat gains (ϕ_i, month) include metabolic heat gains from humans, heat gains from the hot water system, heat gains from cooking, heat gains caused by the lighting system, heat gains from various electrical devices used in buildings. These values are taken as the average and considered constant throughout the year. For our building category (school), internal heat gain can be calculated via:

$$\phi_{i,\ month} \leq 5 \times A_n \text{ (W)} \tag{8}$$

Here, A_n is the usage area of the building that can be obtained as follows:

$$A_n = 0{,}32 \times V_{gross} \tag{9}$$

V_{gross} is the heated gross volume of the building. On the other hand, the monthly solar gain ($\phi_{S,\ month}$) refers to the amount of energy gained by solar radiation from sunlight through the windows. The gains from passive solar energy systems are neglected in this work. The average solar gain is calculated using equation (10).

$$\phi_{S,\ month} = \Sigma\, r_{i,\ month} \times g_{i,\ month} \times I_{i,\ month} \times A_i \tag{10}$$

where, $r_{i,\ month}$ is the monthly average shading factor of transparent surfaces in "i" direction, $g_{i,\ month}$ denotes the solar energy transmission factor of transparent elements in "i" direction, $I_{i,\ month}$ is the monthly average solar radiation intensity on vertical surfaces in the "i" direction, and A_i is the total window area in the "i" direction. While $r_{i,\ month}$ and $I_{i,\ month}$ values are provided by the TS825, $g_{i,\ month}$ is calculated with the help of Eq. (11).

$$g_{i,month} = F_w \cdot g_{\perp} \tag{11}$$

Here, F_w is the correction factor for glasses and $g_{\perp}$ denotes the solar energy transmission factor for the beam perpendicular to the surface measured under laboratory conditions. It is not always appropriate to consider the sum of the internal gains and solar energy gains as useful energy in terms of reducing the heating energy need. Because in times of high heat gains, the gains may be more than the instantaneous losses, or the gains may come when heating is not needed. The indoor temperature control system is not perfect, and some heat is stored in the building elements. Therefore, internal gains and solar gains are reduced by a utilization factor (η) that is the magnitude of this factor depends on the relative size of the gains and losses and the thermal mass of the building. The calculation of (η) is made using equations (9) and (10):

$$\eta_{month} = 1 - e^{(-1/KKO_{month})} \tag{12}$$

where KKO_{month} is the gain/loss ratio, and it is calculated as follows:

$$KKO_{month} = (\phi_{i,month} + \phi_{s,month}) / H(\theta_{i,month} - \theta_{e,month}) \quad (13)$$

Here, ϕ and θ are the abbreviation of heat gains and temperature levels. Note that, when the KKO_{month} value is 2.5 or above, it is considered that there is no heat loss for that month. The monthly average internal and external temperatures, $\square_{i,ay}$ and $\square_{e,ay}$ are provided by TS825 in Annex B, section 1 and 2 respectively. With the help of the parameters calculated in the previous steps, we finally obtain the annual heating energy need for our building adding up the monthly heating energy need values for our building according to equations (14) and (15).

$$Q_{year} = \sum Q_{month} \quad (14)$$

$$Q_{month} = \left[H(\theta_{i,month} - \theta_{e,month}) - \eta(\phi_{i,month} + \phi_{s,month})\right].t \quad (15)$$

where, Q_{year} and Q_{month} are the annual and monthly heating energy need of the investigated building, t is the time in the unit of seconds. The energy demand other than heating energy has been considered for the electrical devices used in the daycare. Main equipment list contain computer, washing Machine (A++), camera system, fridge (A++), deep-freeze (A+, 102L), microwave (A++), oven, fume hood and kettle. The annual energy requirement for these devices was calculated according to the number of devices, the power they consume and their respective daily working hours.

It is important to mention that the building investigated in our study lacks insulation in its components. Insulation represents a major parameter in the calculation method of TS825. The use of insulation material in the building components is recommended because it has a significant impact on the heat loss of the building by conduction, resulting in lower energy need (Turkish Standards Institution, 2018). Since the investigated daycare does not have any insulation material in its walls and other building components, we have conducted separate calculations for the heat loss through conduction and convection, assuming cases in which insulation materials are used for the walls and ceiling. The insulation material used for this purpose were selected according to the recommendations from TS825. This step is conducted for comparison purpose to analyse the impact of using insulation material.

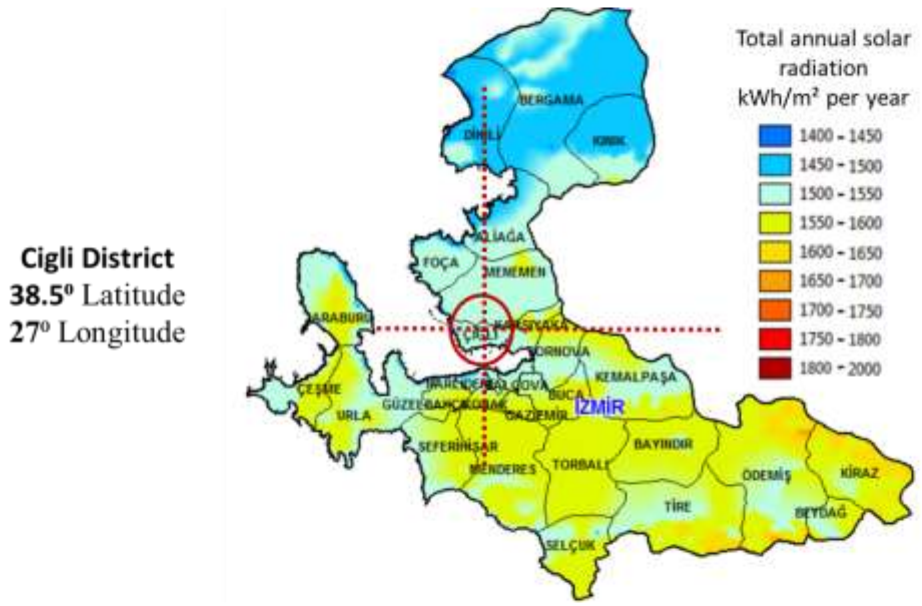

Figure 2. Solar irradiation map and latitude of Çiğli District (GEPA, 2023)

Once the energy demand of the selected building has been calculated for monthly and annual periods, PV panel type and required number of PV panels were investigated. Figure 2 presents the solar irradiation map of Çiğli district. Furthermore, latitude of the selected building is a crucial parameter for PV system design as tilt angle of the PV panels is directly depended on the latitude. We utilize from a simplified equation set to calculate the optimal tilt angle (β) of each season:

$$\begin{array}{r} \text{During summer:} \\ \text{For spring and autumn months:} \end{array} \quad \begin{cases} \beta = (0.9 \times \text{Latitude}) - 23.5^0 \\ \beta = \text{Latitude} \pm 2.5^0 \\ \beta = (0.9 \times \text{Latitude}) + 29^0 \end{cases} \tag{16}$$

Figure 3. Effects of latitude and longitude on PV panel tilt angle

PV panel orientation should be altered according to the PV panel tilt angle calculations. In most of the PV panel applications in our country, tilt angle is kept constant. In this case, an optimal angle value should be determined for annual radiant harvesting. Note that tilt angle only varies with latitude (Fig. 3). We may sum winter, summer, spring, autumn tilt angles and divide by four to find an approximate annual tilt angle. Another simplified equation can also be utilized for annually constant tilt angles:

$$\beta = (0.87 \times \text{Latitude}) + 3.1^0 \tag{17}$$

3. Results and Discussions

The results of our work using the methods described in Section 2, are reported in this section. Parameters and properties used at each calculation step are described in tables and values found are reported. As mentioned in the first section, the energy need for heating purpose in the building (H), is the dominant factor when determining the total energy need. It is defined in section 2 as the sum of heat loss through conduction and convection (H_T), and heat loss through ventilation. (H_v). Table 2 describes the calculation of (H_T).

Table 2. Building heat loss through conduction and convection: calculation steps

Surface type	Layer element	Element thickness d (m)	Thermal cond. λ (W/mK)	Conduction resistance R, (m^2K/W)	Overall coefficient U (W/m^2K)	Surface area A (m^2)	Heat loss A x U (W/K)
Wall surfaces	Ri			0.13			
	Plaster	0.02	1	0.02			
	lime sandstone	0.172	0.35	0.491			
	Plaster	0.008	0.35	0.023			
	Re			0.04			
			Total	0.704	1.419	202.5	287.5
Wall surfaces (reinforced concrete)	Ri			0.13			
	Plaster	0.02	1	0.02			
	Reinforced Concrete	0.172	2.5	0.069			
	Plaster	0.008	0.35	0.023			
	Re			0.04			
			Total	0.282	3.551	53.4	189.6
Ceiling	Ri			0.13			
	Plaster	0.02	1	0.02			

	Reinforced Concrete	0.18	2.5	0.072			
	Re			0.08			
			Total	0.302	2.65	484.2	1478.3
Floor	Ri			0.17			
	PVC flooring	0.005	0.23	0.022			
	Screed	0.03	1.4	0.021			
	Leveling Screed	0.02	1.4	0.014			
	lightweight concrete	0.1	1.1	0.091			
	Re			0			
			Total	0.317	1.573	484.2	761.9
External Door					4	7.92	31.68
Window					2.4	65.48	157.15
Sum of the heat loss from the building elements by conduction and convection $\mathbf{H_T}$.							2710.4

The value for the total heat loss through conduction and convection of the daycare was found as H_T = 2710.428 W/K. Next, the heat loss through ventilation, (only natural ventilation in our building) was calculated using Eq. (7) and the following value was found as H_V = 378.3 W/K. Finally, the total heat loss of the building was obtained by summing up H_T and H_V according to equation (1). The total heat loss coefficient of the building is **H = 3088.78 W/K.**

Once the heat losses due to the building structure and ventilation system were determined, we calculated the heat gains of the building as the sum of internal gains and solar gains. The internal heat gain was calculated as an average value using Eq (9), which is about 2866.3 W. On the other hand, the average solar gain was calculated monthly, in each cardinal direction, as described in Eq. (10). The calculation steps and results are reported in Table 3. Note that $r_{i,month}$ and $g_{i,month}$ values are taken from the TS 825 standard as 0.8 and 0.68, respectively.

Table 3. Average monthly solar gains: calculation steps

	$\mathbf{I_{i,month}}$ (kg.m²/h)			$\mathbf{A_i}$ (m²)				$\boldsymbol{\phi_s}$ (W)
	I_{South}	I_{North}	$I_{East/West}$	A_{South}	A_{North}	A_{East}	A_{West}	
Jan.	72	26	43	15.6	20.58	16.3	13	1587.5
Feb.	84	37	57					2035.6
Mar.	87	52	77					2547.8
Apr.	90	66	90					2937.2
May	92	79	114					3482.3

Jun.	95	83	122		3680
Jul.	93	81	118		3576.9
Aug.	93	73	106		3296.1
Sept.	89	57	81		2684.5
Oct.	82	40	59		2084.1
Nov.	67	27	41		1524.4
Dec.	64	22	37		1379.2

Gain utilization factor was calculated for each month via Eq. 12, and the values are reported in Table 4. At last, the annual heating energy requirement of the building (Q_{year}), was determined as the sum of the monthly heating energy requirement values (Q_{month}) by using Eqs. (14) and (15), respectively.

Table 4. Main calculation steps and results on the annual heating energy requirement of the building

	Heat losses			Heat gains				
	Specific Heat loss	Temp. diff.	Heat loss	Internal heat gain	Solar energy gain	KKO	Gain utilization factor	Heating energy require-ment
Months	$H=H_T+H_V$ (W/K)	θ_i-θ_e (K,°C)	$H(\theta_i$-$\theta_e)$ (W)	ϕ_i (W)	ϕ_s (W)	γ (-)	η_{month} (-)	Q_{month} (kJ)
Jan		11.6	35829.8		1587.5	0.12	0.99	8.13×10^7
Feb		11	33976.6		2035.6	0.14	0.99	7.53×10^7
Mar		8.4	25945.8		2547.8	0.20	0.99	5.33×10^7
Apr		4.2	12972.9		2937.2	0.42	0.90	2.02×10^7
May		θ_e high	0		3482.3	0	0	0
Jun	3088.78	θ_e high	0	2866.3	3680	0	0	0
July		θ_e high	0		3576.9	0	0	0
Aug		θ_e high	0		3296.1	0	0	0
Sep		θ_e high	0		2684.5	0	0	0
Oct		1.5	4633.2		2084.1	1.004	0.63	4.21×10^6
Nov		7	21621.5		1524.4	0.190	0.99	4.47×10^7
Dec		10.7	33049.9		1379.2	0.12	0.99	7.47×10^7

The total heating energy requirement of the building was calculated as the sum of the monthly heating energy needs and found as: Q_{year} = 3.54 $\times 10^8$ kJ. This value corresponds to 9.83 $\times 10^4$ kWh. This theoretical value obtained using the TS 825 standard assumes a permanent daily and monthly use of electricity in the building. In reality, the building is functional 12 hours a day, 23 days a week, or 276 hours monthly. It represents only 38% of 720 hours calculated. This means that in reality, only 38% of the energy calculated is needed. The real heating energy requirement becomes 3.74$\times 10^4$ kWh.

Table 5. Annual energy consumption of devices in the daycare

Device	Pcs.	Power (W)	Daily working hour (h)	Daily Energy consumption (kWh)	Monthly energy consumption (kWh)	Annual energy Consumption (kWh)
Computer	1	15.2	8	0.12	3.6	108
Washing Machine (A++)	1	800	1	0.8	24	720
Camera System	1	10	24	0.24	7.2	216
Fridge (a++)	1	60	24	1.44	43.2	1296
Deep Freeze (A+, 102 litres)	1	50	24	1.2	36	1080
Microwave (A++)	1	300	1	0.3	9	270
Oven	1	2500	1	2.5	75	2250
Fume Hood	1	12	1	0.012	0.36	10.8
Kettle	1	1200	0,5	0.6	18	540
	1	28	8	0.224	6,72	201.6
Total				7.436	223.1	6692.4

We have calculated that the annual energy consumption of electrical devices used in the daycare is about 6692.4 kWh; therefore, the total energy requirement of the building per year rises to 4.40$\times 10^4$ kWh.

The remaining energy requirement for the daycare was assessed by identifying all devices consuming electricity in the building and calculating their monthly and annual consumption, reported in Table 5.

Five different types of PV-panels were investigated to provide the amount of energy needed for the investigated daycare, t. The criteria considered for this selection are the amount of solar irradiation at the building location, the total area to be covered with PV-panels considering individual panel size, and the calculated energy requirement of the building. The average daily irradiation time for each month at the building location are presented in Table 6.

Table 6. Çiğli district annual sunbathing time (GEPA, 2023)

Month	Duration (h)
January	4.98
February	5.99
March	7.17
April	8.19
May	9.88
June	12.07
July	12.38
August	11.6
September	9.8
October	7.78
November	5.69
December	4.39

The types of PV-panels investigated in our work and their properties are reported in Table 7.

Table 7. Monocrystalline PV-panels and main properties (solaravm.com/solar-gunes-paneli, 2023)

Panel	Power (W)	Dimensions (mm)	Weight (kg)	Efficiency (%)	Price (TRY)
Jinko Solar JKM370M-72-J	370	1956×992×50	27	19.1	3689
Jinko Solar JKM535M-72H	535	2278×1134×35	28	20.8	5632
Lexron LXR-410M	410	1987×1001×35	22	19.1	5044
AlfaSolar 3S72M400	400	1994×1008×42	24	20.0	4016
ELINPlus ELNSM6612M	395	1979×1002×40	22.5	19.9	3965

For each PV-panel type investigated, the corresponding number of panels and the total area needed to provide the amount of energy requirement of the daycare, were calculated according to the amount of solar irradiation. The calculation was made for the month of January as it is the month during which the energy need reaches its peak value: 9142.58 kWh. Table 8 presents the values obtained.

Table 8. Number of PV-panels required

PV-Panel	Sunbathing time (h)	Panel Power (kW)	Energy generation (Jan) (kWh)	Energy requirement (Jan.) (kWh)	Number of PV	Total surface needed (m^2)
Jinko Solar JKM370M-72-J		0.37	55.278		166	320.93
Jinko Solar JKM535M-72H		0.535	79.929		115	295.5
Lexron LXR-410M	149.4	0.41	61.254	9142.58	150	296.87
AlfaSolar 3S72M400		0.4	59.76		153	307.5
ELINPlus ELNSM6612M		0.395	59.013		155	307.21

We observed that with the PV-panels investigated, the number of panels needed to cover the daycare energy needs, is in the range of 115 to 166, meaning an average of 140 panels depending on the panel power. It corresponds to an area between 307 and 321 m^2, or an average of 315 m^2. Among our PV-panels, the best performer is the Jinko Solar JKM535M-72H: with its efficiency of 20.8% it can generate enough energy for the daycare with 115 panels, which represents a surface of just 296 m^2.

The optimal tilt angle (β) for the panels was calculated for the investigated building located in the Cilgi district in Izmir, at a latitude of 38.5°. The results are reported in Table 9.

Table 9. Optimal tilt angle for Çiğli district

Season	β
Summer	11.15
Spring	41
Autumn	36
Winter	63.65

Alternatively, a constant value for (β) can also be calculated using Eq. (17) in case the solar panel will stay in the same direction all through the year. In our case, the annually constant tilt angle was found as β = 36.6°.

As mentioned in the previous sections, our building does not have insulation although it is recommended in the TS825 standard. In this view, we have conducted theoretical calculations assuming cases in which a layer of insulation material is applied to the walls and the ceiling components of the daycare. Three cases have been considered. For each case, a different insulation material was selected for the walls, while one single material was maintained for the ceiling in all three cases. The materials used for the wall insulation are Extruded Polystyrene (XPS) Styrofoam, Glass foam, and Wood fiber, while the ceiling insulation was evaluated using Expanded Polystyrene (EPS) Styrofoam. These materials were selected based on their thermal conductivity values in accordance with the suggestions from TS828, and their availability on the market. The thickness of the materials is an important factor when considering insulation. Thicker layers allow better insulation, but they should remain in compliance with local building codes and regulations. In our work, we have calculated the thickness of the investigated materials in order to obtain a reduction of 50% in heat loss through conduction and convection (H_T) value, for each case considered.

The insulation materials investigated with their properties and the calculated thickness values required for the desired insulation performance are shown in Table 10.

Table 10. Properties of insulation materials used in experimental cases

Material	Wall insulation			Ceiling insulation
	Case 1	Case 2	Case 3	
	XPS Styrofoam	Glass foam	Wood fibered	EPS Styrofoam
Thermal conductivity (W/mK)	0.035	0.055	0.065	0.04
Thickness required (m)	0.01536	0.0158	0.016	0.02

The impact of these insulation materials on the heat loss and the total energy demand of the building were calculated and compared with the real case where there is no insulation. The results are presented in Table 11.

Table 11. Impact of insulation on heat loss and total energy demand

	Insulation Material	Thermal conductivity (W/mK)	Thickness required (m)	Heat loss (W/K)	Energy need (kWh)
Case 1	XPS Styrofoam	0.035	0.01536	2180	63730.39
Case 2	Glass foam	0.055	0.0158	2206	64748.32
Case 3	Wood fibered	0.065	0.016	2215	65087.57
Real Case	No insulation			3088.79	98292.18

As we can see from these results, the use of insulation material to reduce (H_T) value by 50%, results in 29.4%, 28.5% and 28.2% drops in heat loss for insulation cases 1, 2 and 3 respectively.

Consequently, the annual total energy need of the building in each of the three insulation cases drops by 35.2%, 34.1%, and 33.8% respectively. With these new values, the corresponding number of PV panels required was determined for the three insulated cases, with each of the five PV-panels selected previously, and comparison was made with the real situation where there is no insulation. These results are detailed in Table 12.

Table 12. Number of PV-panels needed for insulation cases

	Case 1	Case 2	Case 3	Real Case
Jinko Solar JKM370M-72-J	113	115	115	165
Jinko Solar JKM535M-72H	78	79	80	114
Lexron LXR-410M	102	104	104	149
AlfaSolar 3S72M400	105	106	107	153
ELINPlus ELNSM6612M	106	108	108	155

As shown from these results, when insulation is applied, the number of PV-panels needed to cover the entire energy need of the daycare decreases by approximately 30% depending on the PV-panel used. From these panels, the Jinko Solar JKM535M-72H has the best performance and would allow to cover the energy demand with just 78, 79, or 80 panels in each of the three insulated cases respectively, while the initial case without insulation requires 114 panels. We observe here the use of insulation plays a very important role in limiting the heat loss of the building, allowing the energy need to decrease significantly. While our theoretical study assumed insulation layers only on the wall surface and ceiling components of the building, it is important to remember that insulation layers can also be applied to other components like the reinforced concrete part of the walls or the floor. Furthermore, the thickness of the insulation layers used in our study was minimized in order to provide the most realistic case possible, but the average thickness of insulation layers is well above our values, as it can be seen in the examples from the TS825 standard, where the thickness of the layers is about 3 times our value. All these remarks imply that the use of insulation have potential to reduce exponentially the energy need.

In order to evaluate the real cost of utilizing the investigated PV-panels to meet the total energy demand of the daycare building, a cost analysis was conducted. This analysis takes into account the price of the PV-panels, estimation of Turkish market prices for installation and maintenance costs.

The prices of the investigated PV-panels are provided in Table 13.

Table 13. Total price of the investigated PV panels

Panel	Price for single panel (TRY)	Number of panels	Total Price (TRY)
Jinko Solar JKM370M-72-J	3689	166	612374
Jinko Solar JKM535M-72H	5632	115	647680
Lexron LXR-410M	5044	150	756600
AlfaSolar 3S72M400	4016	153	614448
ELINPlus ELNSM6612M	3965	155	614575

The price varies from approximately 613000TRY to 757000TRY, depending on the type of PV-panel used, with an average of 700000TRY.

The most recent information we have gathered concerning the installation price for PV-panels from suppliers and reviewers indicates that installation of solar panels costs between 21TRY and 25TRY per Watt installed (globalenerjimarketim.com and keremcilli.com/gunes-enerjisi-santrali-kurulum-maliyeti-2022 websites both accessed in 2023). This value is fairly in the range of prices given by Forbes (forbes.com/home-improvement/solar/cost-of-solar-panels) for PV-panels installation in the US. This represents on average of 1.4 million TRY to be paid for labor.

The total cost of the project is found to be in the range of 2.023 to 2.18 million TRY. The maintenance of PV-panels is estimated to be between 1% and 2% of the installation cost. In our case, this represents approximately 21000TRY per year. On the other hand, when we consider the insulated cases, the cost of PV-panels changes according to the new number of PV-panels needed to cover the energy demand. For each case, the total prices of the PV-panels are given in detail in Table 14.

Table 14. Total price of the PV-Panels for insulated cases

Panel	Price for single panel (TRY)	Number of panels			Total Price		
		Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Jinko Solar JKM370M-72-J	3689	113	115	115	417671	423398	425306
Jinko Solar JKM535M-72H	5632	78	79	80	440998	447045	449059
Lexron LXR-410M	5044	102	104	104	515370	522436	524790
AlfaSolar 3S72M400	4016	105	106	107	420592	426359	428280
ELINPlus ELNSM6612M	3965	106	108	108	420508	426273	428194

The results show that the total prices of the PV panels decrease by around 30% for the insulation cases. The price of the insulation materials was calculated according to their unit price and the surface to be covered: 202.5m of wall surface, and 484.1m for the ceiling. Table 15 shows an estimation of these prices for each case.

Table 15. Price of insulation materials

	Material	Price (TRY)
Case 1	XPS Styrofoam	21796,93
Case 2	Glass foam	65390,78
Case 3	Wood fibered	54492,32
Ceiling	EPS Styrofoam	3647,57

In order to get the total cost of the project, the labor cost was also calculated with the same method used previously for the real case and found to be in the range of 966000TRY and 985000TRY. According to these data, the total cost of the project for insulation cases ranges between 1.38 and 1.56 million TRY.

4. Conclusions

In this work, we have explored the feasibility of meeting the energy needs of a daycare building through the use of photovoltaic (PV) solar cells. The global increase in energy demand and the need for sustainable and environmentally friendly solutions, has led to a growing interest in renewable energy sources such as solar power and emphasized the importance of solutions like PV-aided net zero-energy buildings. Our study focused on the heating, ventilation, and air conditioning (HVAC) energy requirements, as they represent the biggest share in both residential and commercial buildings. By utilizing the TS825 standard, which provides guidelines for calculating the energy performance of buildings, the heating energy requirement of the daycare building was determined. The analysis took into account factors such as building dimensions, thermal insulation properties, heat losses, and heat gains. The monthly and annual energy demand of the building was accurately estimated based on these calculations. We then considered other energy needs, including lighting and electrical devices, to determine the overall energy requirement of the building.

Based on our analysis, we proposed the use of monocrystalline PV panels to meet the energy demand of the daycare building. After scaling the selected PV-panels to our project, the orientation and power potential of the PV panels were determined based on the maximum energy requirement experienced in January. The required number of PV-panels needed to cover the energy demand of the building was found to be in the range of 115 to 166 panels. Since our building lacks insulation which is an important parameter when dealing with heat loss and energy demand in buildings, as shown in the TS825 standard, theoretical calculations were conducted, assuming the presence of insulation layers in the walls and the ceiling components of our building. Three cases have been considered. For each case, a different material with different thermal conductivity was selected for the wall insulation, while one standard material was kept constant for the ceiling insulation. Comparison between the results of real case without insulation and theoretical cases with insulation, showed that the total energy demand of the building can be reduced by 33.8%, 34.1%, and 35.2%, which are very significant. Likewise, the number of PV-panels required to cover the energy demand of the daycare dropped by approximately 30%, with an optimal value of just 78 PV-panels, using the Jinko Solar JKM535M-72H under the insulation conditions described in case 1.

We conducted a cost analysis to evaluate the economic aspects of implementing the solutions suggested. The total cost of the project includes the price of the panels and the labour for installation and was found in the range of 2.023 to 2.18 million TRY depending on the PV - panel selected. The initial investment associated with implementing a PV panel system capable of meeting the entire energy demand of the building may represent a challenge, especially for buildings with limited budgets. On the other hand, the use of insulation material allows this initial investment to be reduced by a very significant amount as shown by our theoretical calculations with insulation, where the total cost of the project dropped to values between 1.38 and 1.56 million TRY. Furthermore, insulation has potential to reduce the initial cost even more, as layers could be applied to other components of the building. A good number of insulation materials can be chosen from, according to the cost and the thermal conductivity, among other factors. The optimal thickness can be determined according to the building regulation and the desired insulation performance. For these reasons, the use of insulation is our main recommendation in view of the implementation of the project. Besides insulation, some other options remain available to make the project more realistic and deserve further evaluations. A more specific PV-panel system could be considered, with usage exclusively limited to the ideal irradiation conditions, allowing a reduced dependence on the grid electricity. Also, the use of energy storage could have a great positive impact since solar energy is intermittent. Additional energy generated in peak irradiation period would serve during days with less daylight.

Overall, our findings suggest that it is indeed possible to cover the entire energy needs of the daycare building through PV-panels, making it a net zero-energy building. The use of renewable energy sources like solar power not only reduces greenhouse gas emissions but also contributes to a sustainable and environmentally friendly future. The results of this study provide valuable insights and recommendations for improving energy efficiency in commercial and residential buildings.

Acknowledgments (Optional)

This research has been funded by the Scientific Research Council of Izmir Katip Çelebi University under grant number of 2023-TYL-FEBE-0015.

Author Statement

All authors reviewed the results and approved the final version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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