von Karman Institute for Fluid Dynamics
Chaussée de Waterloo, 72
B - 1640 Rhode Saint Genèse - Belgium

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J. Sanz Rodrigo, J. van Beeck, C. Gorle,
J. Berte, L. Dewilde, Y. Cabooter, F. Pattyn

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Wind Power in the future Belgian Antarctic Research Station

Javier Sanz Rodrigo, Jeroen van Beeck & Catherine Gorle (VKI[1])
Johan Berte (IPF[2])
Luc Dewilde & Yves Cabooter (3E[3])
Frank Pattyn (ULB[4])
[1] von Karman Institute for Fluid Dynamics, Environemental and Applied Fluid Dynamics Department,
Chaussée de Waterloo 72, 1640 Rhode-Saint-Genèse, Belgium.
sanz@vki.ac.be, vanbeeck@vki.ac.be, gorle@vki.ac.be, Tf:+32 2 359 96 27, Fax: +32 2 359 96 00
[2] The International Polar Foundation
Rue des Deux Gares, 120A, B-1070 Brussels, Belgium
johan.berte@polarfoundation.org
[3] 3E nv
Rue de l'Association 39, B-1000 Brussels, Belgium
Luc.Dewilde@3E.be, Yves.Cabooter@3e.be
[4] Université Libre de Bruxelles, Départment des Sciences de la Terre et de l'Environnement,
50, av. F.D. Roosevelt, B-1050 Brussels, Belgium
fpattyn@ulb.ac.be

Summary (250 words)

The new Belgian Research Station will be constructed in the Sor Rondane Mountains, Antarctica, by the end of 2007. The base, currently in its final design phase, is conceived as a prototype to achieve the minimum environmental impact and the highest efficiency in the use of energy resources and waste management, fundamental issues of the Antarctic Environmental Protocol. The integration of renewable energies is a must due to the isolated conditions of the site. The resulting station aims at being a reference of the state of the art in sustainable development in isolated areas. The main design drivers are described with special regard to wind power systems. The wind resource assessment is done using wind atlas methodology and CFD, making use of the historical records at Novolazarevskaya station to predict the long term wind conditions. The selection of the wind turbine model is still under discussion. A layout maximising the power output from the available terrain is given as a reference for a wind turbine model of 22kW. A feasibility study on this reference case shows that the use of wind power can result 5-10 times more competitive than its conventional use in Europe.

Sustainable design of the Belgian Antarctic station

Scope of the project

The site for the new station is situated approximately 1 km North of Utsteinen Nunatak, on a small relatively flat granite ridge (71°57'S 023°20'E, 1390m a.s.l.), 173 km inland from the former Roi Baudouin base and 55 km from the former Japanese Asuka station. With the closing of Asuka station in 1992, the 20-30 degrees east sector of Antarctica became again a vast territory having witnessed up to now only brief periods of systematic investigation. The new station will thus reoccupy the 1072 km empty stretch between Syowa station (684 km) and the Russian station Novolazarevskaya (431 km).

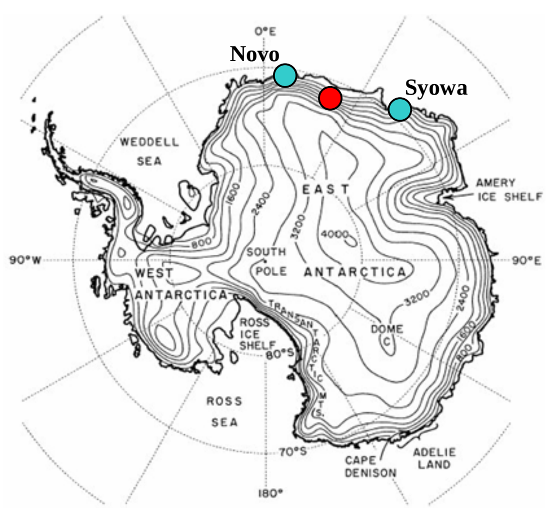

Figure 1: Situation map of the future Belgian Antarctic Station and the nearest permanent stations.

The construction of the summer station is planned in the austral summer of 2007-2008. In this period the station will be built, the system acceptance test performed and then it will be handed over to the Belgian Science Office at the end of the season. The expected design life is 25 years minimum.

The new platform is offered to the Belgian and international scientific community in a flexible way both operationally and with respect to research opportunities. The station will serve as a hub for field exploration in the 20-30 degrees east sector of Antarctica. The station is designed for optimal use by 12 people with a surface area (living, technical, research, storage) of 800 m². The use of a station "extension" will make it possible to accommodate another 8 to 18 people. This extension consists of heated shelters used for sleeping only. The station's facilities (kitchen, sanitary installations, offices …) are designed to cope with the larger occupation.

Figure 2: Southernmost edge of the ridge with the 4m height AWS

Consistent with the philosophy of the project, the station design will make best use of the terrain conditions for the integration of the buildings and will be such that it minimises impact on the environment and on the landscape during the construction, operation and removal of the station. The station has a hybrid design, with the main building above ground-level and anchored onto snow-free rock area. The adjacent garage/storage building is located nearby and is mainly constructed under the surrounding snow surface. Both buildings are inter-connected by a weather protected corridor. The design and layout of the facilities will minimise snow management.

Sustainable technology design

The use of sustainable technology as the primary energy source, without compromising functionality, comfort or safety demands, implies an integrated design methodology similar to the one used in applied technology projects (cfr. industry & space). The project management has been structured according to this method. On the conceptual design level a verification method with four major lines of approach (environment, human factors including safety, technology and cost) is used to evaluate and steer all conceptual decision making. All prime project partners work together from the start of the iterative design process thereby guaranteeing that the different fields of interest are taken care of in a homogeneous way. The system design of the station is based on sustainable technology and high energy efficiency, with a full-year monitoring and remote sensing capability. Nevertheless safety, health, comfort, functionality and cost are equally important design drivers. The facilities will use renewable energy as the primary energy source, integrating a comprehensive energy management regime, thereby minimising the use of fossil fuels. To assure a constant energy supply, two back-up generators will be installed. The amount of fuel used at the station will be mainly for vehicles.

The air-conditioned main building is the living area of the station and has a usable floor space of approximately 350 m². The "garage/storage" building accommodates secondary functions such as work shops and storage of supplies and spare parts. The station will provide an efficient and pleasant living/working environment for the crew but the programme is also developed according to energy efficiency needs and the specific technical demands imposed by the winter close-down of the station.

The main building has a concentric architecture laid out around a "technical core". All temperature-sensitive installations and equipment, such as the waste water treatment system, are concentrated in this area of the building. A second concentric layer around the technical core consists of space for active systems such as the kitchen, sanitary, laundry and the station's energy management system. It also has storage for fragile office equipment during winter. A third concentric layer consists of "passive" areas, for example, the living and sleeping rooms. Temperature buffer spaces are included below the floor and above the ceiling. The fourth and last of the containment levels is the outer shell. This structure consists on a number of passive and active elements such as insulation materials, air-gaps for buffering and energy-related systems. For winter close-down each individual layer is "sealed" thereby creating a number of temperature-controlled buffer zones against the cold exterior environment. This makes it possible to maintain all layers at a guaranteed minimum temperature with minimal energy supply, protecting installations and whole year active systems located in the technical core as well as the appliances located in the second layer. The "passive" area (third layer) acts as an additional buffer zone. All building zones will be monitored for temperature routinely.

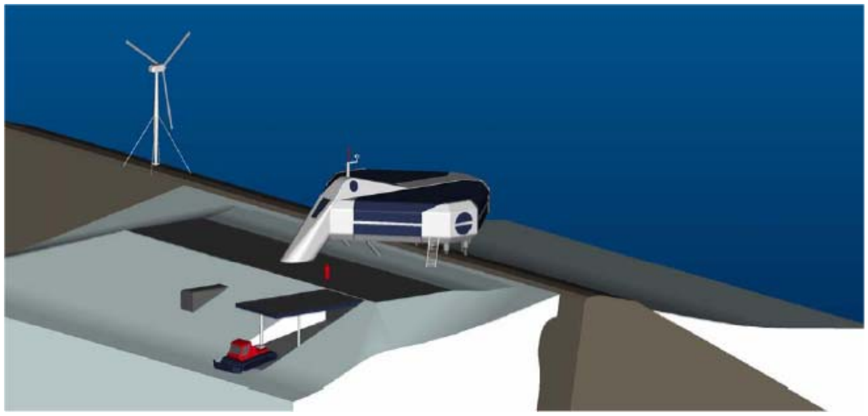

Figure 3: Impression of the new station at 45° wind incidence with a connection bridge with the under-snow garage/storage building. The black areas covering the surfaces of the main building are solar collectors combined with windows. Wind comes from the right.

The garage/storage building is an under-snow surface construction connected by an aerodynamically shaped and weather-protected staircase to the main building, and follows the design philosophies of minimal environmental and visual disturbance, best comfort and energy efficiency.

The water supply for the station will use solar thermal panels to melt the snow thereby limiting the use of electrical energy to pumping the water. In addition electrical heating, eventually backed-up with waste heat originating from co-generation (multiple sources possible), can be used in the system.

The waste water treatment plant consists of a grey and black (black water includes urine and human solid waste) water system. The proposed design minimises water demand by reducing fresh water consumption. Water coming from the snow melting facility, stored in a buffer tank, will be used for all potable functions, including showers and cooking. Other building functions will use recycled water.

The use of sustainable technology as the primary energy source without compromising functionality, comfort or safety requires a cautious approach in the system engineering. Making best use of co-generation and enhancing energy efficiency implies a high level of integration but this could have a major disadvantage: vulnerability of the whole system for partial break-downs. Therefore in the conceptual design the following approach has been used:

- Reliability: where possible subsystems are composed of modules built up from proven technology extended to (relatively) new technology for highest efficiency. The minimum functionality of the subsystem is assured by the core system.
- Independency: the interaction (e.g. co-generation) of subsystems does not compromise the functioning of the individual subsystems.
- Redundancy: detailed Failure Mode Effect Analysis (FMEA) analysis of the whole building is used as an input to the design process, safety measures, maintenance and other applicable strategies are tailored according to this.

Prior to the concept phase of the project an extensive technology survey was conducted looking at potential solutions for energy generation, distribution, storage and sustainable energy system in general. Such a survey was also applied for most aspects of the building physics such as Heating, Ventilation, Air Conditioning (HVAC)… Brainstorms for possible solutions were backed-up by preliminary energy simulations taking into account the on-site weather data (wind/sun/temperature), user (consumer) profiles, user scenarios, materials used, the building geometry and orientation.

Wind and snow management

Wind conditions have a major impact on the structural aspects of the building but also heavily influence operations, comfort and energy efficiency. Aerodynamic testing is used to:

- limit the expected snow accumulation in the lee side of the building;
- prevent snow accumulation upwind of the building;
- control wind-induced forces on the building;
- set mechanical engineering specifications;
- enhance the comfort inside (and outside) the building by reducing noise and vibrations;
- validate the numeric wind model to assess wind power potential;
- assign positions for stand-alone facilities.

Figure 4: Wind tunnel testing of snowdrifts using sand (VKI L1-B wind tunnel: 2m high, 3m wide and 20 m long)

The selected design generates manageable snow accumulation and erosion features for the prevalent wind direction. It also prevents snow build-up on the windward side of the building. Such a snow build up would continuously change the incoming airflow characteristics creating unpredictable behaviour in terms of long term snow accumulation. The vortex path generated by the building has positive and negative side-effects depending on the relative position of the garage building and its entrance. The erosion regions are exploited enabling a low maintenance entrance.

Energy

The energy generation side of the system consists of different elements that function separately or combined depending on the demands and circumstances. The station site has a sheltered nature but the site still provides sufficient wind to use wind energy as a major electrical energy source.

The concept consists of a number of relatively small wind turbines positioned along the ridge. On the building both solar thermal and photovoltaic panels are used. For solar passive energy there are, apart from the strategically positioned glazing, also "solar transparent" insulation panels on the roof used for pre-heating ventilation air and warm up the thermal masses situated in the building roof buffer zones. The distribution of the different panel types is defined by the user profiles (energy needs) and the position of the sun during the day. The photovoltaic system will be capable to provide up to 10 % of the electrical load and mainly will reduce the storage capacity in batteries as much as possible.

A (typical) problem with renewable energy is its intermittent character. The energy stored in the buffer battery pack will be reduced as much as is reasonably feasible by the following measures:

- It has been decided to rely on photovoltaic as well as wind energy production as primary electricity sources.
- A fly-wheel will be installed to buffer fast variations in the consumption and electricity production of the wind turbines. This will also help to level out energy input variations and can be used as an Uninterrupted Power Supply (UPS) providing an emergency back-up system.
- Electricity consumption will be matched to electricity production by demand side management.

The enrgy budget is around 45kW most of it covered by renewable energies. Diesel generators are considered as a backup for wind rather than the opposite.

Scope of the presented paper

The scope of the presented paper is to describe a rather exotic environment where the use of renewable energies is not only a necessity, due to the isolated conditions, but also a very competitive energy source. The wind climate is characterized by the presence of the most extreme wind on Earth, the katavatic. Its influence is put into evidence even on a sheltered area like this one. The wind resource assessment is done using conventional methodologies, making use of the historical records at Novolazarevskaya station to predict the long term wind conditions. The selection of the wind turbine model is still under discussion. A layout maximising the power output from the available terrain is given as a reference for a wind turbine model of 22kW. A feasibility study on these reference conditions shows how competitive the use of wind power in Antarctica results. The resulting station aims at being a reference of the state of the art in sustainable development in isolated areas.

Wind Climate

An automatic weather station (AWS), placed at the site since December 2004, delivers synoptic data by satellite of wind velocity, direction and gust among other variables. The data availability is sufficiently high to assess the local wind climate throughout the year 2005, with an annual mean velocity of 5.9m/s and a prevailing wind direction sector form E to SSE. The most energetic wind direction is E with 90% of the energy content. The monthly variability follows almost the same pattern observed at the Russian station Novolazarevskaya[1], situated 450km apart. The wind climate at both sites is very similar, with a 40^o rotation of the windrose between one another (Figure 5). wind climate at both sites is very similar, with a 40^o rotation of the windrose between one another (Figure 5). This shift is due to the position of Utsteinen at proximity of the Sør Rondane mountain range. The katabatic is mainly deflected through the outlet glaciers that cut through the range. Wind coming from the East is deflected through Jenningsbreen; wind from the southeastern sector through Gunnestadbreen. The correlation with this 45-years-old station enables the determination of the long-term wind speed. When considering the average wind speed over 20 years of the Russian station, it turns out to be 3.5% higher than the equivalent one derived from recordings on the Belgian site during the year 2005 (Figure 6).

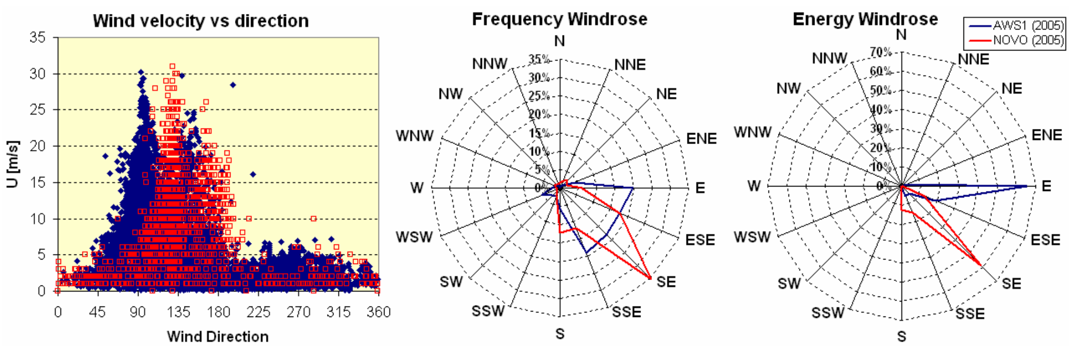

Figure 5: Comparison of AWS and Novolazarevskaya wind direction distributions

The estimated mean velocity is rather low if we consider the typical wind conditions found in other stations in Antarctica.

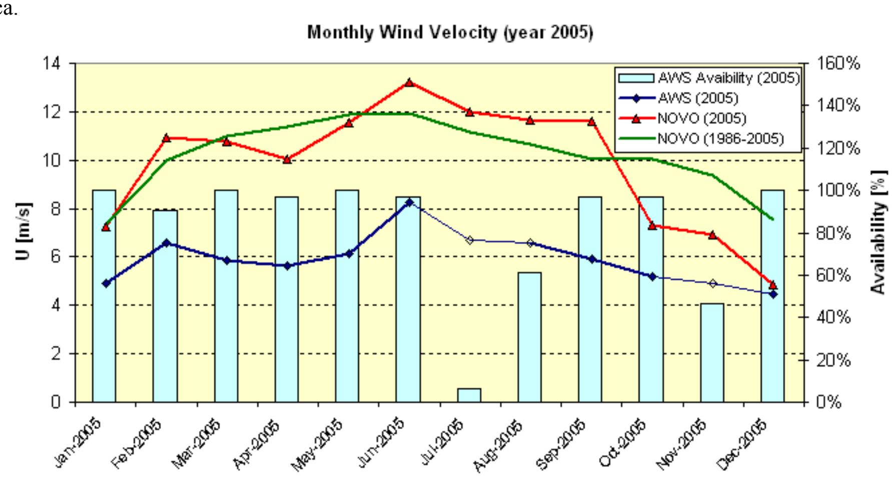

Figure 6: AWS monthly wind velocity during the year 2005 compared with Novo station

This is also due to the proximity and sheltering effect of the mountain range. For instance, wind speed measured at Asuka Station between 1986 and 1991, a station 60 km to the northeast of Utsteinen are twice as high, as the

[1] Information on monthly meteorology were obtained from the Russian Federation NADC, Arctic and Antarctic Research Institute (AARI), http://south.aari.nw.ru

katabatic wind encounters less obstruction. Novolazarevskaya is situated near the coast and therefore under direct influence of the katabatic wind. Katabatic winds are gravity driven surface winds originating at the South Pole and progressively accelerate as the smooth slope gets steeper near the coast.

Even though the mean wind speed is not high, the site is characterised by the presence of intense wind storms, especially during the winter season. This is revealed by a velocity distribution with a very long tail (Weibull shape factor k=1.24).

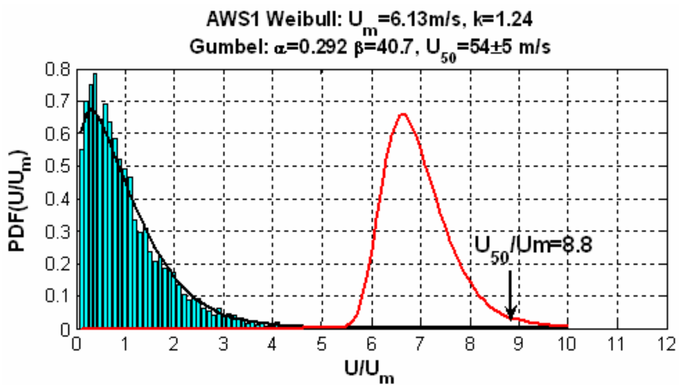

Figure 7: Extreme Value Analysis on AWS1 wind distribution

The extreme velocity estimated for a recurrence period of 50 years is 54m/s, as high as the one expected at Novo station even though the mean velocity there is more than 50% higher. This will be certainly an important issue when selecting the wind turbine model.

A second AWS was installed at the top of the ridge during the last expedition in November 2005. A Measure-Correlate-Predict method is used to extend the measurement period of the second AWS from the measurements of the reference one. Both stations have been used to calibrate the wind resource map simulated by WasP.

Wind Resource assessment

The low complexity of the site topography enables a reliable wind resource assessment using Wind Atlas methodology [1]. The lack of field measurements at a second height on any of the masts leaves the consideration of the vertical velocity profiles to a qualitative estimate of the appropriate roughness length. The snow-covered surroundings can be characterized by a rather low value. It has been found that a value of 0.03m (typical for open field terrain) matches the speed-up ratio between the two AWS. Figure 8 shows the vertical profile found at the two AWS positions from the wind atlas generated by both stations.

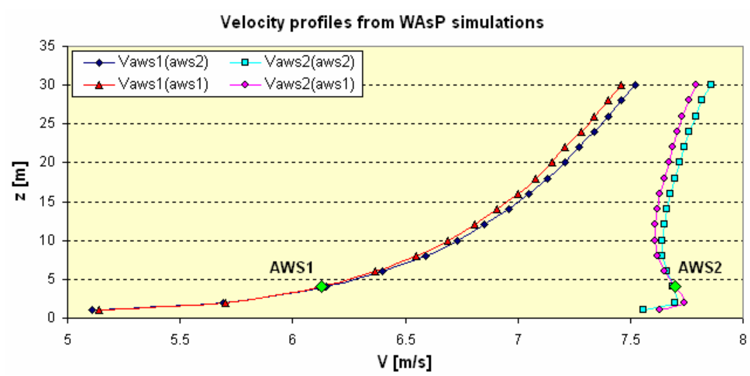

Figure 8: Velocity profiles from WAsP simulations at the AWS positions (long term correction included)

It is remarkable the speed-up generated at the top of the ridge (AWS2), with a maximum at 2m which leads to a vertical profile between 5 and 30m. The difference between the velocity profiles predicted from both AWS is less than 1%. The speed-up between the two AWS decreases with the height, from 35% at 2m to 4.5% at 30m. Figure 9 presents the wind speed contour map at 20m above ground level (the typical hub height of the wind turbines).

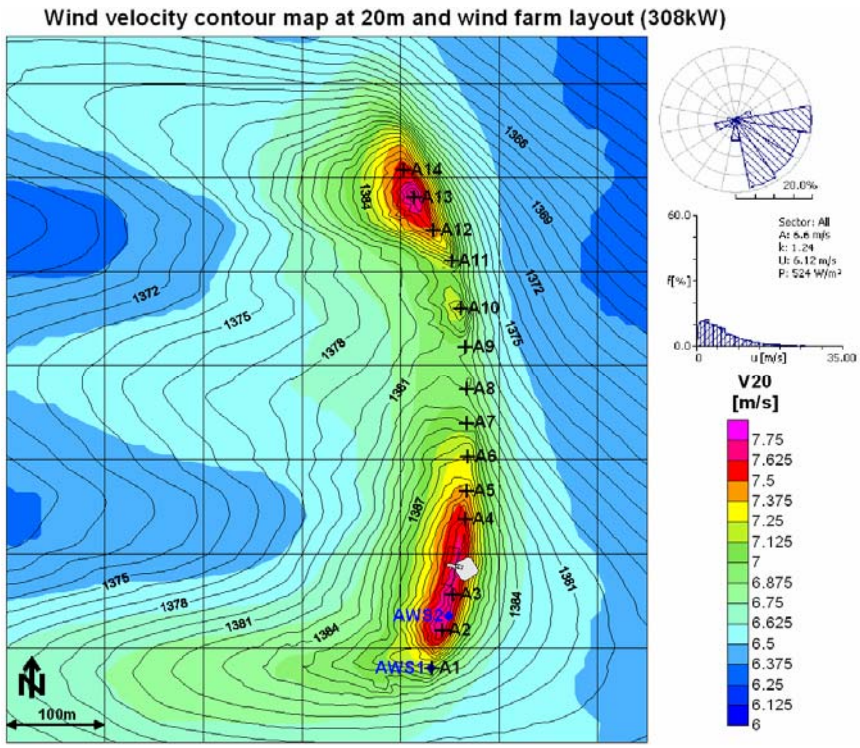

Figure 9: Wind velocity contour map at 20m and wind farm layout (308kW)

Fluent CFD simulations have been also conducted to complement the simulations fro WAsP. A k-ε turbulence model has been used. Figure 10 presents a comparison between WAsP and Fluent simulations. The speed-up between the velocity at each point of the map and the corresponding one at the AWS1 position is calculated. Then the difference between the two models is calculated at 4 (AWS height) and 20m (hub height).

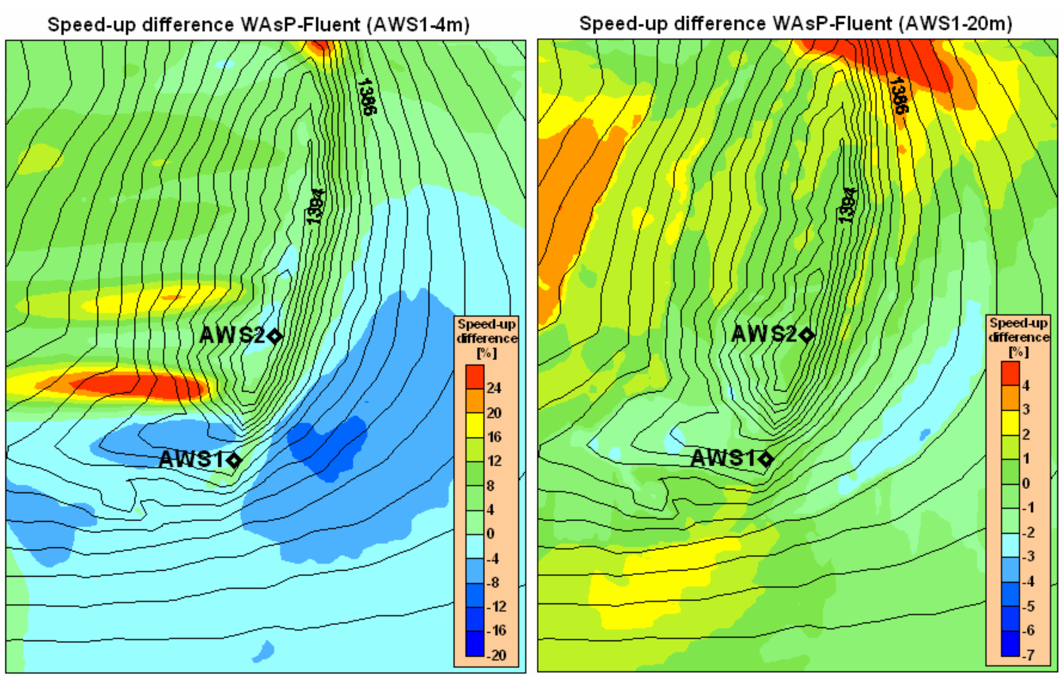

Figure 10: Comparison between WAsP and Fluent simulations for the East wind direction. The speed-up is calculated with respect to the AWS1 velocity at 4 and 20m height. Then the difference in % between the two models calculated (mind the different scale bar in the two figures).

Near the ground, WAsP presents the largest deviations in the regions where the flow is likely to detach from the ground. In the ridge top, where the wind turbines will be placed, the deviation between the two models is around 4% at 4m. At 20m, the flow becomes more uniform and the differences between WAsP and Fluent are considerably reduced with a deviation of 1% at the ridge top. Therefore, we can still rely on WAsP to make the energy predictions of the wind turbines.

Wind farm layout for maximum power output

At present, the selection of the wind turbine model is still under discussion. The following guidelines are considered for its selection:

- High reliability at extreme weather conditions (survival speed above 55m/s).
- Low temperature operation (as low as -35ºC).
- Use several turbines of small size (range 10-20kW) to distribute the risk of break down.
- Prevent from ice formation.
- Simple mainatenance
- Easy to errect (anchoring)
- Relatively compact for transport

A generic 22kW wind turbine has been selected to obtain a first estimate of the power and energy yield that could be extracted if all the available terrain of the ridge was used. With a rotor diameter of 14m, a total of 14 wind turbine positions can be installed (Figure 9). The wind farm profits from a perpendicular orientation to the prevailing wind from the East. Besides, the incoming turbulence is rather low above the snow covered surface. Therefore the separation of the wind turbines can be shortened significantly.

For a hub height of 20m the mean annual energy yield of the wind farm is around 1000MWh/year, i.e., the wind farm can run 3250 hours at its nominal power 308kW (capacity factor 0.37).

A more realistic scenario will be based on two or three wind turbines that would operate during summer season and would be dismounted during the winter season. A smaller and more robust wind turbine would be set for the winter season, when the station is inhabited and the energy demands are the lowest, just to maintain the monitoring equipment.

Feasibility study

The conditions in Antarctica are the most suitable for renewable energy, more particularly for sun and wind power. First, the cold air is denser providing more thrust on the wind turbines for any given speed than warmer air does. Cold temperatures also make solar panels more efficient. Additionally, the snow surface reflects the 24-hour summer sunlight increasing even more their efficiency. A solar panel in Antarctica can double its efficiency with respect to its conventional use in mid latitudes. When talking about wind power the scenario is even more favourable. Apart from the high energy content of the wind, it is normally very unidirectional with rather low turbulence levels.

Considering the power concept consisting of 1 wind turbine of 22 kW, two diesel generators of 20 kW each, 10 battery units of 6 kWh per unit and one bi-directional convertor of 30 kW, the reduction of the cost of energy would drop with 31% compared to the power concept consisting of only two diesel generators with 10 battery units and the convertor. Fuel save would be up to 68%. The avoided cost of fuel and its transport would be paid back within 11 years with respect to the current fuel price. Just considering the savings in fuel transport, in general renewable energies can reduce its payback time by a factor five to ten with respect to an average situation in Europe.

More important than the significant cost savings, the reduction of fuel consumption and generator use diminishes the emissions and the risk of fuel spills, keeping the environmental impact to a minimum.

Conclusions

The future Belgian Antarctic Research Station has been presented. It has been conceived as a reference of the state of the art on sustainable building design and energy efficiency in isolated areas. An assessment of the wind resource has been made using standard wind atlas methodology with the aid of CFD. A maximum power output of 308kW has been calculated for the available terrain of the ridge using 14 22kW wind turbines. The long term annual capacity factor results in 0.37. A feasibility study shows that renewable energies can reduce its payback by a factor five to ten.

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