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*Research Article*

# APPLICABILITY OF SOLAR AND WIND ENERGY TECHNOLOGIES FOR A NON-RESIDENTIAL BUILDING

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**ABSTRACT**
In this study, applicability of wind and solar energy technologies in a non-residential building located in Mersin, Turkey is investigated. As the non-residential building, a polyclinic was examined. Meteorological data was obtained from Turkish State Meteorological Service to investigate the solar and wind energy technologies. The data was examined statistically. By using wind turbine with 0.9 kW rated power, 2223.5 kWh electricity energy was generated. Similarly, PV panel with 20 % panel efficiency, 5kW total power and 15 m$^2$ surface area, 4240 kWh electricity energy was generated. Annual energy consumption of the polyclinic was calculated 26107.52 kWh by using EnergyPlus software. To meet heating and cooling loads of the polyclinic, the air source heat pump was preferred. 8.51 % of the total demand can be supplied from wind turbine and 16.24 % by photovoltaic panels. The proposed wind-solar hybrid system for investigated region is not applicable due to low of the wind energy potential of the investigated region, the high price of the wind turbine and the proximity to the lifetime of the utilized components in the system to depreciation time. On the other hand, by using only photovoltaic panels system to generate electricity, it was determined that depreciation time will decrease from 17 to 11 years.

***Keywords:*** *Wind Energy, Solar Energy, Photovoltaic Panel, Heating Load, Cooling Load*

## 1. INTRODUCTION

The use of renewable energy sources has become important due to the limited life of fossil fuels and their hazard to nature. That topic is now very attractive issue in order to reduce energy dependency on the energy side in terms of Turkey. It is known that one third of the energy expenditure in our country is spent for non-residential buildings, especially for office buildings, and buildings equipped with air conditioning systems hold an important place within this group **(**WECTNC, 2002). For this reason, increasing the use of renewable energy technologies in non-residential buildings is important.

The aim of this study is to investigate the applicability of wind and solar energy technologies in a non-residential building in Mersin, Turkey. Mersin is located on the south region of Turkey and has a coast to the Mediterranean Sea. As a non-residential building, a polyclinic belonging to the public was examined. The main common applications of wind and solar energy technologies are about electricity generation. Therefore, wind turbine and photovoltaic panels are emphasized.

The climate data file for EnergyPlus software, which is used to calculate the heating and cooling loads of a non-residential building, is available in Turkey only for Istanbul, Izmir and Ankara. The climate data file for Mersin was created according to the data obtained from Turkish State Meteorological Service. This study is generally considered as a regional feasibility assessment.

## 2. LITERATURE REVIEW

In the literature, numerous studies are available about the application of wind and solar energy technologies in buildings. Brief literature rewiev is as follow.

Panapakidis *et al.* (2012) examined PV-Diesel, PV-Wind, Wind-Diesel and Wind-Fuel cell hybrid systems for different sites of Greece. Bekele *et al.* (2012) investigated the possibility of supplying electricity from a solar–wind hybrid system to a remotely located model community in Ethiopian remote region. Islam *et al.* (2012) and Hoque *et al.* (2012) modelled PV–wind–diesel generator hybrid power system for St. Martin Island and a village in Comilla respectively. Lal and Raturi (2012) investigated the feasibility of a wind–PV–diesel generator based hybrid power system for a remote location on the island of Vanua Levu, Fiji. Essalaimeh *et al.* (2013) showed an experimental investigation of using a combination of solar and wind energies as hybrid system for electrical generation under the Jordanian climate conditions. Nogueira *et al.* (2014) have developed model for sizing a PV–wind–battery hybrid energy system, which is applicable for a small rural property in the south of Brazil. Rohani and Nour (2014) modelled and design PV array- wind turbines-batteries-diesel generators hybrid system for the remote area in the western region of Abu Dhabi. Dalwadi and Mehta (2012) examines the feasibility of PV–wind hybrid system for six different locations of Indian state Gujrat. Meherchandani *et al.* (2012) discuss the economic feasibility of standalone hybrid power system consisting of biomass–PV–wind for electrical requirements of a remote rural area in Rajasthan. Vani and Khare (2013) modelled PV–wind–diesel hybrid system with battery storage for a village in Madhya Pradesh. Sharafi *et al.* (2017) found that the best configuration of PV array, wind turbines converter and batteries storage bank to the minimum levelized cost of energy at Yanbu area in Arabia. Chadel *et al.* (2017) presented first, a method to determine the size and optimization of a PV-wind hybrid system for medium power. Secondly, determined the optimum techno economic configuration for the site of Tlemcen. Sorgato *et al.* (2017) analyzed for the first time in Brazil and under current PV module prices, the technical and economic potential of PV modules on a commercial building.

## 3. METHODOLOGY

The non-residential building discussed in this study is a single-storey building used as a policlinic building and has a total floor area of 200 m$^2$. The general appearance of the building is given in Fig. 1.

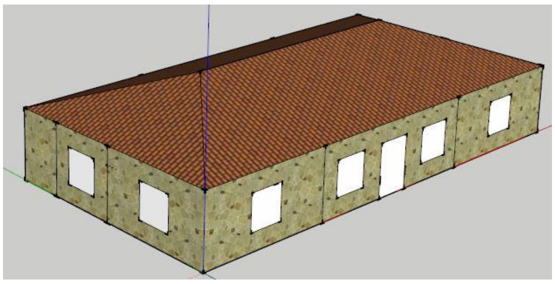


Fig. 1. EnergyPlus model for polyclinic in Mersin

Heating and cooling loads of the policlinic were found using EnergyPlus software.

The coefficient of performance (COP) of the heat pump to be used for heating and cooling the polyclinic is 4.13 and energy efficiency ratio EER is 2.28.

Scheduling of the parameters used to determine energy demand of the polyclinic is done for weekdays between 08.00-17.00.

For the examination of the heating and cooling loads of the polyclinic, the building is divided into 7 zones. Floor plan for polyclinic is given in Fig. 2.

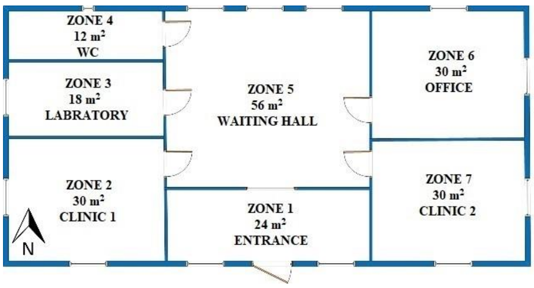



Fig. 2. Floor plan for polyclinic

The structural components of the building are given in table 1.

Table 1. Structural components of the polyclinic

| | | | |
|---|---|---|---|
| Roof | Tile, 100 mm | Internal wall | Plaster cover plate, 5.9 mm |
| | Shingle backer, 9.5 mm | | Gypsum plate, 19 mm |
| | Wood, 25 mm | | Brick, 100 mm |
| | Ceiling air space resistance | | Insulation board, 50 mm |
| | Glass wool insulation, 75 mm | | Gypsum plate, 19 mm |
| | Asphalt coating | | Plaster cover plate, 5.9 mm |
| | Lightweight concrete block, 150 mm | Outer wall | Insulation board, 10 mm |
| Ceiling | Artificial marble, 25 mm | | Insulation board, 75 mm |
| | Cement plaster, 10 mm | | Brick, fired clay, 102 mm |
| | Heavyweight concrete, 100 mm | | Wall air space resistance |
| Window | Clear glass, 3 mm | | Gypsum plate, 19 mm |
| | Air gap, 13 mm | Floor | Artificial marble, 25 mm |
| | Clear glass, 3 mm | | Cement plaster, 10 mm |
| Door | Wood, 25 mm | | Heavyweight concrete, 100 mm |

In order to use EnergyPlus software for Mersin, a climate data file with epw extension was needed. This file is available only for İstanbul, İzmir and Ankara in Turkey. Therefore, a climate data file with epw extension was created for Mersin. Dry bulb temperature, relative humidity, atmospheric pressure, wind direction, wind speed and cloudiness rate data required for the software obtained from Turkish State Meteorological Service. Dew point temperature and solar parameters were calculated using the matlab code.

For thermal calculations required lighting power density, human occupancy, heat gain from devices, filtration and infiltration rates, set point temperatures for heating and cooling for each zone are determined according to 55, 62.1 and 90.1 ASHRAE standards. These values are given in Table 2.

Table 2. Design criteria for each zone

| Zones | Lighting Power Density (W/m$^2$) | Human Occupancy (m$^2$/person) | Heat Gain From Devices (W/m$^2$) | Ventilation Flow Rate (m$^3$/s) | Infiltration Rate (m$^3$/m$^2$s) | Setpoint Temperature for Heating / Cooling (°C) |
|---|---|---|---|---|---|---|
| 1 | 2 | 4 | 15.42 | - | 0.001 | 24/26 |
| 2 | 8 | 5 | 4.6 | 0.4 | 0.001 | 24/26 |
| 3 | 8 | 4.5 | 46 | 0.37 | 0.001 | 24/26 |
| 4 | 5 | 3 | 0 | 0.46 | 0.001 | 24/26 |
| 5 | 8 | 28 | 17.86 | 0.5 | 0.001 | 24/26 |
| 6 | 8 | 5 | 42.27 | 0.3 | 0.001 | 24/26 |
| 7 | 8 | 5 | 4.6 | 0.4 | 0.001 | 24/26 |

In this study, all energy gains or demands were calculated hourly. By using sum of these, daily, monthly and annual values were found.

### 3.1. Wind Energy Analysis

In this study, the wind data measured at the height of 10 m was obtained from Turkish State Meteorological Service. Wind frequency profile for Mersin, Turkey is illustrated in Fig. 3.

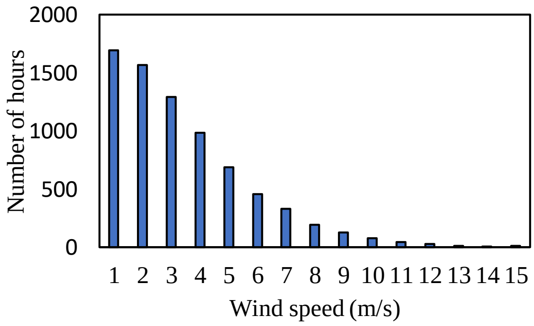



Fig. 3. Wind frequency profile for Mersin, Turkey

About 55 % wind speed in Mersin ranges from 2 m/s to 5 m/s. High-efficiency small wind turbine at 2-5 m/s band for domestic usage is applicable for non-residential buildings.

Fig. 4 illustrates the average, maximum and minimum monthly dry bulb temperature distribution. The annually highest statistic temperature is 39.1 ºC and the lowest statistic temperature is -1.8 ºC. The cooling load of the polyclinic will be higher than the heating load because the Mersin has warm climate.

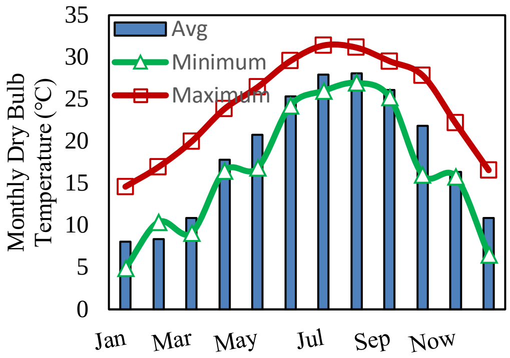



Fig.4. Monthly dry bulb temperature distribution for Mersin, Turkey

There are many distribution functions that are used to determine the distribution of wind speed. Weibull distribution function, which is common in the calculation of wind energy potential, is used in this study. To find the Weibull probability function, two parameters must be known. These are k, shape and c, scale factors. Weibull probability function is calculated from Eq. (1).

$$f(V)=\left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1}\exp\left(-\left(\frac{V}{c}\right)^{k}\right) \tag{1}$$

The shape factor k and the scale factor c of the Weibull distribution are estimated using Eq. (2) and Eq. (3).

$$k=\left(\frac{\sum_{i=1}^{n}V_i^k\ln(V_i)}{\sum_{i=1}^{n}V_i^k}-\frac{\sum_{i=1}^{n}\ln(V_i)}{n}\right)^{-1} \tag{2}$$

$$c=\left(\frac{1}{n}\sum_{i=1}^{n}V_i^k\right)^{1/k} \tag{3}$$

The average velocity can be written as in Eq. (4) by calculating from the probability distribution function.

$$V_{avg}=c\Gamma\left(1+\frac{1}{k}\right) \tag{4}$$

Where $V_i$ is the wind speed in time step i and n are the number of non-zero wind speed data points.

Actual power generated by wind turbine can be calculated by using Weibull distribution function and parameters. Actual power is defined according to the power curve of the wind turbine. Power curve of the wind turbine is given in Eq. (5).

$$P_T(V)=\begin{cases} 0 & V<V_K \\ (a_1V^3+a_2V^2+a_3V+a_4) & V_K\le V<V_R \\ P_R & V_R\le V<V_B \\ 0 & V\ge V_B \end{cases} \tag{5}$$

$V_R$, $V_K$, $V_B$ are rated, cut-in and cut-off wind velocities, respectively. Constants defined as $a_1$, $a_2$, $a_3$ and $a_4$ are obtained by regression analysis of the power curve between $V_R$ and $V_K$ velocities. Actual power generated by wind turbine is obtained by multiplying the produced power at each wind velocity by the Weibull distribution function.

$$E_{TG}=T\int_{V_K}^{V_B}P_T(V)f(V)dV \tag{6}$$

$$E_{TG}=T\int_{V_K}^{V_R}(a_1V^3+a_2V^2+a_3V+a_4)\frac{k}{c}\left(\frac{V}{c}\right)^{k-1}e^{-(V/c)^k}dV + TP_R\int_{V_R}^{V_B}\frac{k}{c}\left(\frac{V}{c}\right)^{k-1}e^{-(V/c)^k}dV \tag{7}$$

In that study, wind turbine with capacity 0.9 kW are used. Specifications of the wind turbine is given in Table 3.

Table 3. Specifications of the wind turbine

| | |
|---|---|
| Rotor Diameter (m) | 2.4 |
| Swept Area (m$^2$) | 4.52 |
| Rated Power (kW) | 0.9 |
| Cut-in Wind Speed (m/s) | 2.3 |
| Rated Wind Speed (m/s) | 60 |

Power curve and generated power equation are obtained according to the fabrication data of the wind turbine and are shown in Fig. 5.

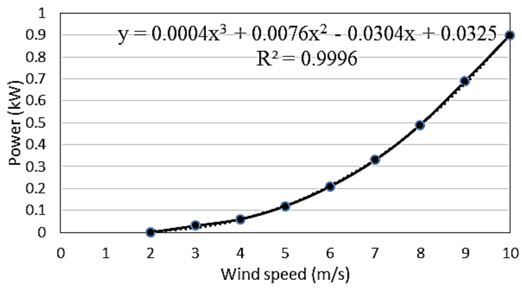



Fig. 5. Power curve and generated power equation

### 3.2. Solar Energy Analysis

The simplest model given in Eq. 8 for predicting photovoltaic energy production is used in that study.

$$P=A_s.f_a.G_T.\eta_{cell}.\eta_{invert} \tag{8}$$

P is the electrical power produced by photovoltaics, $A_s$ is net area of surface (15 m$^2$), $f_a$ is the fraction of surface area with active solar cells (0.8), $G_T$ is total solar radiation incident on PV array, $\eta_{cell}$ is module conversion efficiency (% 20) and $\eta_{invert}$ is DC to AC conversion efficiency (%95). It is assumed that wind turbine and PV panel are connected to region electricity grid. If electricity generated from wind turbine is not enough for the whole building electricity demand, required amount of energy is obtained from the region electricity grid. Otherwise, excess produced energy is transmitted to the grid.

The correlation given in Eq. (9) is known as the Angstrom equation. Where Q is daily global horizontal solar radiation, Qo is daily extraterrestrial solar radiation, t is sunshine duration and $t_o$ is day length. Constants a and b are determined by statistical methods based on measurements of all solar radiation and sunshine duration. In this study, Kılıç and Öztürk (1980) model was used. According to this model coefficients a and b are given in Eq. (10) where Z is altitude, e is latitude and d is declination angle.

$$\frac{Q}{Q_o} = a + b\frac{t}{t_o} \tag{9}$$

$$\begin{aligned} a &= 0{,}103 + 0{,}000017Z + 0{,}198\cos(e-d) \\ b &= 0{,}533 - 0{,}165\cos(e-d) \end{aligned} \tag{10}$$

### 3.3. Cost Analysis

The total cost of the hybrid system consisting of wind and solar energy in non-residential buildings consists of capital cost ($C_C$), energy cost during operation ($C_E$) and operating cost ($C_O$). This relation is given in Eq. (11).

Capital cost includes annual depreciation or amortization cost.

$$C_T = C_C + C_E + C_O \tag{11}$$

The cost of the wind turbine system ($I_{WT}$) and the cost of the photovoltaic panel system ($I_{PV}$) are components of the capital cost. This relation is given in Eq. (12).

$$\begin{aligned} C_C &= \left(\frac{1}{n} + \frac{z}{2}\right)(I_{WT} + I_{PV}) \\ &= \alpha(I_{WT} + I_{PV}) \end{aligned} \tag{12}$$

Where n is the period of recycling, z is the interest rate and α is refund coefficient. α takes a value ranging from 0.1/year to 0.25/year.

Energy cost during operation ($C_E$) equal to the energy generated by wind turbine and photovoltaic panels multiplied by unit price of electricity. This value reduces the total cost.

The operating cost ($C_O$) consists of items such as maintenance, cleaning and repair of the solar and wind energy system and is practically used as in Eq. (13). Where GE is generated energy (MWh) and UOE is unit operating expenses. UOE is 50 TL/MWh for wind turbine, 50 TL/MWh for PV (Zile, M. 2013).

$$C_O = \text{GE } x \text{ UOE} \tag{13}$$

## 4. RESULTS AND DISCUSSION

### 4.1. Wind Speed Distribution of Mersin

In this section, the velocity distributions obtained by using hourly wind data measured at a height of 10 m in Mersin station are examined monthly and annually. The annual average wind speed obtained by using 10 m high wind data from Mersin Station is 1.41 m/s. Daily average wind speed exchange rate according to the months is illustrated in Fig. 6. Accordingly, it is understood that the month with the highest average daily wind speed is May and the month with the lowest wind speed is January.

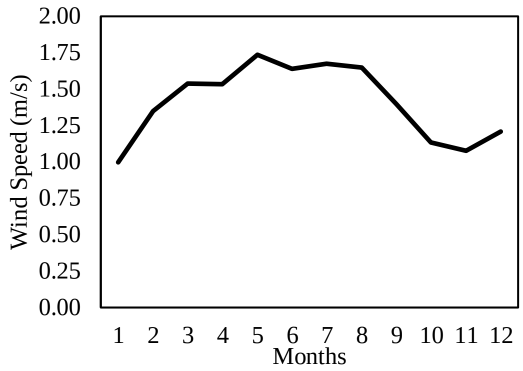



Fig.6. Mersin station average monthly wind speeds

The Weibull probability function for May and January is given in Fig. 7. Accordingly, it is understood that the wind frequency values for high speeds are higher in May than in January. It is also understood that wind speeds in January are 1-2 m/s band, and in May are at 2-4 m/s band.

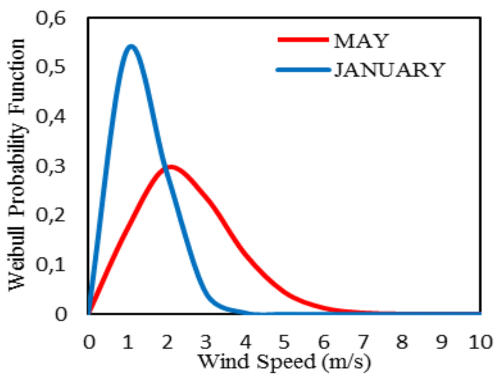



Fig. 7. January and May wind distributions

The annual Weibull probability function is given in Fig. 8. Accordingly, it is understood that the wind speeds are at 1-3 m/s band.

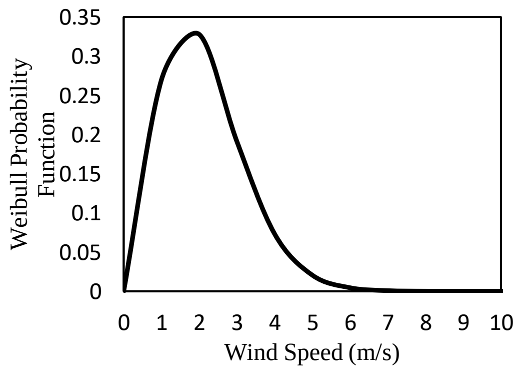
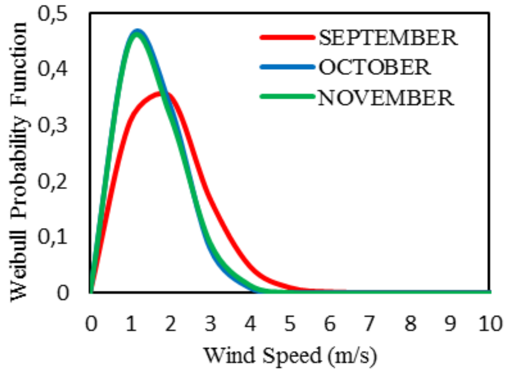
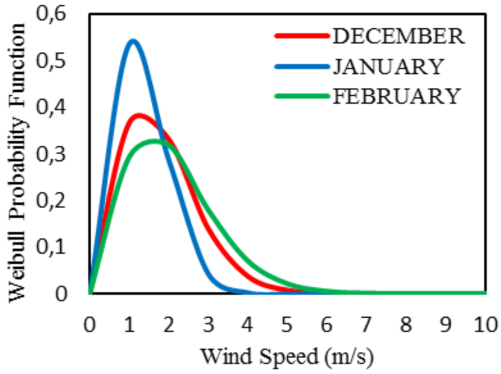



Fig. 8. Annual wind distribution

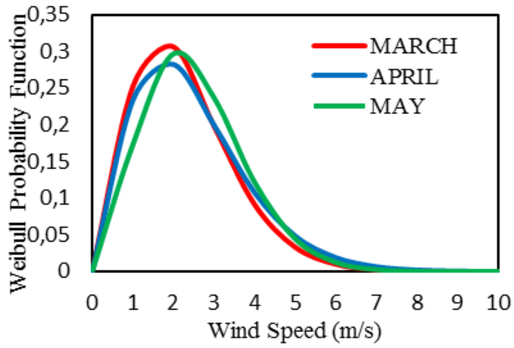
The Weibull probability function for seasons is given in Fig. 9.



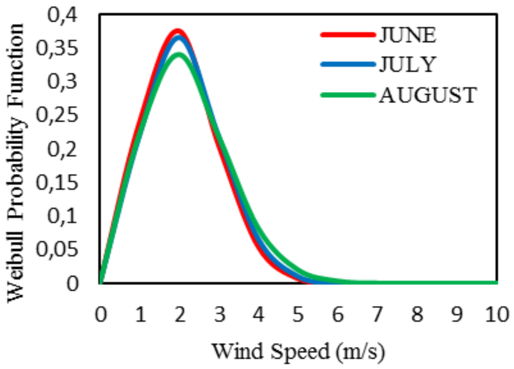

(a)




(b)




(c)




(d)

Fig. 9. Seasonal wind distributions; (a) for autumn; (b) for winter; (c) for spring; (d) for summer

### 4.2. Generated Energy from Wind Turbine

Generated daily energy from the 0.9 kW capacity wind turbine is illustrated in Fig. 10. The total annual energy generation by the wind turbine is 2223.5 kWh and the average daily energy production is 6.1 kWh.

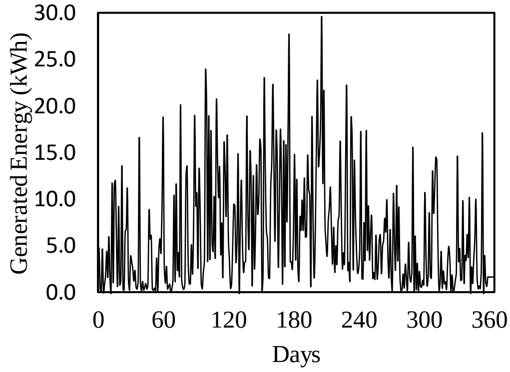



Fig. 10. Daily generated energy from the wind turbine

### 4.3. Solar Radiation Values

Daily total horizontal plane radiation is given in Fig. 11. Accordingly, Average daily total horizontal radiation is 4642 W/m$^2$. On summer days this value is up to 7287 W/m$^2$.

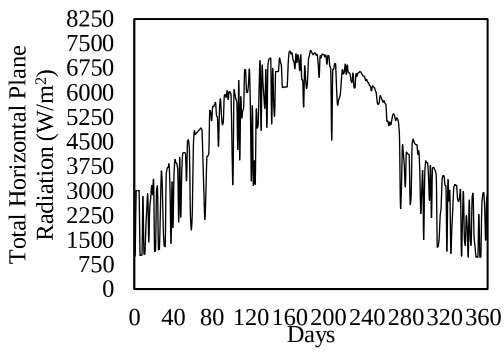



Fig. 11. Daily total horizontal plane radiation

Daily total inclined plane radiation is given in Fig. 12. Accordingly, average daily total inclined plane radiation is 5144 W/m$^2$. On summer days this value is up to 6697 W/m$^2$.

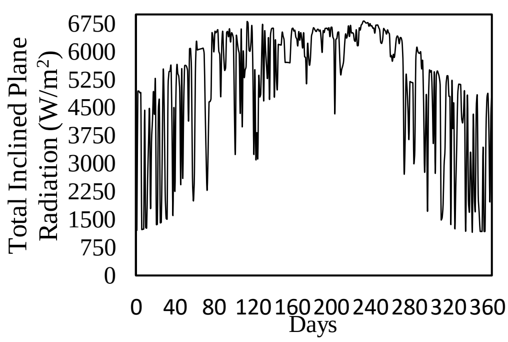



Fig. 12. Daily total inclined plane radiation

### 4.4. Generated Energy from PV Panels

The daily energy obtained by using 10 pieces of photovoltaic panel with 1.5 $m^2$ area is given in Fig. 13. A total of 4240 kWh of energy can be generated annually from these photovoltaic panels. The average daily energy production is 11.62 kWh.

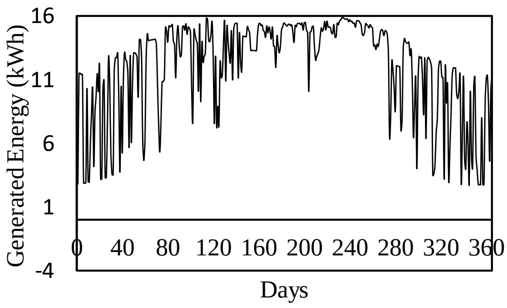



Fig. 13. Daily generated energy from the pv panels

### 4.5. Amounts of Energy Consumed

The daily heating and cooling loads of polyclinic are given in Fig. 14. The average daily cooling load is approximately 33 kWh on annual basis. Total annual thermal load is 12076.92 kWh.

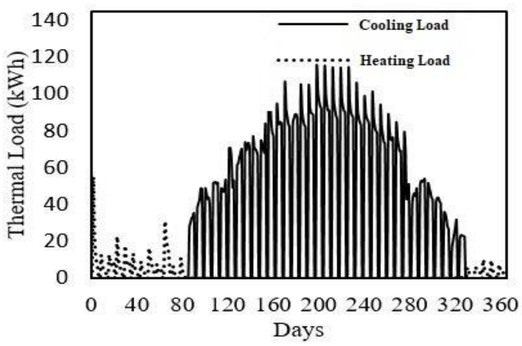



Fig. 14. Heating and cooling loads of the polyclinic

The daily electrical energy consumed by the air-source heat pump to meet the heating and cooling load of the polyclinic is given in Fig.15. Accordingly, consumed energy for cooling is fairly higher than for heating.

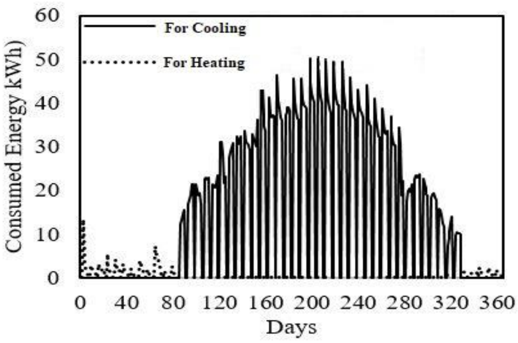



Fig. 15. Air-source heat pump energy consumption

In addition to the heating and cooling loads, the energy consumed by the electrical equipment needs to be taken into account when determining the total energy demand of the non-residential building. The total energy consumed by electrical equipment is 38.44 kWh. The annual total energy consumption is 14030.6 kWh.

Coverage ratio of total daily energy demand from the sum of solar and wind energy is given in Fig. 16.

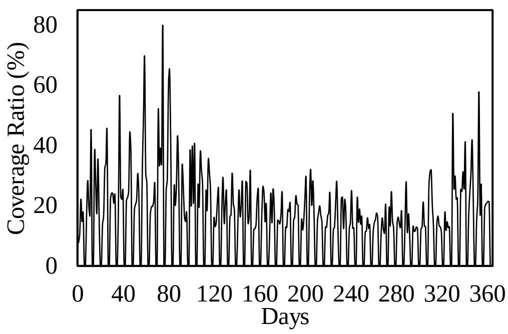



Fig. 16. Coverage rate of daily energy demand

Total consumed energy forms thermal loads and other electrical equipment. Thermal loads are 12076.92 kWh and other electrical equipment constitute annual energy consumption of 14030.6 kWh. Sum of these (26107.52 kWh) represents the annual total energy demand of the polyclinic. 8.51 % of this energy demand is covered by wind turbines and 16.24 % by photovoltaic panels.

### 4.6. Hybrid System Cost Analysis Results

According to market research, the cost of 15 photovoltaic panels (total power = 5kW) together with the whole system (installation, inverter, battery and connections, etc.) costs 10000 TL. The cost of the 0.9 kW wind turbine with the whole system (installation, battery, charging unit, battery group, inverter, tower etc.) is 6500 TL. Total annual energy production of the solar-wind hybrid system was calculated as 6463.5 kWh. When this value is multiplied by unit price of electricity (0.39 TL/kWh), 2520.76 TL/year profit is obtained. As a result, the lifetime of these two systems is n = 20 years. The depreciation time of the hybrid system that is considered to be established is calculated as 17 years. If the hybrid system did not include a 0.9 kW wind turbine and only solar panels were used, the depreciation time would be reduced to 11 years.

## 5. CONCLUSION

In this study, a single-floor polyclinic building with a covered area of 200 $m^2$ located in Mersin was dealt with. In this building, the applicability of wind and solar energy technologies has been investigated. The results of the study are as follows:

- The wind energy potential of the studied region is low. The average annual speed of the Mersin Station using 10 m high wind data is 1.41 m/s. The average daily energy production from the wind turbine is 6.1 kWh.
- The solar energy potential of the region studied is high. The average daily solar radiation from the photovoltaic panel with a slope angle of 30º is 5144 W/$m^2$.

The average daily energy output from the photovoltaic panels is 11.62 kWh.

- The daily average energy demand of the non-residential building is 35 kWh.
- 8.51 % of the annual energy requirement of the non-residential building is covered by wind turbines and 16.24 % by photovoltaic panels.
- The hybrid system, which consists of wind and solar energy, has a depreciation of 17 years. It is not applicable to use this system in the non-residential building since the system lifecycle is 20 years.
- If only the photovoltaic panel system is used, the depreciation time will be reduced to 11 years and a similar system is applicable.

## ACKNOWLEDGEMENTS

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