INTERNATIONAL ENERGY AGENCY

TASK 19
WIND ENERGY IN COLD CLIMATES

FINAL REPORT

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for
Research , Development and Deployment
of Wind Energy Conversion Systems

FINAL REPORT

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FOREWORD

This report summarizes the results of the International Energy Agency working group IEA Wind Task 19. The report includes sections on activities in participating countries during the Task 19 period, main results achieved in course of the projects and summary on administrative issues.

The section on national activities gives an introductory to those activities that took place in each of the participating countries. Chapter on main results summarises the main findings and achieved results.

The work of the Task 19 was the first attempt to collect and provide information on wind energy development and deployment at such sites where severe winter conditions form an extra challenge to wind energy project development and for use of turbines. Thus the work was started in 2002 by defining expression “cold climate wind energy” to refer to sites that experience either icing events or low temperatures outside the operational limits of standard wind turbines.

The information collected, produced reports, conference papers and posters in the course of the project are presented as Annexes of this document.

NOTICE:
IEA Wind Task 19 functions within a framework created by the International Energy Agency (IEA). Views, findings and publications of IEA Wind Task 19 do not necessarily represent the views or policies of the IEA Secretariat or of all its individual member countries.

CONTENTS

1. INTRODUCTION

1.1 Background

Since mid nineties a considerable number of wind turbines have been installed at sites where atmospheric icing and low operating temperatures have a significant effect on the operation of standard equipment. Standard turbines in extreme environments are facing considerable production losses and higher than normal loads, which will cause financial losses and risk premature mechanical failure.

Consequently turbine manufacturers are developing technical solutions for low temperatures of their standard turbines and first commercial solutions for de-icing and anti-icing of wind turbine blades are in use. However, public information on the topic and performance of the adapted technology was sparse and distributed all over the world.

As a conclusion improve the situation International Energy Agency; IEA R&D Wind, started a Task 19; “Wind Energy in Cold Climates” in 2002. This international collaboration has gathered information about wind turbine operation cold climates ever since. The starting point of the work was to collect the information available for those parties interested in deploying wind turbines to cold climate sites. Database of wind turbines operating in cold climate conditions was collected in order to gain access to needed and already available information and experience. In the course of the first three year period, cold climate wind potential, measurement issues, project planning and economics and construction all the way to decommissioning of a cold climate wind turbine plant were considered. The second Task 19 period continued the work and updated and further extended the work started in 2002. The final outcome of work were two reports, summary on available state-of-the-art cold climate wind turbine technology and a report containing recommendations on those special features that need to be addressed when developing wind energy project at cold climate site.

1.2 Objectives of the work

The general objective of the first Task 19 period in 2002 was to gather available information and establish first classification methods that could be used in classification of cold climate wind turbine sites. The objectives for the first period were to:

1. Gather and share information of wind turbines operating in cold climates.
2. Establish a site-classification formula that would combine meteorological conditions and local needs.
3. Establish a classification formula on standard and adapted technologies and strategies to match the site assessment classification.
4. Monitor the reliability and availability of standard and adapted wind turbine technology.
5. Establish and present guidelines for applying wind energy in cold climates.

The objectives for the second period were identified at the end of the first period of the Task 19. The primary goal for the second period was to respond to those issues that were recognised to slow down the development of wind energy in areas relevant regarding the scope of the Task 19.

The objectives for the period 2005-2008 were to:

1. Determine the current state of the cold climate solutions and especially anti- and de-icing solutions that are in or are entering the market.
2. Review the current standards and recommendations from the cold climate point of view and identify the possible needs for updates.
3. Find and recommend a method to estimate the effects of ice on production and thus reduce the amount of incorrect estimates and the risks that are involved in cold climate wind energy projects currently. Verify the method on the basis of data from national projects according to the possibilities.
4. Clarify the significance of extra loading that ice and cold climate induce on wind turbine components and disseminate that result
5. Perform a market survey for cold climate wind technology, including wind farms, remote grid systems and stand-alone systems
6. Define a recommended limits for the use of standard technology (site classification)
7. Update state-of-the-art report and update the expert group study on applying wind energy in cold climates to guidelines.

2. ADMINISTRATION AND MANAGEMENT

2.1 Participants

Participants of the task are presented in Table 1.

Table 1. Participants of the Task 19

Country	Contracting party	Company	Representative	2002-2005	2005-2008
Finland	TEKES	Technical research centre of Finland	Esa Peltola	X	X
Norway	ENOVA	Kjeller Vindteknik	Lars Tallhaug	X	X
Sweden	Energimyndigheten	FFA/FOI, WindREN AB	Göran Ronsten	X	X (3)
Switzerland	Swiss Federal Office of Energy	ENCO AG	Robert Horbaty	X	X
USA	NREL	NREL	Ian Baring-Gould	X	X
Canada	Natural Resources Canada	Natural Resources Canada	Antoine Lacroix	X	X
Germany	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	ISET	Michael Durstewitz		X
Italy	University of	University of Trento	Lorenzo Battisti		X (1)

	Trento				
Denmark	Risø National Laboratory	Risø National Laboratory	Per Lundsager	X (2)	

(1) Italy joined the Task 19 in 2005 in the beginning of the second period. Representative of Italy participated in one planning meeting in Finland and after that Italy withdrew from the work and no longer participated in the work of the Task.
(2) Denmark was one of the founding members of the Task, however, Denmark withdrew from task after kick-off meeting due to the lack of funding
(3) Sweden was full participant of the Task during the first period, but could not participate in the second period from the beginning due to lack of funding. Sweden joined the Task again in the beginning of 2008.

2.2 Budget

The associated costs of Task 19 were those of Operating Agent salaries, travel, and other expenses. Total sums for the Operating Agent expenses are presented in Table 2.

Table 2. Summary on operating agent budgets.

Time period	2002-2004 (EUR)	2005-2008 (EUR)
Salaries	42800	60000
Travel	7600	7500
Other expenditures	5400	5500
Total	55800	73000

The Operating Agent costs were paid jointly and in equal shares by the participating countries. During the first period seven participant countries shared the Operating Agent costs equally. During the second period Operating Agent costs were paid evenly by participant countries each year i.e. Italy paid for one year in 2005 and Sweden for one year in 2008. The total Operating Agent costs of 48900 USD were paid during the first period and correspondingly 73003 € during the second period.

2.3 Operating Agent

The Technical Research Centre of Finland was the Operating Agent of the Task and thus responsible for the performance of the Task to the Executive Committee.

The Operating Agent was responsible for organizing annual meetings in cooperation with the host country representative. The Operating Agent prepared mandatory annual reports regarding Task progress and administrative status to the IEA Wind Executive Committee.

2.4 Work procedure

The work was started by collecting available information on existing cold climate wind energy projects and by creating definition for the expression Cold Climate. Cold Climate was defined to refer to sites that experience either icing events or low temperatures outside the operational limits of standard wind turbines.

On the basis of the collected results first version of report State-of-the-art of cold climate wind energy technology was written. That report summarized the available cold climate adapted technology.

Simultaneously a first database on existing cold climate wind farms was created. This first database contained wind energy projects only from the participant countries and contained wind turbines for some 500MW.

Estimation of the ice induced production losses were studied on the basis of computer models and by validating the results of the computer modelling with data produced in onsite measurements and power performance measurements from sites that experience annual icing and fit for the definition of cold climate site.

Task 19 has web page that serves information dissemination and data collection.

2.5 Schedule

During the Task 19 period together 14 meetings were organised. The list of meetings and meeting hosts is presented in Table 3.

Table 3. Meetings during the Task 19 periods

Date	Venue	Country	Host
17.-18.12.2001	Risoe	Denmark	Per Lundsager
21. -22.5.2002	Kjeller	Norway	Lars Tallhaug
13. -14.11.2002	Bromma	Sweden	Göran Ronsten
8. - 9.4.2003	Pyhätunturi	Finland	Esa Peltola
6. - 7.10.2003	Charlottetown	Canada	Antoine Lacroix
17. - 18.3.2004	Andermatt	Switzerland	Robert Horbaty
1. - 3.12.2004	Boulder	USA	Ian Baring-Gould
29.-30.8.2005	Bubendorf	Switzerland	Robert Horbaty
27. - 28.3.2006	Tromso	Norway	Lars Tallhaug
1. - 2.11.2006	Calgary	Canada	Antoine Lacroix
6-7.9.2007	ISET Kassel	Germany	Michael Durstewitz
28.-29.4.2008	Anchorage	USA	Ian Baring-Gould
16.-17.9.2008	Espoo	Finland	Esa Peltola
8.12.2008	Norrköping	Sweden	Göran Ronsten

3. NATIONAL ACTIVITIES IN THE COURSE OF TASK 19

3.1 Finland

Finland has participated to IEA Wind R,D&D Task 19 at the beginning of project in 2001. Since then plenty of activities have been done. In the latest period of project from 2005 to 2008 following activities have been done:

Master's thesis, "The effect of icing on wind turbine energy production losses with different control strategies". The thesis dealt with icing of wind turbine and its effect to energy production. The focus of the study was behaviour of different control system under icing conditions. As a result of the thesis was a method for predicting ice induced production losses and knowledge how the stall and pitch controlled turbines operate when the turbines are iced.

A relationship between chord length and icing was studied using numerical ice accretion model TURBICE. The results of the study yield that larger turbines with larger leading edge radius in blades collect relatively less ice than smaller turbines. The study was restricted only to rime ice conditions and the result cannot be generalized to all icing conditions and every type of turbines. A paper of this study was sent to Wind Energy journal, where it is currently under review.

Finnish Meteorological Institute has made a study "Assessing icing conditions with measurements and with an icing index". The aim of this work was to assess icing conditions at selected sites in coastal and fell areas in Finland using measured icing data and an icing index calculated from data of a numerical weather prediction (NWP) model. Comparison of the index values to the in-situ icing measurements clearly shows that the method has some ability to predict the start and end of the icing event. However, the method is far from perfect and further studies are needed. There is also needs to understand how to relate the predicted index values to the severity of the icing event.

3.2 Switzerland

An important issue of the wind energy research program in Switzerland focuses on "Development of specific concepts and components for installations in difficult area and under rough climatic conditions". In 2007, the budget for wind energy-related R&D projects was 308'000.- CHF (187'000 €). Switzerland participates since 2002 in Task 19 of the IEA wind energy research activities. The main projects were:

- **Wind Turbine Gütsch** Important experience on the use of wind energy under climatically extreme conditions were gained, with the 800 kW plant on the Guetsch near Andermatt (2300 m above sea-level) which was commissioned in spring 2002. This is the first wind turbine in Switzerland that uses adapted technology because of icing and low temperatures. Due to various problems (not related to cold climate) this turbine was replaced in 2004 by a 600 kW machine. With now more than 3 years of continuous operation, various important lessons were learned with this installation:

  - Influence of blade heating
  - Testing of ice sensors
  - Ice throw
  - Monitoring of ice build up with a web cam

- **Alpine Windharvest** was a project within the frame work of EU INTERREG III B Alpine Space Programme. Goals of this project were: *Development of Information Base Regarding Potentials and the Necessary Technical, Legal and Socio-Economic Conditions for Expanding Wind Energy in the Alpine Space*. Participating partners from Austria, Slovenia, Italy, France and Switzerland, www.alpinespace.org/alpinewindharvest.html

- **Alpine Test Site Gütsch** links the activities of Task 19 with the research activities of COST 727 "Meteorological measurements and wind turbine performance analysis ". Issues treated were monitoring ice detectors and wind measuring equipment in relation to the performance of a 600 kW wind turbine and establishing tools and guidance for operating wind turbine under harsh climatic conditions. **www.meteotest.ch/cost727/index.html**

- **Nano Technology on rotor blades of wind turbines** Main objectives of this project is to investigate the possibilities to implement Nano materials in coatings of wind turbine blades to reduce the freezing point of the surface. The responsible researcher presented promising results at a task 219 meeting in Kassel 2007. A major wind turbine manufacturer and a Swiss chemical company are pursuing this development.

- **Site assessments** on more than 30 locations at over 1'000m.a.s.l. contributed important knowledge and experiences for the installation of wind turbines in mountains regions with harsh climatic conditions.

Swiss researchers contributed papers on 2 Boreas conferences and on the Winterwind event and two papers at EWEC conferences. 4 national meeting were organised for the dissemination of the results of the task.

3.3 Sweden

The interest for wind energy in cold climate in Sweden boomed in 2008. Two wind energy conferences were arranged during the year. One was held in Swedish and one was held in English[1]. Both had some 150 participants. The Swedish representative to IEA RD&D Wind task 19 was responsible for proposing the programs of both conferences. The conferences were sponsored by the Swedish Energy Agency.

Sweden did only participate in IEA's Task 19 during 2008. The contact with the Task 19-working group was, however, as a consequence of good will, kept alive also during 2005-2007 although there were no national projects going on (except for the Uljabuouda project where 10 WinWind turbines are to be built in 2009 and 2010 equipped with anti-icing systems). The attitude towards wind energy in cold climate changed rapidly in Sweden during the first half of 2007 as E.ON declared that the offshore wind farm Utgrunden II, although supported by $10M in wind pilot project funding, could not be realized due to the high cost of building and maintaining the offshore wind farm.

Mastering wind energy in cold climates is now considered important for Sweden. There are currently some 54 TWh of large scale projects in various stages in the planning process of which 30 TWh is planned for at potential cold climate sites.

Enercon's de-icing system has been shown to improve the energy production during light icing conditions. Another two or three de-/anti-icing systems are currently planned for to be tested in 2009-2011 in wind pilot projects organized by The Swedish Energy Agency.

The wind turbine manufacturers keep on asking for market studies concerning the potential for wind farm in icing climates. A market study is, however, hard to carry out if the magnitude and geographical distribution of icing are unknown. Consequently, mapping of icing and low temperatures are needed to enable the assessment of energy production losses due to icing and low temperature. Such mapping requires icing to be measured. In Sweden, development of ice

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[1] Presentations are available at http://winterwind.se/.

detectors and ice load sensors as well as icing measurements, frequency mapping of icing and the development of icing forecasting methods are planned for within the next three year period.

3.4 Norway

In 2001 Institute for Energy Technology, The National Met Office and Kjeller Vindteknikk initiated a project for the development of icing prediction tools. A test station was installed at the coastal mountain Gamlemsvæten 830m a.s.l. At the site the icing can reach more than 25kg/m. Two web cameras were installed. One of them took pictures of the ice thickness on a guy wire; the other web camera took images of 8 signs on increasing distance from the camera. The images of the signs were used to calculate the visibility. A method based on climatic parameters from a Met station or an airport to calculate ice on a standard object has been developed. For cases with accumulation, good match was found with the observations. Larger discrepancies were found for cases where the ice melts or falls off.

In 2007, the method for calculating ice thickness on a standard object was implemented as a post processor for the meso-scale model WRF. Since WRF operates in the time domain, time series for specific points can be compared with observations. The comparisons so far show the same pattern as the airport data, the model works well for accumulation but discrepancies appears for situations where the amount of ice decreases. There are also other situations where the model does not reproduce the observations. For strong inversions, the model can overestimate the ground temperature leading to too small amounts of ice. Since the model calculates the ice in a geographic grid, it is well suited for making icing maps.

A method for calculating production losses using a two parameter power curve has also been developed. The two parameters are wind speed and ice thickness.

In 2008 two web cameras has been installed on a wind turbine at Nygaardsfjellet 430m asl and 68° north. One of the web cameras takes pictures of one of the blades of the turbine, the other one takes pictures of the instruments on the nacelle. The WRF model is also run in parallel. One of the goals with the project is to develop the production loss method further.

3.5 Canada

Early in the fall of 2002, Yukon Energy Corporation (YEC) installed a Goodrich 0871LH1 ice detector on a mountain near Old Crow, Yukon. The ice detector was part of an autonomous wind resource assessment station that included anemometers and data loggers. The icing severity at Old Crow proved too much for the limited built-in deicing function of the ice detector. Only the 2.5-cm sensing probe got deiced once every detection cycle. This was insufficient and the whole detector assembly soon became engulfed in rime ice. This caused the detector to become inoperative and confirmed the importance of having an ice detector with full deicing capability.

Another project was done in collaboration with the University of Manitoba where experiments were performed in a state-of–the-art academic wind tunnel with icing capabilities. One of the objectives of this project was to simulate the icing conditions found in Southern Manitoba near St. Leon where there is a large wind farms. Experiments in the tunnel helped to understand the fundamentals of ice formation and to estimate how the turbines production is affected by the presence of ice. The work also focused on optimising ice mitigation techniques and allowed for progress towards developing new innovative design solutions for wind turbine applications in cold climates.

A third project consisted in the acquisition of scientific material to study and document the climatic conditions of a cold climate area favourable for the operation of wind turbines. This area is located at an elevation of approximately 610 meters in a mountainous domain of Eastern Canada. Two towers were instrumented to characterize the local environment in terms of wind speeds, wind direction, atmospheric pressure, humidity, duration of icing events and precipitation. The scientific information collected will help explain the failures of turbines that were designed for the European climates. It will also help to design turbines that are more adapted to severe North American climatic conditions.

3.6 USA

The U.S. has not conducted cold climate specific research projects during the course of the second period of Task 19. NREL has continued to conduct deployment related activities in cold climates, specifically in Alaska, Greenland, and Antarctica. These activities have helped to support U.S. state and federal activities regarding turbine implementation and operation in cold and extreme climates. A key focus of multiple projects has included wind turbine foundation design in cold climates with a specific emphasis on foundations designed to address the impacts of changing permafrost depth due to annual freeze thaw cycles. A second prime focus of the U.S. participation in Task 19 have been outreach based on fundamental knowledge and basic information on cold climate related issues with wind turbines. These activities have been carried out primarily through lectures, conference papers, posters and the redrafting of the Experts Group Study on Wind Energy Projects in Cold Climates. Efforts have also been undertaken to better document the implementation of wind projects in U.S. cold climate regions and supporting the assessment of resources in cold climate environments, specifically Alaska.

3.7 Germany

ISET has not had any other cold climate specific projects during the course of Task 19. In the frame of national funding programmes “Scientific Measurement and Evaluation Programme” and the “German Windmonitor” ISET is contributing to the Task 19 work programme with support of the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). The main activities of ISET during its participation to Task 19 have been to spread fundamental knowledge and basic information on cold climate related issues to administration, industry and education. Several lectures, conference contributions, posters etc. have been given in national seminars and abroad.

ISET’s wind energy database, first established under the “250MW Wind”-programme, including hundreds of reported icing observations in Germany, has provided valuable information for the annex by means of a broad statistical basis of sites affected by atmospheric icing, observed downtimes, repaired components and related cost figures.

ISET is presently analysing the influence of specific weather situations and meteorological parameter with possible incidence of atmospheric icing in order to improve the quality of wind power forecasts.

4. RESULTS

Considerable number of wind turbines has been and is located to such sites where turbines are exposed to such low temperatures outside the standard operational limit and to sites where turbines are operating in icing conditions, which retard energy production, at the winter time. Currently capacity of about 500MW locates on sites, which can be defined, as cold climate wind turbine sites. Such sites are often elevated from the surrounding landscape. Wind turbines have been recorded to operate in cold climate in Scandinavia, North America, Europe and Asia. The graph presented in Figure 1.

Also considerable amount of R&D work has been done to solve the challenges of cold climate sites.

This chapter briefly summarizes the main results of the Task 19.

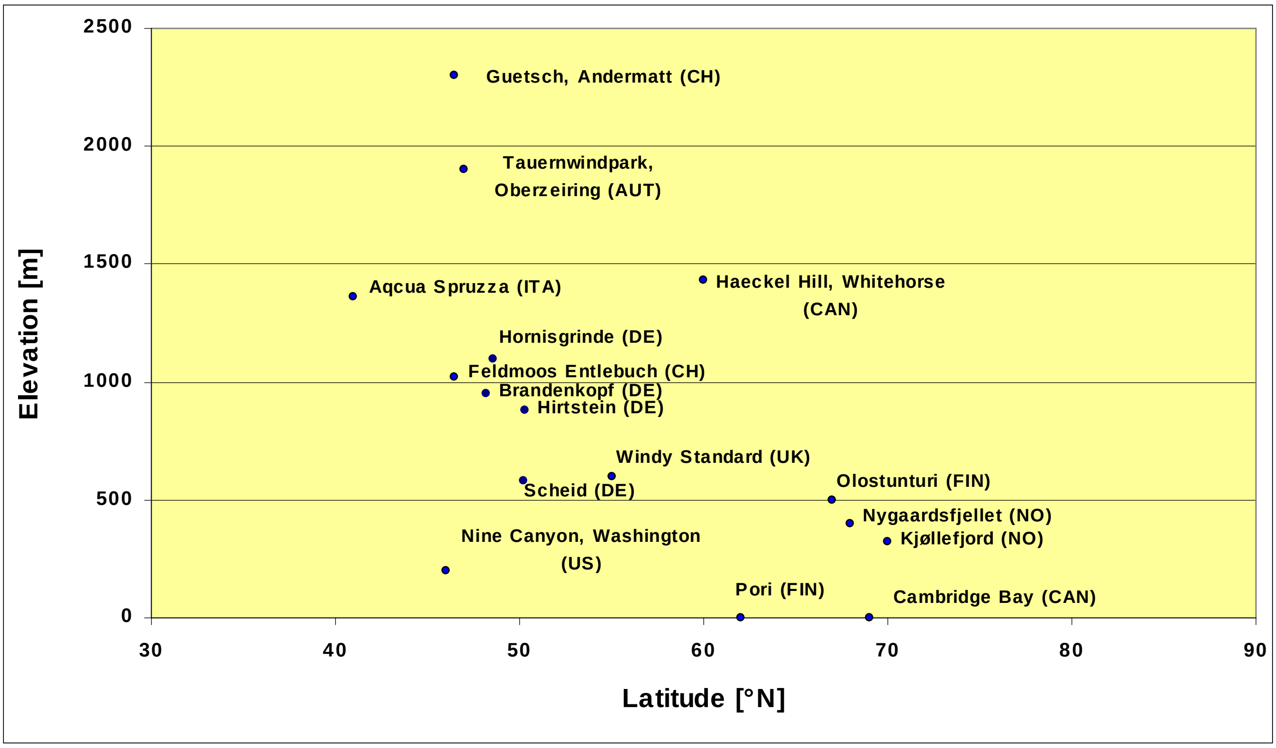

Figure 1. Latitude and elevation of typical cold climate sites.

4.1 Definitions

Cold climate (CC): Wind turbines in cold climates refer to sites that may experience significant time or frequency of either icing events or low temperatures outside the operational limits of standard wind turbines.

Ice accumulation: The amount and speed at which ice accumulates on structures, specifically on turbine blades, towers, and guy wires. It depends on many factors and affects turbine performance and safety. Ice accumulation must be measured to understand the need for deicing and anti-icing equipment.

Icing event: The length of time weather conditions that cause icing last. This needs to be measured to assess the amount of time that anti-icing equipment will need to operate. It reflects a specific storm or weather system.

Duration of icing: The amount of time ice stays on a turbine, structure, or instrument. It differs from an icing event in that once a structure is covered with ice it may remain for a considerable time before it melts or is removed. This information is important to assess the need for and impact of anti-icing or de-icing equipment.

4.2 Cold Climate experiences

Wind turbines have been sited to cold climate sites for some years and today operational experiences exist. In Scandinavia downtime for older turbines have been recorded due to low temperature, modern turbines instead are already adapted to the low temperatures and recorded down times have been relatively low. Low temperatures have also recorded to extend the duration of maintenance and reparation breaks during winter. Severity of icing varies a lot depending on local parameters especially altitude compared to surrounding landscape has great effect on severity of icing. Icing has been recorded to retard energy production at elevated sites in Scandinavia, Alpine and elevated regions in Europe as well as elevated sites in North America in Canada and Alaska. But in Norway for example icing has not had that kind of effect to wind power production as it has been expected, even though turbines locate up to 200m level above sea level and even higher latitudes than for example in Finland. Previous underlines the fact that icing is very much local phenomenon. Similar to low temperature icing and snow has been recorded to extend the duration of maintenance and reparation breaks. Snow may even prevent accessing to site during winter. In severe icing climate of Canada and Finland systems that keep blades free of ice have been found compulsory.

4.3 Key findings

Safety

Estimation of economic risks difficult for project developers as there is no verified method available.

No fallen ice chunks have been found further than 5 rotor diameter from the tower base of a wind turbine. The size of fallen ice chunks can be everything between few grams to several kilograms. Thus, there is a clear need to protect the risk area and mark it properly.

Resource Assessment

Commercial ice detectors are available. However, limited amount of experience and no recoconised calibration routines are available. No commercial anti- or de-icing available for heavy icing conditions.

Ordinary measurement equipments are seldom sufficient for cold climate sites, especially for sites that experience icing annually. Proper heated equipments are available but not often used due to the higher project development costs in the early phases of the project. There seems to be not enough documented information on the risks of underestimation of the effects of icing. Also the reliability of Sodars and Lidars is uncertain in complex terrain. There is simply not enough experience from complex cold climate sites from these equipments.

Production

Difficult to collect and obtain statistical production figures, especially regarding ice induced production losses, from wind farms that are located at sites that are located on areas that are prone to icing. Owners of the wind farms and especially turbine manufacturers are not keen to shere the information. Experience based on individual projects and no public database is available. Public production statistics seldom contain information on icing or low temperature events.

We also experienced that there is substantial number of operating wind farms that experience considerable production losses due to atmospheric icing however quantification of that was not possible in the course of the project.

Turbine technology and ice induced loading

The present standards and recommendation do not take turbine operation in icing conditions into account, but recommend that turbines ought to be shut down during the icing events. Market for the cold climate technology potentially large but the market does not exist yet.

4.4 State of the art of cold climate wind energy technology – report

Updated report on the available cold climate technology was first written during the first Task 19 period and then it was updated during the second period. The state-of-the-art of Cold Climate wind energy technology report is presented as an Annex of this report. Conclusions and some results are presented in this chapter.

Several wind energy related technical solutions covering adapted turbine technology and cold climate engineered meteorological sensors are available commercially or are under development and in prototype stage around the world. Meteorological community alone has done considerable amount of work in order to solve the problem of anemometer and wind vane icing, which in cold climate wind turbine installations is perhaps the first and likely the largest source of error. The importance of correct wind measurements cannot be overemphasized. Appropriate anemometers for cold climate applications are commercially available. However, expertise will be needed when selecting the instruments as well as when interpreting the results as anemometer 100% ice free does not seem to exist up to now. As an example a small amount of rime on the cups and shaft of an anemometer may lead to underestimation of wind speed about 30 % at wind speed of 10 m/s. Cables, connectors and cable ties specified for low temperature usage should be employed in order to maximize the reliability of a measurement setup. Also heating for the boom of wind sensors in severe icing climates should be provided to avoid distorted results.

Several methods to detect ice and icing are available. Ice detectors for meteorological, aviation, road safety, power line monitoring etc. purposes are on offer. It is possible to measure icing indirectly with dew point detector or with pair of anemometers, one heated and one unheated. However, a standardised method for the calibration of ice sensors does not exist. Icing maps describing annual icing time have been developed on the basis of the results of existing ice measurement and computer based climate simulations, but a verified method to map icing and ice loads still lacks. In general the cover of ice measurement network is scarce and it can be difficult to obtain accurate icing estimate for a certain site, since typically ice parameters are not routinely measured in any country by the national meteorological services. Also a verified method for the calculation of icing time from routine meteorological measurements does not exist. Considerable progress is expected to happen in this field during the next few years as an international collaboration has been formed to tackle the above mentioned topics.

Wind turbine icing appears to the owner of a wind project as a reduced energy production. The origin of the reduced performance is the adverse effect of ice to the rotor aerodynamics. It was found that wind energy, meteorological and aviation communities have all developed models for the estimation accumulated ice shapes on a windward side of objects, meteorologists for optimization of power line support structures and aviation industry to improve the safety of air passengers. However, due to the complexity and randomness of the physics of icing and aerodynamics, the development of accurate models for the estimation of the ice induced changes in aerodynamic forces of a wind turbine blade, has been moderate. Wind tunnel tests have been carried out up to now mainly by the aviation industry. Therefore the effect of ice on the performance of a wind turbine is not completely clear yet and partly because of that a verified method for the estimation of ice induced production losses does not exist at the present moment. Technical solutions for wind turbines operating at low temperature are available. Low temperature specified materials and oils should be used if temperatures outside the standard limits are probable. Many turbine manufacturers have already so called low temperature versions of their standard turbines available. In addition to cold specified materials used, those turbines often are equipped with gearbox or nacelle heaters. Some manufacturers have also adapted technology for icing climate on offer. In addition to low temperature versions, those turbines usually include some measures against icing of the rotor. This could mean ice detectors, coatings that prevent ice to stick to the blades or a blade heating system. The experience from the anti- and de-icing systems is still, however, relatively small.

4.5 Examples of cold climate sites.

4.5.1 Olos

The Olos wind farm in Finland is one of the most Northern wind farms in the world. It is located at N 67.55 E 23.48 and 500 m above sea level on the top of a fjell, where are significant topographical variations. The Olos wind farm consists of five Bonus Mk IV 600 kW turbines with arctic modifications, including JE-System’s blade heating by Kemijoki Arctic Technology Oy and ice detectors. With help of blade heating systems turbines can operate satisfactory almost whole year. Only during the most severe icing events the blade heating system is unable to keep the blades clean and therefore the production of turbines falls down from rated power. Annual production losses can be from 10 to 20 % depending annual icing conditions.

4.5.2 Nygaardsfjellet, Norway

The highest elevated wind farm in Norway is the Nygaardsfjellet wind farm. It consists of 3 2.3MW turbines and is located at 68° north and 430m a.s.l. At this site the owner, Nordkraft Vind AS are using one of the turbines for R&D purposes. Ice detectors and two web cameras are installed on the turbine. The experience with the turbine so far is that the production losses are small and the order of 3% on an annual basis.

4.5.3 Mount “Gütsch”Alpine wind test site in Switzerland

At Mount “Gütsch”, 2’350 m.a.s.l near Andermatt in Switzerland, an interesting set up was installed in order to investigate the problems of icing on wind turbines under alpine conditions. Next to a test bench for anemometers and ice detectors from the Swiss Met Institute, there is an Enercon E40 class 1 wind turbine installed, equipped with various additional data collecting instruments. The data collection system at the test site comprises:

- Wind speed at hub height
- Wind direction at hub height
- Air temperature at hub height

- Air humidity at hub height
- Liquid water content and droplet size
- Ice detector on the hub
- Ice detection by webcam

In addition, to that, a continuous observation of ice throw took place.

Tasks of the research on this site are:

- Studying icing process on rotor blades and other structures
- Analysing quality of icing detecting devices
- Improvement of the de-icing strategy Enercon E-40
- Verification of the recommendations from the IEA wind annex XIX "WECO" for the alpine area
- Verification of the "Guidelines for the security of wind-power installation in Switzerland"
- Optimization the operating strategy of the wind turbine E-40 Gütsch under icing conditions (from "De-Icing" to "anti- Icing") l
- Development and publication of a manual "Operating wind turbines under freezing conditions in the alpine region "

in collaboration with COST 727 and IEA Wind Task 19.

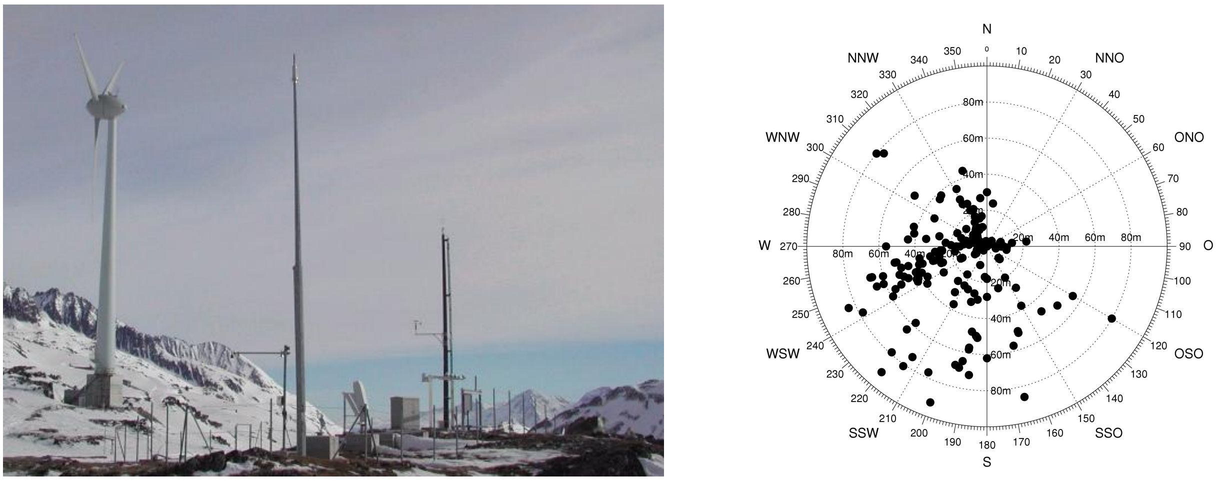

Figure 2. Installation on Mt. Gütsch with Enercon E-40 and test bench of the Swiss Met Institute and results of collecting samples of ice throw

The goal of the Swiss project "Alpine Test Site Gütsch" is to expand the knowledge base on atmospheric icing specifically in the Alps. The project includes an inter-comparison of ice detectors, the performance monitoring of a wind turbine and recommendations for the estimation of icing conditions at sites not equipped with ice detectors.

The ice detector inter comparison showed surprisingly poor results so far, no device being able to measure icing correctly for a whole winter season. The monitoring of the wind turbine pointed out deficiencies concerning ice detection as well as blade heating performance. An extensive observation of the wind turbine's ice throw proved that a significant safety risk has to be taken into account at this site. Furthermore, a simple meteorological approach to identify icing conditions was tested with fairly good results and finally, modelling of two icing events with the NWP model WRF was accomplished, showing promising agreement with on site observations.

4.5.4 Sites Germany

Icing is being observed in all regions of Germany. In coastal areas and the plains in northern Germany the duration of icing events is mostly only a couple of days. Sensors and blades and thus turbine performance are affected by icing situations. With increasing heights e.g. mountainous areas failures caused by cold climate conditions can result in downtimes of several weeks due to continuous weather conditions and access limitations.

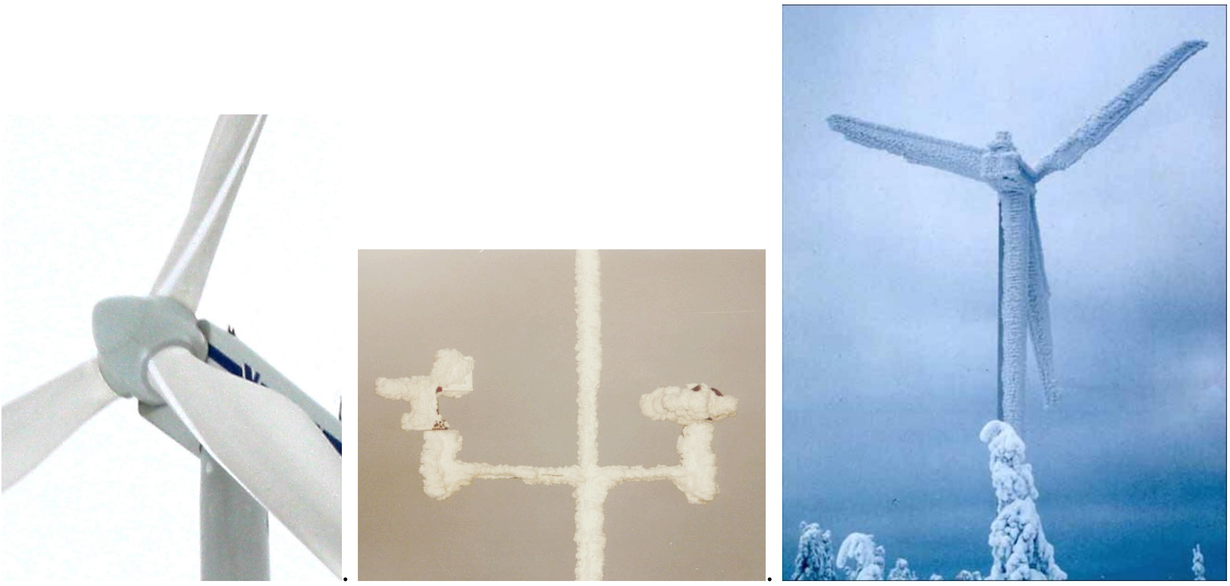

Figure 3. Typical icing observations from sites in Germany (development of clear ice on leading edge, accumalition of rime ice on heated(!) WT sensors, severe icing on wind turbine.

4.5.5 Murdochville, Canada

The Murdochville area is located in Eastern part of the Appalachian Mountains. This region features a very good wind resource and is located at an elevation of approximately 800 meters. It is currently host of 60 turbines totalling 108 MW.

It has been reported that in the Appalachian domain, rime conditions can be expected approximately 12% of time between November and April. Natural Resources Canada has provided financial support to quantify the amount and duration of icing on the summits around the Murdochville area. While it can be determined the duration of each icing episode, it is more difficult to evaluate how long will the ice remains on the surfaces once it is deposited.

4.6 Estimation of ice induced production losses

Norway has developed a simple method for estimation of production losses. It is based on a two-parameter power curve. In addition to wind speed, the model use ice on a standard object as input. The model assumes a strong correlation between ice on a standard object and ice on a wind turbine blade. The physical process for ice on the turbine will not be the same as the physical process for ice formation on a standard object. The rotation of the turbine and the size of the blades are two important parameters. Concurrent data of ice thickness and wind speed are necessary for the model since the model is run on time-series. The time-series can be generated from model or directly from observations. The loss of power with increasing ice thickness is based on a literature study. Observations of concurrent production loss and ice thickness are believed to improve the model. The model is well suited for calculation of losses for different blade heating systems under different climatic conditions.

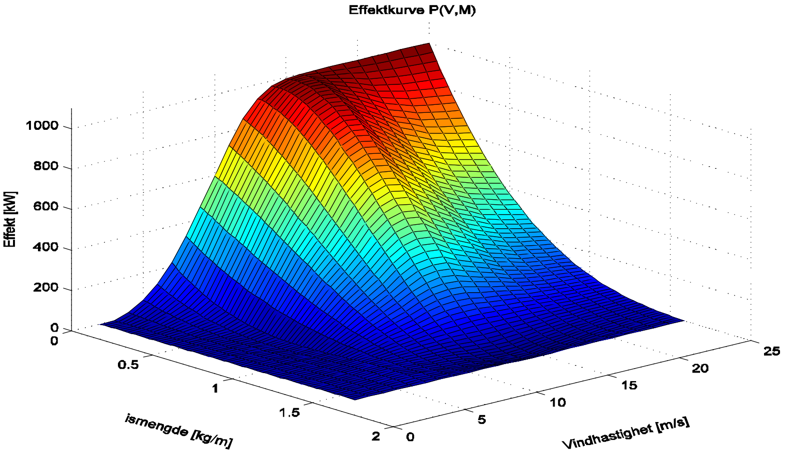

Figure 4. The two parameter power curve

In Finland a method for predicting ice induced production losses of wind turbines was developed as a master's thesis study [2]. The method is based on the dynamic simulation of wind turbine and annual energy production estimation (AEP) using annual mean wind speed distributions. The main idea is to generate power curves for iced wind turbine and use these curves to AEP calculations. Power curves are generated with dynamic simulations of wind turbine using modified drag and lift coefficients to describe aerodynamics of the iced blades. The method with model of 600 kW stall controlled turbine gave quite good correlation to measured data from similar real wind turbine.
Biggest disadvantage of the method is the lack of reliable determination of aerodynamic properties of iced blades: Different variables like blade profiles, wind turbine operational characteristics and icing conditions leads to a complex problem.
This production loss estimation method can be applied especially to large wind energy projects where relatively laborious and expensive tools can be used during the project development phase.

4.7 Recommendations for the Development of Energy Wind Projects in CC-report

In addition to the information on best available cold climate technological solutions, well tried experiences related to cold climate wind energy project development from the participant countries were compiled. The result was the Wind Energy Projects in Cold Climates report. The report provides a good starting point for development of a cold climate site.

In general standard best practises provide a good starting point for developing a cold climate site. Those practices should be used as far as possible, even though they do not normally consider cold climate issues. The additional risks that are involved in cold climate wind energy projects must be assessed in detail. Cold climate conditions directly affect site access, working conditions, technology selection, safety, and energy production. The importance of thorough site assessment is emphasized in cold climate and icing conditions, which can complicate the measurements. It is the most important phase, however, as project decisions are based on the results. A thorough site measurement, including ice measurements for at least one year with the correct measurement devices is recommended. The complexity of a measurement program will vary greatly, depending on location and parameters. A proper measurement campaign also provides valuable information on site access and working conditions. Instrument and turbine manufacturers have solutions

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[2] Wallenius, T., The effect of icing on wind turbine energy production losses with different control strategies. Master's Thesis. Helsinki University of Technology, Department of Mechanical Engineering, Espoo, 2007. p. 75

available. Potential solutions for each project need to be surveyed individually because cold climate circumstances vary greatly and thus the needed solutions are different. Solutions for low temperatures are generally more mature, because most of that technology has been introduced in other fields of engineering. A distinctive feature is the lack of proven anti-icing and de-icing technology for different icing climates. Icing may significantly influence energy production. There is no verified method for estimating ice induced production losses, but simple approaches have been presented that can reasonably evaluate the effects of extreme low temperatures. Additional costs that are related to working conditions, construction, and site access, can be limited with careful planning. Cold climate wind energy projects can maintain high safety standards.

Cold climate wind projects involve higher risks than normal lowland undertakings. Planners, operators, authorities, insurers, and investors should use a risk evaluation to determine the kinds of risks a cold climate wind turbine installation will face and the measures that have to be taken to avoid or decrease these risks. Although cold climate projects will have additional risks, their assessments will be no different than that of other wind farm development projects.

The summary of the recommendations

IEA Task 19 has elaborated and published recommendations and guidelines how to handle and assess potential installations at sites considered to be as cold climate sites. The basic messages and recommendations can be summarized as follows:

- Be aware of the extra risks involved in cold climate wind energy production at early stages of the project.
- Employ available best practises as far as possible, even though they generally do not consider cold climate issues.
- Instrument and turbine manufacturers have cold climate solutions available. Conduct a survey to find solutions for each project, because cold climate circumstances vary greatly.
- Perform a thorough site assessment measurement of at least one year with measurement devices, including ice measurements. This phase provides valuable information on site a cold climate and working conditions.
- There is no standard method for estimating ice induced production losses. Make the best estimate based on the results of site measurements.
- Notice the cold climate related safety aspects, low temperature working conditions, and risk of ice throw in the project planning phase.
- Carry out a risk assessment that includes assessment of the quality of the selected turbine and experience and references of the installation company, contractors, and operator.
- Include the results of the risk assessment as part of the specifications for turbine, equipment, manufacture, installation, and operation.

4.8 Other results

In the course of the duration of Task 19 it has been observed that the perception, visibility and awareness of CC issues to turbine development and operation has been significantly improved, at least partially under the responsibility of the work provided in Task 19. Objective indicators for this can be seen by the amount of papers published, presentations to conferences, third party contacts etc.. Meanwhile CC issues are prominent enough to have their own dedicated sessions on international wind energy conferences (DEWEK 2008). Furthermore cold climate topics have moved to the agendas of EWEAs wind technology platform.

5. DISSEMINATION OF INFORMATION

The results of the research that were done in course of the Task 19 were documented in four reports and conference papers which are appended as Annexes of this document. The main results were the two documents that summarized the work of the Task 19, a report on presently available cold climate wind energy technology State-of-the-art of Cold Climate Wind energy and report on best available practises for cold climate wind energy development, Specific Recommendations for the Development of Energy Wind Projects in Cold Climates. In addition to these reports, annual reports of task performance were submitted to the IEA Wind Executive Committee by the Operating Agent. Web page of the Task 19 can be found in http:// arcticwind.vtt.fi.

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6. CONCLUSIONS

First wind turbines with real cold climate modifications were built some decade ago and recently the first steps from demonstrations into fully commercial implementations have been taken. The development of ice free wind sensors and ice sensors has advanced alongside. However, it can be said that from project developer point of view there is neither reliable commercial ice sensors nor commercial wind turbine technology that would enable development of high wind areas where icing conditions at winter time are challenging.

Technical development continues and turbine and sensor manufacturers are demonstrating new solutions. As the applications are entering a commercial phase, there is a need to gather experiences in a form that can be utilised by developers, manufacturers, consultants and other financiers. This is especially the case in present situation where more challenging inland sites, including cold climate sites, are becoming more and more competitive with offshore wind due to the increased offshore deployment costs.

It is likely that increasing numbers of wind turbines will be installed to the sites within next five to ten years that can be described as cold climate sites. The areas where cold climate sites will be developed at increasing pace are Scandinavia and Northern parts of America and mountainous areas of Europe. There are also several R&D projects taking place and starting in the member countries of present task 19. Thus, it seems clear that cold climate wind energy development will continue during the next years. Moreover, the size of the cold climate market may be similar size to offshore i..e. around 2000MW to 4000MW annually. Some of the sites can be described as cold climate sites due to low temperatures and some due to atmospheric icing and at some sites both.

There still is a need to develop methods for project developers for the estimation of cold climate related risks that originate from cold climatic conditions. There are still not available methods for the estimation of production losses due to ice and low temperature and thus it is still typical that the uncertainties regarding production estimates of cold climate sites are higher compared to standard low land undertakings. Icing atlases are not easily available. Methods to produce such maps exist but are still not often used. Operational experiences exist but are also not easily available as the owners of the turbines are often not willing to share the experiences gained often the hard way. Thus the collection and dissemination of the cold climate specific information is still very much topical.

Seminars dealing with cold climate specific issues have recently collected high number of participants e.g. Winterwind 2008. Increasing need for additional information has been recognised by banks financing the projects, turbine manufacturers supplying turbines to cold climate sites and also project developers developing wind energy projects at sites where they have experienced additional difficulties and challenges that originate from cold climate conditions. To summarize the latest development, it seems apparent that the work of Task 19 needs to continue in one way or the other.

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ANNEXES

1. State-of-the-art of wind energy in cold climates.
2. Wind Energy projects in cold climates