· Review · **Advances in Polar Science**
doi: 10.13679/j.advps.2021.0024 September 2021 Vol. 32 No. 3: 185-194

Utilization of clean energy and future trend of Antarctic research stations

LI Zhao, LÜ Dongxiang*, SUN Zilu & LI Chuan

The 18th Research Institute of China Electronics Technology Group Corporation, Tianjin 300384, China

Received on 24 May 2021; accepted on 30 September 2021; published online 30 September 2021

Abstract The polar regions are rich in resources with high scientific value. Polar scientific research is of great significance to natural environment, climate, astronomy and geology. Polar scientific research is closely related to polar energy supply. Most research stations still use fossil fuels as the main source of power generation. This kind of power supply not only pollutes the environment, but also consumes a lot of manpower and material resources. As a kind of renewable energy such as solar energy and wind energy, renewable energy not only has the characteristics of sustainable development, but also has the characteristics of local power generation and transportation cost saving. At present, several countries have started the construction and application of polar renewable energy, and achieved good results in some Antarctic stations. Based on the investigation and summary of the application of renewable energy in various countries, this paper discusses the development trend of polar energy supply in the future, and provides a clear idea and direction for the development of polar renewable energy.

Keywords **Antarctic search station, renewable energy, wind power, solar power**

Citation: Li Z, Lü D X, Sun Z L, et al. Utilization of clean energy and future trend of Antarctic research stations. Adv Polar Sci, 2021, 32(3): 185-194, doi: 10.13679/j.advps.2021.0024

1 Introduction

The polar region are the regions within the earth's Antarctic Circle and Arctic circle. They are the driving force of global climate change, the source of global climate change and the hub of the earth's close relationship with extraterrestrial systems. Especially in Antarctic (Figure 1), the Antarctic Treaty declares the region it covers and the Protocol on Environmental Protection points out that activities in the Antarctic region should limit adverse effects on the Antarctic environment and its dependent and related ecosystems. As a result, Antarctica is one of the few undeveloped, unpolluted and pure areas on the earth, it has a high value of scientific exploration and is of great significance for us to understand and protect the earth. At the same time, Antarctica contains more than 220 kinds of mineral resources and energy. There is an "iron mountain of the world" for the world to develop and utilize for 200 years, and a huge coalfield with a total production capacity of about 5.0×10^{11} t (Zhu et al., 2006). The Antarctic Peninsula is also rich in copper, lead, zinc, molybdenum and a small amount of gold, silver, chromium, nickel, cobalt and other non-ferrous metal reserves. The polymetallic manganese resources in the Southern Ocean are also considerable. Antarctic oil and gas are mainly distributed in the Antarctic continental shelf and the western part of the Antarctic continent. According to the survey, the Ross Sea, Weddell Sea, Bellingshausen Sea shelf area and Prydz Bay area are the main prospective areas and exploration areas with the largest oil and gas resources potential. The oil reserves in Antarctica are about $5.0–10\times10^{10}$ barrels, and the natural gas reserves are about $3.0–5.0\times10^{11}$ m^3 (Zhu et al., 2006).

In the 20th century, more than 40 countries have established over 100 research stations in the polar regions

* Corresponding author, E-mail: dongxianglv@163.com

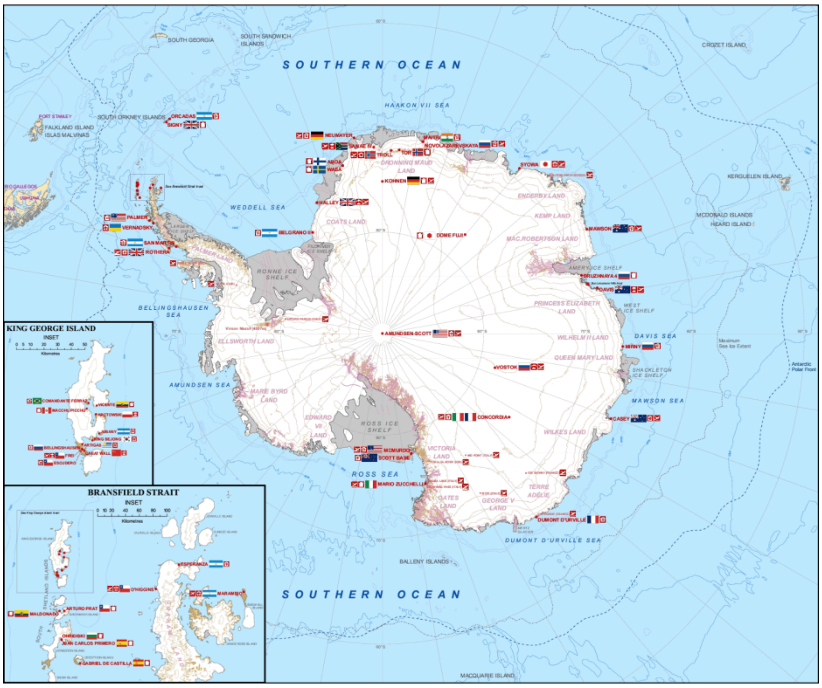

Figure 1 Distribution of Antarctic research stations (COMNAP, 2017).

and conducted research on the polar regions in many disciplines. Several major scientific researches have made breakthroughs in the polar regions, such as the discovery and study of the ozone depletion in the Antarctic atmosphere and the discovery and study of the Lake Vostok, a large lake under the Antarctic ice sheet (Sun et al., 2020). Therefore, the Arctic and Antarctic regions are the holy land for scientific research and experiments, the last frontier that is closely related to global environmental changes, sustainable economic development, and the survival and destiny of human beings. For the exploration of the polar region, the use of electric energy is indispensable (Lü et al., 2020). The exploration of the polar region is inseparable from the use of electric energy. At present, fossil fuels are still the main energy source of the Antarctic research station. Relevant studies show that by applying a bottom-up Antarctic emission inventory method, emissions at different spatial levels can be summarized from emission sources at monitoring points (Kakareka, 2020). In the case of Vincene Oasis, Enderby Land and East Antarctica, the proposed diesel generators in the area will produce NO_2 concentrations of more than 50 $\mu g \cdot m^{-3}$ per hour. In order to further improve fuel efficiency, some stations have developed and used efficient heating systems and achieved excellent energy saving results (Kakareka and Salivonchyk, 2020). In addition, some newly-established stations have also incorporated renewable energy into their energy-saving strategies, making full use of the abundant wind energy in Antarctica and collecting and using solar energy for building power and heating during sunlight hours. However, there are problems in the utilization of renewable energy such as unstable energy supply and difficulties in equipment maintenance, which to some extent limit the large-scale use of renewable energy systems. With the development of construction technology, some new research stations make full use of the physical characteristics and advantages of the environment to develop and adopt special and suitable technologies to further reduce the building energy demand (Boccaletti et al., 2014).

1 Polar environment and renewable energy sources

Due to its unique geographical location, Antarctica has the most extreme climate and environment, with summer temperatures usually ranging from −30°C to above 0°C and winter temperatures ranging from −15°C to −65°C. The lowest temperature ever measured was −89.2°C near Russian Vostok Station in 1983 (Crossin et al., 2020).

Because the Antarctic continent is high inside and low outside, cold air from the interior sinks from the sloping edge of the plateau and rushes along the surface of the ice sheet to the edge of the continent to form high-speed air currents, which are known as downwelling winds. Some parts of the Southeast Antarctic experience gusty weather up to 340 $d \cdot a^{-1}$. Antarctic gales can often reach wind speeds of 50–60 $m \cdot s^{-1}$, with a maximum of about 100 $m \cdot s^{-1}$ (Ramesh et al., 2021). If being used properly, Antarctic wind energy has great potential. Because of the excessive wind speed and the harsh natural conditions of the polar regions, the utilization of wind energy has created a serious challenge.

At the same time, the polar region is also relatively rich in solar energy, and the establishment of photovoltaic power plants is a practical energy utilization strategy. But there is an unstable supply of solar energy in the polar region, with large seasonal differences and a complete lack of light during the polar night. While during the polar day, light is also affected by weather conditions. Therefore, the energy demand and the energy output of renewable energy need to be reasonably matched to maximize the use of renewable energy for building energy supply. Studies in Comandante Ferraz Station have shown that the total radiant solar energy in the station area in January 2009 was about 125.59 $kw \cdot h \cdot m^{-2}$. But the technical parameters on which the construction and use of solar panels in Antarctica are based need to be distinguished from those in other conventional climate zones due to the presence of large amounts of snow and high surface reflection coefficients in Antarctica (Yavaşoğlu et al., 2019).

Both photovoltaic and wind power are intermittent in nature, with unstable energy generation. In order to supplement these two new sources of power generation, in addition to using traditional diesel generators, energy storage batteries such as hydrogen fuel cells can be used as energy storage devices. Due to the abundance of water resources in polar regions, the surplus energy can be used to produce hydrogen by electrolysis using water resources when there is excess power generated by photovoltaic and wind power (Crossin et al., 2020). And hydrogen can be stored, while hydrogen fuel cells can be used to supplement the insufficient power when the power generated by solar and wind is not enough to meet the load demand, so as to achieve the purpose of balancing the power production and consumption. The utilization of hydrogen energy in Antarctica is still in the verification stage.

2 New polar energy systems in various countries

Due to the abundant renewable energy in polar regions and the limitation of traditional fossil fuels, nearly 10 countries have carried out the construction of using renewable energy to supply power to the research stations and achieved good results, among which wind and solar power are the most prominent.

2.1 United States

The McMurdo Antarctic Station of the United States (the largest station in Antarctica) used diesel generators as the only power supply at the beginning of the station (Figure 2). Since 2010, the U.S. McMurdo Station and New Zealand Scott Base have built three 330 kw wind turbines on the Ross Island wind farm for base power supply, which is expected to reduce diesel consumption by about 463000 L and CO_2 emissions by 1242 $t \cdot a^{-1}$, with the ultimate goal of relying on wind power to provide all the energy for the two stations and diesel generators only as a backup. By April 2012, the combined wind power system at McMurdo and Scott stations was generating 111% of the planned capacity, providing 11% of the energy needs of Scott and McMurdo stations (the largest stations in Antarctica) (Crossin et al., 2020; Sun et al., 2020).

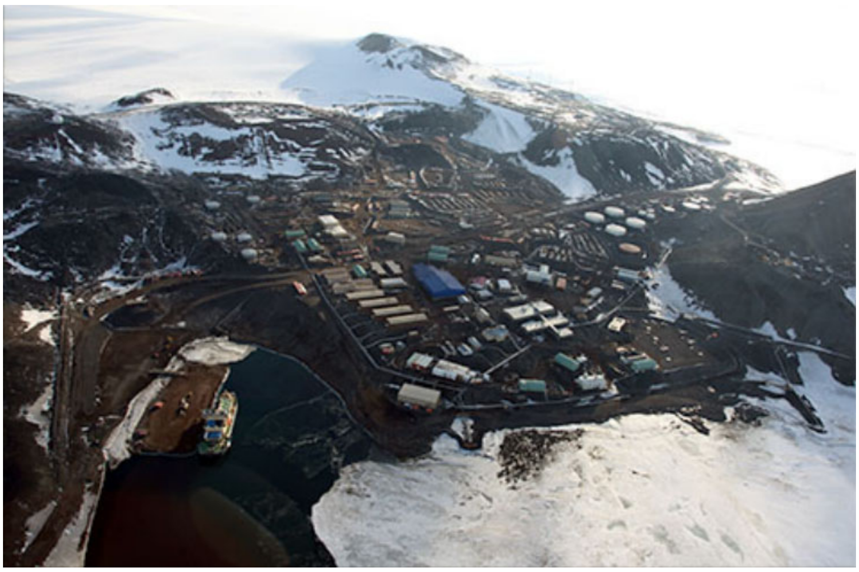

Figure 2 McMurdo Station (Werner, 2019).

2.2 United Kingdom

Solar hot water systems have been installed at King Edward Point, South Georgia and Signy stations of the UK, and another system is being installed in the existing infrastructure at Bird Island station. In addition, a large system of 36 solar panels has recently been completed at Rothera Station (Figure 3), which is used to provide solar heating for fresh air at the New Bransfield House residence. The best opportunity for large scale renewable energy is at

Figure 3 Rothera Station (BAS, 2021b).

Rothera Station, where large wind turbines and solar PV arrays can be used simultaneously. The British Antarctic Survey (BAS) has started a detailed feasibility study for a large-scale renewable energy installation at Rothera Station (BAS, 2021a; Ramesh, 2021).

2.3 Belgium

The Belgian Princess Elisabeth Station is the world's first zero-emission Antarctic station, relying entirely on renewable energy for building operations and personnel living needs. Elizabeth Station building electricity is provided by a combined wind and solar power plant (Figure 4). The station is equipped with 408 photovoltaic solar panels that provide 52.72 kw of electricity, with an annual output of about 45700 kw·h. The batteries are used to store energy to meet the multi-hour power demand, and the thermal solar panels installed on the roof are used to melt snow and heat water in the station bathrooms and kitchen. Solar power provides one-third of the station's electricity needs, with wind turbines providing the rest of the power (Llano and McMahon, 2018; Kennedy, 2020). The station is supplemented by nine self-regulating wind turbines on a ridge near the station, installed by International Polar Foundation staff to generate a total of up to 54 kw·h of electricity, with an average statistical power output of 10 kw from its wind turbines (Kennedy, 2020). The blades of the wind turbine can be shut down in case of storms, thus reducing the rotation speed to prevent any damage to the wind turbine. In addition, the site selection of the Elizabeth station is one of the important conditions for its zero-emission operation. Through a detailed analysis of the area to be selected, the most suitable area for the use of wind power generation was found under the conditions of ensuring the needs of scientific research and convenient transportation. Together with solar power generation, an energy supply system based on renewable energy sources was finally successfully realized (Sun et al, 2020). The research station has also installed two generators as a backup to provide the full station electrical load in the event of both wind and solar power shortages. At the end of March 2020, engineers at the Princess Elizabeth Research Station installed five power controllers, which will no longer limit the input to the PV controller when it detects excess power supply, but will increase the thermal power of the system to balance the input and output, thus enabling the use of excess solar energy to heat snowmelt and provide indoor heating, greatly increasing the utilization of renewable energy sources (Kennedy, 2020). The

Figure 4 Princess Elisabeth Station (SOHU, 2019).

engineering team also plans to use hydrogen fuel cells in the future to store excess power and add it to the system as a supplement to the energy storage battery.

2.4 Australia

In 2003, two 30-meter-tall, 300 kw wind turbines were installed at Australian Mawson Station (Figure 5). The system is capable of providing 600 kw of renewable energy to power and heat the research station. In 2017, one of the turbines suffered a serious failure and is no longer operating. The remaining turbine continues to provide power to the Mawson power station. The blades of the wind turbines are cast in special steel. When wind resources exceed about 40% of the station's load, short-term energy storage systems (such as flywheels, batteries or hydrogen-powered fuel cells) are used to carry the station's load, while wind and diesel are grid-connected to power the research station. Mawson Station is the only Antarctic station that uses wind turbines to meet more than 70% of its power needs, saving about 600000 L diesel fuel per year, equivalent to a savings of USD $ 160000.

In March 2019, Australia's first solar power station in Antarctica was commissioned at Casey Station (Figure 6). There are 105 solar panels installed on the north wall of the green store, providing 30 kw renewable energy for the research station's electrical system. This represents approximately 10% of the total requirements of the research station.

2.5 Brazil

Brazilian Comandante Ferraz Station, has established a complete energy system based on the results of an energy assessment and analysis of the system, integrating cogeneration, wind, solar and organic solid waste utilization systems. In terms of renewable energy, Comandante Ferraz is located in a location with an average wind speed of more than 5.2 $m \cdot s^{-1}$ throughout the year, making it suitable for wind power generation. In 2009, the hybrid power system of wind power and diesel engine was built and put into operation. Wind power accounted for 43.2 MW·h of the total energy supply of 99.2 MW·h, reducing carbon emissions by 43% (Llano and McMahon, 2018). After the fire in 2012, eight vertical axis wind turbine generators were set in the southwest of Base, and a photovoltaic plate was provided in the northern side of the Base. There was also a standby generator for backup.

Figure 5 Mawson Station (AAD, 2020a).

Figure 6 Solar panels installed at Casey Station (AAD, 2020b).

2.6 New Zealand

The Scott Base of New Zealand is designed and used by the New Zealand Antarctic Research Institute (NZARI) with a load-adjustable power generation system consisting of two 180 kw diesel generators. One generator is used as a base load generator to run continuously to meet the base load, and the other one assumes the peaking role and turns on when the demand for electricity is high, thus ensuring that the base load generator can run at high load most of the time and improving the generation efficiency of the unit. In terms of renewable energy, the Scott site shared power with the U.S. McMurdo Station with three 330kw wind turbines, saving 463 kL of fuel consumption per year, taking up 11% of the fuel volume and saving approximately USD$ 122000 in expenses. In addition to this, nearly 1000 MW of geothermal power plants have been installed at the Scott site, which has increased power generation by 250% in the last 10 years alone, increasing the total renewable energy generation at the site from 65% to 80% (Crossin et al., 2020).

2.7 Russia

For years, Russia's Vostok Station in Antarctica has been in a state of disrepair. In 2019, the Russian government finally ordered the reconstruction of a brand new complex, and one of Russia's wealthiest citizens invested about 4 billion rubles in the project. Four diesel generator sets with a generating capacity of 200 kw each will power the complex, and two additional backup generator sets will be installed. The new polar research station will be operational in 2023. In November 2020, the Russian Cabinet of Ministers allocated more than 3.5 billion rubles (USD$ 46.6 million) from the federal budget to transport and build the complex to Antarctica. However, due to the epidemic, the project was postponed (Boccaletti et al., 2014).

2.8 China

The natural conditions of Chinese Antarctic Zhongshan Station are similar to those of Mawson Station, which is a good reference value for the realization of wind power generation at Zhongshan Station. In fact, China's Great Wall Station and Zhongshan Station are located in an area rich in wind resources, with maximum wind speeds of 36.5 and 50.3 $m \cdot s^{-1}$, respectively, and the number of days with strong winds (wind speed over 17 $m \cdot s^{-1}$, equivalent to a 8 Beaufort wind force or higher) is 132 and 171 $d \cdot a^{-1}$, respectively. At the same time, the diesel power generation facilities currently used in Chinese stations have a certain impact on the environment, in addition to the expensive fuel input. Since 2011, Chinese domestic units have also carried out research work and preliminary tests on the application of wind and solar power generation technology at the Antarctic Zhongshan Station. Combining with the design work of 15 kw photovoltaic power generation system of Zhongshan Station in Antarctica, Boccaletti et al. (2014) studied the influence of low temperature environment and photovoltaic array spacing on photovoltaic gust wind load, and determined the photovoltaic array layout scheme of the whole photovoltaic power generation system on this basis. Then, combining the layout design of PV array and wind load analysis results, the mechanical analysis model of PV bracket is established, and various technical solutions of PV bracket steel structure and base are studied. Besides, the key technical parameters of steel structure and base are optimized.

China's Taishan Station is the first domestic large-scale adoption of renewable energy power supply Antarctic inland research station with abundant wind and solar energy (Figure 7). It is geographically located in Princess Elizabeth

Land, and the annual average wind speed reached 11 m·s^{-1}. In 2018, Taishan Station planned to use renewable energy instead of some fossil fuels for power supply. After demonstration and construction, the installation and commissioning of the renewable energy system was completed in 2020, and a total of 60 kw of wind-light-combustion-storage multi-energy complementary smart microgrid system was finally built (Figure 8). The system has an average daily power generation of 15 kw, covering more than 50% of the station area's electricity demand. Taishan Station innovatively adopts underground energy building structure, burying energy storage, control system, diesel generator and snow melting system under the snow, using the heat generated by the diesel generator to heat the energy building and the station area, effectively improving the energy utilization rate.

2.9 Utilization of clean energy

At present, several countries in the world begin to use renewable energy instead of fossil fuels, and gradually develop to zero emission mode. Table 1 summarizes the use of renewable energy in Antarctic research stations by these countries mentioned above.

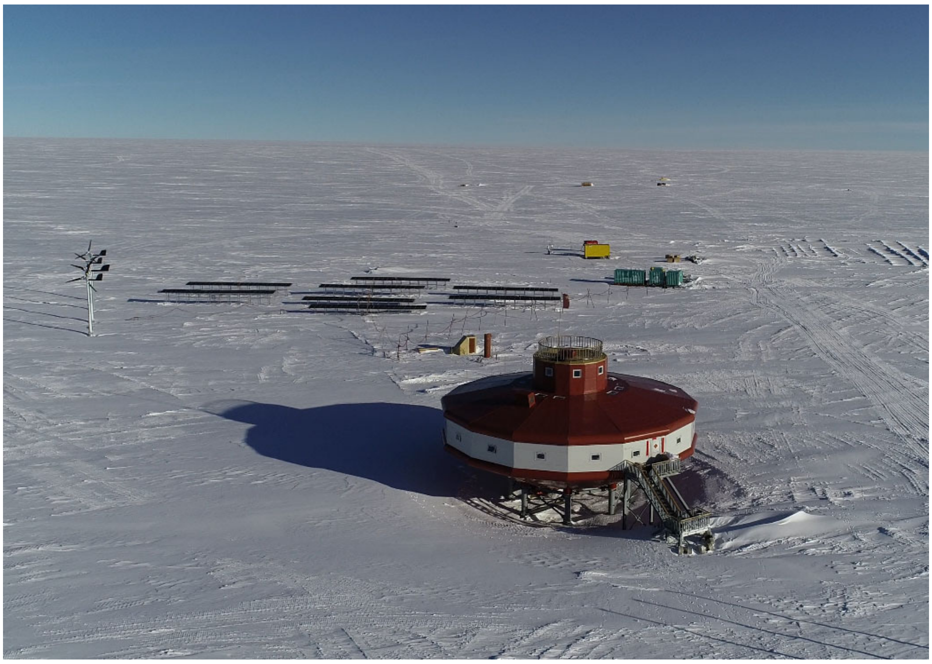

Figure 7 Taishan Station.

Table 1 New polar energy systems in various countries

Country	Station	Types of energies	Scale
United States	McMurdo Station	Wind and diesel	Three wind turbines with an output of 300 kW.
United Kingdom	South Georgia and Signy stations	Wind and solar energy	A system of 36 solar panels has been completed.
Belgium	Princess Elisabeth Station	Battery, wind and solar energy	Wind and solar energy with an annual output of about 45700 kw·h.
Australia	Mawson Station; Casey Station	Wind and solar energy	Two wind turbines of 300 kW (one was broken now); Solar power station with an output of 30 kw.
Brazil	Comandante Ferraz Station	Cogeneration, wind, solar， organic solid waste and diesel	Wind power of the hybrid power system accounted for 43.2 MW·h of the total hybrid energy supply of 99.2 MW·h.
New Zealand	Scott Base	Wind, geothermal power and diesel	Two diesel generators of 180 kW, three wind turbines of 330 kW and geothermal power plants of 1000 MW.
Russia	Vostok Station	Diesel	Four diesel generator sets with a generating capacity of 200 kw (postponed)
China	Taishan Station	Wind, solar power, battery and diesel	60 kw of wind-light-combustion-storage multi-energy complementary smart microgrid system with an average daily power generation of 15 kw.

3 Polar energy system development trend

Fossil fuel has the characteristics of high energy density, small space occupation, high reliability and controllability, etc. It is still the main source of energy supply for most polar research stations. At the same time, fossil fuels still have many disadvantages.

(1) The use of fossil fuels is dangerous. When diesel generators are in operation, they need to be guarded, which takes up a lot of labor costs. In February 2012, a fossil fuel leak at Brazilian Ferraz Station in Antarctic was not detected and remedied in time, causing a fire at the station and resulting in the death of two expedition members. In 2020, renewable energy power generation will reach 2.2 trillion kwh, accounting for 29.5% of the total social electricity consumption, an increase of 9.5 percentage points compared with 2012. China's full-scale non fossil energy power generation was 2.58 trillion kw·h, up 7.9% year on year, accounting for 33.9% of China's full-scale power generation, up 1.2 percentage points year on year, and the power supply capacity of non-fossil energy continued to increase.

(2) The cost of transporting fossil fuels is high, especially in the Antarctic interior, which is seven times more expensive than the coastline due to the harsh environment and potential ice crevasses.

(3) The exhaust gas from fossil fuels will pollute the environment, and the burning of fossil fuels will produce carbon dioxide, which is the main factor causing the greenhouse effect. In the polar regions, especially in the Antarctic, it is important to keep the environment pristine for us to understand the polar regions and explore the world, so we should avoid causing pollution to the environment as much as possible. At present, countries around the world have researched various technologies to mitigate the many problems caused by fossil fuels. As long as fossil fuels are used, the problems they create cannot be completely eradicated.

Therefore, one of the trends in the energy system of the Antarctic research infrastructures is to reduce fossil fuel consumption. And the measures to reduce fossil fuel consumption in Antarctic observatories include both improving energy efficiency and adopting renewable energy sources. (1) The first approach is to improve energy efficiency and reduce fuel combustion by reducing heating demand. This includes efficient building design, temperature control in enclosed spaces, energy-efficient lighting, better use of daylight, and recovery of waste heat from diesel power systems. (2) The second approach is through renewable energy sources, including wind and solar. Renewable energy sources can save fossil fuels by meeting a portion of the total energy demand of a power plant, but they cannot completely replace fossil fuels due to the inherent variability of the resources. Wind energy has been exploited for the longest time in Antarctica, with two 300 kw wind turbines installed at the Australian Mawson Station in 2003, providing 35% of the station's load and 93% of its availability from 2003 to 2008. In addition to Mawson Station, Neumayer Station (Germany), Scott Base (New Zealand), Arctowski Station (Poland), Johann Gregor Mendel Station (Czech), Juan Carlos I Station (Spain), St. Kliment Ohridski Station (Bulgaria), Zhongshan Station (China) and Princess Elisabeth Station (Belgium) all have wind turbines for their respective testing years (Llano and McMahon, 2018). The development of wind energy in Antarctica is partly due to favorable environmental conditions (e.g., strong year-round winds) and the fact that off-the-shelf wind equipment can be easily adapted to the specific technical conditions of Antarctica. However, for wind technology to work properly, technical challenges need to be overcome to meet critical conditions such as extremely cold, extremely strong winds and snow accumulation, turbines with specially modified cryogenic steel, turbine height control, special dimensions, materials and foundations. Among them, the material and bearing of the turbine can be significantly improved, which can make the fan provide higher power generation performance, guarantee lubricity through internal sealing, and carry overspeed system to protect the fan from excessive wind damage (Jimenez, 2020). Solar energy is also used in the Antarctic during the summer months for thermal power generation for heating and photovoltaic power generation for DC power. Sites like Wasa, Syowa, Arctowski, Johann Gregor Mendel, Princess Elisabeth, Rothera and St. Kliment Ohridski stations have solar systems at their respective inspection years, while other sites like Aboa and Palmer use this energy for remote sites or field work. Solar energy is well available in Antarctica and can be further improved by new technologies such as bifacial solar panels and better use of albedo.

The second trend of the Antarctic energy system is to be as energy efficient as possible. (1) Analysis of the application of passive energy-saving strategies in Antarctic observation stations: the use of passive energy-saving measures can fundamentally reduce the heating load of buildings, such as the use of highly airtight windows and doors and highly insulated building envelopes. But reasonable materials need to be selected according to local characteristics, and the difficulty of transporting building materials and the length of the construction cycle also need to be considered. Therefore, Antarctic passive energy-saving construction cannot copy domestic passive building technology, but should adopt building materials and construction methods suitable for local construction characteristics, such as using specially designed building envelopes. This not only facilitates transportation and installation, but also realizes passive energy conservation. Assembly-type construction can also be used to shorten the construction cycle of high-performance buildings. At the same time, it is necessary to take into account the local climatic characteristics, such as wind direction, to reasonably arrange the building group to achieve the best comprehensive performance of the building group.

(2) Analysis of the application of active energy-saving strategies in Antarctic research stations: On the basis of passive energy-saving, active energy-saving measures are also needed to further reduce the demand for carbon-based fuels. Common measures include cogeneration, renewable energy (e.g., solar, wind), and some localized measures (e.g., polar frozen lake water extraction technology, geothermal power generation, etc.). Cogeneration, on the basis of ensuring the efficiency of generator power generation, can maximize the recovery and utilization of waste heat from flue gas after power generation. A reasonable system setting can not only use the heat for building heating, but also further heat the antifreeze water at a lower temperature. The Antarctic region is rich in solar and wind energy, but there are characteristics of unstable energy supply and obvious peaks and valleys (such as seasonal differences in solar resources and large fluctuations in polar wind speed). Therefore, it is necessary to reasonably match energy demand and renewable energy, and maximize the use of renewable energy for building energy supply. The new locally adapted system needs to be developed and designed according to the environmental characteristics of the local area, taking into account the ease of construction and operational stability. And it should also be verified for feasibility.

(3) Energy-saving design guidelines for Antarctic research stations: Environmental protection in Antarctica is one of the most important elements of scientific research missions. At present, national research stations use carbon-based fuels as energy supply, and there have been many leaks in history, which pose a great threat to the natural environment of Antarctica. So we should fundamentally get rid of the demand for carbon-based fuels to achieve sustainable development of Antarctic scientific research. Due to the special geographical location of Antarctica, we should make full use of renewable energy and achieve self-sufficiency as much as possible. In the passive and active energy-saving design, the characteristics of each energy use (such as energy characteristics, energy use characteristics) and local climate characteristics (such as winter and summer time, special local climate, etc.) should be considered comprehensively, and reasonable energy synergy planning should be carried out. The energy storage and power storage materials should be used appropriately, so as to realize all-round freedom from the demand of fossil fuels.

4 Conclusion

In short, clean energy is an important measure to reduce fossil fuel consumption and protect the environment. Clean energy has great potential to save energy and reduce consumption and improve energy efficiency in polar regions. Antarctica is an ideal test field for clean energy technology research. Antarctica is a place with extremely high wind speed on the Earth. The average annual strong wind days at Antarctica are nearly 200 d. In addition, solar energy resources in Antarctica are also very rich, with sunshine in addition to the polar night of three months in winter. What's more advantageous is that the wind speed is relatively small and the sunshine is strong in summer, while the wind speed is very strong in winter. The two aspects complement each other and ensure a stable power generation energy. After several years of efforts, the application of clean energy in Antarctica has begun to take shape. At present, most countries have begun to use clean energy to supply power for Antarctic research stations. According to the analysis of the International Energy Agency, by 2050, the new energy utilization rate of the polar station is likely to exceed 50%. There is no doubt that the use and development of clean energy can alleviate the energy crisis, reduce carbon dioxide emissions, and achieve a low-carbon economy, which is an urgent need for environmental protection and the unity of economic, environmental and social benefits. And it is the inevitable trend of future development.

Acknowledgments We would like to thank the two reviewers, Dr. Burcu Oszoy and Dr. Jie Li, and Associate Editor Prof. José Retamales for their valuable suggestions and comments that improved this article.

References

Australian Antarctic Division (AAD). 2020a. Mawson research station. (updated 2020-09-15). https://www.antarctica.gov.au/antarctic-operations/stations/mawson/.

Australian Antarctic Division (AAD). 2020b. Casey research station. (updated 2020-09-15). https://www.antarctica.gov.au/antarctic-operations/stations/casey/.

Boccaletti C, Felice P D, Santini E. 2014. Integration of renewable power systems in an Antarctic research station. Renew Energy, 62: 582-591, doi:10.1016/j.renene.2013.08.021.

British Antarctic Survey (BAS). 2021a. Renewable and alternative energy in the Antarctic. https://www.bas.ac.uk/renewable-and-alternative-energy-in-the-antarctic/.

British Antarctic Survey (BAS). 2021b. Rothera research station. https://www.bas.ac.uk/polar-operations/sites-and-facilities/facility/rothera/.

Council of Managers of National Antarctic Programs (COMMAP). 2017. Antarctic station catalogue. First published in August 2017. https://www.comnap.aq/wp-content/uploads/2019/11/COMNAP_Antarctic_Station_Catalogue.pdf.

Crossin E, Verghese K, Lockrey S, et al. 2020. The environmental impacts of operating an Antarctic research station. J Ind Ecol, 24(4): 791-803. doi:10.1111/jiec.12972.

Kakareka S. 2020. Air pollutants and greenhouse gases emission inventory for power plants in the Antarctic. Adv Polar Sci, 31(4): 274-283, doi:

10.13679/j.advps.2020.0032.

Kakareka S, Salivonchyk S. 2020. An assessment of the impacts of diesel power plants on air quality in Antarctica. Adv Polar Sci, 31(1): 74-87, doi: 10.13679/j.advps.2019.0029.

Kennedy E. 2020. Antarctica as a solar hub: possible or pipe dream? (2020-04-28). Solar Magazine. https://solarmagazine.com/antarctica-solar-hub-possible-or-pipe-dream/.

Jimenez C L. 2020. Installing a prototype wind turbine to produce energy in Antarctica to allow a permanent Colombian scientific base to be established. Adv Polar Sci, 31(4):258-273，doi:10.13679/j.advps.2020.0031

Llano D X, McMahon R A. 2018. Modelling, control and sensorless speed estimation of micro-wind turbines for deployment in Antarctica. IET Renew Power Gener, 12(3): 342-350, doi:10.1049/iet-rpg.2016.0528.

LÜ D X, Li C, Wang Z C, et al. 2020. Design and implementation of a multi-energy complementary microgrid system at Taishan Station, Antarctica. Chin J Polar Res, 32(2): 184-194 (in Chinese with English abstract).

SOHU. 2019. Princess Elisabeth Station. (2019-09-03). https://www.sohu.com/a/338365489_120123283 (in Chinese).

Suryawanshi M R, Tripathi N, Oza S R. 2021. Analysis of surface weather parameters and energy fluxes over the Indian Antarctic stations: Maitri and Bharati. Proc Natl Acad Sci India Sect A: Phys Sci, 1-12, doi:10.1007/s40010-021-00738-9.

Sun H L, Duan M F, Zhao H T, et al. 2020. Energy saving strategies for Antarctic research stations at home and abroad. Building Energy Saving, 48(9): 1-7.

Werner B. 2019. McMurdo Station expansion relies on Coast Guard heavy icebreaker. (2019-09-30). https://news.usni.org/2019/09/30/mcmurdo-station-expansion-relies-on-coast-guard-heavy-icebreaker.

Yavaşoğlu H H, Karaman H, Özsoy B, et al. 2019. Site selection of the Turkish Antarctic research station using analytic hierarchy process. Polar Sci, 22: 100473, doi:10.1016/j.polar.2019.07.003.

Zhu J G, Yan Q D, Ling X L. 2006. The dispute of Antarctic resources and our countermeasure. Chin J Polar Res, 18(3): 215-221 (in Chinese with English abstract).