Basic information about developed

Calculator for solar / wind hybrid power supply

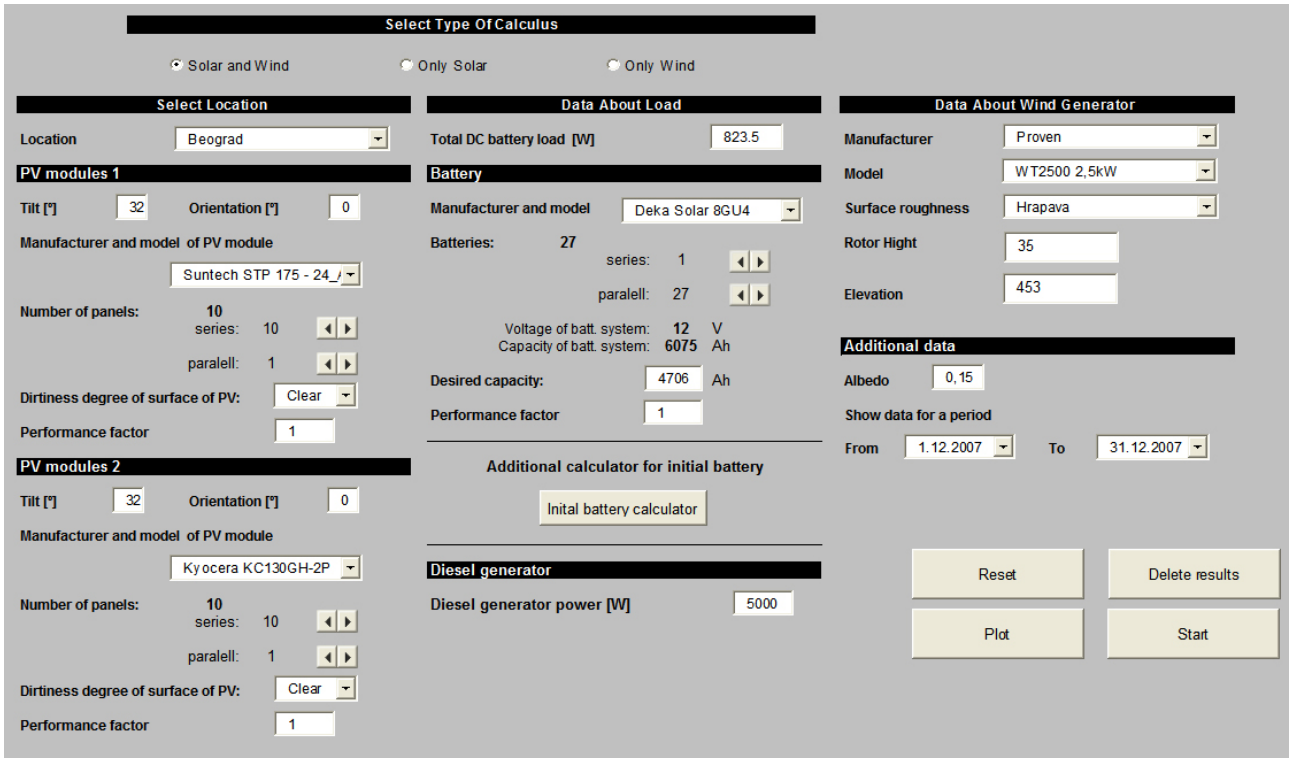
- It simulates behavior of the system for off grid power supply (components: solar panels, wind generator, batteries and diesel generator)
- Enables omitting of each of the components (for example wind generator)
- Available extendible data base with:
    - relevant catalogue data about commercial equipment
    - latitude of locations
    - relevant parameters for solar calculator
    - ambient temperature

1. Input data

Main input data:

- Location
- Electric load
- Wind input data
- Specification of equipment
- Period of calculation

Data specified in data base are available from internet sites.



2. **Solar calculator**

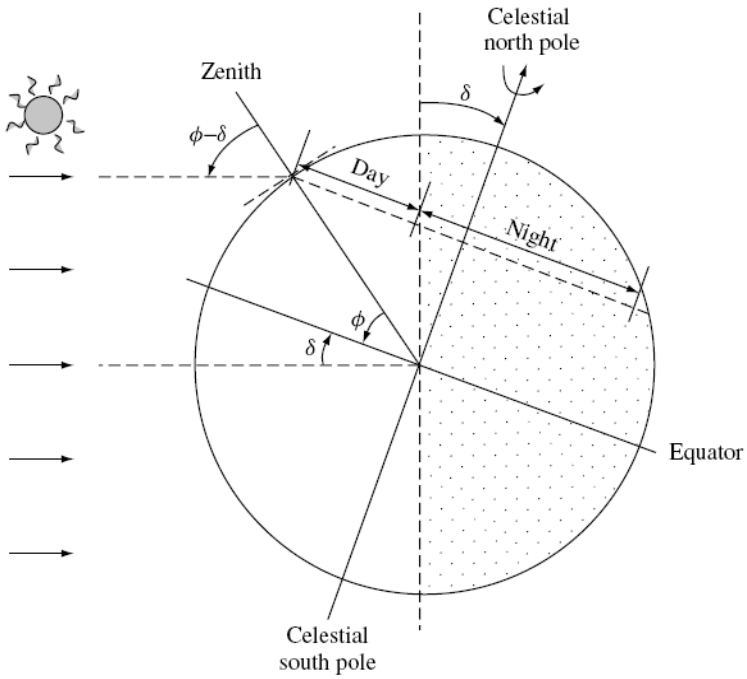
- The calculation is based on daily values of clearness index (ratio of horizontal irradiance at the earth surface to horizontal extraterrestrial irradiance)

Relevant factors for the energy produced by solar panels are considered:

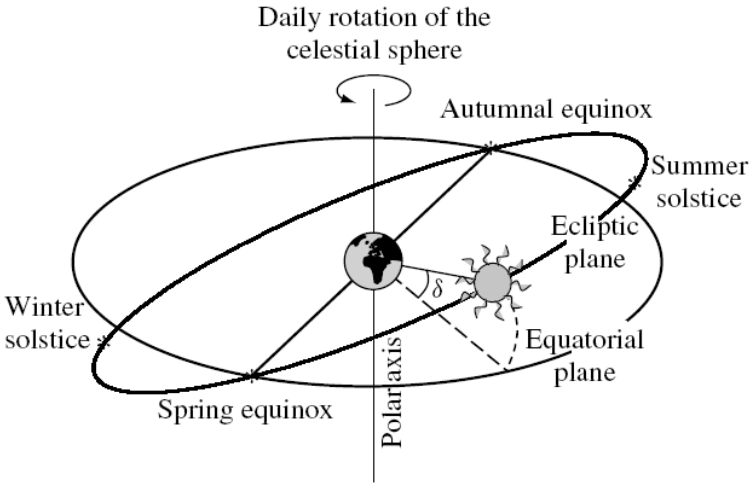
- Three existing components of solar irradiance (direct beam, diffuse and reflected)
- Orientation (slope and azimuth) of solar panels
- Ambient temperature (available from database)
- Dirtiness degree of PV module surface
- Factor of ageing of solar panels

Some highlights from the methodology:

- Calculation of the angle between beam, coming directly from the sun, toward the horizontal surface
- Precise position of the earth (orbiting around the sun) at ecliptic plane for every given day during the year, and sun position on the sky during the day

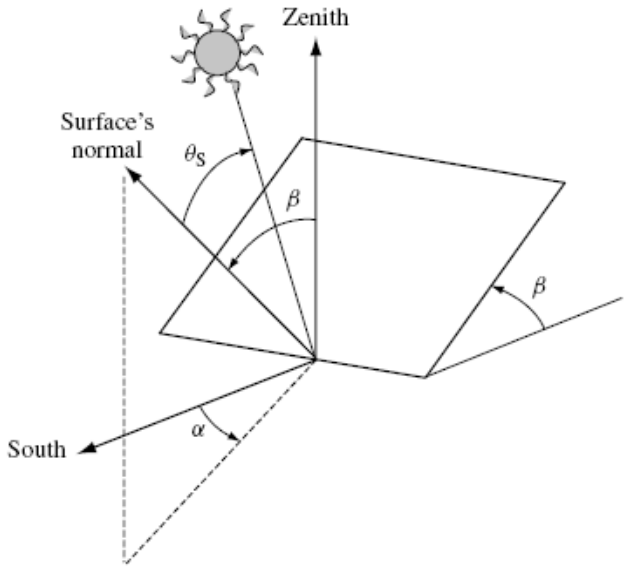


Relative Earth–Sun position at noon of a negative declination day (winter in the Northern Hemisphere, and summer in the Southern Hemisphere). (φ – latitude, δ – declination for specific day of the year)



The celestial sphere and the equatorial plane

- The influence of orientation of solar panels to irradiation on its surface



Influence of receiver orientation (slope β and azimuth α) to the incidence angle of direct beam θ_S

Energy produced by the panels calculated from input irradiance:

- Based on equations derived from equivalent circuit of solar panel
- Standard parameters of solar panels are used (open circuit voltage, short-circuit current, MPP voltage and current etc.)

3. **Wind calculator**

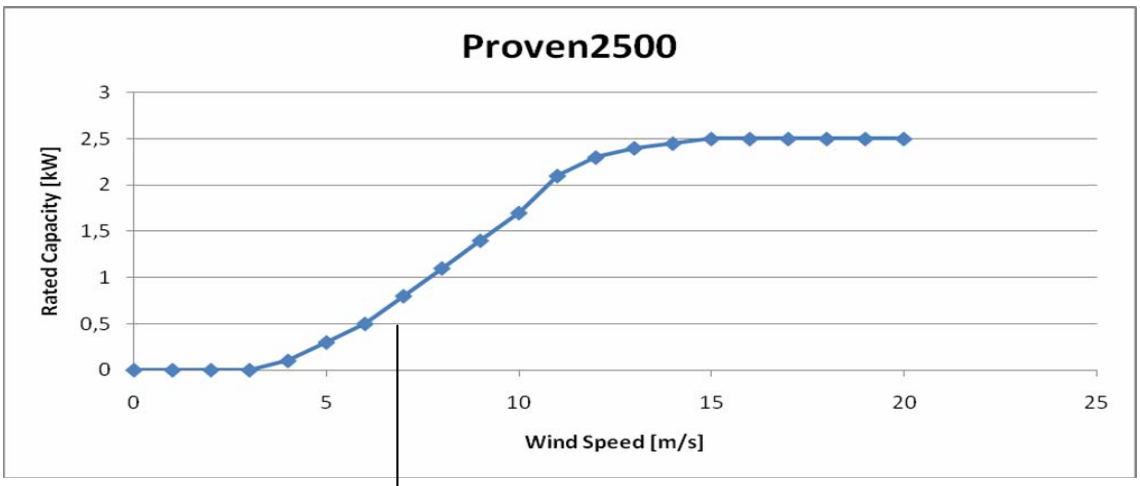
Input data for wind calculus are:

- Necessary: to define the data about wind velocity on specific height (at least one)
- Surface roughness factor
- Rotor height
- Elevation (h)
- Temperature (available from data base)

Some highlights from the methodology:

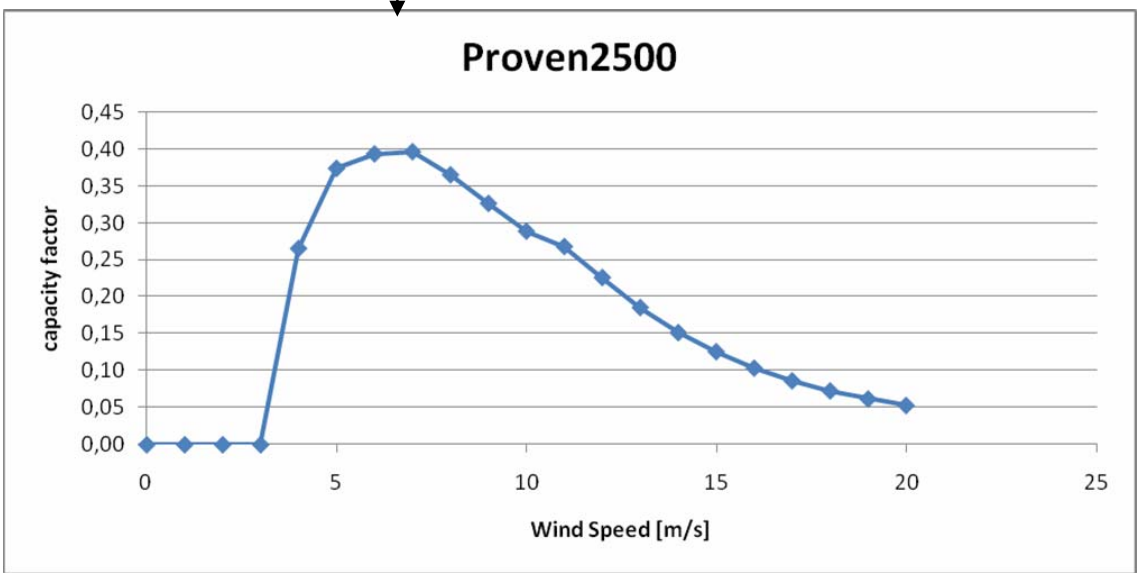
- The energy produced by the wind generator is estimated based on wind velocity at the position of wind generator
- The re-calculation of measured wind velocity at specific height to rotor height:
    - Based on typical roughness factors
    - Based on roughness factors estimated on measurements on two heights

Power of wind generator calculated from wind velocity at rotor height:



Characteristic obtained from the manufacturer $P_e = f(v)$; ρ=1.225kg/m^3; A-rotor swept area

$$C_p = \frac{P_e}{\frac{1}{2}\rho A v^3}$$



$$P_e = \frac{1}{2}\rho K_T K_a A C_p v^3$$

$$K_T = \frac{28,97}{1,225 \cdot 0,080256 \cdot (273,15 + T)}$$

$$K_a = e^{-1,185 \cdot 10^{-4} \cdot h}$$

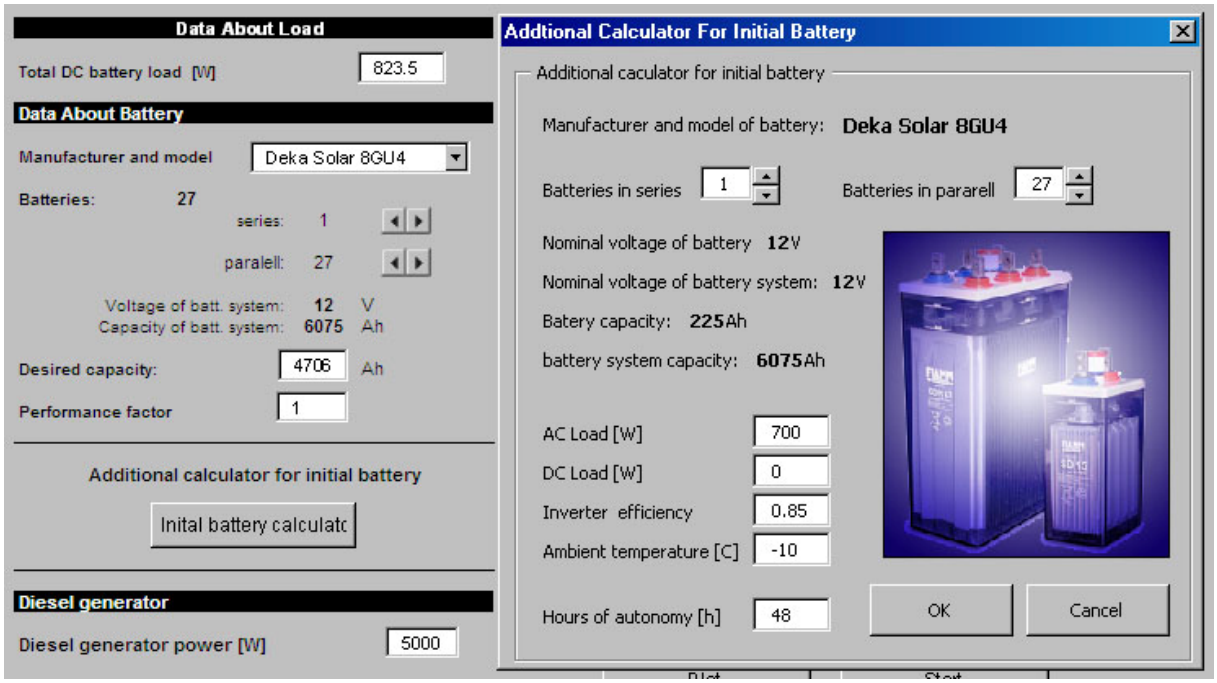
Produced energy in given time period:

$$W_e = \frac{1}{2}\rho K_a A \sum_{i=1}^{N} K_{Ti} C_{pi} v_i^3 \Delta t_i$$

4. **Battery calculator**

Some highlights from the methodology:

- The capacity is being continuously re-calculated to actual ambient temperature
- The dependence of energy lost on temperature dependent internal resistance of the battery is being continuously calculated
- There is auxiliary program for initial design of the battery (for a given load, critical ambient temperature and hours of autonomy, initial battery is calculated). Such battery can be used in further simulations.



5. **Concept of the software**

- Applied tools
  - Excel (input and auxiliary output data),
  - VBA (calculation routines and generation of graphical reports),
  - Access (data base)

6. Results and other output data

Following output data of hourly values for every day of a chosen period:

- Power output of PV modules
- Power output of wind generator
- Capacity of battery
- Amount of energy drawn from battery
- Energy of diesel generator to Load
- Energy of diesel generator to Battery
- Beam, Diffuse and Reflected irradiance
- Global irradiance (the sum of previous three)

Output data of daily values of:

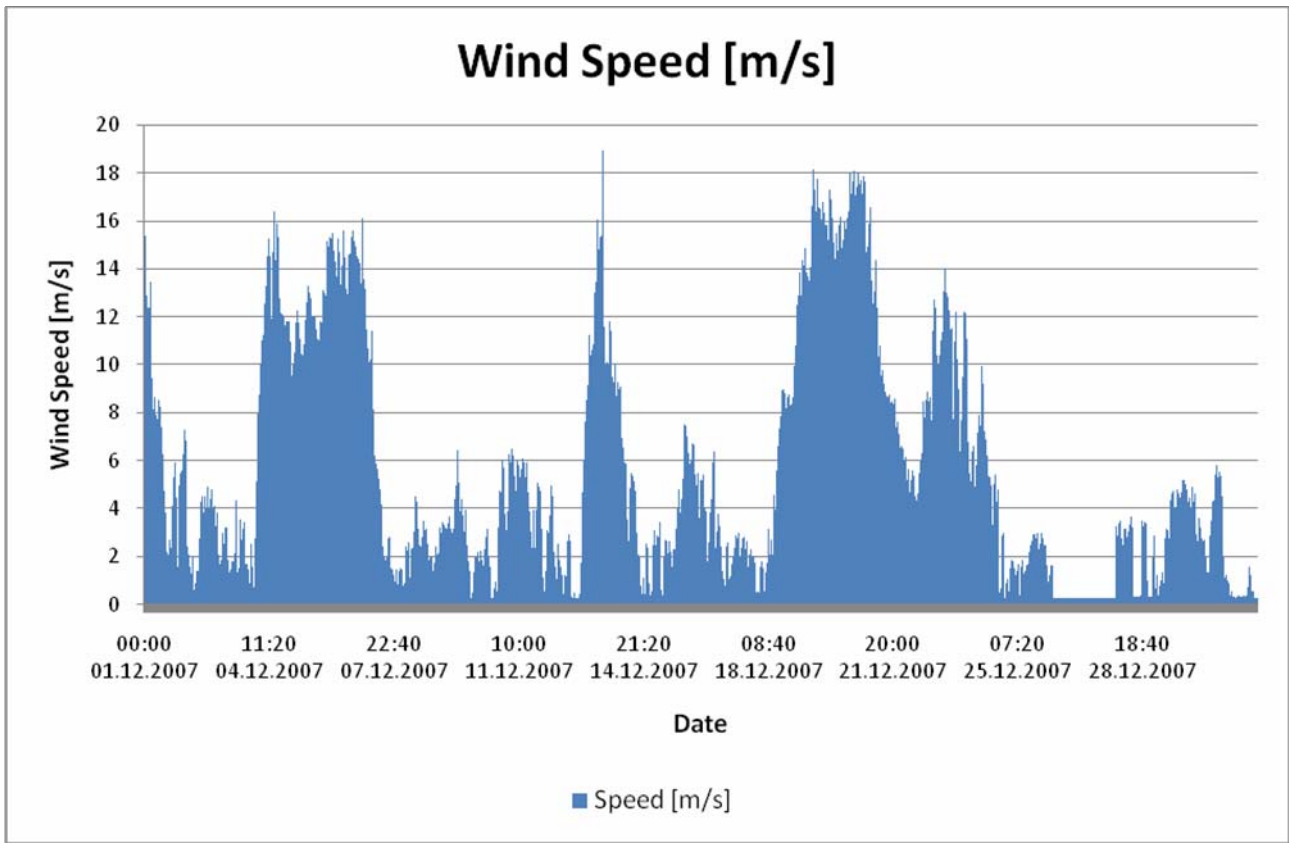
- Generated energy by PV modules
- Generated energy by wind generator
- Used energy created by solar and wind
- Unused energy created by solar and wind
- Generated energy by diesel generator
- Capacity of battery at the end of the day
- Total irradiation reaching the surface of PV module

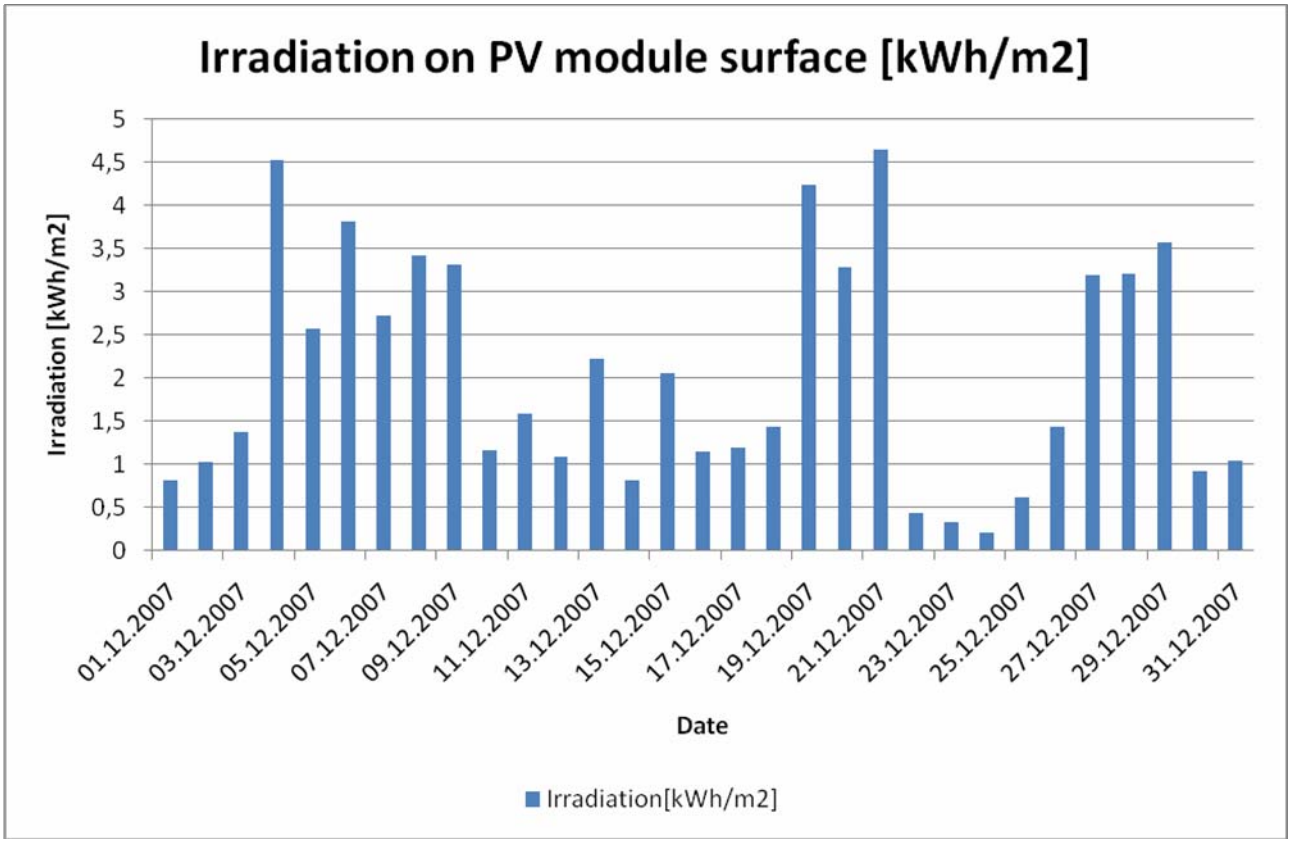
Global data for the complete specified period:

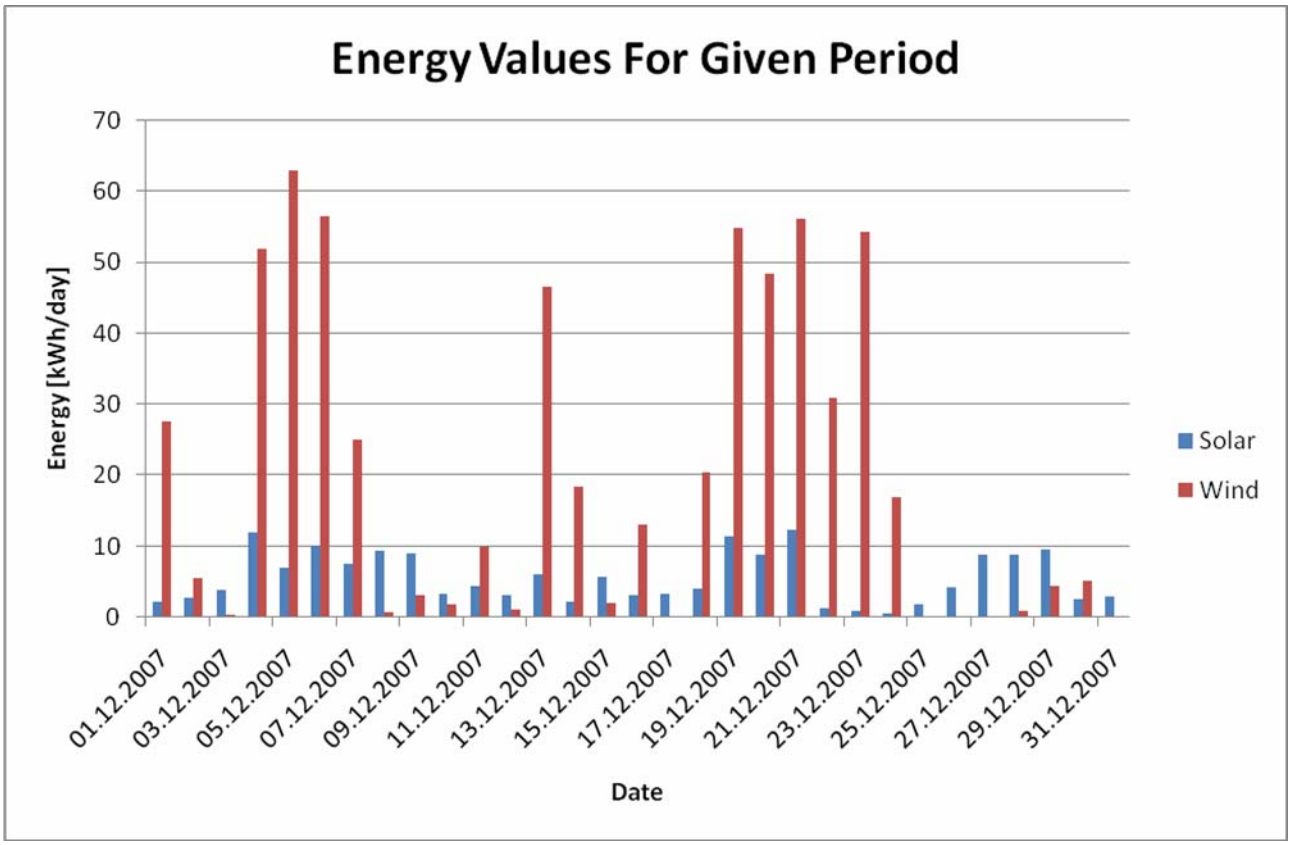
- Estimated investment and operational costs
- Overall produced energy by PV modules and wind generator
- Total wasted energy by PV modules and wind generator
- Total given energy by diesel for a specified period of time
- Number of working hours of diesel generator

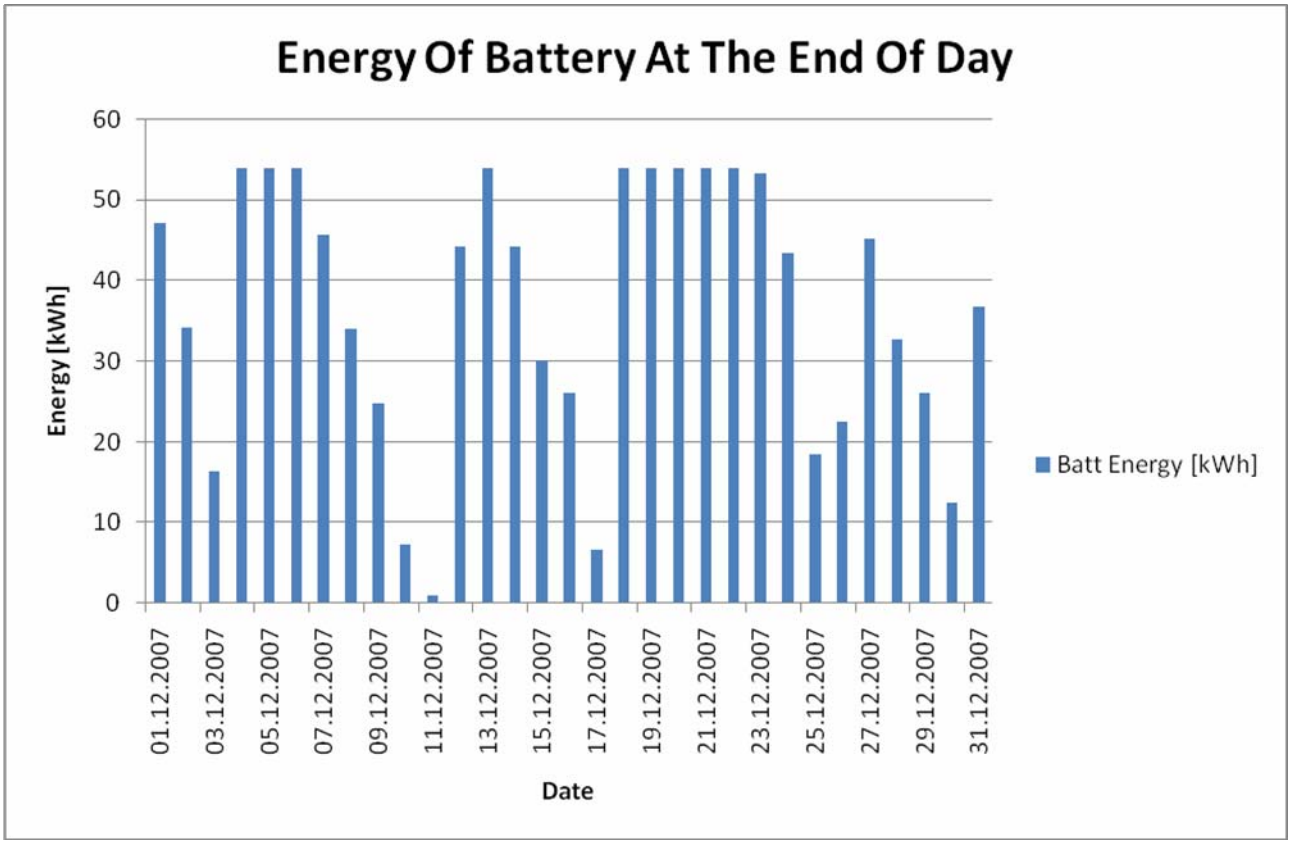
The most important results are presented in graphical forms:

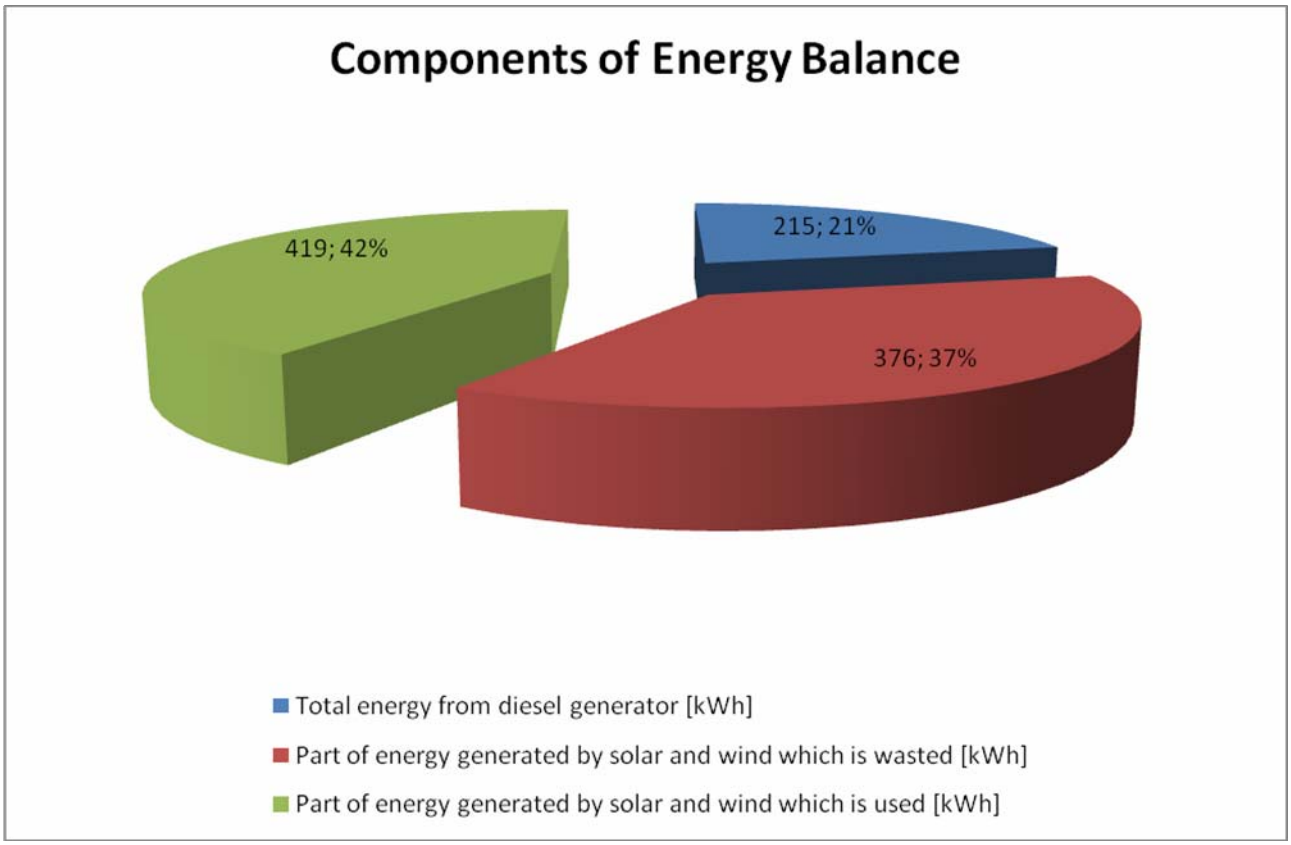
(Configuration: 15 x 175W Solar panel, Wind generator 2.5kW, Battery capacity 6075Ah, Diesel 10kW)

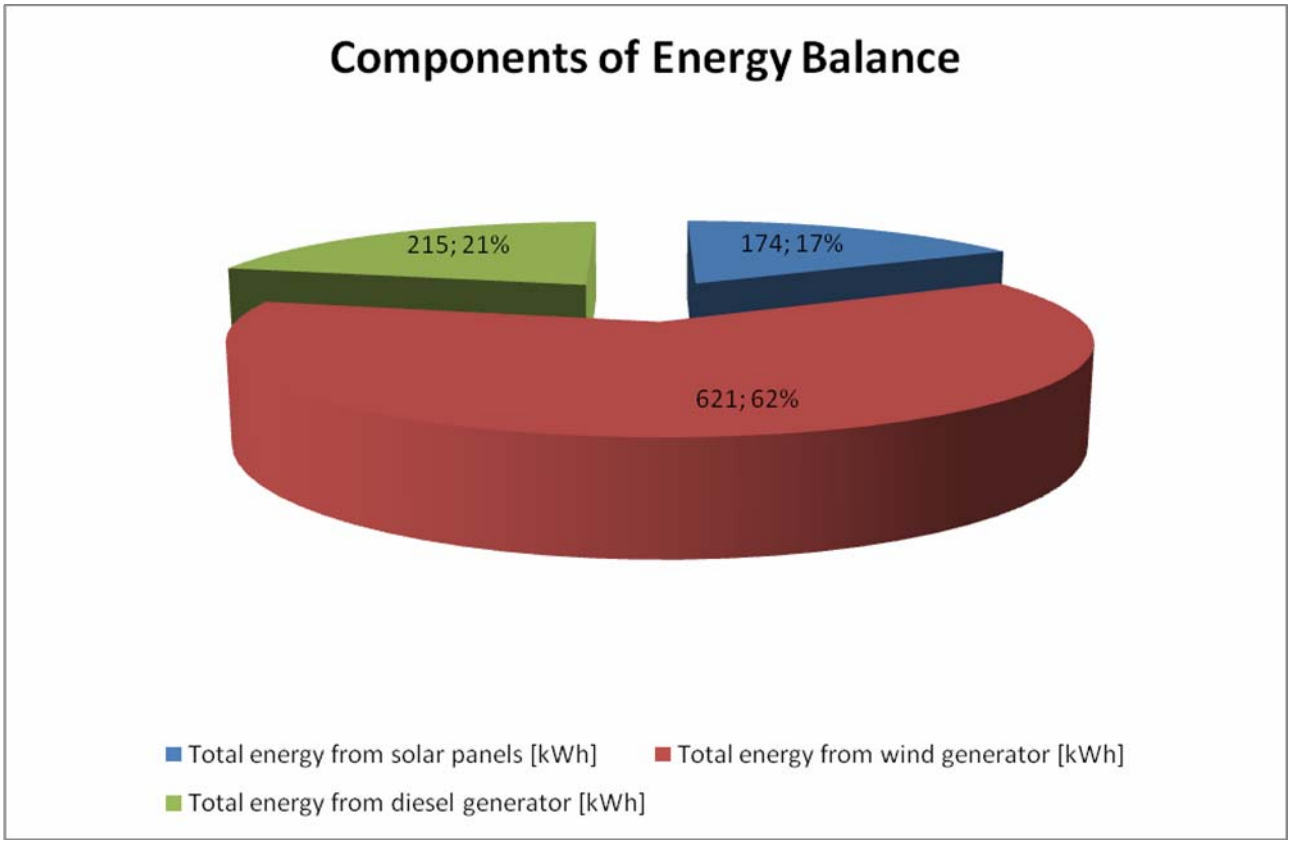





Energy Values For Given Period
Energy [kWh/day]
70
60
50
40
30
20
10
0
01.12.2007
03.12.2007
05.12.2007
07.12.2007
09.12.2007
11.12.2007
13.12.2007
15.12.2007
17.12.2007
19.12.2007
21.12.2007
23.12.2007
25.12.2007
27.12.2007
29.12.2007
31.12.2007
Date
Solar
Wind


Energy Of Battery At The End Of Day
Energy [kWh]
60
50
40
30
20
10
0
01.12.2007
03.12.2007
05.12.2007
07.12.2007
09.12.2007
11.12.2007
13.12.2007
15.12.2007
17.12.2007
19.12.2007
21.12.2007
23.12.2007
25.12.2007
27.12.2007
29.12.2007
31.12.2007
Date
Batt Energy [kWh]





7. Literature

1. Antonio Luque and Steven Hegedus: "Handbook of Photovoltaic Science and Engineering", 2003

2. J. A. Duffie, W. A. Beckman: "Solar engineering of thermal process"