Solar energy utilization in overall energy budget of the Johann Gregor Mendel Antarctic station during austral summer season

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Abstract
It is well known that the utilization of renewable energy sources is inevitable for a sustainable future. Besides the fact that other energy sources such as coal, gas or nuclear power have limited reserves the proper use of increasingly higher shares of renewable energy sources may lower negative impacts of traditional energy sources on the ecosystems. This is especially important in naturally protected areas located in remote Earth locations. Such areas are still almost untouched by mankind, *e.g*. Antarctica. The research activities in the area of renewable energy sources have increased rapidly within the last few decades. It is of a global interest to carry out the research in an ecologically sensitive way, *i.e*. balance the outputs and the effects of infrastructure on environment. In this paper, a project of installation of a photovoltaic system on the Czech Antarctic Station (Johann Gregor Mendel) on the James Ross Island is described and the first experience from the system run is reported. The contribution of this system to the overall energy production on this station shortly after commissioning of the system is presented as well. In discussion, a possible future development of the system is suggested.

Key words: J. G. Mendel Station, photovoltaics, hybrid PV system, Antarctica

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Introduction

The solar radiation has been extensively studied throughout the world as far as its determination and its availability during the days of the year and during the hours of the day itself. The intensity of the solar radiation during the year is a measure of the usage and the applications to be designed (Kaplanis et Kaplani 2013). Antarctica also has large PV potential because of its high irradiation and low temperature (Mason 2007). The early attempts to introduce PV technology to Antarctic stations started in the 80-ies of the last century (Kohout et al. 1993). Recently, many Antarctic stations have started measures to increase the share of PV-based energy in

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Antarctica and gained first experience (see *e.g.* Olivier et al. 2008, Obara et al. 2013).

The Czech Antarctic Station (J. G. Mendel) situated on the James Ross Island is a seasonal operated station, the expeditions usually arrive at the beginning of January and leave the station at the end of February or in the first weeks of March. From the very beginning, the energy system of the station was designed to utilize both fossil fuel and renewable energy as well (Prošek et al. 2013). After the main completion of the station in 2006, the energy generation was based on using two diesel generators with 25 kW power (one of them as reserve) together with 8 pcs of 1.5 kW wind turbines charging nickel-cadmium (NiCd) batteries and thus lowering the fuel consumption and diesel generator operating period (Neruda et. al 2013).

Unfortunately, severe damage to the mechanical parts of the wind turbines were caused by heavy wind storms within the first years of operation. Despite a high effort of the technical staff, only 4 of them remained fully working after such episodic events. Also one of the inverters transferring the accumulated energy in the batteries to the alternative (AC) current was broken.

Based on these facts, a modification of the energy system was inevitable. As the station is seasonally operated (during the austral summer season), it has been decided to integrate a powerful photovoltaic generator into the present system and replace the inverters with new ones. A company with experience with PV systems (Sunnywatt CZ – see *e.g.* Wolf 2009) was selected in a competitive tendering to design and deliver the components for this system modification. A close cooperation between the company and the Czech station operator (Masaryk University in Brno) helped a lot for the final success of this project.

The new designed energy system was facing several challenges, a list of which is summarized in Table 1.

Unfortunately, the heavy sea ice formed in Prince Gustav Channel disabled cargo delivery by a ship and the components were delivered to the J. G. Mendel station two years later than expected. During the expedition 2014/2015 all of the components were unpacked and build on place, the system was commissioned and first data from its operation was collected.

1. The photovoltaic energy gain on place was not known – only data about horizontal radiation and temperature were available
2. There was lack on information about the energy demand of the station, there was no measured daily profile of the energy load
3. The rough climate can cause severe problems to the technology installed (low temperatures, rime, storm, blizzards)
4. The delivery of the components on place is a tough task, all necessary components must be included in the shipment, a single missing component or tool can postpone the project for another year (delivering by the next expedition)
5. The mounting and servicing must be done using common tools available on place or intentionally delivered and with limited number of personnel. There is no chance on using special equipment like crane or excavator.

Table 1. Challenges of the new designed energy system.

Material and Methods

Original hybrid system design and the energy utilization

In Fig. 1, a simplified scheme of the original system is presented. Charging the battery and its energy utilization using an inverter was mostly done manually according to the expected energy demands and battery state of charge. The two installed inverters could not have been switched parallel, therefore the diesel generator had to operate even the high charge state of the battery in a case of high energy demand. There was no data acquisition unit installed to measure and store the energy data and to monitor the system behavior, only current values of voltage and current were indicated on the panels in the switching station container.

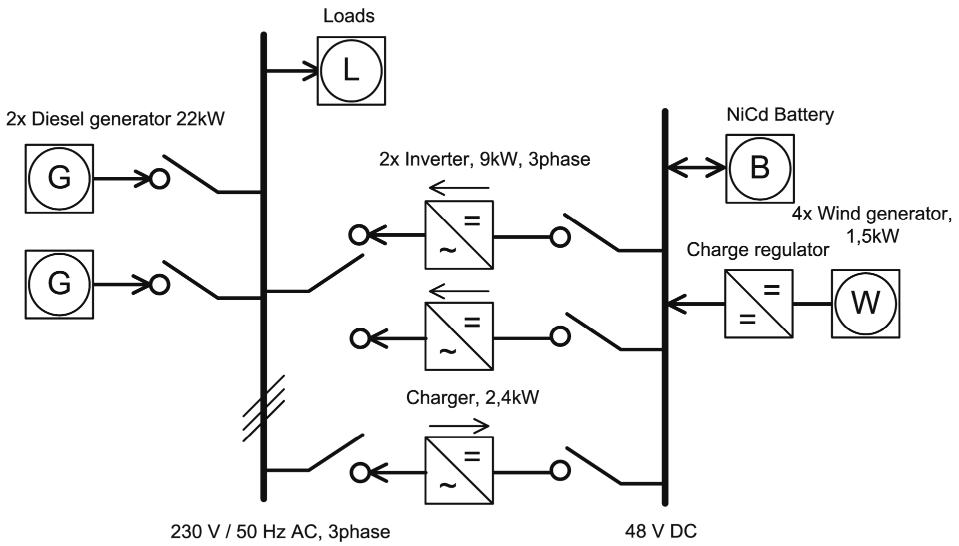

Fig. 1. Scheme of the original energy supplying system of J. G. Mendel station.

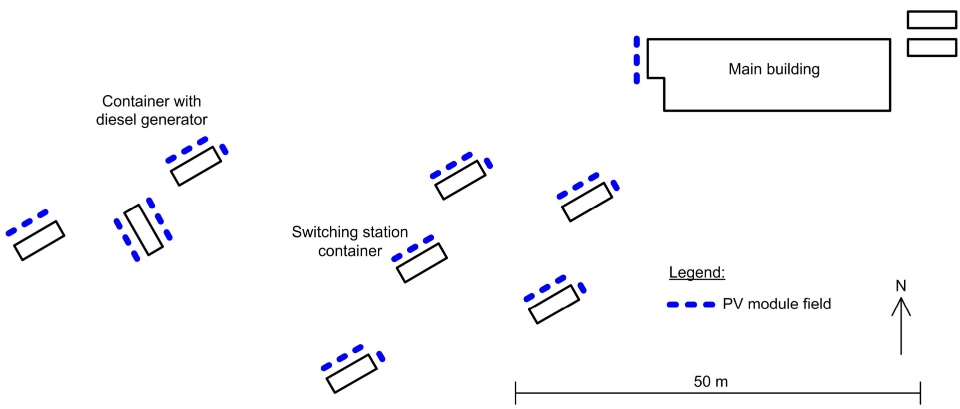

Fig. 2. Layout of J. G. Mendel station and location of PV system.

General layout of the station is shown in Fig. 2. Most of the components (inverters, main switchboards, battery and charger) are located in the switching station container, diesel generator is situated in a separate container; the majority of the energy is being consumed in the main building.

Hybrid system modification

The new modified system consisted of two parts – a photovoltaic system and a new inverter set together with data monitoring and semi-automatic energy management (Fig. 3).

The photovoltaic system for energy generation and battery charging consisted of photovoltaic modules, photovoltaic battery chargers with maximal power point tracking, mounting construction, cabling and switchboards. It was decided to utilize the area on the east, north and west sides of most of the containers for the installation of photovoltaic modules. A special construction holding the modules was fixed using welding on several points to the containers. It can be easily turned in angle 70° of 90° (vertically) from horizontal plane to minimize wind storm impact during winter in the Northern Hemisphere. The complete system consisted of 108 pcs of crystalline silicon modules with overall 21 kW peak power.

East, north and west orientation of PV modules provided a uniform daily profile of energy gain. The sun path (Sun elevation angles for particular days) on the place according on the time is presented in Fig. 4. The analyses of Sun elevation angles was essential for the optimization of the module inclination and orientation. The PV module locations can be found on the layout of the station (*see* Fig. 2). Fig. 5 shows some of the newly installed PV modules on the container wall.

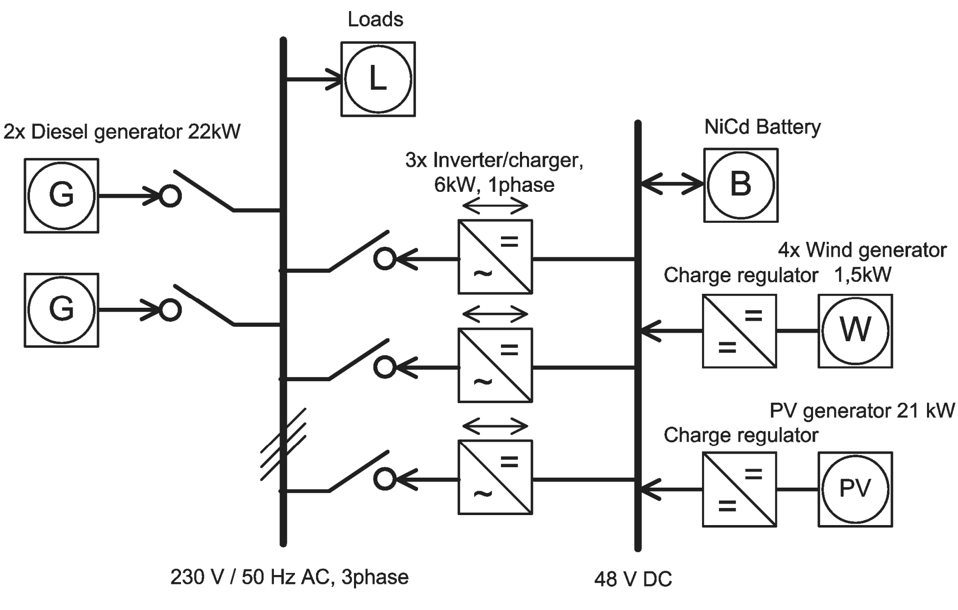

Fig. 3. Scheme of the new modified energy supplying system of J. G. Mendel station.

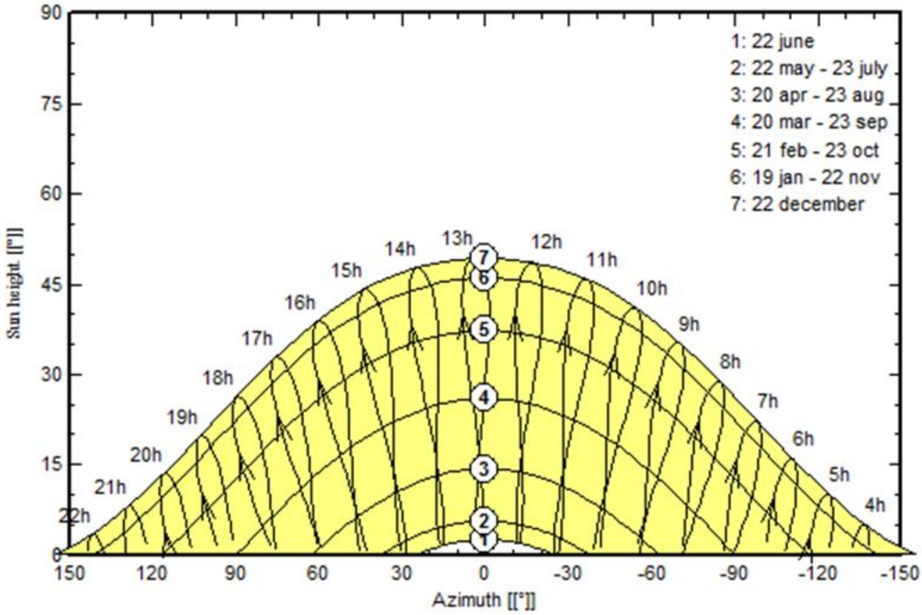

Fig. 4. Sun elevation angles, the paths for the J. G. Mendel station (created by PVsyst software).

Fig. 5. PV modules installed on the container.

A new inverter set was based on three general purpose battery chargers and inverters produced by SMA company (SMA Solar Technology AG, Germany) enabling to set up a 3 phase 230 V / 50 Hz autonomous grid. These units also had an input for connecting external power source such as electrical grid or diesel generator. They enabled remote monitoring and operation control of several devices including control of the diesel generator based on energy state (SMA Solar Technology AG. 2015). These new functions enabled a semi-automatic operation of the whole system and simultaneously reduced the work of technicians to control the system. They also assisted to control the loads and utilize the excess energy (*e.g.* the excess energy of the renewable sources was used in electrical heaters; the heaters were automatically switched off in case of energy shortage) and provided a continuous data measuring and storage that can be used for further system optimization. Last but not least, the high power output of the inverters enabled to operate the system without the need of diesel generator performance in case of high energy demand and fully charged battery, or in case of high energy production on the DC side by the renewable sources.

Results and Discussion

Energy system evaluation

Heating, hot water preparation and kitchen appliances represent the highest energy demands at J. G. Mendel station, followed by water pumps, lighting, computers (notebooks) and various special laboratory equipment and other occasionally used electrical tools. Fig. 6 depicts daily profiles of electrical energy load and energy generation measured for the period of February 1st – February 3rd, 2015. There was a big difference between the night and day energy demands. During the night, the load was almost constant and remained below 1 kW. During the day, contrastingly, the power consumption varied a lot and often reached peaks of 8 kW or higher.

Fig. 7 shows the total daily energy generation and consumption. Both parameters have very similar values. The only difference was caused by the amount of energy stored or released from the battery. The total daily consumptions varied significantly, but can be adjusted according to the energy situation and availability, especially sun and wind situation. The energy management based on restricted operation of appliances helped a lot in saving fuel and maximizing the utilization of the renewable energy sources, but lowered the personal comfort. This was typical for the periods lasting for couple of hours when heating was reduced and air temperature in the station decreased. From the experience gained during the Jan–Feb 2015, it might be concluded that the best way is to reach a compromise between the personal comfort and optimal energy utilization by implementation of several rules. Among them, *e.g.* heating of rooms and hot water preparation should be optimized. In case of excess supply of renewable energy, full heating of rooms to target temperature and hot water preparation for shower should be operated with no limits. In case of energy shortage, contrastingly, a reasonably high air temperature of the rooms should be managed and hot water for a short-term shower has to be provided only each 2-3 days.

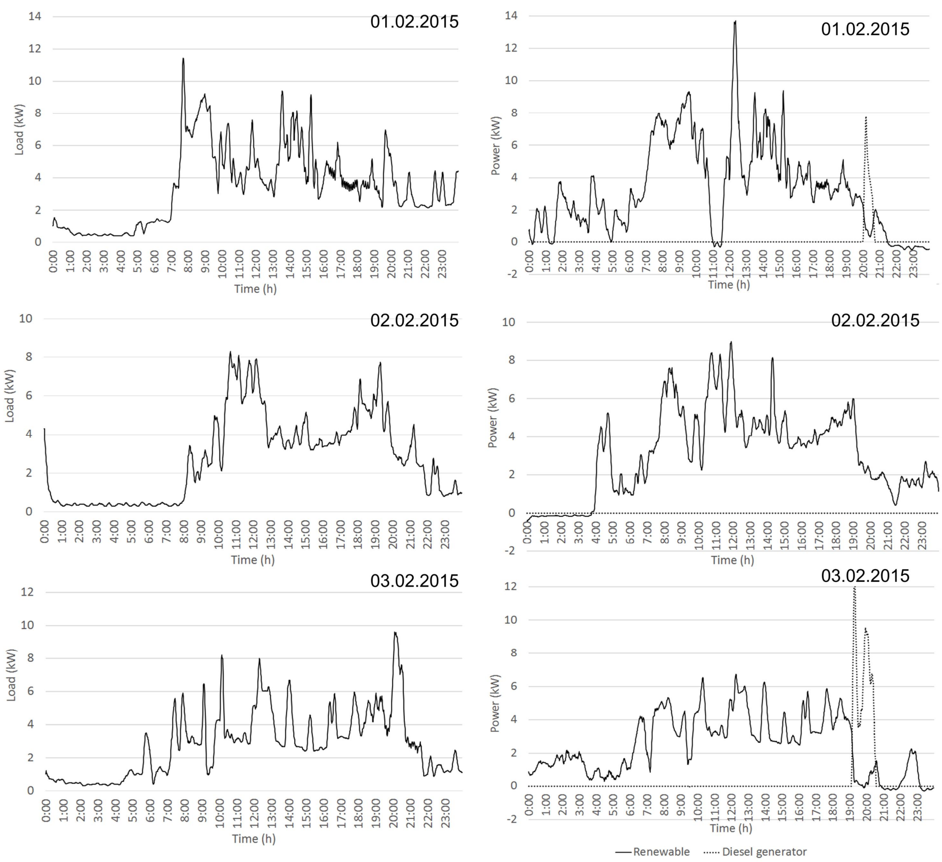

Fig. 6. Daily profiles of the electrical energy load (left) and generation (right).

Total daily energy generation by renewable sources (photovoltaics and wind) and diesel generator is presented in Fig. 8. On 11 out of 24 inspected days, the renewable energy sources fully covered the station demand on energy. Thus, the diesel generator was off and not contributing to overall energy budget. The overall energy contribution in the period 28.1. – 20.2. 2015 by photovoltaics, wind and diesel generators is presented on Fig. 9. Most of the energy was generated by the newly installed photovoltaic system. Such system significantly saved the fuel consumption and reduced the operating time of the diesel generator. The wind energy stays in the overall energy yield of small significance. It can be more extended in the future by installing new wind generators that can sustain the rush environment, especially the strong katabatic reaching speeds of more than 100 km.h^{-1} (Láska et Prošek 2013).

Distribution of total daily energy generation and consumption is shown in Fig. 10. The data showed that the most common energy generation by the renewables as well as energy consumption was between 60 and 80 kWh per a day. Energy consumption was also common in the interval of 80 – 100 kWh per day, the energy generation by the renewables, on the contrary, was common in the low energy intervals (0 – 60 kWh per day).

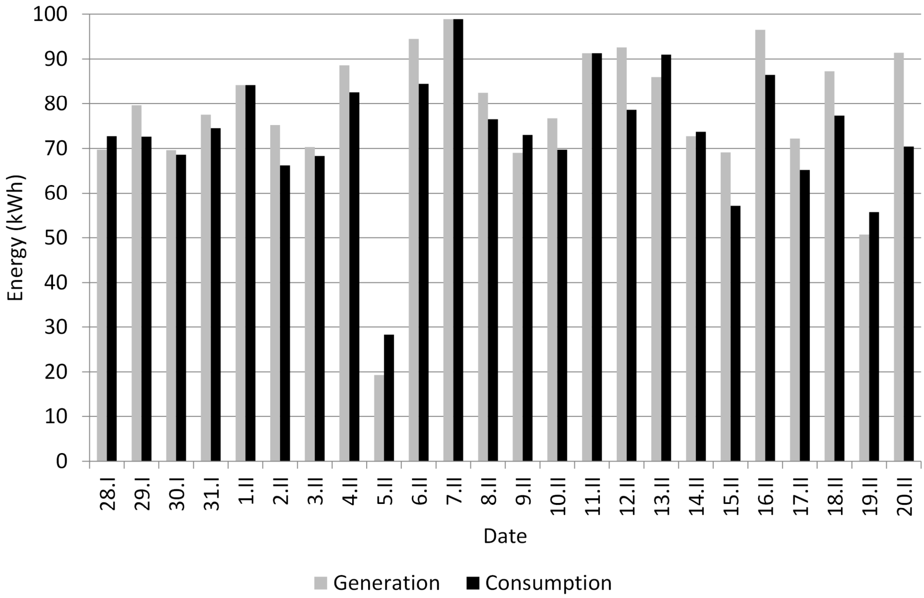

Fig. 7. Total daily energy generation and consumption.

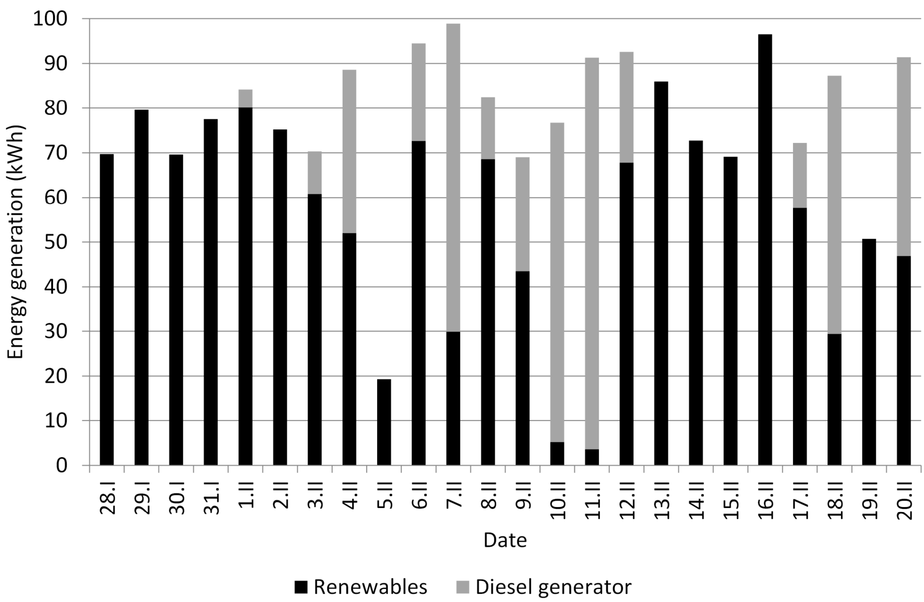

Fig. 8. Total daily energy generation by energy source.

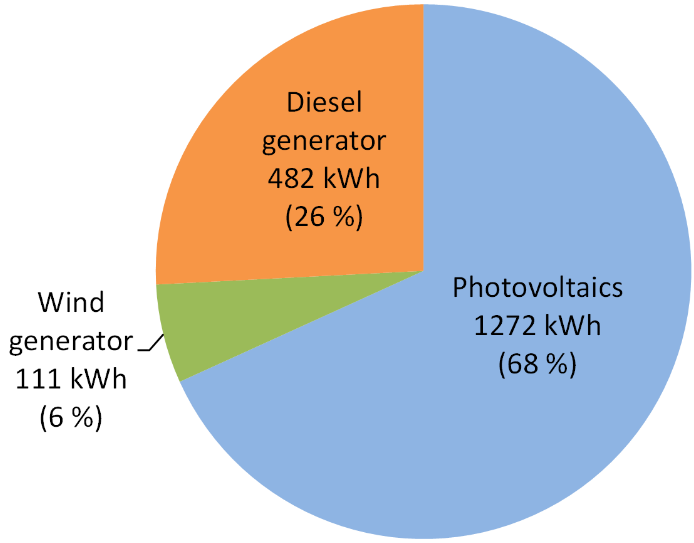

Fig. 9. Overall energy yield in the period 28.1. – 20.2.2015 by energy source.

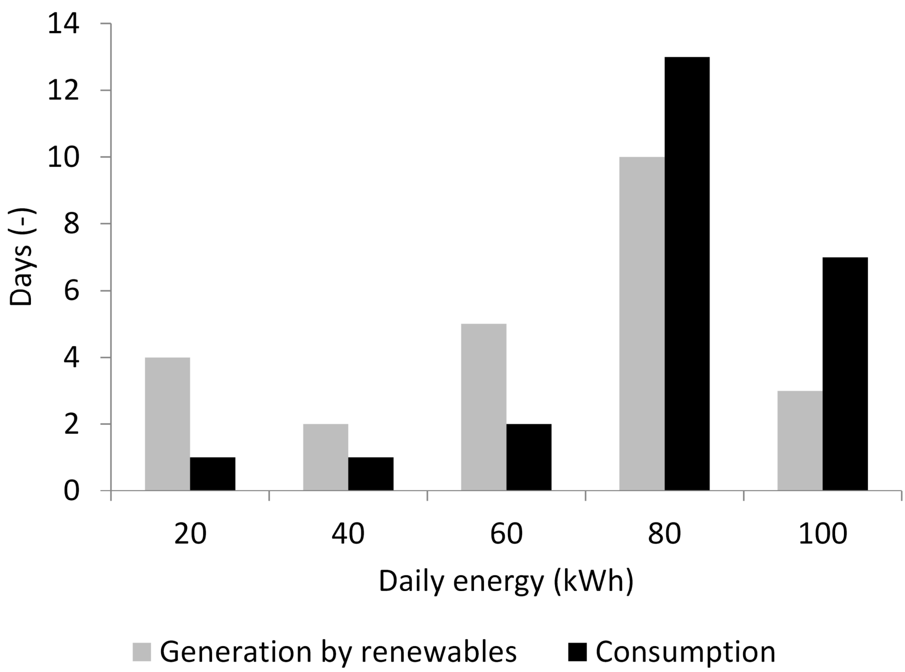

Fig. 10. Distribution of total daily energy generation by renewables and energy consumption.

As most of the energy from renewables was produced by the photovoltaics, it might be concluded that a further effective development of the energy system can be done by installing a more powerful and effective wind generators. From climatic measurements and experience of station staff, it could be pointed out that solar and wind energy are complement to each other, *i.e.* in case of small radiation there is a high probability of heavy wind and vice versa. Therefore, it can be assumed that increasing number of installed wind generator power will shift the energy generation distribution towards high energy intervals and will further increase the renewable energy portion. Such conclusion is well comparable to commonly-accepted hybrid power systems based on renewable energy (Henryson et Svensson 2004), *i.e.* systems combining several sources to generate energy quantities sufficient to run Antarctic stations. Therefore, recent trend in Antarctic stations is to increase the shares of wind- and photovoltaic-cased energy in total energy budget of Antarctic stations (*e.g.* Boccaletti et al. 2014). Newly-built Belgian station (Princess Elizabeth) follows such direction and energy policy (Cheek et al. 2011). The power budget of the station is composed of 48% of wind power from nine wind turbines, 20% of solar photovoltaic from 380 m^2 of solar panels and 12% solar thermal with 22 m^2 of solar panels (Sanz Rodrigo et al. 2012). An increased share of renewable energy generation and utilization may, however, have certain limits and meet some technical and organizational problems in Antarctic stations (Tin et al. 2010). Therefore, further experience and data collection on the effectivity of PV energy production are needed in follow-up studies so that optimization of renewable energy production/ consumption for particular Antarctic station could be done.

Conclusion

The energy system modification on the J. G. Mendel station based on implementation of PV resulted in a significantly increased share of renewable energy of the overall energy generation. The newly-installed photovoltaic system produced 68% of total energy generation (in the period of January 28th to February 20th, 2015). The new inverters installed into the system enabled to monitor and control the whole energy system. They provided more comfort and effectivity of energy exploitation at the station. A further development of the energy system is expected by installing new powerful wind generators resistant to the rough climate on James Ross Island.

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