EXPERT GROUP STUDY

ON

RECOMMENDATIONS FOR

WIND ENERGY PROJECTS IN COLD CLIMATES

EDITION 2011

Submitted to the Executive Committee
of the International Energy Agency Programme
for
Research and Development
on Wind Energy Conversion Systems

WIND ENERGY
PROJECTS IN COLD CLIMATES

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Cover Photo: Three Vestas V27 wind turbines installed on St Paul Island, Alaska, as part of a wind-diesel power system. Photo Credit: TDX Power, USA

FOREWORD

Numerous cold climate sites around the world offer great wind energy potential in demanding winter climates. Activities have been conducted in a number of countries to master the difficulties that atmospheric icing and low temperatures pose for wind energy technology. The current wind capacity in cold climates (defined as those that experience either icing events or temperatures lower than the operational limits of standard wind turbines) in Scandinavia, North America, Europe, and Asia, is about 60 GW. Increased experience, knowledge, and improvements in cold climate technology have enabled the economics of wind projects to become more competitive in relation to standard wind projects. The internationally accepted procedures for testing and evaluating wind turbines or wind energy conversion systems encompass a variety of aspects. Although there is vast wind energy potential in cold climates, little attention has so far been paid to the environmental impacts of wind projects in these areas.

The large-scale exploitation of cold climate sites has been limited by our lack of knowledge about their special challenges and the lack of proven and economical technological solutions.

The purpose of this report is to provide the best available recommendations on this topic, reduce the risks involved in undertaking projects in cold climates, and accelerate the growth of wind energy production in these areas. This document addresses many special issues that must be considered over the lifetime of a cold climate wind energy project. The importance of site measurements, project design, and system operation is emphasised.

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EXECUTIVE SUMMARY / SUMMARY OF RECOMMENDATIONS

Cold climate sites around the world offer large wind energy potential in demanding winter climates. National activities have been conducted to master the challenges that atmospheric icing and low temperatures pose for wind energy development. Our lack of knowledge of special cold climate (CC) issues and the lack of proven and economic technological solutions have limited the large-scale exploitation of these sites. For the sake of this document, the concept of CC includes low temperature and icing environments.

A generic wind energy development best practise guide provides a good starting point for developing a CC site. Those practices should be used to the extent possible, even though they do not normally consider CC issues. The additional risks that are involved in CC wind energy projects must be assessed in detail. CC conditions directly affect site access, working conditions, technology selection, loads, noise, health and safety, public safety and energy production.

The importance of thorough site assessment is emphasized in CC 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 may have CC solutions available. Options for each project need to be surveyed as CC circumstances vary greatly. This is partly because commercial and prototype level sensors, anti-icing and de-icing devices and other solutions for icing conditions have been presented, but only limited information has been published. Solutions for low temperatures are generally more mature, because most of that technology has been introduced in other fields of engineering. The climatic circumstances at CC sites demand high reliability of adapted technology.

Icing may significantly influence energy production. However, there are no verified methods for estimating ice-induced production losses. More work is needed, especially in the development of solutions to prevent turbine icing.

CC wind energy projects can, and need to maintain high safety standards as such projects involve higher risks than undertakings in standard climates. Planners, operators, authorities, insurers, and investors should use an established risk evaluation method to determine the kind of risks a CC wind turbine installation will face and the measures that have to be taken to avoid or decrease these risks. Although CC projects will bring about additional risks, their assessments will be no different from those of other wind farm development projects. Implementation of projects in CC will incur aadditional costs that are related to working conditions, construction, and site access. Some of these costs can be mitigated with careful planning.

A summary of recommendations as addressed in this document are:

- Be aware of the extra risks and costs involved in CC wind energy production at early stages of the project.
- Employ available best practises to the extent possible, even though they generally do not consider CC issues.
- Conduct a survey to find solutions for each project understanding that CC circumstances vary greatly between different sites. Perform a thorough site assessment measurement campaign

during at least one year including ice measurements. This phase provides valuable information on site access and working conditions.

- Make the best estimate of ice-induced production losses based on the results of site measurements.
- Be aware that lower availability of wind measurements will increase the uncertainty in energy production estimates.
- Ensure that in the project planning phase CC-related safety aspects, such as low-temperature working conditions and the risk of ice throw, are addressed.
- Carry out a risk assessment that includes assessment of the quality of the selected turbine and experience and references of the installation companies, contractors, and operators.
- Include the results of the risk assessment as part of the specifications for turbine, equipment, manufacture, installation, and operation.
- Consider the consequences of increased noise due to operation with iced-up blades and/or cylindrical sound propagation under stable atmospheric conditions.
- Consider turbine manufacturers' CC packages as part of the turbine selection process.
- Apply anti- or de-icing systems if site conditions require, provided proven technologies are available.
- Ensure that selected wind turbines are only operated under conditions for which they have been certified.

LIST OF ABBREVIATIONS

CC	Cold climate
HSE	Health, Safety and Environment
IC	Icing Climate
LTC	Low Temperature Climate
WT	Wind turbine

CONTENTS

1. INTRODUCTION

Wind turbines in cold climates are exposed to icing conditions and low temperatures outside the design limits of standard wind turbines. Standard turbines operating in such extreme environments are prone to production losses and increased loads, which in turn will cause a risk of premature mechanical failure and financial losses. Although exact numbers are hard to assess, some 60 GW of installed capacity is located in cold climate (CC) areas in Scandinavia, North America, Europe and Asia. Narrowing this assessment only to regions with high likelihood of extended CC operation; Scandinavia, Switzerland, Canada, and northern parts of the U.S. and China, wind turbines worth of 20 GW were conservatively estimated to be installed in CC areas in 2009 [1,2]. Additionally, microclimates with these same conditions are found in more temperate areas such as central and southern Europe, China, Japan, many parts of the United States, and locations in the southern hemisphere such as Australia, New Zealand, and southern South America. Recent interest in offshore wind power development introduces further demand for knowledge in dealing with icing, as turbines installed in the shallow waters off northern Europe and off the coast of New England in the United States also face icing conditions.

Sites within CC constitute a vast wind energy production potential. Since fewer temperate sites are available and the offshore wind development faces higher than expected costs, large wind energy projects in CC become tempting and are likely to be implemented. Increased experience and knowledge, combined with improvements in technology directed to be used within CC, have enabled such projects to become more competitive when compared to those onshore with low wind resources and those offshore to be built at higher costs.

Limited effort has been made to assess the potential of wind development in arctic and arctic-like microclimates. Publications by Tammelin et al. [3,4] report potential markets of 20% of the installed capacity by 2010. This outdated estimate would correspond to wind power worth of some 40 GW in CC, if combined with the forecast for 2010 wind production presented in BTM's 2008 World Market Update [5]. There is however an inherent lack of market studies for the potential of wind energy in cold climates. The main reason for this has been a natural choice to focus initially on sites where no CC adaption is required.

The conditions within CCs are insufficiently included in the design limits presently covered by national and international standards for wind turbine design and implementation. The lowest permitted operating temperature varies between wind turbine manufacturers and models. Apart from requiring a shutdown, neither the International Electrotechnical Commission (IEC) standard [6] for permissible loads nor the standard certification requirements for cold climate certified wind turbines from Germanischer Lloyd Industrial Services GmbH [7,8] deal with operation in icing conditions. However, there is currently no IEC load case which would require simulation of long time operation with significant ice loading.

The purpose of this report is to provide developers, owners, and operators of wind projects within CC with the best available information on this topic. The incentive is to reduce the risks and accelerate the growth of wind energy production. This document also provides preparatory information that should benefit manufacturers, banks, and insurance companies.

The document includes sections on site classification, measurements and monitoring, technology, production, health and safety, project economics and project design. Each section addresses issues that are relevant to wind energy in CCs. The document also provides recommendations aiming to bring forth solutions for the CC-specific challenges and reduce the cost of wind energy by lowering the social, technological, and economic risks.

2. COLD CLIMATE

Cold Climate (CC) areas are regions where icing events or periods with temperatures below the operational limits of standard wind turbines occur, which may impact project implementation, economics and safety. Areas where periods with temperatures below the operational limits of standard wind turbines occur are defined as **Low Temperature Climate (LTC)** whereas areas with icing events are defined as **Icing Climate (IC**). Although theoretically possible, active icing rarely occurs at temperatures below minus 25°C. In some areas wind turbines (**WT**) are only exposed to either icing or low temperature events. In some regions both low temperatures and icing events may take place. Therefore, a site can be in a Low Temperature Climate or in an Icing Climate or both while they are still all denoted Cold Climate sites. These definitions are further illustrated in Figure 2-1.

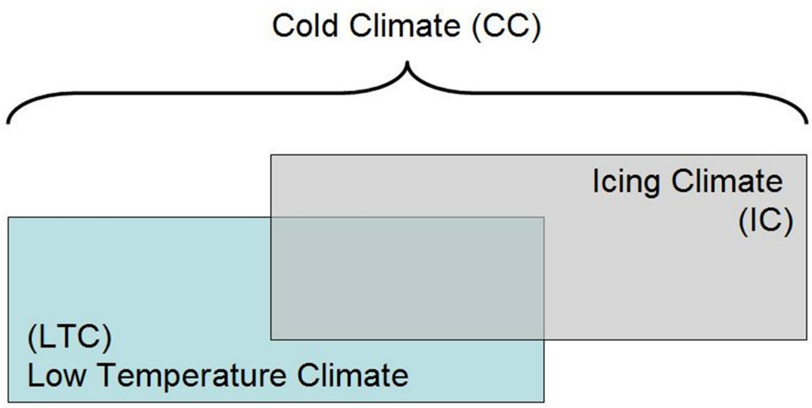

Figure 2-1 Definition of Cold Climate, Low Temperature Climate and Icing Climate.

Further information about the typical temperature range of icing and a more detailed overview about available LTC definitions are given in chapter 3.1, while a site classification for IC is shown in chapter 3.2.

Best practise guidelines for implementing wind energy projects are available from many national, international, professional, and industrial organisations. These are recommended to be used as much as possible, even though they do not typically consider CC circumstances. An example is the “Best practice guidelines for wind energy development” presented in [9].

2.1 Low Temperature Climate

In many areas, extremely low temperatures are typically caused by clear sky radiation during the winter time, which is often associated with high pressure zones. Furthermore, the elevation of a site plays an important role.

An LTC can have the following effects on a wind energy project:

- Materials used in turbines and components can be affected by low temperatures
- High air density leads to higher energy densities and thus needs to be considered in the control of power generation.
- Maintenance work at low temperatures is more time consuming
- Cold start of wind turbine can be more difficult at low temperatures.
- Oils and lubricants can lose their viscosity.

- Heating of the components increases wind farms internal energy use and thus reduces the energy production.

All the example items listed above and more have been addressed in following chapters.

2.2 Icing Climate

2.2.1 Atmospheric Icing

Atmospheric icing is defined as the accretion of ice or snow on structures which are exposed to the atmosphere. In general, two different types of atmospheric icing that impact wind turbine development can be distinguished: **in-cloud icing** (rime ice or glaze) and **precipitation icing** (freezing rain or drizzle, wet snow).

The different forms of atmospheric icing can be described as follows:

- **Rime Ice:** Supercooled liquid water droplets from clouds or fog are transported by the wind. When they hit a surface, they freeze immediately. If the droplets are rather small, soft rime is formed, if the droplets are bigger, hard rime is formed. Its formation is assymetrical (often needles), usually on the windward side of a structure. Its crystalline structure is rather irregular, surface uneven, and its form resembles glazed frost. Rime ice typically forms at temperatures from 0°C down to -20°C. The most severe rime icing occurs at exposed ridges where moist air is lifted and wind speed is increased. **Hard rime** is opaque, usually white, ice formation which adheres firmly on surfaces making it very difficult to remove it. The density of hard rime ice ranges typically between 600 and 900 kg/m^3 (ISO 12494). **Soft rime** is a fragile, snow-like formation consisting mainly of thin ice needles or flakes of ice. The growth of soft rime starts usually at a small point and grows triangularly into the windward direction. The density of soft rime is usually between 200 and 600 kg/m^3 (ISO 12494), and it can be more easily removed.
- **Glaze:** Glaze is caused by freezing rain, freezing drizzle or wet in-cloud icing and forms a smooth, transparent and homogenous ice layer with a strong adhesion on the structure. It usually occurs at temperatures between 0 and -6°C. Glaze is the type of ice having the highest density of around 900 kg/m^3. **Freezing rain** or **freezing drizzle** occurs when warm air aloft melts snow crystals and forms rain droplets, which afterwards fall through a freezing air layer near the ground. Such temperature inversions may occur in connection with warm fronts or in valleys, where cold air may be trapped below warmer air aloft. **Wet in-cloud icing** occurs when the surface temperature is near 0°C. The water droplets which hit the surface do not freeze completely. A layer of liquid water forms which, due to wind and gravity, may flow around the object and freeze also on the leeward side.
- **Wet snow:** Partly melted snow crystals with high liquid water content become sticky and are able to adhere on the surface of an object. Wet snow accretion therefore occurs when the air temperature is between 0 and +3°C. The typical density is 300 to 600 kg/m^3. The wet snow will freeze when the wet snow accretion is followed by a temperature decrease.

There exists another phenomenon called **sublimation,** which means direct phase transition from water vapour into ice, producing hoarfrost. Although it is known to cause transmission losses through corona effects, hoarfrost is of low density, adhesion and strength, and therefore does not cause significant loads on structures. Therefore it will not be considered in this report.

It has to be noted that in many cases the frequency of icing and the ice loads increase with increasing height above ground. This is due to a higher probability of a structure being inside clouds (icing frequency) and surrounded by high water content (ice load).

2.2.2 Icing definitions Phases of an icing event

An icing event can be described with the following expressions (Heimo;Cattin;& Calpini, 2009), applicable to all structures and instruments exposed to atmospheric icing:

- **Meteorological icing:** Period during which the meteorological conditions for ice accretion are favourable (active ice formation)
- **Instrumental icing:** Period during which the ice remains at a structure and/or an instrument or a wind turbine is disturbed by ice.
- **Incubation time:** Delay between the start of meteorological and the start of instrumental icing (dependant on the surface and the temperature of the structure)
- **Recovery time:** Delay between the end of meteorological and the end of instrumental icing (period during which the ice remains but is not actively formed)

Figure 2-2 illustrates how a wind measurement is affected by icing according to the definitions described above. When meteorological conditions for ice accretion are given (start of the meteorological icing), there is a certain delay – the incubation time - until ice accretion at the anemometer begins. By using **anti-icing** measures (coatings, warm surfaces etc.), the incubation time can be extended, in an ideal case until the end of meteorological icing avoiding icing of the instrument. As soon as there is ice on the sensor (start of the instrumental icing), the measurement is disturbed. Ice is accreted continuously on the sensor until the meteorological conditions for icing are not present anymore (end of the meteorological icing). But the ice will remain at the instrument for a certain time – the recovery time - until it melts or falls off (end of the instrumental icing). This delay can be much longer than the period of meteorological icing. Although the meteorological conditions for ice accretion are not present anymore, the readings of the instrument have to be discarded until the instrumental icing has ended. By using **de-icing** measures (heating, manual interference etc.), the recovery time can be shortened.

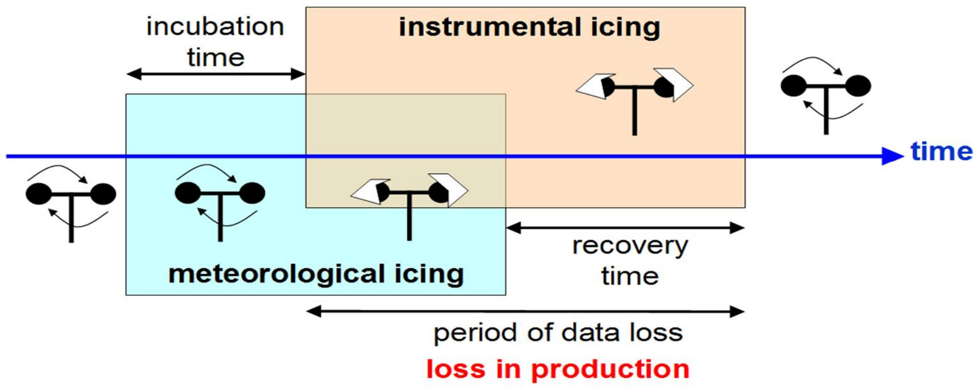

Figure 2-2: Definition of Meteorological Icing and Instrumental Icing.

Additional parameters to further describe the icing conditions at a site are:

- **Icing rate:** Ice accumulation per time [g/hour]
- **Maximum ice load:** Maximum ice mass accreted at a structure [kg/m]
- **Type of ice** [rime, glace, wet snow]

At sites where there is adequate solar radiation during the winter months, the ice can melt away within a rather short time after the end of the meteorological icing. At northern sites, the ice can remain on a structure for a very long time after the meteorological icing. Such site specific characteristics can be described with the **Performance Index.** It is defined as the ratio between instrumental icing and meteorological icing:

$$Performance\ Index = \frac{Instrumental\ Icing}{Meteorological\ Icing}$$

2.2.3 Icing and wind energy

Icing Climate can have the following effects on a wind energy project:

- Icing affects wind measurements and typically causes data losses and uncertain readings from the measurement equipment.
- Heavy ice loads can cause the collapse of measurement towers
- Ice on the wind turbine blades increases the noise levels of a wind turbine considerably
- Ice throw from the blades of a wind turbine is a safety issue
- Ice on a rotor blades always leads to production losses.
- Energy yield calculations for sites where icing condition prevail have a higher uncertainty compared to standard conditions.
- Ice on wind turbine blades causes aerodynamic imbalance and with long exposures can increase the loading of components.
- The presence of ice may make maintenance and repairs more difficult

All the example items listed above and more are addressed in the following chapters.

3. SITE CLASSIFICATION

The first step when developing a wind energy project in a potential Cold Climate (CC) site is to check if it is a Low Temperature Climate (LTC) site or an Icing Climate (IC) site or both. If the site is an IC site, there is the further need to define the IEA ice class for this specific site.

3.1 Low Temperature Climate Classification

Figure 3-1 shows the position of LTC and IC with respect to ambient temperature.

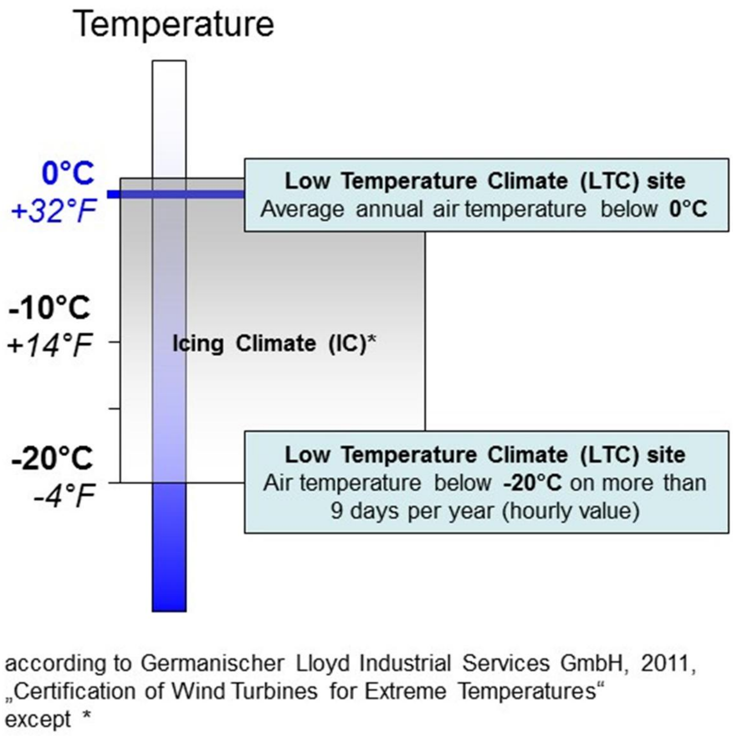

Figure 3-1 Low Temperature Climate and Icing Climate with respect to ambient temperature.

3.2 IEA Ice Classification

This chapter presents an ice classification for wind energy sites, which gives a first indication on the severity of icing and its consequences at a given site. In a later phase of the project it is recommended to carry out more detailed analyses on the site specific icing conditions and possible consequences icing may cause at the site under consideration.

The IEA Ice Classification is based on the classification which was elaborated in the EUMETNET/SWS II project [**Error! Bookmark not defined.**]. However, this classification was established with a focus on meteorological stations and therefore covers a very wide range of ice frequencies. Especially Classes LII4 and LII5 in the EUMETNET/SWS II classification are in a range where it is not feasible to develop wind energy projects. Therefore, IEA proposes a modified classification which is shown in Table 3-1. The classification is based on the following definitions (more detailed explanation in Chapter 2.2.2)

- **Meteorological icing:** Period during which the meteorological conditions for ice accretion are favourable (active ice formation)

- **Instrumental icing:** Period during which the ice remains at a structure and/or an instrument or a wind turbine is disturbed by ice.

Meteorological icing can be modelled numerically with mesoscale weather prediction models. If there is an icing map available, one can obtain some good starting figures there. The best way to obtain data for the site classification is, however, to measure the meteorological icing directly with an ice detector at the site.

The IEA classification of instrumental icing is defined as the duration when an unheated standard cup anemometer is disturbed by icing. A cup anemometer is typically disturbed by icing when its values are lower than those of a heated cup or heated ultrasonic anemometer. However, also a heated cup anemometer can be affected by icing. For example, heated sensors are found to experience ice build-up during heavy snowfall. There is more information about how to obtain the values for meteorological and instrumental icing in Chapter 2.2.2.

Table 3-1 IEA Ice Classification with estimate of resulting production losses.

IEA Ice class	Met. icing	Instru-mental icing	Production loss
	% of year	% of year	% of annual production
5	>10	>20	> 20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0 - 0.5

When using the classification there is a chance that a site can end up in two or three different IEA ice classes depending on whether the meteorological icing, the instrumental icing or the production loss is used as input. Variations may also occur depending on the used instrumentation and the chosen measurement period. In such case it is recommended to use the highest class.

4. SITE MEASUREMENTS

Monitoring the wind resource at a potential site is typically one of the first steps of any wind power development project. The complexity of a measurement program will vary greatly depending on the location and the parameters that need to be measured. The Cold Climate (CC) issues, icing in particular, complicate matters further. The investment required for CC measurement campaigns, including the potential need for independent power, is considerable. However, the potential cost of missing data and increased maintenance warrants an appropriate investment. Issues associated with the implementation of monitoring programs in CCs, including equipment and accessibility, are addressed in this section.

4.1 Meteorological towers

Ice build-up should be recognised as a selection criterion for the tower if icing is likely at the installation site, as towers have to be designed to support heavy ice loads [10]. For example, a mast with a mass of around 1000 kg can collect as much as 5000 kg of ice on the mast structure and guy wires in heavy icing conditions (Figure 4-1). Such ice loads can be critical to the mast, especially if the ice load is combined with high wind speeds. Additionally the lower ends of tower guy wires (where they are attached to anchors) need to be protected in severe icing climates, as ice build-up on the guy wires may slide down, damaging cable clamps or anchor rods.

Figure 4-1: A collapsed meteorological tower, likely due to heavy icing.

Before erecting a met mast in a region with ice, a calculation of the highest ice load and the highest wind load is recommended. For masts for long term installation the standard ISO 12494 states that a combination of the three (3) year maximum ice load with a fifty (50) year maximum wind speed should be used. For constructions that are designed to be short term in nature and if the site can be closely monitored, the maximum wind speed and ice loading can be reduced. This type of calculations will usually show that common wind measurement masts are not strong enough for locations with severe icing. This might increase the cost for non-permanent met masts significantly compared to locations in climates without icing.

Besides the challenges resulting from ice accretion, standard steel structures may become brittle in low temperatures. A tubular tower may fail, so caution should be applied when planning installations at low temperature sites.

Additionally, details like the quality and strength of all equipment, lightning rods, mounting booms, cable straps, wind vanes, and anemometers must be considered.

4.2 Measurement Sensors

4.2.1 Wind

Wind measurements in CCs can be challenging. Many factors can reduce their quality and availability. Anemometers may stop or slow down, wind vanes might stop, ice build-up on booms or lightning rods may affect the measurements (Figure 4-2).

In an icing environment, ice build-up on mounting booms, guy wires, lightning rods, tower, and other components should be expected. The dimensions of the iced structures and their influence on the measurements need to be considered.

As a rule, heated sensors are recommended at sites with potential icing. Various types of heated sensors such as shaft heated, fully heated, and heated ultrasonic are available. The fully heated sensors have varying amounts of heating power output that will dictate the conditions under which they will remain ice free. No sensor can stay ice free under all conditions. A shaft heated sensor should not be considered ice free, but is suitable to keep the bearing at constant temperature, improving readings in LTCs. If grid power is not available, an autonomous power supply is recommended (see Chapter 4.3).

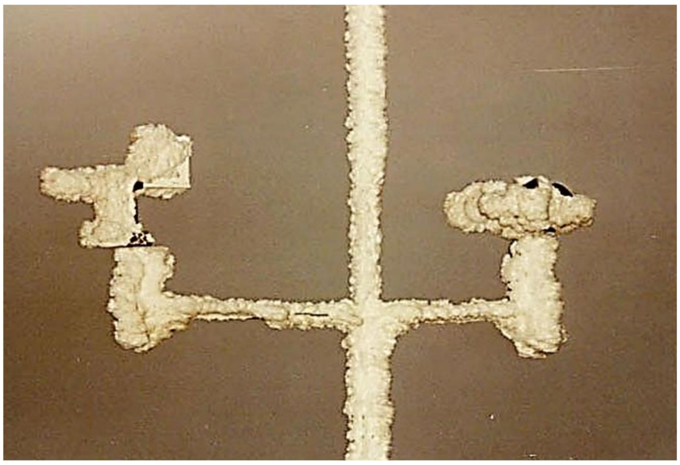

Figure 4-2 The impact of ice build-up on mounting hardware and sensors must be considered to ensure the accuracy of wind speed and direction measurements. Photo credit: Michael Durstewitz. Germanv.

Because most heated sensors have disadvantages like high mass or sensitivity to vertical wind, conventional cup anemometers that fulfil the IEC recommendations should also be used. A significant difference in measured average wind speed is a likely indication that the unheated sensor is being impacted by icing. Heated sensors may melt the snow and produce self-induced icing.

Another possible solution is to install a heated sensor where power is available and as close as possible to the site. This approach can be used if the winds at the two locations can be expected to be reasonable similar. The sensor can then be redundant to the unheated ones at the site. The relationship between the site and the heated sensor must be established during non-icing periods to allow the heated sensor to be used when the unheated sensor is not operating.

At sites where icing occurs less frequently, filtering techniques can be used to remove samples that are affected by icing. For example, a significantly lower standard deviation of the wind direction signal occurs when sensors are iced up. A filter that combines the standard deviation of wind direction and temperature will allow identification and removal of most periods when wind speed measurements are likely to be compromised by icing [11]. Because the icing process is slow, samples should be removed some hours before and after a suspected icing event to ensure data quality. This technique might not be appropriate for all climatic conditions.

The use of redundant and heated anemometers will not guarantee accurate wind resource data collection. Additionally, other parameters such as outside air temperature, ice accumulation and ice duration should be measured. This information will allow an accurate assessment of potential turbine availability due to conditions outside of the turbine’s normal operating regime. It also benefits the economic assessment of different mitigation options, such as cold weather packages and de- or anti-icing approaches (see Chapter 7).

The use of remote sensing techniques such as SODAR and LIDAR has been applied in CC. The advantage of these technologies is that they have no exposed moving parts although snow accumulation may hinder proper operation. A larger body of experience is available for the use of SODAR systems, however, extensive testing of both devices in climates exposed to moderate to severe icing have not been completed. Generally these devices should only be used to provide secondary site assessment until further research has been completed. For example, measurement campaigns in arctic conditions revealed that the low amount of aerosols in the air lowers data availability of the measurement significantly at high levels above the ground. More information and testing on these technologies will be undertaken over the next few years. The power supply for SODAR and LIDAR devices can often be a challenge when grid power is not available. These units are typically not designed for CC conditions and hence modifications to the housing, sensors, and instrument may be required.

4.2.2 Ice

It is important to assess the site specific characteristics of atmospheric icing in relation to wind power development, including the start, intensity, duration and frequency of icing, maximum ice load and type of ice as specified in Chapter 2.2. It is recommended that each of these parameters is measured or estimated based on other measurements. Measurement of site specific icing characteristics allows for an assessment of the potential production loss and the requirements for anti- or de-icing technologies.

Equipping the measurement mast with one properly heated and one unheated anemometer to estimate wind resource measurements is relatively inexpensive and highly recommended. This arrangement gives an overall picture of the icing climate restricted to instrumental icing. At a minimum it provides an initial assessment of ice class. When the approach above is combined with a camera system, meteorological icing, maximum ice load, type of ice and icing rate can also be assessed.

Ice detection may also be carried out using devices that specifically detect the existence of atmospheric icing. There are a number of instruments currently available although no single one can be used for all intended purposes. Only few, if any, of the ice sensors are well proven. For this reason many different approaches have been used to assess the icing environment, such as visibility sensors, ceilometers and dew point detectors. Acquiring information such as time series of cloud base height from the nearest airport and comparing that with the measured data is also advisable. At least for locations in flat terrain, these two methods are likely to give a fairly good assessment of the time that ice is likely to affect the operation of the wind turbines.

A dew point detector that has been designed for sub-zero temperature operation could also provide valuable information of high humidity as the frost point is a good indicator of in-cloud icing.

Some turbine manufacturers use the sensitivity of rotor blade profiles against change in contour and roughness and the resulting change in a WEC´s operating performance to detect ice build-up (interrelation of wind / rotational speed / power / blade angle). The Advantage of this approach is that ice formation can even be detected in a situation when ice detectors on the nacelle are not detecting ice because WEC´s with large rotor blades may dip into clouds and thus be affected by icing conditions. The main disadvantage is that ice cannot be detected during standstill of the rotor.

Recent research indicates that a once-per-revolution (1P) imbalance in torque, caused by a change in individual blade aerodynamics is typical even for lightly iced up wind turbine rotors. The occurrence of 1P variations in torque, and thereby electrical power, can be used as an early indication of icing.

4.2.3 Temperature

Radiation shields around temperature sensors need ventilation to work properly. The ventilation in conventional small shields with lids may become filled with ice or incased in snow, and provide false readings. The use of high power heating capability and/or large housings such as those used on meteorological stations may be necessary.

4.2.4 Atmospheric pressure

Measuring pressure in an icing environment is similar to measuring pressure at a conventional site. Care should be taken to ensure that the pressure sensor is being exposed to the surrounding atmospheric pressure since, if the air intakes are obstructed by ice, a false reading may occur.

4.3 Site power supply

Monitoring systems implemented in arctic and icing climates need additional power for the use of heated sensors and other equipment, which may greatly expand installation requirements and cost.

Power for heated sensors can often be a challenge when grid power is not available. Depending on the type of sensor up to 250 W (for a heated Ultrasonic) may be required to keep the sensor ice-free.

Small wind turbines, photovoltaics, diesel engines, fuel cells and hybrid power systems are options. Remote monitoring should be implemented to allow early warning of power system problems. The design and implementation of remote power systems are non-trivial tasks. Additionally organizations that are well acquainted with remote power systems in harsh environments should be employed.

Figure 4-3 Accessing power system in a remote location. The whole 2.5-meter high container apart from the air inlet to the engine has been buried. Photo credit: Lars Tallhaug, Norway

4.4 Setup and Operation & Maintenance of measurements

4.4.1 Installation

Meteorological monitoring installations should be set up during warm weather for improved safety and to increase the quality of measurements. Winter installation is possible, but should be generally discouraged (Figure 4-4). Ground conditions, such as permafrost or seasonal changes in soil conditions must also be considered

Figure 4-4 Winter meteorological tower installation in Alaska. Photo: Doug Vought, USA

4.4.2 Accessibility and site communication

Site communication at remote CC sites can be challenging. Since conditions are likely be quite harsh, redundant measurements and expanded data logging capability to ensure a high percentage of data capture are also recommended. Limited site accessibility also justifies extended data retention and multiple sensors for high-priority signals such as wind speed and temperature. Since a great effort and expense is going to be required for any CC measurement program, the small incremental cost to improve reliability is quite appropriate. Measurement data should be checked regularly, as the quality of data depends on the reliability of subsystems and ultimately how well supervision can be arranged. Covers and locks for the equipment should be selected so that they can be used with winter gloves and are not likely to be impacted by ice and snow.

4.5 Checklist of key issues for site measurements

Checklist of key issues

- Measurement mast designed for the local wind and ice conditions.
- Remote sensing can be considered viable for CC conditions.
- Strong and good quality equipment and materials are being used.
- At least minimum level of ice measurements being conducted.
- Sufficient data filtering to remove ice influenced data.
- Year round measurement site accessibility ensured.
- Power supply ensured for wintertime.
- Robust and tested remote communication and data transfer in place.
- Devices should be designed and installed to allow service during cold and inclement weather.

5. TECHNOLOGY FOR COLD CLIMATE WIND ENERGY

5.1 Recommendations for selecting technologies and wind turbines for cold climate

Low temperatures and atmospheric icing cause additional challenges for wind turbines compared to conditions at standard sites. Thus, special technologies are recommended for cold climate (CC) sites; materials shall withstand low temperatures, the control system and procedures need to be adapted for low temperature operation and rotor blades might need anti- or de-icing systems if the site so requires. Figure 5-1 illustrates when CC adaptations for wind turbines may be needed.

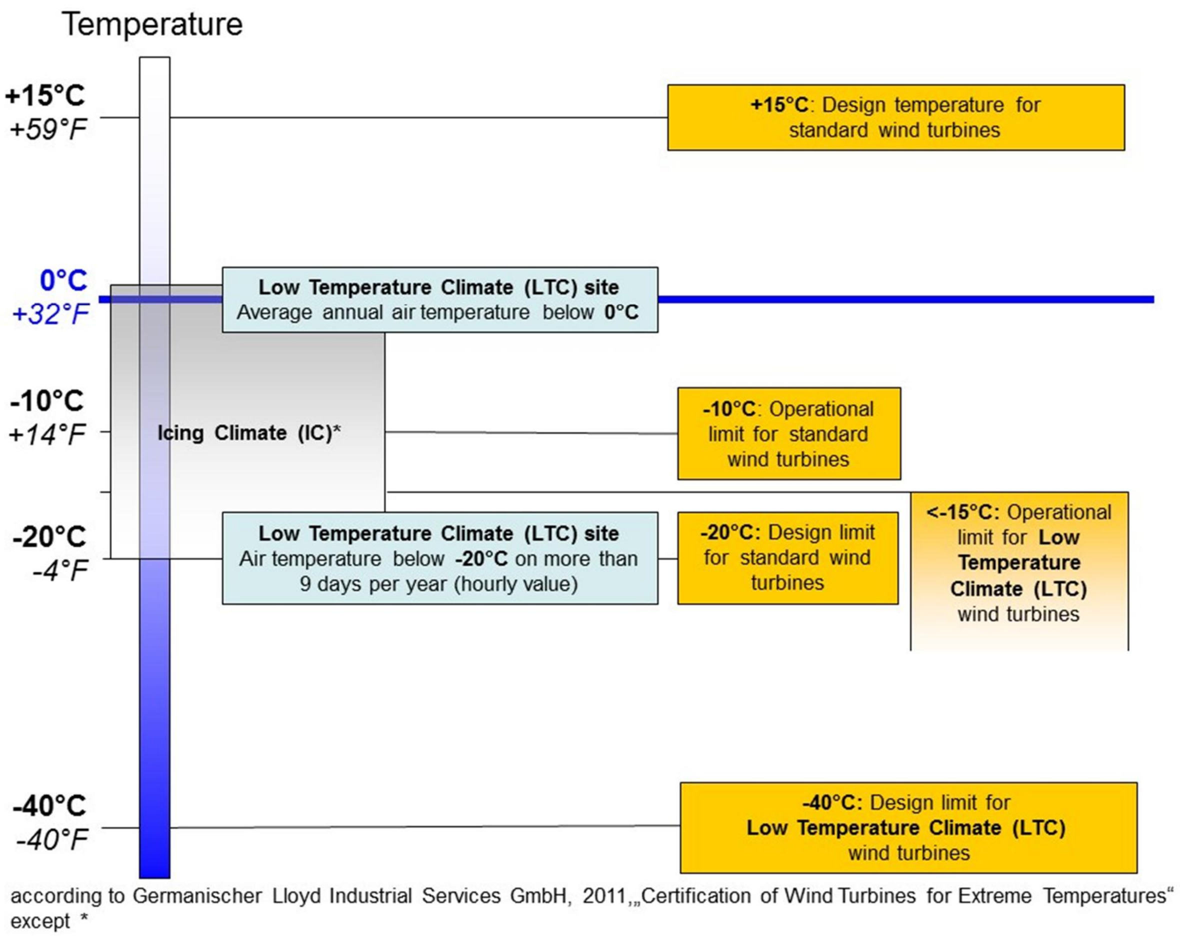

Figure 5-1 Low Temperature Climate and Icing Climate with respect to ambient temperature and wind turbine design.

In order to decide if a site is an LTC site or not, IEA recommends using the GL definition which is described in Table 5-1. The values for standard turbines are according to GL, and the modified wind turbines are examples from turbines on the market today (2011). It is up to the manufacturer to choose the limits for the modified turbines. IEC 60721-3-3 standard defines the limits, related to climatic conditions, for electrical equipment such as transformers and switch gears needed in wind farms.

Table 5-1 Typical and recommended temperature limits for wind turbines.

Limits	for standard turbines GL(1 [Ref]	typical for LTC(2 turbines
Operational temperature limits	-10 ºC	-30 ºC
Survival temperature (stand still)	-20 ºC	-40 ºC

1) GL: Germanischer Lloyd

2) LTC stands for Low Temperature Climate turbines i.e. turbines with low temperature modifications provided by the turbine suppliers.

Wind turbines with technologies adapted for operating in low temperatures and/or icing conditions typically cost more compared to standard wind turbines. Depending on the climatic site conditions and requirements of local authorities these extra investments may be mandatory to improve the energy yields, safety, lower maintenance costs, or simply a prerequisite for permits.

It is recommended to: Use wind turbines designed for low temperatures if the annual average temperatures is below 0°C or below -20°C for more than nine days a year (the nine-days criteria is fulfilled, if the temperature at the site remains below -20°C for one hour or more on the respective days). Criteria for low temperatures according to Germanischer Lloyd, [15]

5.2 Technologies for low temperatures: low temperature package for wind turbines

Wind turbine manufacturers offer readily available and reasonably priced options for low temperatures, typically denoted as Cold Climate Packages (CCPs). The following modifications and items are typically included in a low temperature package offered, although this varies depending on the turbine manufacturer:

- Materials and components adapted for low temperature applications such as low temperatures alloys, special elastomers instead of standard rubber, and CC control systems.
- All welding procedures competed with special low temperature flux
- Lubricants (grease and oils) and hydraulic fluids suitable for low temperature.
- Heaters for components and lubricants e.g. for generator, gear box, yaw systems, and control boxes.
- Cooling system suitable for low temperature operation to avoid icing of condensers or other systems.
- Control system designed with low temperature features such as cold start after grid failure with preheating of components and subsystems, etc.
- Appropriate measurement systems including heated sensors. .
- Nacelle heating to allow a reasonably safe and comfortable working environment for turbine maintenance.

Although not typically included, it is recommended that the measurement system support structures are also heated. Above all it is important to determine the level of experience the manufacturers have in turbine installation and operation in low temperatures and/or icing conditions. Additionally, it is recommended to negotiate icing as a factor in the turbine availability guarantee and to consider anti- and de-icing technologies

Atmospheric and precipitation icing cause ice accretion on rotor blades, which leads to reduced aerodynamic performance of the rotor blades and reduced energy production, possibly increased fatigue loads, and an increased risk of ice throw. These adverse effects can be reduced by means of anti- or de-icing systems. Such systems exist, although the industry is yet to mature- Currently there are many different technologies under development. The most promising are based on heating the blade surfaces actively, normally only on the leading edge, either by hot air circulation inside the blades or electro thermal heating foils on the blade surface.

The recommendation is to use anti- or de-icing systems for improved energy production, safety, and reducing fatigue loads if economical calculations show the benefits or local regulations require. Table 10-1 presented later can be used as a guideline whether anti- or de-icing systems are needed, but the need for anti- or de-icing systems is always case and site sensitive, especially for IEA Ice classes 1 and 2.

5.3 Foundations

Permafrost soil adds another element to the wind energy development in CC sites. It is recommended to analyse the soil and if permafrost exist take actions to mitigate the effects of permafrost.

Installing a wind turbine foundation in permafrost may require substantial changes in its design; freeze-back pylons (see Figure 5-2), rock anchors, or other proven construction techniques may be necessary.

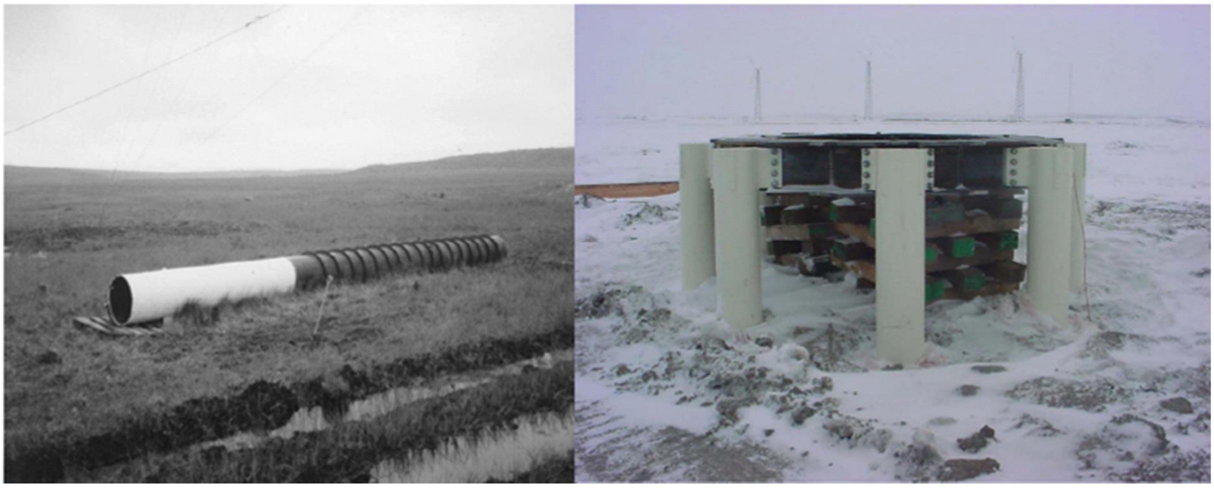

Figure 5-2 Freeze-back pylons used for turbine (and other) foundations in permafrost areas. Photo credit, Northern Power Systems, USA

5.3.1 Grid connection

Generally permafrost or solid rock limits the use of buried cable, both because of the expense of trenching and the dynamic behaviour of the permafrost soil which can rupture conduits and damage cables. An overhead cable can be damaged by the ice, or the effects of permafrost freezing cycles on power poles. Instead, a cable can usually be laid on the ground affixed to concrete blocks or other ground ties and protected by simple wooden structures or steel conduits. In such case, armoured cable is needed to protect against animals or other mechanical hazards.

5.4 Turbine certification

Current national and international standards (for example IEC standards) for wind turbines do not typically address low temperature and icing conditions. A typical statement is that operation outside of “normal” conditions can impact performance and maintenance contracts. This makes it difficult to find turbines which have certification for low temperatures and/or icing conditions. Wolff [12] and Ganander [13] discuss icing impacts in current and proposed standards in greater detail.

Germanischer Lloyd has developed certification criteria for turbines operating in low temperatures, [14,15]. The low temperatures influence the loads, safety, sensors, materials and operation. Because the scope of the GL certification is in low temperatures, icing is not dealt with; the certification simply requires an ice detection equipment or procedure and a shutdown of the turbine during instrumental icing event. This procedure may not be applicable, or desired, for turbines operating at sites with frequent meteorological icing, especially at site class 3 or higher, because here, icing significantly affects the energy production.

5.5 Checklist of key issues for cold climate technology

Checklist of key issues

- Site temperature and wind speed distribution are needed to determine if the site requires low temperature adaptations
- Ice maps and results of site ice measurements are needed to determine if anti- or de-icing systems should be applied for energy production reasons
- Review of local regulations and icing conditions are needed to see if anti- de-icing is required for permitting purposes
- Experience of turbine supplier and technology track record in cold climate conditions should be considered
- Contents of the turbine suppliers Cold Climate Package should be considered
- Possibility to negotiate icing to be included in the availability/production guarantee is recommended
- Special foundations may be required.
- Construction in cold climates (LT and icing) might take relatively/considerably longer compared to in standard climates.
- Use covers instead of applying salt for de-icing of components to be installed. Salt will cause corrosion of metal parts if not carefully washed away.

6. OPERATION AND MAINTENANCE

6.1 Operation and maintenance

At cold climate (CC) sites, low temperature and icing of wind turbines make the operation and maintenance of turbines more demanding compared to standard sites.

It is recommended to pay extra attention to the contract negotiation when buying turbines to be installed at CC. When negotiating the availability guarantee, icing is, ideally, to be included. The exact site conditions and turbine specifications should be undertaken in consultation with the wind turbine manufactures and project engineers.

Operation of turbines needs to be adapted to low temperatures, including cold starts, heated sensors, heating and cooling configurations. Normally these issues are taken into account if the turbine is equipped with a low temperature package, but the level of low temperature adaption varies with the turbine supplier.

Icing affects the turbine operation by decreasing the production and by increasing vibrations, noise and the risk of ice throw. Icing also affects the nacelle wind speed measurements. The direct influence of icing on operation, unless equipped with anti- or de-icing system and heated wind sensors, will be an increased number of “lower than expected power” stops, stops due to high vibration amplitude, and stops due to faulty wind measurements. Also the available anti- and de-icing systems and heated sensors don’t always guarantee the 100 % fault free operation in icing conditions. The indirect consequences of icing on operation might be a reduced technical life, bodily injuries and material damages caused by falling ice and an increased noise level-.

Local rules and regulations have to be considered; a wind turbine with iced blades may not be operated in certain regions and in some countries. In many countries, icing or vibration alarms cannot legally be reset without a visual observation of the conditions of the rotor blades. Communication including remote sensing, web based or direct video cameras and other relevant sensors could in some areas be used to enable a legal remote restart procedure of the turbine. Adequate warning signs and marked safety zones may allow turbine operation in icing conditions in some countries. (read more in Chapter 8).

The operator or owner of a WT should learn the operational behaviour of his/her turbine in low temperature and icing conditions by studying the turbine owner’s manual. Operators should follow-up the turbine behaviour and all abnormal situations should be investigated so that the life-time of turbine is not lowered by faulty operation.

To help the operation and maintenance in CC, a SCADA system (*Supervisory Control and Data Acquisition*) can be fitted with ice detection, condition monitoring (both working condition and turbine condition) purposes. Important information is, for example; ambient temperature, visibility at the site, web camera photos of rotor blades, turbine wind sensors and met mast. An assessment of the local conditions will likely indicate which specific level of monitoring and remote communication is most appropriate. However, erring on the conservative side will pay off greatly over the lifetime of the project.

Maintenance of turbines should preferably be scheduled to avoid harsh conditions (read more about working conditions in Chapter 8).

6.2 Accessibility

Icing and snow drifts can make vehicle access to CC sites difficult or impossible without snowmobiles or other over snow transport. Also the possibility of swampy conditions or flooding during the spring and summer time has to be accounted for. Typical snow depths, flood frequencies and high stream levels caused by snow melt and soil type must also be studied to design adequate road surfaces, culverts, fords, bridges, and road marking poles that will keep the site accessible and road visible.

Logistics of turbine installation must be planned according to seasonal conditions. Seasonal limitations on accessibility may cause project construction to be implemented over more than one season.

Adverse conditions may prevent evacuation for medical or work related emergencies, so contingency planning for such occurrences must be undertaken early in the implementation process.

Site accessibility may impact the overall economics of a project. It must therefore be carefully analysed in the early stages.

6.3 Checklist of key issues regarding operation and maintenance

Checklist of key issues

- Check if low temperature operation of turbine is permitted by the manufacturer
- Check if turbine operation during icing is permitted.
- Check if maintenance scheduling addresses the harsh conditions
- Consider wintertime siteaccess limitations.
- Consider additional monitoring systems such as webcams etc.

7. ENERGY YIELD CALCULATIONS

7.1 Low temperature effects

Temperatures below the operational limit of the wind turbine will prevent it from operating and thus impact turbine availability. The effect of extreme low temperatures on energy production may be estimated with

$$E_T = EO(1 - \int_{-\infty}^{T} f(t)dt)$$

where E_T is energy output in low temperature, *EO* Energy output, *T* low temperature limit of the turbine and *f(t)* the probability density function of air temperature.

A normal distribution may be assumed if no defined function is available for the temperature function. In calculating energy output, one should notice the correlation between wind speed and temperature. In many areas very low temperatures are tied to high-pressure systems during which winds are often weak. Based on measurement data incorporating wind speed and temperature, an analysis should be conducted to calculate the loss of energy production when temperatures are below the specific threshold as defined by the turbine manufacturer. A statistical analysis can be conducted based on long term diurnal and seasonal temperatures and wind speed profiles, allowing a generally accurate assessment of power production losses due to low temperatures.

There is clearly some potential overlap with downtime expected due to icing. However, simultaneous periods with extremely low temperatures and active icing events are rare.

7.2 Ice effects

Ice build-up on the blades usually reduces lift and increases drag, which results in reduced power output and eventually turbine shutdown.

Atmospheric icing reduces the aerodynamic performance of a wind turbine rotor significantly, as the blade aerodynamics is sensitive to extra surface roughness and shape alterations caused by ice [16] (Figure 7-1). The most important parameters for estimating ice induced energy production losses are intensity, duration and frequency of icing, maximum ice load and type of ice with respect to the wind conditions. It is necessary to know how these parameters correlate as a function of time. Annual standard deviation of ice induced production losses should be considered as, when combined with standard deviation of wind speed, may result in higher inter annual power production variability. This adds additional complexity to calculation of short term production uncertainty (P75, P90, etc.) Other issues that need to be addressed are the anti- and de-icing systems, the configuration of turbine control systems under icing conditions and local regulations.

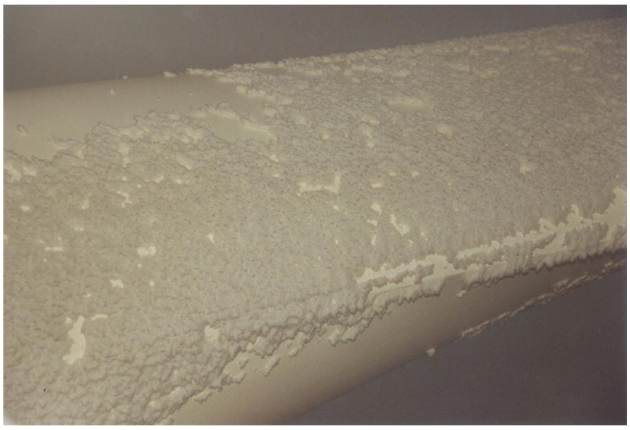

Figure 7-1 Additional roughness on a WT caused by rime ice. The turbine didn't work for a while despite adequate wind. Photo: Michael Durstewitz, Germany.

Significant decrease in production with stall-regulated wind turbines is to be expected, even after short icing periods. This impact is less severe with pitch regulated wind turbines, specifically in light icing conditions (Figure 7-2).

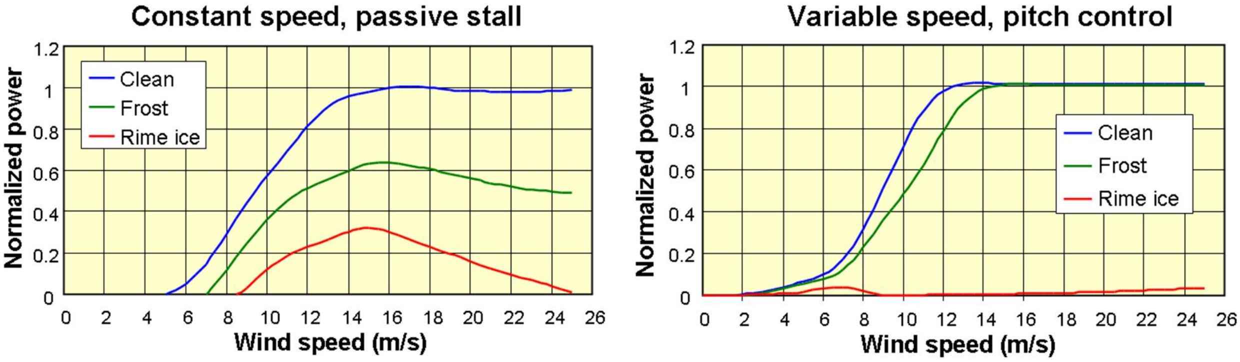

Figure 7-2: The impact of wind turbine control on the power curves of passive stall and active pitch regulated wind turbines in different icing conditions. Graph source: VTT Finland

Regardless the uncertainty in estimating the aerodynamic properties of an iced up blade, it is recommended that time-series of wind, ice accumulation and temperature are produced. The time-series of ice accumulation can be obtained from a mesoscale model or measurements. The wind series can be obtained from measurements. With the concurrent wind and icing data, different cases can be analysed. Examples of these are

1. No production during meteorological and instrumental icing
2. No production during meteorological icing followed by the de-icing procedure
3. Reduced production during meteorological and instrumental icing

In examples 1 and 2, it should be noted that regulatory requirements may increase the production losses, as turbine inspections may be required before restart. In example 3, the production losses are defined based on turbine specific ice impacted power performance curves, as illustrated in Figure 7-3.

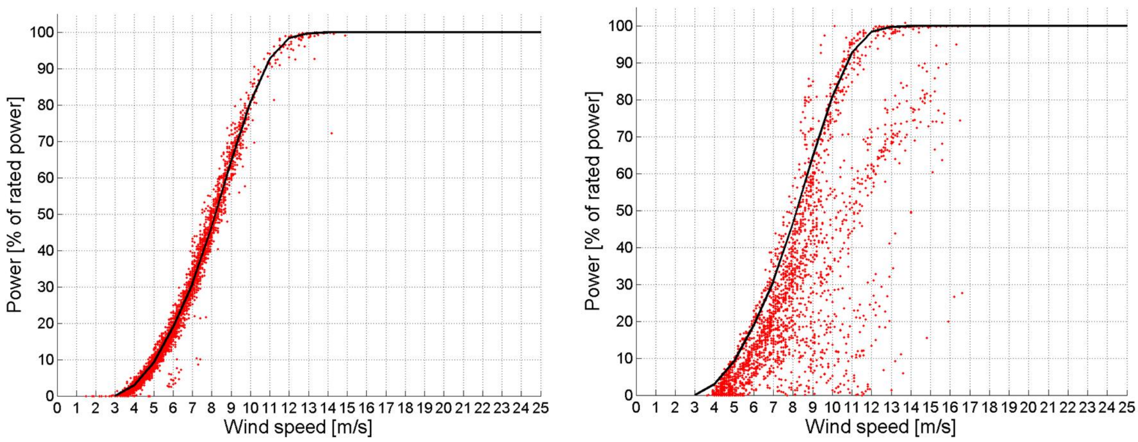

Figure 7-3 Power (% of rated power) as a function of wind speed in two cases. On the left: A power curve registered in May 2010. On the right: An ice-impacted power curve registered in November 2009.

Typical levels of production losses to be expected in different icing climates have been presented in Table 3-1. However, these should not be used over site specific assessments of potential ice driven reduced energy production.

7.3 Checklist of key issues regarding energy yield calculations

Checklist of key issues

- An assessment of AEP impacts due to CC should be undertaken
- Lower turbine availability/production should be assumed due to the effects of CC, such as lower measurement data availability should be incorporated in AEP calculations
- Additional uncertainties incorporated in AEP calculations due to low temperature and ice induced production losses

8. HEALTH, SAFETY AND ENVIRONMENT

8.1 Public safety

Iced up WT blades and towers can pose a safety risk for wind farm visitors and staff. See Figure 8-1 for an example. The fact that no serious accidents caused by ice throw have been reported is no reason to think otherwise. Special technical solutions may have to be implemented to prevent accidents on CC sites accessible to the public.

Figure 8-1: Ice falling or being thrown off a wind turbine poses a safety threat to turbine maintenance staff and, depending on turbine siting, the general public. Photo credit: Jeroen Van Dam, USA

Turbine operation with iced up blades may not be permitted in certain countries or permitted only in the case of rime ice, as glaze ice is considered more dangerous. However, rime ice can be almost as dense as glaze ice, so there is no obvious reason to treat the cases differently. As visibility can be extremely poor under active icing conditions, warning signs should be closely spaced unless the area is accessible only via specific posted entry points.

The areas of potential ice throw should be calculated and the proximity of developed areas, roads, and tourist infrastructure such as, for example, ski slopes, lifts, footpaths and parking areas must be taken into account when placing the turbines.

Signs that warn of falling ice, visual warnings after icing events and horns or other active attention devices implemented before turbine start-up should be incorporated to help ensure public safety, Figure 8-2.

Figure 8-2 Warning signs for falling ice. Photo credit Lars Tallhaug, Norway.

Simple formulas for calculating the zone of likely ice throw is presented in [17]. For an operating turbine the following has been suggested for ice throw:

$$d = 1.5(D + H) \tag{8-1}$$

and for a turbine still standing:

$$d = v\frac{(D/2 + H)}{15}, \tag{8-2}$$

where

d = maximum falling distance of ice (in m)

D = rotor diameter (in m)

H = hub height (in m)

v = wind speed at hub height (in m/s)

Seifert et al. [18] suggest that the formulas should be used only as a rough estimate and recommend more detailed calculations, including risk assessment. (Described more in detail in Chapter 8.3)

In many cases the area around the turbine will be accessible to the public either intentionally or because fencing is buried under snow. Warning signs and assistance to visitors who could possibly be injured while touring the turbines should be accounted for. General alarm and security measures need to be incorporated into the project design. Insurance coverage should be planned, and the necessary analyses done to estimate visitor frequency and plan mitigation measures. In order to address the issues above in a formal manner, an assessment of mitigation options should be carried out to limit the risks associated with wind farm deployment at specific sites.

8.2 Labour safety

Working in cold conditions poses particular challenges in terms of labor safety. Outdoor activities should generally be avoided when temperatures are very low. Humans' capability to focus on safety and problem solving quickly decreases in adverse conditions, such as low temperatures, high winds, and during precipitation. Thus, apart from being more costly by requiring extra time and equipment, low temperatures may pose significant safety hazards. Already limited exposure to extremely cold conditions can lead to frostbite and other injuries.

Figure 8-3 Work in extreme and cold climates requires special equipment, increased focus on personnel safety and expanded planning. Photo credit: Lars Tallhaug, Norway

Heated accommodations, proper clothing, proper training, shelter, survival equipment and machine design to allow service and maintenance during extremely cold or adverse weather should be implemented. Extended ice and snow storms deteriorate access roads and can isolate construction sites. Emergency response and evacuation procedures need to be implemented and tested on a regular interval.

Routine maintenance visits should be scheduled during periods of best accessibility, but if they must be made during more unstable climatic conditions, the time to carry out the service is likely to be longer. Special vehicles such as snow mobiles, snow cats and bulldozers may be required.

8.3 Planning for H&S by assessing the risk of ice throw

The risk of injuries caused by falling ice from high buildings, masts and towers should always be treated seriously. The area in which ice throw may be expected to occur is denoted "Danger zone". There is, by definition, a risk of injury and property damage within the danger zone. The danger zones for ice throw (in operation) and ice fall (at stand still) can be estimated and limited by formulas 8-1 and 8-2 in Chapter 8.1. For a wind turbine with a 100 m diameter rotor and a 100 m tall tower, a safe distance is 300 m, considering ice throw, and 70 m for ice fall assuming hub height wind speed 7 m/s. Ice throw from a WT blade typically occurs downstream of the rotor plane.

Ice in general and clear ice in particular, can be very difficult to see on a WT blade from the ground. Ice can also fall from places that are not visible from the ground, such as from the nacelle and the blade roots. A dangerously thick layer of clear ice can form on top of the nacelle if heat from the nacelle is allowed to melt accumulated snow. Ice sublimates or falls off tall structures and it seldom melts completely.

The danger zone is to be clearly marked in the terrain by means of reasonably located and designed warning signs. Warnings signs indicating the danger zone might, however, not be sufficient as the only means of risk mitigation for ice throw if a more detailed site specific risk analysis is required by authorities.

A risk analysis of ice throw can be presented as iso-IR (individual risk) lines. IR is defined as the risk per m^2 and year to be hit by an object of significant size. The IR should be calculated for the winter season only. Iso-IR lines are to be drawn for 10^{-4}, 10^{-5} and 10^{-6} and must take into account the actual wind direction and wind speed frequency distributions during icing situations as well as the prevailing wind directions when the temperature tend to rise towards zero degrees. Currently there is no commercial planning tool available for the risk assessment of ice throw or ice fall.

Flashing lights at the park entrances during periods with risk of ice throw are an option. Installing a properly designed de-icing system on a WT may reduce the risk of ice throw and make the danger zone significantly smaller.

8.4 Cold climate specific environmental considerations

Chemicals – Manufacturers are installing their WT at standard sites during winter conditions. Liquid salt solutions have been used on the ground to keep components to be installed free of ice. Metal surfaces exposed to salt might corrode. It is important to obtain approval from the local authorities to use such mixtures and to remove all traces of salt before installing the components.

Noise – Iced up WT blades will cause additional noise, which may violate the original assumptions made in the building- and environmental permit. The use of de- or anti-icing systems may be the only option to stop the operation if neighbours are affected in a non-acceptable way.

8.5 Checklist of key issues regarding HSE

Checklist of key issues

- Address the risk assessment procedures as required by local authorities
- Calculate ice throw and ice fall risk zones
- Install warning signs
- Address labour and public safety issues with respect to CC
- Consider site access and possible emergency shelters

9. PROJECT ECONOMY

Independent of the climate, a multitude of economic risks is associated with utilising wind power. Operating in arctic and arctic-like climates adds costs and performance variability that must be assessed when a wind turbine site or project is considered. When siting a new wind power plant, understanding the potential loss of availability and production is crucial to determining if the project is economically feasible and what mitigation measures might be cost effective. This section provides a framework for assessing the economic risks related to operating turbines in CC.

9.1 Estimating financial losses due to climate conditions

Financial losses result from a combination of several issues: assumed risk increase due to CC, lost energy production because of ice build-up, low temperatures and the costs of more demanding maintenance. If the site is remote, malfunctions that require site visits may extend the downtime. Financial losses should be estimated so that the effects of ice and low temperature on energy production are taken into account as described in Chapter 7. It should be noted, however, that both low temperatures and icing events may occur simultaneously. Care should be taken to insure that downtime for both low temperatures and icing are not double-counted from a turbine availability point of view.

Examples of CC-specific economic risks are listed below:

- Increased initial costs of the turbine project because of limited installation schedules and higher equipment and installation costs. Due to a short construction season, foundations might for example have to be installed one season before the turbines are erected.
- Increased downtime or power reduction caused by icing events over seasons or even in relation to forecasted spot markets if a storm results in an un-expected icing event.
- Turbine downtime and liability because of concerns for public safety from turbine blades and tower ice throw.
- Long exposure of rime ice, which may increase fatigue loading and cause premature failures.
- Increased downtime caused by extreme low temperatures in combination with any potential increase in power from higher air density in passive stall controlled wind turbines.
- Increased maintenance costs because of low temperatures and the likely higher average downtime between repairs because of turbine inaccessibility.

Calculated estimates for financial losses due to CC should be assessed and weighed against the additional cost that derives from applying some counter measures. An example of mitigation measures is cold climate packages available from some turbine vendors. The energy consumption of adapted technology should also be included in the calculations according to the best information from the manufacturer. Shortcoming of availability caused by remote site location and accessibility should be determined during the project planning phase. It is clear that the economic uncertainty associated with CC projects is higher than at conventional sites. Increased uncertainty lowers the 75 % and 90 % production probability of the wind power project (typically referred to as P75 and P90). There are no specific guidelines for assessing the economic impacts and risks associated with projects in extreme and arctic climates. It is expected, however, that this understanding will increase as more projects are developed and implemented. It is certainly important to pay attention to the recommended practices when designing a project.

As discussed above, applying wind energy in cold and adverse climates requires special consideration of many factors. Although these considerations affect the project design and system economics, the potentially higher costs can be more than offset by the increased energy production available at high altitudes, in coastal areas and in the high latitudes where these conditions persist. That is, the additional complications of harnessing wind energy within a CC must be weighed against the positive impacts of developing these projects. High wind potential, the availability of land for project installation and the need for clean and renewable energy all lead to a market that will increasingly favour wind projects in CC areas.

9.2 Summary of key issues regarding project economy

Summary of key issues

- Higher project development costs at CC sites
- Thorough assessment of the effect of low temperatures and icing on energy production
- Assessment of CC induced uncertainty in energy production
- Assessment and quantification of CC related technology risk
- Additional maintenance costs have been properly addressed
- Mitigation of CC related technological and O&M risks during contracting.
- Address the increased overall uncertainty of CC projects
- Conservative financial analysis

10. SUMMARY AND PROJECT CHECKLIST

Various issues need to be considered in a typical cold climate (CC) wind power project. Many of them are not necessary when it comes to a wind power project developed and constructed in a mild standard climate. A summary of recommendations for each IEA Ice class is presented in Table 10-1. This chapter also provides a simple check list (

Table 10-2) that can be used for a quick check, if certain CC specific and crucial issues have been considered along the project development.

Table 10-1 IEA Ice Classification with recommendations

<table>
<tr><th>IEA Ice class</th><th>Met. icing</th><th>Instrumental icing</th><th>Production loss</th><th colspan="4">Recommendations</th></tr>
<tr><th></th><th>% of year</th><th>% of year</th><th>% of annual production</th><th>Site measurements</th><th>Anti-/De-icing</th><th>Why counter-measures?</th><th>Energy calculations</th></tr>
<tr><td>5</td><td>>10</td><td>>20</td><td>> 20</td><td rowspan="4">Fully heated instruments recommeded</td><td rowspan="3">Recommended</td><td rowspan="4">For safety, energy production gain and reducing fatigue loads</td><td rowspan="4">Calculate production loss scenarios based on site specific data</td></tr>
<tr><td>4</td><td>5-10</td><td>10-30</td><td>10-25</td></tr>
<tr><td>3</td><td>3-5</td><td>6-15</td><td>3-12</td></tr>
<tr><td>2</td><td>0.5-3</td><td>1-9</td><td>0.5-5</td><td>Should be considered</td></tr>
<tr><td>1</td><td>0-0.5</td><td><1.5</td><td>0 - 0.5</td><td>Heated instruments recommended, but not absolutely necessary</td><td>not needed for energy production purposes</td><td>Typically not needed for energy production reasons</td><td>Add at minimum 1-2 % uncertainty</td></tr>
</table>

Table 10-2 Project checklist

	Considered/Applied [Yes/No]		Comments
	Yes	No	
A. SITE CONSIDERATIONS			
Low temperatures (< -20) do exist	X		
Atmospheric icing occurs annually	X		
Ice maps addressed	X		
Clear understanding on site conditions	X		
…			
B. PROJECT DEVELOPMENT PHASE			
CC compatible measurement system deployed to the site	X		
Icing measurements included	X		Both meteorological and instrumental
Heated wind sensors applied in measurement system	X		
Ice throw issue addressed and risk zones calculated	X		If not, is an issue regarding permitting?
Icing and low temperature addressed during the Energy yield calculations	X		
Anti-icing / De icing system considered	X		
Limited site accessibility due to low temperature, snow and ice considered in cost estimates	X		
CC turbines selected for the project	X		
…			
C. CONSTRUCTION AND OPERATIONAL PHASE			
CC considered in HSE procedures	X		
Ice detectors/detecting methods in use during winter operation	X		
Ice fall zones marked with warning signs	X		
…			

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