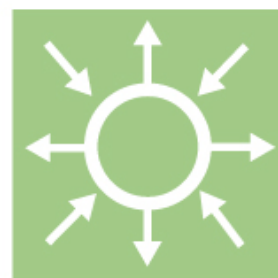


Influence of Icing on the Power Performance of Seven NM82-1.5 MW Wind Turbines in Aapua

Elforsk rapport 09:59



Göran Ronsten

June 2009

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Preface

Iced up wind turbine blades poses a significant challenge to wind turbine manufacturers as well as wind farm developers and owners in affected cold climate regions around the world. The main reasons for the concerns are: a) personal safety, b) loss of production and c) influence on the expected life of components.

In affected areas, icing may have a direct impact on power performance, energy production and ultimately, the economy of a wind turbine/farm project. As of today, countermeasures for medium and severe icing conditions, i.e. anti- or de-icing technologies, are not readily available from any wind turbine manufacturer.

This report constitutes one of the Swedish contributions to IEA RD&D Wind, Task 19 – Wind Energy in Cold Climates. Work within Task 19 has been carried out during 2002-2004 and 2006-2008. During the last three year period, Sweden participated in the cooperation during the last year, 2008. The interest for cold climate locations in Sweden has re-emerged as offshore wind farms currently are more expensive to build and maintain compared to ditto onshore.

The work was carried out by Göran Ronsten at WindREN AB, as a part of the Swedish wind energy research programme "Vindforsk - II". The report is the one report for project V 158. The research programme is funded by ABB, the Norwegian based EBL-Kompetense, E.ON Sverige AB, Falkenberg Energi AB, Göteborg Energi, Jämtkraft AB, Karlstad Energi AB, Luleå Energi AB, Lunds Energi AB, Skellefteå Kraft AB, Svenska Kraftnät, Swedish Energy Agency, Tekniska Verken i Linköping AB, Umeå Energi AB, Varberg Energi, Vattenfall AB and Öresundskraft AB.

Comments on the work and the final report have been given by a reference group with the following members: Fredrik Öhrvall Skellefteå Kraft, Sven-Erik Thor and Roy Lilljeberg Vattenfall Vindkraft AB and Anders Björck Elforsk AB

Stockholm June 2009

Anders Björck

Electricity and Power Production

Sammanfattning

Vindkraftsparken på Etu-Aapua i Övertorneå kommun togs i drift i september 2005. Det är väl känt att nedisning har påverkat produktionen. Storleken på denna inverkan har dock inte tidigare undersökts.

De vintertida energiproduktionsförlusterna, vilka till stor del kan hänföras till nedisning, har i denna rapport befunnits vara betydligt större än de sommartida. Vad som är än mer oroande är den vintertida minskningen i tillgänglighet över åren och ökningen av förluster som kan antas orsakas av nedisning.

Den genomsnittliga förlusten, 205 turbindagar med manuella stopp samt tillfällena när mätdata saknas undantagna, är mer än fyra gånger högre vintertid jämfört med sommartid. Den genomsnittliga energiproduktionsförlusten, baserad på verklig production, var 27,9% vintertid ($t < +2C$) och 6.6% sommartid ($t > +2C$).

Den valda metoden går ut på att jämföra den verkliga produktionen med den nominella (ett börvärde) för att avgöra om ett vindkraftverk är påverkat av kallt klimat-relaterade förhållanden. Det antas här att nedisning, och inte vakeffekter, står för en signifikant ökning av energiproduktionsförlusterna.

Mätdata saknas för inledningarna av såväl nedisningssäsongen 2006/2007 som 2007/2008. Data från dessa perioder har inte återskapats och saknas därför i studien. Den under vintertid ökande spridningen hos effekt som funktion av vindhastighet är uppenbar och signifikant.

De mest frekventa felkoderna presenteras liksom vind-effektsambanden för samtliga 7 vindkraftverk i Aapuparken.

Produktionsförluster orsakade av nedisning kan minskas m.hj.a. avisningssystem. Den f.n. enda svenska parken med avisningssystem består av 5 st E-70 i Långå. Det varmluftsbaseade avisningssystemet förefaller kunna minska energiproduktionsförlusterna för lättare nedisningsförhållanden.

Nästa mål, för att kunna verifiera fynden i denna rapport, blir att installera ett avisningssystem på Aapua 7.

Summary

The wind farm on Etu-Aapua, a hilltop in the Municipality of Övertorneå, was put into regular operation in Sep 2005. It is well known that icing has affected the power performance. The magnitude of this effect has not been investigated previously.

The energy production losses during the winter seasons have been found to be significantly higher compared to those during the summers. What is more alarming is the increase in downtime during the winters over the years due to a lower availability and a reduced energy production.

The average energy production losses, not including manual stops during 205 turbine days, are more than four times higher in the wintertime compared to those in the summertime. The average energy production loss, based on actual production, was 27.9% in the wintertime ($t < +2C$) and 6.6% in the summertime ($t > +2C$).

The method chosen, i.e. comparing the actual power for both summers and winters with the nominal power in each wind speed bin, enables the determination of when the power output is affected by low temperature related conditions. It is, based on a comparison of data from the summer time, assumed that icing, and not wakes, is causing this significant increase in losses.

Data for all turbines are missing during the start of the icing seasons in 2006 and 2007. Data from missing periods are not included in the evaluation. The most recent and frequent error codes are presented as are the power performances for each turbine during winters and summers. The increased spread in power performance data during the winters is obvious and significant.

The losses caused by iced-up wind turbine blades can be decreased by the use of de- or anti-icing systems. The hot air based de-icing systems on five E-70's in Långå are found likely to be effective countermeasures in light icing conditions.

Consequently, the next step will be to install an anti-icing system on Aapua 7 to verify the findings in this report.

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Definitions

Anti-icing	The ice is prevented from building up as opposed to "De-icing".
CC	Cold Climate
COST 727	EU action "Atmospheric icing of structures" with representatives from 14 European countries and Japan.
De-icing	The ice is removed after a build-up as opposed to "Anti-icing".
IEC	The International Electrotechnical Commission
IEA RD&D Wind, Task 19	IEA working group "Wind energy in cold climates" with representatives from US, Canada, Norway, Finland, Germany, Sweden and Switzerland.
O&M	Operation and Maintenance
RD&D	Research, Development and Demonstration
SMHI	Swedish Meteorological and Hydrological Institute
Threshold [in power]	A limit, for example at 85% of the nominal power in a wind speed bin, is used to determine if significant energy production losses have occurred.
WMO	World Meteorological Organization
WT	Wind Turbine

1 Background

Icing of wind turbine blades poses a significant challenge in cold climate regions around the world, as it increases the economic risk thereby reducing the profitability of wind energy projects in affected areas.

The wind farm on Etu-Aapua, a hilltop in the Municipality of Övertorneå, was put into regular operation in Sep 2005.



Figur 1: 7 NM82-1.5MW on Etu-Aapua, Photo: Göran Ronsten, 2008-06-04

It is well known that icing has affected the power performance. The magnitude of this effect has not been investigated previously.

This report has been written as part of Sweden's contribution to its participation in IEA RD&D Wind, task 19 – Wind Energy in Cold Climates.

1.1 Structure of the report

Results from another site exposed to icing, Sveg, are used a) in 2.1 to enable a comparison of the calculated icing risk, b) in 4.1 to show an example of the method used to detect icing and c) in Appendix 4 to show that a density correction is secondary to the influence of icing.

Results from sites other than Aapua and Sveg are shown to enable the reader to compare the conditions and energy production capabilities between sites.

The monthly energy productions at Aapua and Råshön, which are identically equipped wind farms, are compared in Appendix 3.

The monthly energy productions from neighbouring wind farms Råshön, Långå, Rodovålen and the single WT on Digerberget are compared in Appendix 5. These results are the only ones available in Sweden indicating that the de-icing systems used on the 5 E-70's on Långå may indeed have contributed to increasing the energy production.

Appendix 6 shows examples of icing measurements from Sveg and Bliekevare which are included to be used as future references. The icing measurements shown from Sveg are unique in the world as icing data versus height are largely unavailable. Appendix 7 is a list of references to reports related to IEA RD&D Wind Task 19 – Wind Energy in Cold Climates.

2 Frequency of icing

2.1 Icing at Aapua and Sveg according to SMHI

The estimated icing frequencies at two locations, Aapua and Sveg, were calculated to enable a comparison of the different icing conditions at two sites. It is assumed that results from one location would mean less to the reader than if the conditions at two sites can be compared.

The risk of icing at 100 m above the model terrain has been provided by SMHI. This risk, expressed on a scale from 0 (no icing) to 3 (severe icing) is an output from the analysis tool MESAN at 22 km model resolution and from the forecasting model HIRLAM at 22 km resolution during 2005/2006 and at 11 km thereafter.

Sveg is located some 14 km ENE of the WT on Brickan.

Aapua is located in Tornedalen in Övertorneå municipality, N of the Bay of Bothnia. According to SMHI, light and medium icing occur 4 times more often at Aapua, or roughly 10% of the time, compared to ditto in Sveg.

The time covered is Oct 2005 to Dec 2008. The annual icing frequency is overestimated with respect to time as an extra three winter months are included.

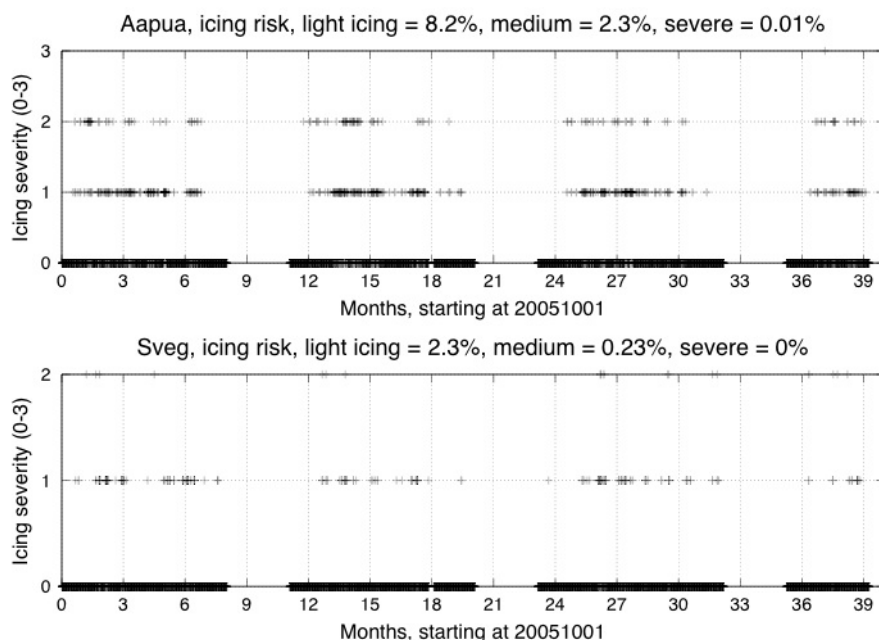


Figure 2: The risk of icing at 100 m above the model terrain.

If the annual icing frequency is overestimated with respect to time in Figure 2 it might not be so due to model resolution.

2.2 Influence of model resolution on icing

The orography based on an 11 km grid is too coarse for estimating local icing conditions on a WT in complex terrain. Bergström and Söderberg presented¹ Figure 3 in Dec 2008.

Here, the influence of horizontal resolution on the vertical cloud water content distribution is shown to be significant.

Historically, the relative humidity has been used to estimate the risk of icing. There are, however, two other parameters that are of more fundamental importance for atmospheric icing of structures; the liquid water content (LWC) and the droplet size distribution. The latter has been shown to be replaceable by the Median Volume Diameter (MVD).

An increase in horizontal resolution has a profound effect on the vertical structure of the simulated boundary layer.

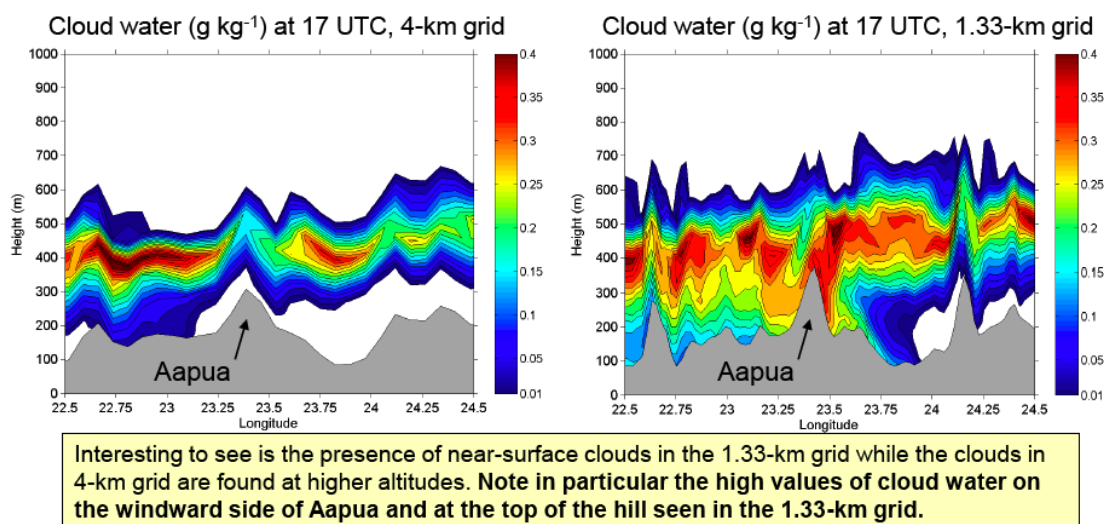


Figure 3: Influence of horizontal resolution on the vertical cloud water content distribution.

There are three main missing links between icing measurements and modelling; a) liquid water content of air, b) droplet size distribution and c) ice accretion on an object under known weather conditions. As been noted before, the former two cloud parameters are currently not possible to measure in the field at reasonable cost. Measuring the visibility and estimating the vertical velocity may instead be used to approximate these parameters. For the latter, ice accretion on an object can be calculated using Makkonen's formula:

¹ Bergström H., Söderberg S., "Estimating icing using 'higher-order turbulence closure' models", WeatherTech Scandinavia AB, Winterwind 2008, Norrköping, Sweden, Dec 2008

$$dM/dt = \alpha_1 \alpha_2 \alpha_3 w A v$$

Where A is the cross-sectional area of the object, w is the mass concentration of the particles (rain drops, cloud droplets, snow or water vapour), v is the particle velocity and α_{1-3} are the correction factors [0-1]. The correction factors can be calculated using physical models or be provided as empirical factors.

- α_1 – collision efficiency, close to 0 for small droplets²
- α_2 – sticking efficiency, = 0 for dry snow
- α_3 – accretion efficiency, = 1 for dry icing, i.e., droplets freeze on impact

2.3 Icing measurements

Icing measurements in Aapua have been carried out since spring of 2008.



Figure 4: Icing measurement set-up on Aapua 7.

Icing situations from Jan to March 2009 have been circled in the following figures.

² SLD - Super Cooled Large Droplets may cause severe icing conditions.

Aapua: Icing and power measurements, January 2009

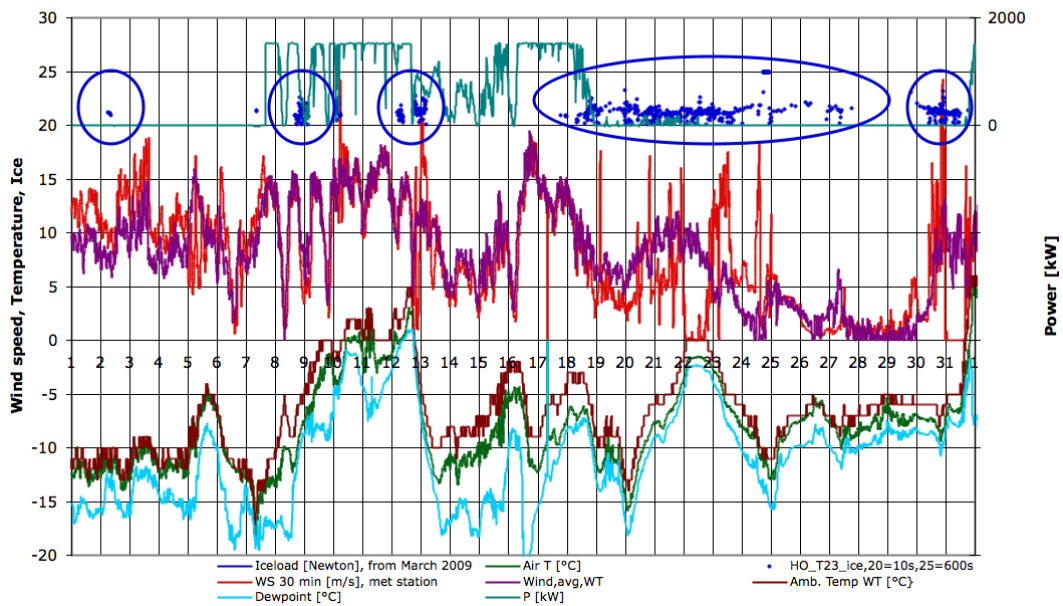


Figure 5: Icing and power measurements in Aapua, January 2009.

Aapua: Icing and power measurements, February 2009

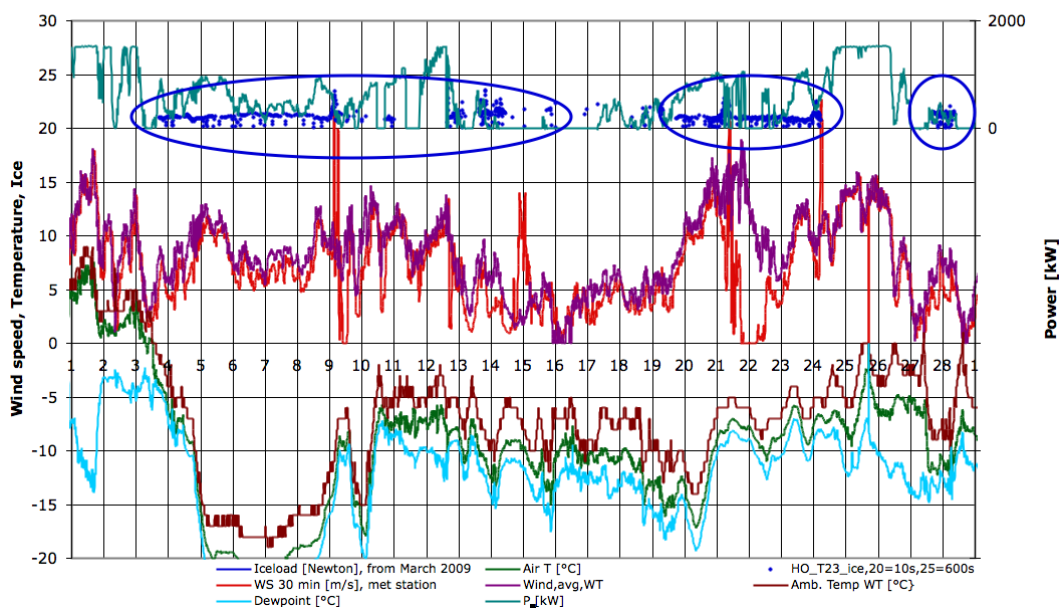


Figure 6: Icing and power measurements in Aapua, February 2009.

Aapua: Icing and power measurements, March 1-9, 2009

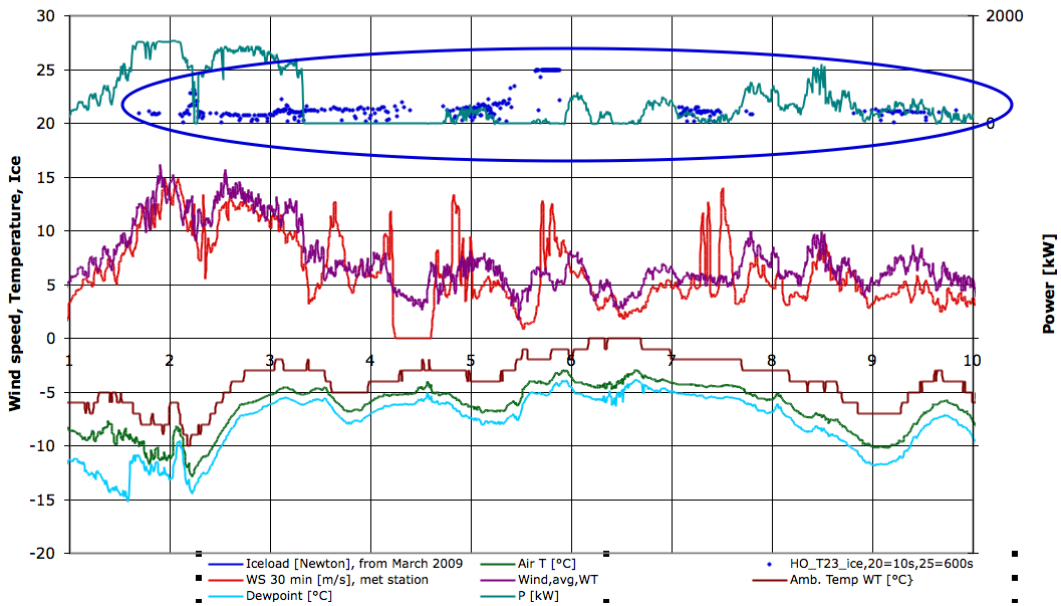
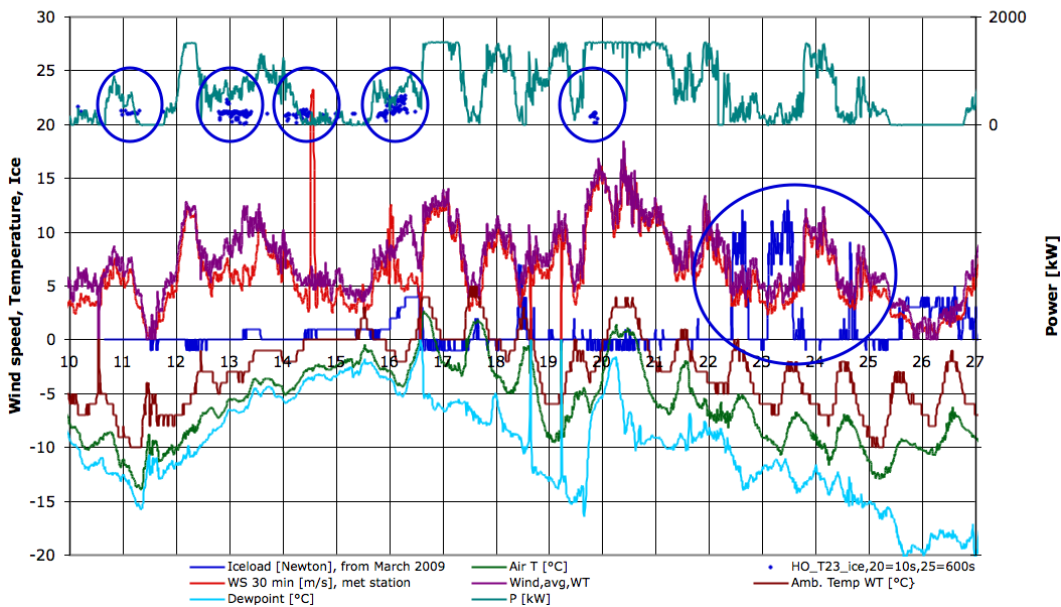


Figure 7: Icing and power measurements in Aapua, March 1-9, 2009.

Aapua: Icing and power measurements, March 10-27, 2009 (incl. ice load)



Figur 8: Icing and power measurements in Aapua, March 10-26, 2009. Ice load measured by IceMonitor.

These icing measurements indicate that icing occurs frequently and that the power performance is affected.

3 Availability and losses

The availability as measured by the data acquisition system in Aapua is shown in Figure 9 and Table 1 while the losses are shown in Figure 10.

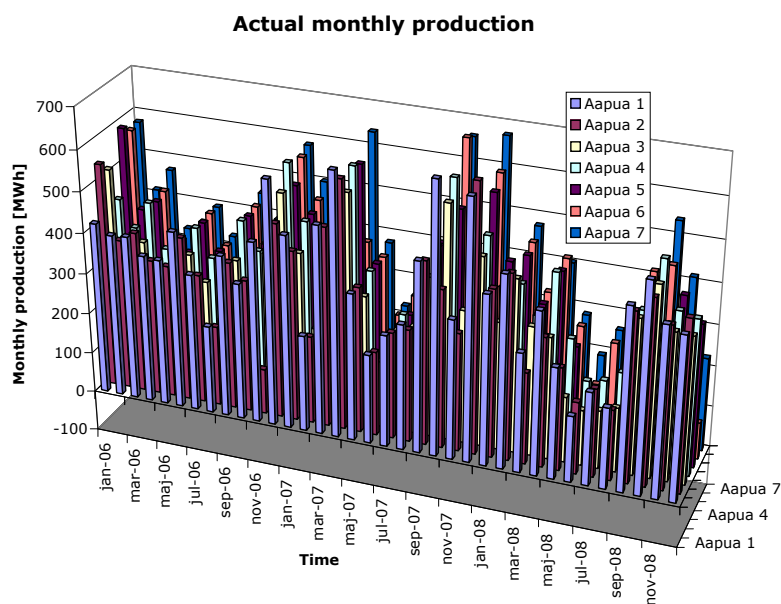


Figure 9: Monthly production [MWh] 2006-01-01 to 2008-12-31.

Availability	%
Aapua 1	95,9
Aapua 2	91,6
Aapua 3	94,1
Aapua 4	94,5
Aapua 5	85,2
Aapua 6	75,8
Aapua 7	96,7
Totalt	90,5
Denmark (1, 2 & 6)	87,8
Sweden (3, 4, 5 & 7)	92,6

Table 1: Availability, excluding icing according to Vestas's definition of availability, between 2005-10-01 and 2009-01-31.

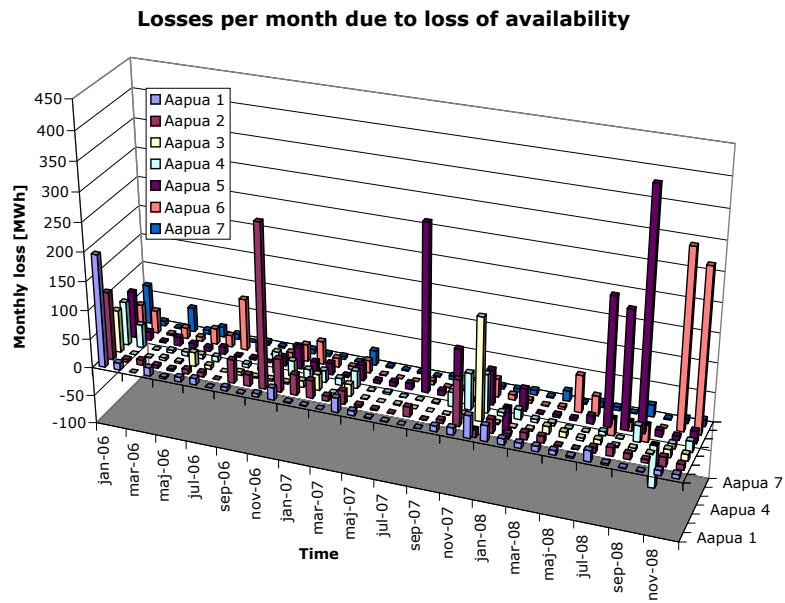


Figure 10: Monthly losses due to loss of availability.

The losses shown are only a consequence of reduced availability. No losses due to degraded performance caused by iced up blades are included.

4 Analysis

4.1 Method used

The following is a plot of the power ratio³ from a V90-2MW in Sveg⁴. The same method has been applied on data from the seven turbines in Aapua. Five major time periods when icing is assumed to cause energy production losses is shown in Figure 11.

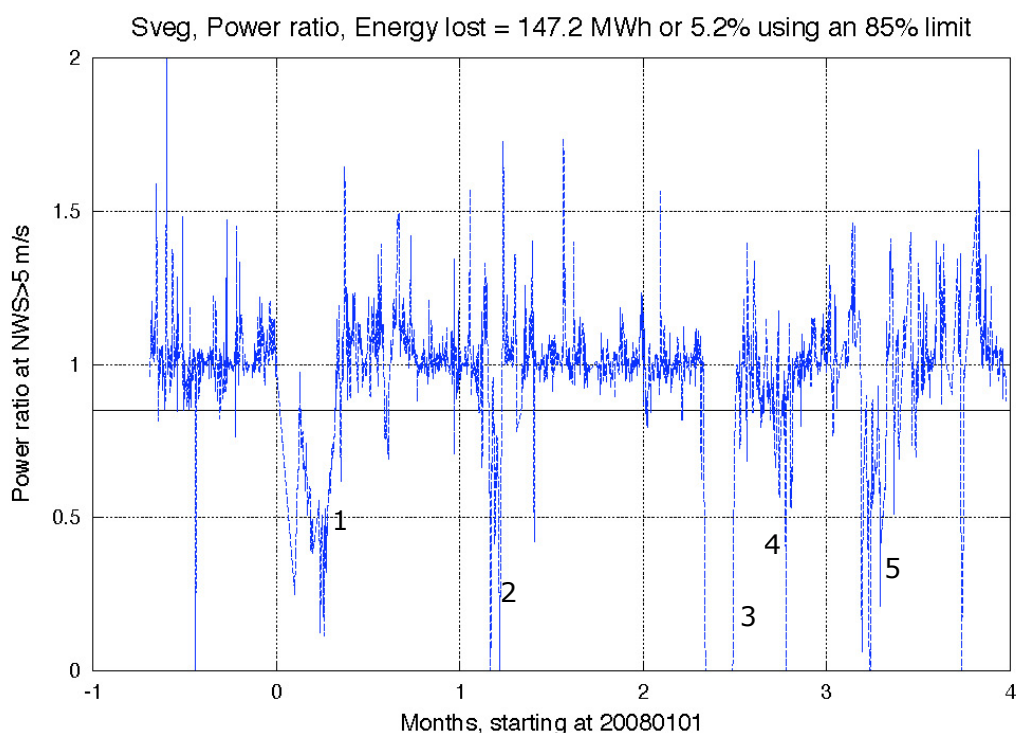


Figure 11: Five periods of icing. The energy production loss due to icing is estimated to be 5% during the period shown. The threshold shown is at 85%.

The energy production loss is dependent on the limiting power ratio used to determine icing. The total energy production in Sveg from 2008-12-11 to 2009-04-30 was 2.8 GWh.

Table 2 shows the sensitivity to the threshold chosen for the energy estimated to have been lost in Sveg.

³ The power ratio is defined as ratio between the actual power in a wind speed bin and the nominal power for that bin.

⁴ Ronsten G, "Influence of Icing on the Power Performance of a V90-2MW Wind Turbine, Brickan (Brickan), Sveg, Härjedalen, Sweden" as published in an Appendix to Persson P-E, "Mätningar av nedisning i en hög mast", Elforsk rapport 09:24, 2009

Threshold (%)	Energy lost MWh	% lost
75	132	4,7
80	139	4,9
85	147	5,2
90	156	5,5
95	167	5,9
100	181	6,4

Table 2: Energy estimated to have been lost in Sveg due to icing at threshold levels between 75% to 100% compared to the nominal energy production.

This chapter has, so far been used to explain the method used by providing an example from previous work concerning a WT in Sveg. The rest of the chapter will be used to present the results from Aapua.

Figure 12 shows 10-minute power versus nacelle wind speed for summer (green, $t \geq +2^\circ\text{C}$) and winter (blue, $t < +2^\circ\text{C}$). Data for the three summers were plotted over the comparatively more scattered data from the four winters.

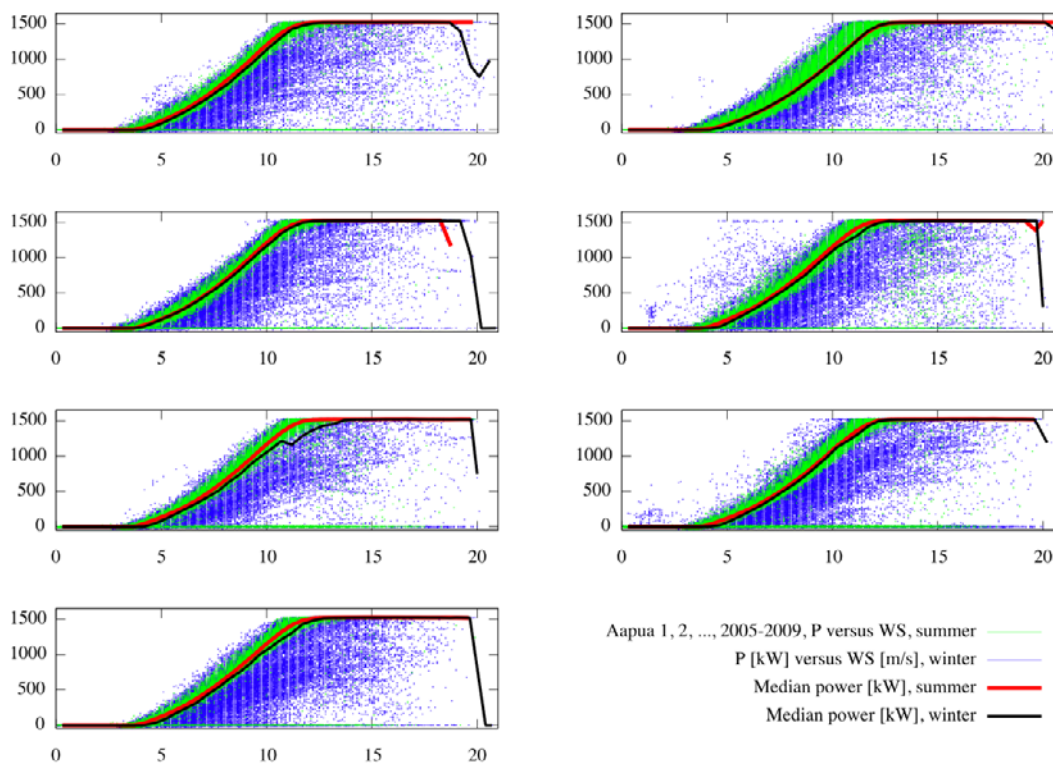


Figure 12: 10-min data plotted for three summers and four winters from October 1st 2005 to March 31st 2009. As data for the winters were plotted first, data for the summers (green dots) are placed on top of the winter data (blue dots). Aapua 1 is top left, Aapua 2 is top right etc.

The red line in Figure 12 was used to determine the nominal power in each wind speed bin. A ratio between the actual power and the nominal power was calculated for each 10 min value.

4.2 Results

Homola M. et al⁵ proposed using a threshold of 1.5 standard deviations in each bin and found relatively small reductions in energy production. The correction proposed by Homola M. et al⁶ couldn't be applied, as no information was available regarding the turbulence intensity.

The sensitivity of the method of using the nacelle wind speed as reference for the power performance was tested using 1-hour data in Sveg and is here being applied on 10-min data using a threshold of 85% of nominal power in each wind speed bin.

The energy production losses in Aapua from October 1st 2005 to March 31st 2009 are shown in Table 3.

Production [MWh]	Aapua 1	Aapua 2	Aapua 3	Aapua 4	Aapua 5	Aapua 6	Aapua 7	Total
Summer	8272	7390	5690	7620	5765	6933	7262	48932
Winter	6844	6799	7131	6641	4027	7170	7866	46478
Total	15116	14189	12821	14261	9793	14103	15128	95409
Losses, Summer	507	448	393	523	479	518	362	3230
Losses, Winter	1850	1308	1600	2157	1314	2286	2454	12968
Total losses	2356	1756	1993	2680	1793	2804	2816	16199
Losses, Summer	6,1%	6,1%	6,9%	6,9%	8,3%	7,5%	5,0%	6,6%
Losses, Winter	27,0%	19,2%	22,4%	32,5%	32,6%	31,9%	31,2%	27,9%
Total losses	15,6%	12,4%	15,5%	18,8%	18,3%	19,9%	18,6%	17,0%

Table 3: Energy production losses in Aapua during summer- and wintertime from October 1st 2005 to March 31st 2009. Winter is defined as $t < +2^{\circ}\text{C}$. All manual stops, a total of 205 days, are excluded, as are periods with missing data.

The energy production losses during the winters are significantly larger than the losses during the summer periods.

It is likely that wake effects cause some of the losses although significant wake effects don't seem to be present in the summers. The latter is likely caused by the fact that also the nacelle anemometer is affected by the reduced wind speed in the wake of neighbouring wind turbines.

The reduced power is assumed to be caused by icing, and to an unknown extent, by wake losses during the more stable atmospheric stratification conditions, which are likely to be more frequently prevailing in the wintertime.

⁵ Homola, M.C., P.J. Nicklasson, P.A. Sundsbø and A.E. Holdø (2008). Experiences from icing at Nygårdsfjell wind park. European Wind Energy Conference 2008, <http://www.ewec2008proceedings.info/>, Brussels, Belgium

http://ansatte.hin.no/mch/documents/EWEC_2008%20-%20Homola%20etal.pdf

⁶ Homola M. et al, "A corrector for windpower estimation and its usage in estimating icing losses", poster at Winterwind 2008, Norrköping, Sweden, Dec 2008

http://www.winterwind.se/Winterwind2008/P08_Homola_Winterwind_2008.pdf

The sensitivity to the threshold⁷ used can be seen in Table 4.

3 Summers

Threshold	Aapua 1	Aapua 2	Aapua 3	Aapua 4	Aapua 5	Aapua 6	Aapua 7	Total
60%	5,6%	4,8%	6,1%	5,9%	7,6%	7,0%	4,6%	5,9%
65%	5,6%	5,0%	6,2%	6,0%	7,7%	7,0%	4,6%	5,9%
70%	5,7%	5,1%	6,3%	6,1%	7,7%	7,0%	4,7%	6,0%
75%	5,7%	5,3%	6,4%	6,2%	7,9%	7,1%	4,7%	6,1%
80%	5,9%	5,6%	6,6%	6,5%	8,0%	7,2%	4,8%	6,3%
85%	6,1%	6,1%	6,9%	6,9%	8,3%	7,5%	5,0%	6,6%
90%	6,6%	6,7%	7,4%	7,4%	8,8%	8,0%	5,4%	7,1%
95%	7,3%	7,4%	8,2%	8,1%	9,5%	8,8%	6,1%	7,8%
100%	7,8%	7,9%	8,7%	8,6%	10,0%	9,3%	6,7%	8,3%

4 winters

Threshold	Aapua 1	Aapua 2	Aapua 3	Aapua 4	Aapua 5	Aapua 6	Aapua 7	Total
60%	22,4%	15,7%	18,4%	28,1%	27,5%	27,5%	26,6%	23,6%
65%	23,4%	16,4%	19,4%	29,1%	29,1%	28,6%	28,0%	24,7%
70%	24,4%	17,2%	20,3%	30,1%	30,3%	29,7%	29,1%	25,7%
75%	25,4%	17,9%	21,2%	31,0%	31,2%	30,7%	29,9%	26,5%
80%	26,3%	18,6%	21,9%	31,8%	32,0%	31,4%	30,6%	27,3%
85%	27,0%	19,2%	22,4%	32,5%	32,6%	31,9%	31,2%	27,9%
90%	27,6%	19,7%	22,9%	33,1%	33,2%	32,3%	31,7%	28,4%
95%	28,0%	20,2%	23,4%	33,5%	33,6%	32,7%	32,1%	28,8%
100%	28,3%	20,4%	23,7%	33,8%	33,9%	32,9%	32,3%	29,1%

3 summers & 4 winters

Threshold	Aapua 1	Aapua 2	Aapua 3	Aapua 4	Aapua 5	Aapua 6	Aapua 7	Total
60%	13,2%	10,1%	13,0%	16,3%	15,8%	17,4%	16,0%	14,5%
65%	13,7%	10,4%	13,5%	16,8%	16,5%	18,0%	16,8%	15,1%
70%	14,1%	10,9%	14,1%	17,3%	17,0%	18,6%	17,3%	15,6%
75%	14,7%	11,4%	14,6%	17,8%	17,5%	19,1%	17,8%	16,1%
80%	15,1%	11,9%	15,1%	18,3%	17,9%	19,5%	18,2%	16,5%
85%	15,6%	12,4%	15,5%	18,8%	18,3%	19,9%	18,6%	17,0%
90%	16,1%	13,0%	16,1%	19,4%	18,8%	20,4%	19,1%	17,5%
95%	16,7%	13,5%	16,6%	20,0%	19,4%	20,9%	19,6%	18,1%
100%	17,1%	13,9%	17,0%	20,3%	19,8%	21,3%	20,0%	18,4%

Table 4: Sensitivity to threshold used compared to nominal power.

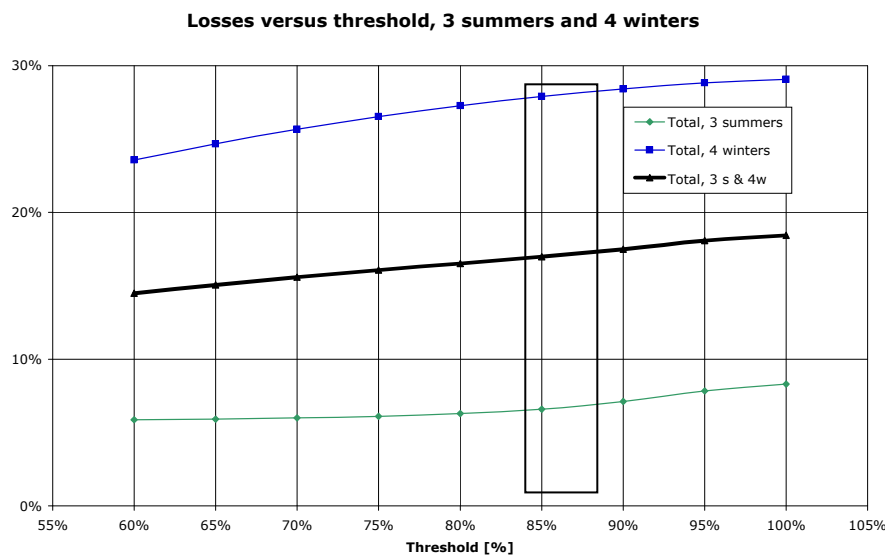


Figure 13: Sensitivity to threshold used compared to nominal power, sum of all turbines.

⁷ Threshold [in power]- A limit, for example at 85% of the nominal power in a wind speed bin, used to determine if significant energy production losses have occurred.

It is, as indicated in Figure 14, obvious that a threshold of 85% is appropriate for the summer conditions whereas the spread in data during the winter time forces a selection to be made at some, not evident which, value.

Losses versus threshold, 4 winters

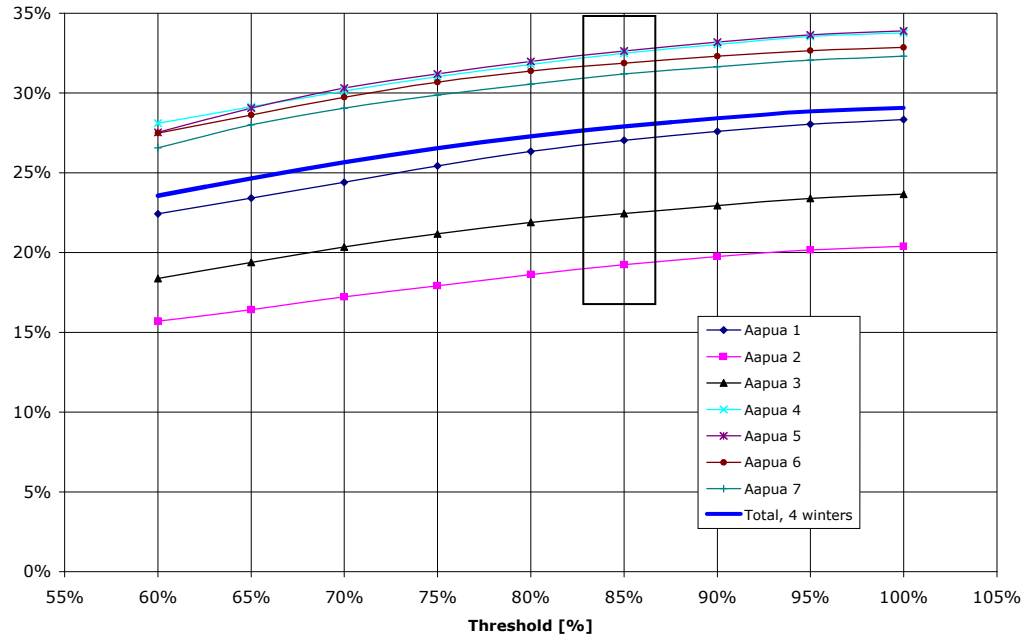


Figure 14: Sensitivity to threshold used compared to nominal power for all turbines during 4 winters.

The turbines most affected by winter conditions are Aapua 4 & 5 closely followed by Aapua 6 and 7. Aapua 1, 2 and 3 are less affected than the average.

5 Conclusions

The losses during the winter seasons are higher compared to those in the summer time. What is more alarming is the increase in downtime during the winters over the years due to a lower availability and a reduced energy production.

The average energy production loss is more than 4 times higher in the wintertime compared to that in the summertime.

The method chosen, i.e. comparing the actual power for both summers and winters with the nominal power in each wind speed bin, makes it easy to determine if the power is affected by low temperature related conditions. It is assumed that icing, and not wakes, is causing this significant increase in losses.

Data has been available for most of the period of operation except for Aapua 5 and Aapua 6, see Appendix 1. Data for all turbines are missing during the start of the icing seasons in 2006 and 2007. Data from missing periods are not included in the evaluation. The most recent and frequent error codes are also shown.

Appendix 2 shows the power performance for each turbine during winters and summers. The increased spread in data from the winters is obvious and significant.

The monthly energy productions from Aapua and Råshön, two similar wind farms with 7 V82-1.5 MW turbines each, have been evaluated in Appendix 3. The turbines in Aapua have produced 16% more than those at Råshön but it isn't possible to use monthly production data to determine the influence of icing on the power performance.

It is shown in Appendix 4 that an air density correction isn't necessary to be included in the analysis as the influence of significant icing is much larger than the variation in air density.

The only de-icing systems in use in a Swedish wind farm are installed on 5 E-70's on Långåvålen. The wind turbine manufacturer Enercon doesn't claim that these hot air-based de-icing systems are effective in medium to severe icing conditions. The findings in Appendix 5 indicate that the de-icing systems on Långåvålen are likely to be effective in the icing conditions at this site.

Appendix 6 shows examples of recent icing measurements from Bliekevare and Sveg. The latter is a unique data set which will be used as comparison to ice modelling simulations to be presented at IWAIS 2009 in Andermatt, Switzerland, 8-11 Sep.

6 References

- [1] Bergström H., Söderberg S., "Estimating icing using 'higher-order turbulence closure' models", WeatherTech Scandinavia AB, poster at Winterwind 2008, Norrköping, Sweden, Dec 2008
- [2] Homola M. et al, "A corrector for windpower estimation and its usage in estimating icing losses", poster at Winterwind 2008, Norrköping, Sweden, Dec 2008
http://www.winterwind.se/Winterwind2008/P08_Homola_Winterwind_2008.pdf
- [3] Homola, M.C., P.J. Nicklasson, P.A. Sundsbø and A.E. Holdø, "Experiences from icing at Nygårdstjønn wind park". European Wind Energy Conference 2008, <http://www.ewec2008proceedings.info/>, Brussels, Belgium
http://ansatte.hin.no/mch/documents/EWEC_2008%20-%20Homola%20etal.pdf
- [4] IEC 61400-12-1, Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines, Edition 1.0 2005-12
- [5] Persson P-E, "Mätningar av nedisning i en hög mast", Elforsk rapport 09:24, 2009, Appendix written by Ronsten G, "Influence of Icing on the Power Performance of a V90-2MW Wind Turbine, Brickan (Brickan), Sveg, Härjedalen, Sweden", 2009
- [6] Ronsten G., Dierer S., Nygaard B.E.K., Makkonen L., Homola M., "Measures needed for the successful development of wind energy in icing climates", EWEC 2009, March 2009.

7 Appendix 1 - Presentation of data from Aapua

- 10-min data from October 1, 2005 to the end of March 2009 have been used.
- Alarm statistics are available from the start.

7.1 Availability of the data acquisition system

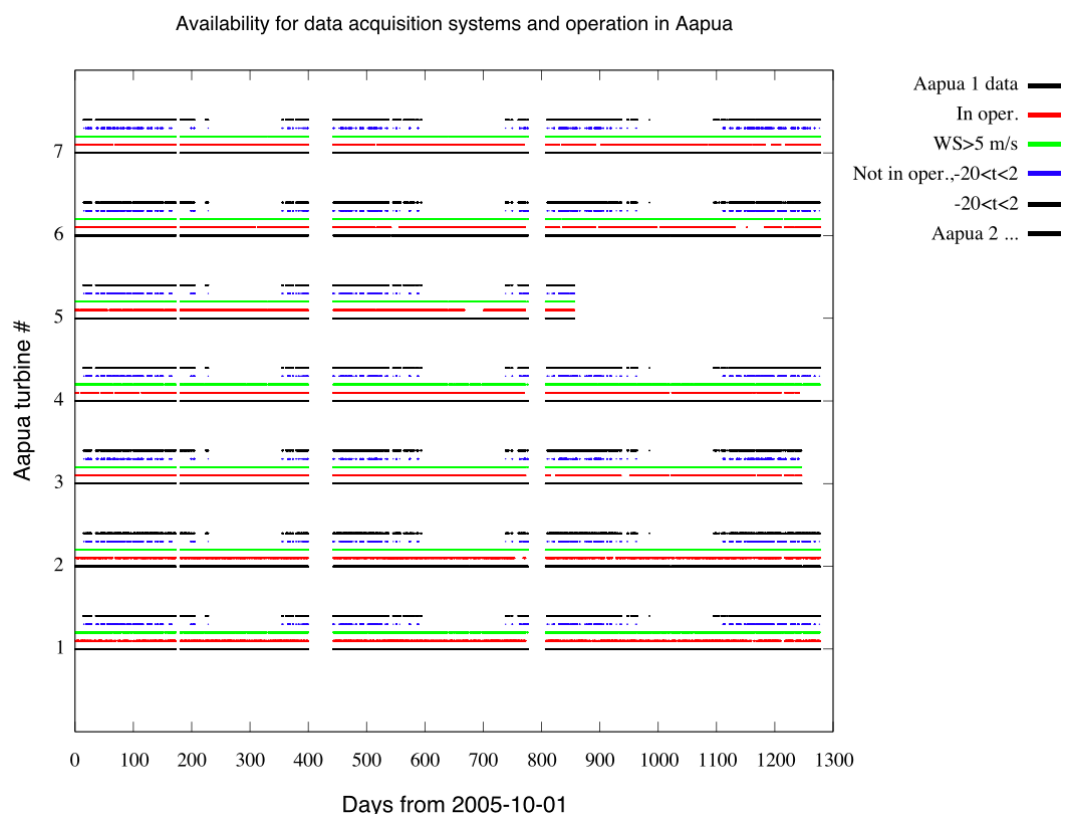


Figure 15: The plot shows when a) data is available, b) the turbine is in operation, c) when the wind speed > 5 m/s, d) the turbine is not in operation AND the temperature is between -20°C and $+2^{\circ}\text{C}$ and e) when the temperature is between -20°C and $+2^{\circ}\text{C}$.

The scale is such that no details can be seen. There have been two longer periods when data hasn't been acquired. Unfortunately, these occurred in the beginning of the icing seasons of 2006/2007 and 2007/2008.

The low temperature seasons are longer than the times when the temperature stays above $+2^{\circ}\text{C}$.

In the following figures, data have been evaluated for each icing season, i.e. from July to June starting with 2005/2006 etc. Data from the periods when data are missing are not included in the evaluation.

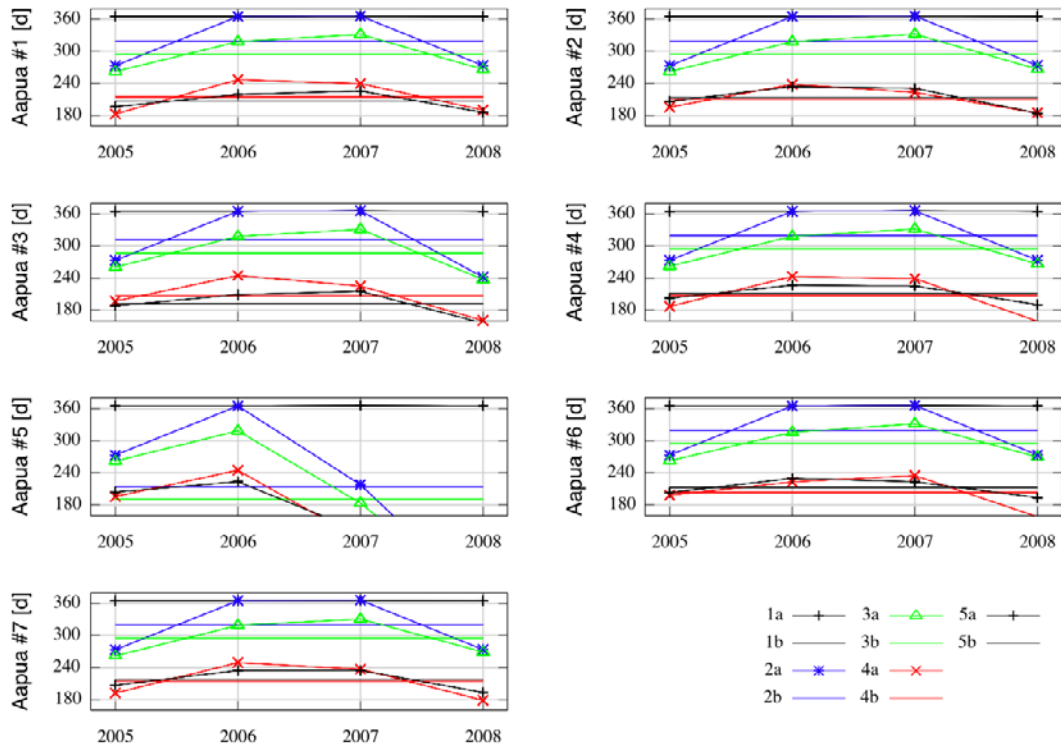


Figure 16: Availability as of March 31 in days for the data acquisition system end the seven Aapua turbines during four winter seasons from 1 July 2005 to June 30 2009. 1a) Tot. # of days, 1b) Total time mean, 2a) Data avail., 2b) Data avail. mean, 3a) Valid data, 3b) Valid data, mean, 4a) In operation, 4b) In oper., mean, 5a) WS>5 m/s, 5b) WS>5 m/s, mean.

Figure 17 shows the same data in %.

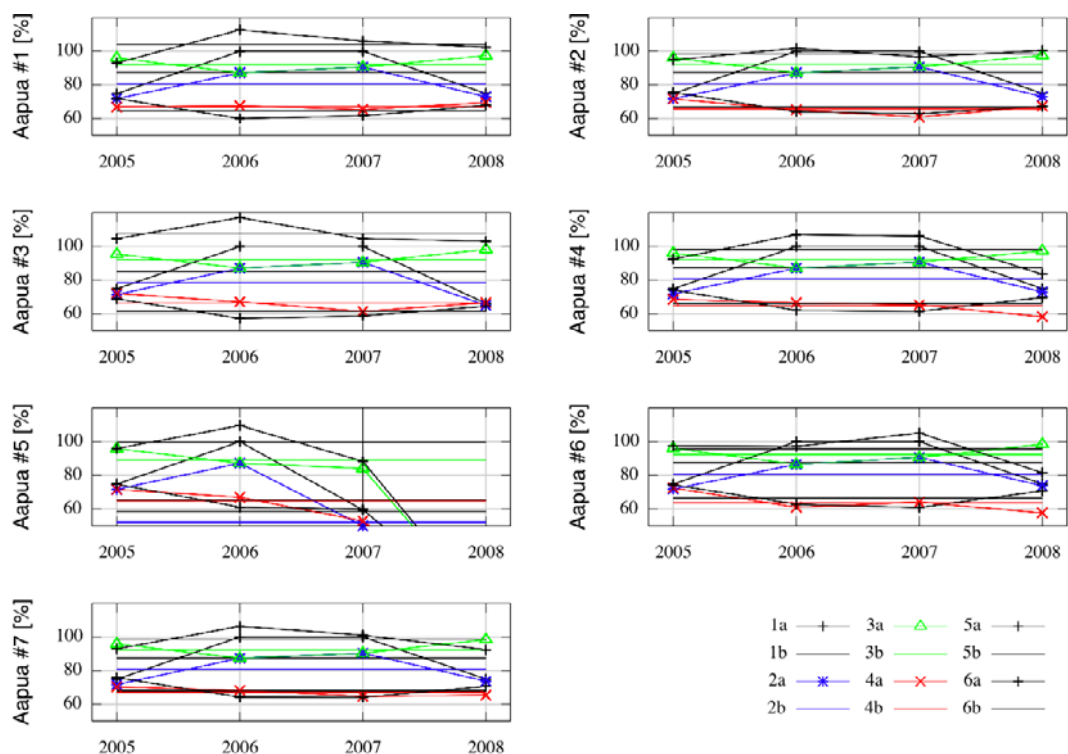


Figure 17: Availability as of March 31 in % for the data acquisition system end the seven Aapua turbines during four winter seasons from 1 July 2005 to June 30 2009. 1a) Data avail. [%], 1b) Data avail. mean, 2a) Valid data, 2b) Valid data, mean, 3a) Valid/avail., 3b) Valid/avail., mean, 4a) In operation, 4b) In oper., mean, 5a) In oper./WS>5, 5b) In oper./WS>5, mean, 6a) WS>5 m/s, 6b) WS>5 m/s, mean.

Figure 18 shows the number of days when summer and winter prevail and the number of days when the turbines aren't operating although the wind speed > 5 m/s.

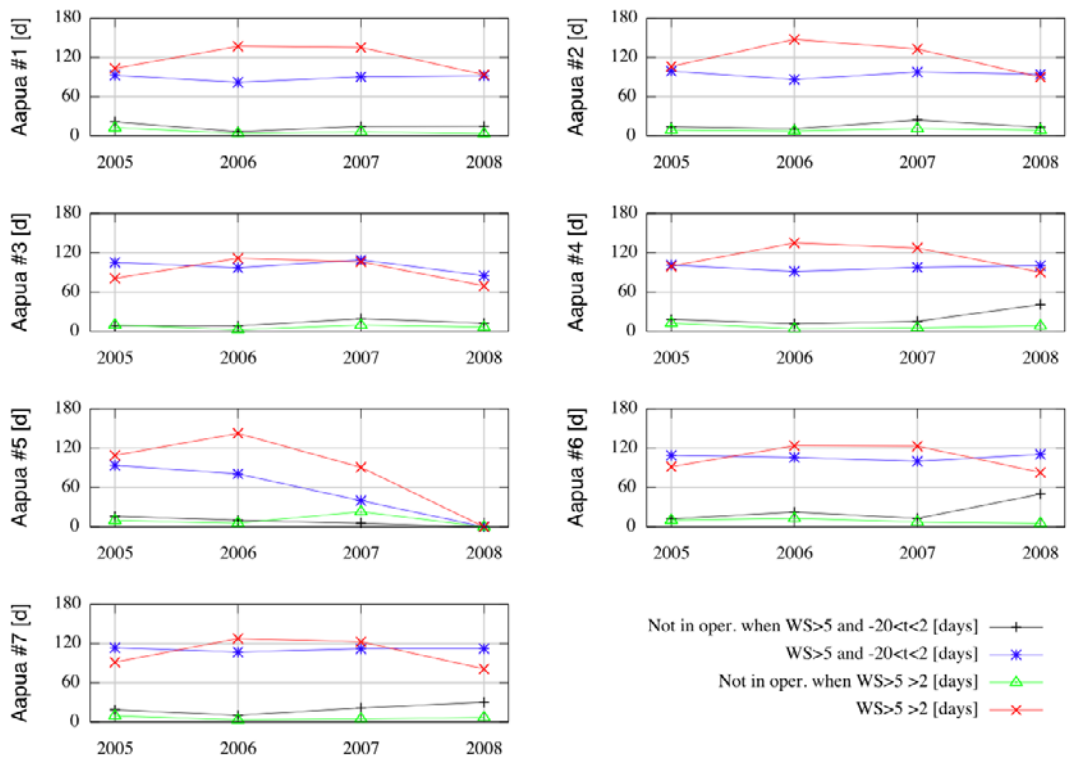


Figure 18: Days when the wind speed is > 5 m/s during winter and summer and days when the turbines aren't operating.

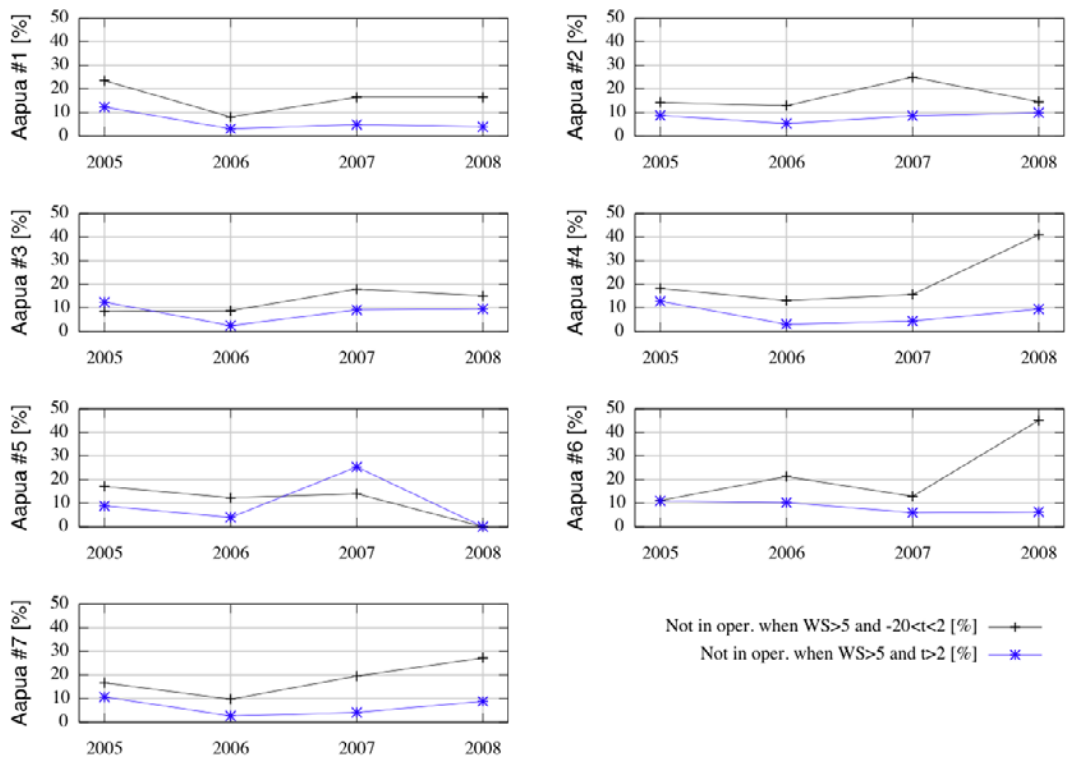


Figure 19: % of time when the wind speed > 5 m/s and the turbines are not in operation during winter and summer.

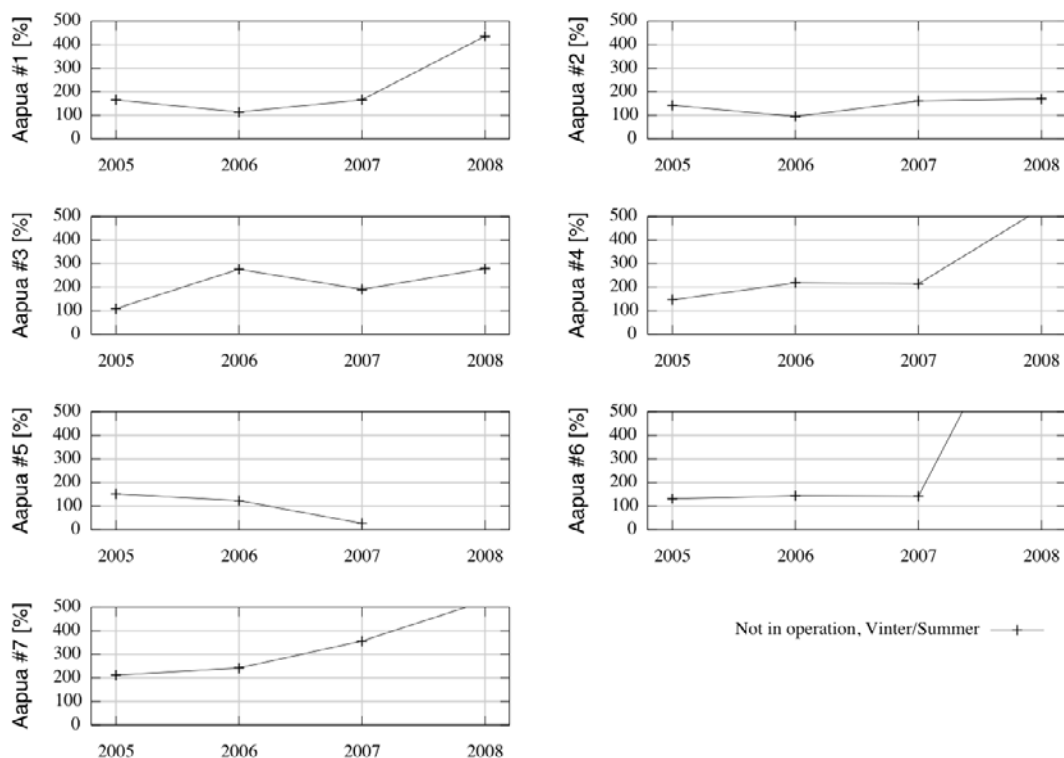


Figure 20: Weighted ratio of downtime for winters over summers.

The downtime is considerably higher during the winters compared to during the summers. More alarming is the increase in downtime as the years pass by. The data used to plot Figure 16 to Figure 20 is shown in Table 6.

1. Total time [days]
2. Data avail. [days]
3. Valid data [days]
4. In oper. [days]
5. WS>5 m/s [days]
6. Data avail. [%]
7. Valid data [%]
8. Valid data/data avail. [%]
9. In operation [%]
10. WS>5 [%]
11. In oper./WS>5 [%]
12. Not in oper.,WS>5&-20<t<2 [days]
13. WS>5&-20<t<2 [days]
14. Not in oper.,WS>5&-20<t<2 [%]
15. Not in oper.,WS>5&t>2 [days]
16. WS>5&t>2 [days]
17. Not in oper.,WS>5&t>2 [%]
18. Not in oper. Vinter/Summer

Table 5: Key to Table 6.

	Aapua 1	Aapua 2	Aapua 3	Aapua 4	Aapua 5	Aapua 6	Aapua 7
1. Total time [d]							
2005/2006	365	365	365	365	365	365	365
2006/2007	365	365	365	365	365	365	365
2007/2008	366	366	366	366	366	366	366
2008/2009	365	365	365	365	365	365	365
2005/2009	1461	1461	1461	1461	1461	1461	1461
2. Data avail. [d]							
2005/2006	273,0	273,0	273,0	273,0	273,0	273,0	273,0
2006/2007	365,0	365,0	365,0	365,0	365,0	365,0	365,0
2007/2008	366,0	366,0	366,0	366,0	217,8	366,0	366,0
2008/2009	273,5	273,5	241,6	273,5	0,0	273,5	273,5
2005/2009	1277,5	1277,5	1245,7	1277,5	855,9	1277,5	1277,5
3. Valid data [d]							
2005/2006	262,3	262,2	260,6	262,3	261,9	262,6	261,7
2006/2007	318,0	318,1	318,1	318,2	318,4	315,9	318,9
2007/2008	331,5	332,0	331,3	331,8	183,1	331,8	330,6
2008/2009	266,4	266,7	237,4	266,4	0,0	269,3	269,0
2005/2009	1178,2	1178,9	1147,4	1178,7	763,5	1179,5	1180,3
4. In oper. [d]							
2005/2006	182,7	185,6	196,8	187,1	185,7	198,0	192,3
2006/2007	246,9	238,1	244,8	242,9	244,6	223,1	249,1
2007/2008	239,5	222,9	225,1	239,1	115,3	234,7	236,9
2008/2009	190,1	184,6	160,8	159,3	0,0	157,9	178,8
2005/2009	859,1	841,2	827,5	828,4	555,7	813,6	857,1
5. WS>5 m/s [d]							
2005/2006	196,5	206,3	188,0	202,2	204,0	203,1	207,0
2006/2007	219,1	234,0	208,9	226,8	223,4	229,6	234,5
2007/2008	225,7	230,5	215,1	225,1	130,5	223,1	234,5
2008/2009	185,8	184,1	155,9	190,6	0,0	193,6	193,4
2005/2009	826,9	854,9	768,0	844,8	557,9	849,3	869,5
6. Data avail. [%]							
2005/2006	74,8	74,8	74,8	74,8	74,8	74,8	74,8
2006/2007	100,0	100,0	100,0	100,0	100,0	100,0	100,0
2007/2008	100,0	100,0	100,0	100,0	59,5	100,0	100,0
2008/2009	74,9	74,9	66,2	74,9	0,0	74,9	74,9
2005/2009	87,4	87,4	85,3	87,4	58,6	87,4	87,4
7. Valid data [%]							
2005/2006	71,9	71,8	71,4	71,9	71,7	71,9	71,7
2006/2007	87,1	87,1	87,2	87,2	87,2	86,5	87,4
2007/2008	90,6	90,7	90,5	90,7	50,0	90,6	90,3
2008/2009	73,0	73,1	65,0	73,0	0,0	73,8	73,7
2005/2009	80,6	80,7	78,5	80,7	52,3	80,7	80,8
8. Valid data/data avail. [%]							
2005/2006	96,1	96,0	95,4	96,1	95,9	96,2	95,9
2006/2007	87,1	87,1	87,2	87,2	87,2	86,5	87,4
2007/2008	90,6	90,7	90,5	90,7	84,1	90,6	90,3
2008/2009	97,4	97,5	98,3	97,4	0,0	98,5	98,4
2005/2009	92,2	92,3	92,1	92,3	89,2	92,3	92,4
9. In operation [%]							
2005/2006	66,9	71,6	72,1	68,5	71,7	72,5	70,4
2006/2007	67,6	65,2	67,1	66,5	67,0	61,1	68,3
2007/2008	65,4	60,9	61,5	65,3	52,9	64,1	64,7
2008/2009	69,5	67,5	66,5	58,3	0,0	57,7	65,4
2005/2009	67,2	65,8	66,4	64,8	64,9	63,7	67,1
10. WS>5 [%]							
2005/2006	71,9	75,6	68,9	74,1	74,7	74,4	75,8
2006/2007	60,0	64,1	57,2	62,1	61,2	62,9	64,2
2007/2008	61,7	63,0	58,8	61,5	59,9	61,0	64,1
2008/2009	67,9	67,3	64,5	69,7	NaN	70,8	70,7
2005/2009	64,7	66,9	61,7	66,1	65,2	66,5	68,1
11. In oper./WS>5 [%]							
2005/2006	93,0	94,8	104,7	92,5	95,9	97,5	92,9
2006/2007	112,7	101,8	117,1	107,1	109,5	97,2	106,3
2007/2008	106,1	96,7	104,6	106,2	88,4	105,2	101,0
2008/2009	102,3	100,3	103,1	83,6	0,0	81,5	92,4
2005/2009	103,9	98,4	107,7	98,1	99,6	95,8	98,6
12. Not in oper.,WS>5&-20<t<2 [d]							
2005/2006	21,8	14,1	8,9	18,5	16,0	12,1	18,9
2006/2007	6,7	11,1	8,5	12,0	9,9	22,5	10,4
2007/2008	14,9	24,4	19,6	15,3	5,6	12,9	21,8
2008/2009	15,1	13,7	12,8	41,1	0,0	49,8	30,6
2005/2009	58,5	63,4	49,8	86,9	31,5	97,3	81,7
13. WS>5&-20<t<2 [d]							
2005/2006	92,7	99,1	105,1	101,2	93,9	109,1	113,5
2006/2007	82,1	86,4	97,1	91,6	80,8	105,9	106,9
2007/2008	90,4	97,8	109,1	97,7	39,8	100,1	111,9
2008/2009	92,1	94,2	85,2	100,3	0,0	110,6	112,2
2005/2009	357,3	377,5	396,5	390,9	214,5	425,5	444,6
14. Not in oper.,WS>5&-20<t<2 [%]							
2005/2006	23,5	14,3	8,5	18,2	17,1	11,1	16,7
2006/2007	8,1	12,9	8,7	13,1	12,3	21,3	9,7
2007/2008	16,4	25,0	18,0	15,7	14,0	12,9	19,5
2008/2009	16,4	14,5	15,1	41,0	0,0	45,1	27,2
2005/2009	16,4	16,8	12,6	22,2	14,7	22,9	18,4
15. Not in oper.,WS>5&t>2 [d]							
2005/2006	12,7	9,3	10,1	12,7	9,7	10,0	9,8
2006/2007	4,2	7,9	2,8	4,1	5,6	12,7	3,4
2007/2008	6,6	11,4	9,7	5,6	23,0	7,4	5,0
2008/2009	3,7	8,9	6,6	8,5	0,0	5,3	7,2
2005/2009	27,3	37,5	29,1	30,9	38,3	35,4	25,3
16. WS>5&t>2 [%]							
2005/2006	103,3	106,2	81,0	99,4	109,1	91,7	91,5
2006/2007	137,0	147,5	111,7	135,2	142,6	123,7	127,5
2007/2008	135,3	132,7	106,1	127,4	90,7	123,1	122,6
2008/2009	93,6	89,9	69,5	90,3	0,0	83,0	81,3
2005/2009	469,2	476,4	368,3	452,2	342,4	421,5	422,9
17. Not in oper.,WS>5&t>2 [%]							
2005/2006	12,3	8,7	12,4	12,8	8,9	11,0	10,7
2006/2007	3,1	5,4	2,5	3,0	4,0	10,3	2,6
2007/2008	4,9	8,6	9,1	4,4	25,4	6,0	4,1
2008/2009	4,0	9,9	9,5	9,5	0,0	6,3	8,8
2005/2009	5,8	7,9	7,9	6,8	11,2	8,4	6,0
18. Not in oper. Winter/Summer							
2005/2006	166,0	143,6	109,4	146,4	151,8	131,3	212,1
2006/2007	114,5	95,4	276,3	217,9	123,2	143,3	241,9
2007/2008	166,3	161,7	190,3	214,1	26,7	141,2	356,1
2008/2009	435,2	170,5	278,7	533,6	NaN	1141,6	525,7
2005/2009	45,7	35,5	46,4	62,2	24,0	65,2	76,4

Table 6: Data for Figure 16 to Figure 20.

7.2 The most frequent, recent error codes

The most frequent, recent error codes until Feb 12 2009 are found in Table 7:

Aapua 1	Event	Events	Time [h]
393	Vibration TAC84	81	23,7
593	Vibration TAC84 downwind	108	20,5
237	Extreme flap moment protection	167	14,9
Aapua 2	Event	Events	Time [h]
393	Vibration TAC84	123	35,2
237	Extreme flap moment protection	211	27,6
244	EFM yaw error too high	23	19,2
Aapua 3	Event	Events	Time [h]
223	Wind sensor right fault	16	293,7
244	EFM yaw error too high	42	286,6
237	Extreme flap moment protection	170	43,5
393	Vibration TAC84	95	24,4
598	Vibration TAC84 lateral	20	14,7
Aapua 4	Event	Events	Time [h]
223	Wind sensor right fault	48	965,8
244	EFM yaw error too high	38	207,9
393	Vibration TAC84	427	159,6
237	Extreme flap moment protection	129	104
598	Vibration TAC84 lateral	172	12,9
226	10 min wind speed high	31	10,8
Aapua 5	Event	Events	Time [h]
236	Wind vane fault	25	100,9
393	Vibration TAC84	212	79,8
232	Anemometer 1 fault	21	73,8
244	EFM yaw error too high	11	18,2
237	Extreme flap moment protection	39	7,1

Aapua 6	Event	Events	Time [h]
223	Wind sensor right fault	95	3643
486	Unbalanced pitch	262	333
237	Extreme flap moment protection	124	102
355	Too slow rotation	25	55
499	Unbalanced pitch - Generation	16	36
393	Vibration TAC84	109	23
457	Unbalanced pitch shutdown	34	20
598	Vibration TAC84 lateral	37	12
Aapua 7	Event	Events	Time [h]
223	Wind sensor right fault	140	2634
244	EFM yaw error too high	76	326
237	Extreme flap moment protection	266	81
219	Wind sensor fault	59	42

Table 7: Most common and recent, until Feb 12, 2009, error codes.

The three most common errors, "Vibration TAC84", "Extreme flap moment protection" and "EFM yaw error too high" can be found in the log of most of the turbines. Wind related errors account for most of the event time for Aapua 4, 6 and 7. It is not known why the latter type of error isn't present to the same extent in the logs of the other turbines. It is assumed that all of these errors can be related to icing of the wind turbine blades or the sensors. Frequent older errors, from the first winter season 2005/2006, include "Ice detected" and "Ice sensor fault".

As the alarm boundaries have been altered over the years, the turbines seem to have become individuals. As this report is written this is about to change. An updated version of the control software is to be installed and the settings are to be reset to more identical values for all turbines.

With slightly more than a year until the warranty expires, the owners of the Aapua wind farm are eager to make sure that the turbines will continue to perform as intended.

The next chapter deals with production losses and will hopefully provide a basis for making, or not making, investments in anti-icing systems.

8 Appendix 2 - Power performance during summer and winter

The power performances over the years, 2005/2006, 2006/2007, 2007/2008, 2008/2009 and 2005/2009 for the Aapua turbines during "winter" and "summer" have been plotted in Figure 21 to Figure 27. The power versus wind speed during the summers is generally well assembled whereas this isn't the case during the winter seasons.

Data for Aapua #4 are obviously different compared to the other turbines during the summer season, i.e. icing can't cause this discrepancy.

The losses during the winter time seem surprisingly big.

2005/2006 is shown in the top left corner, 2006/2007 in the top right corner, etc.

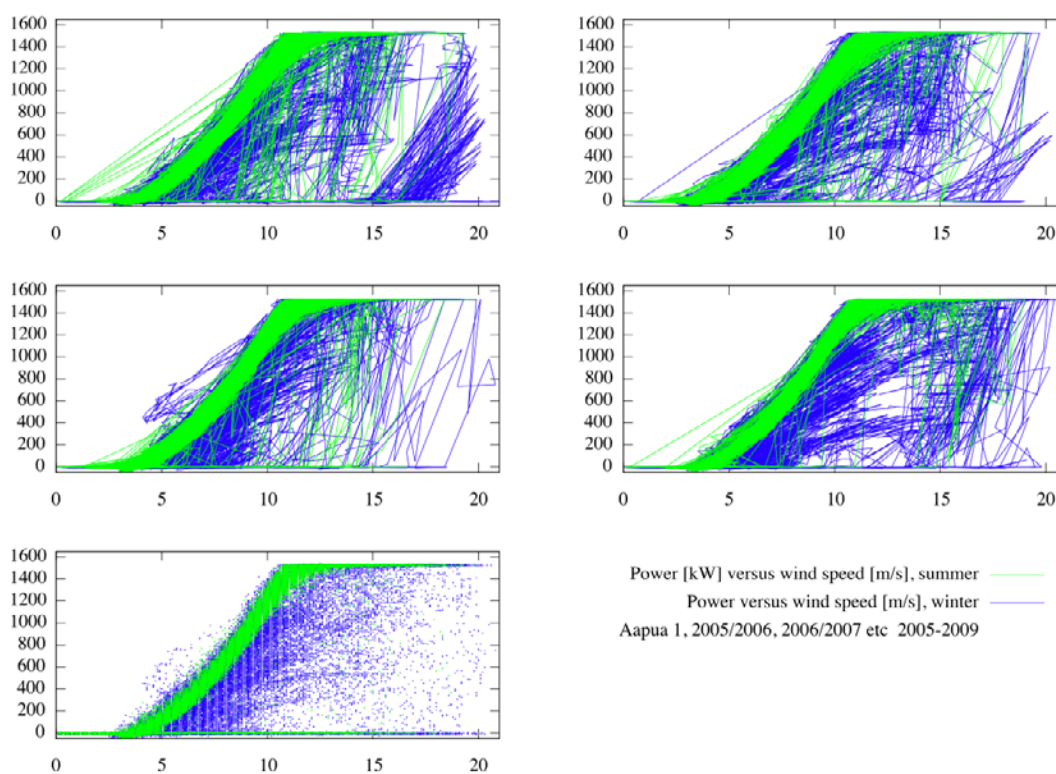


Figure 21: Power performance, 3,5 years for Aapua 1.

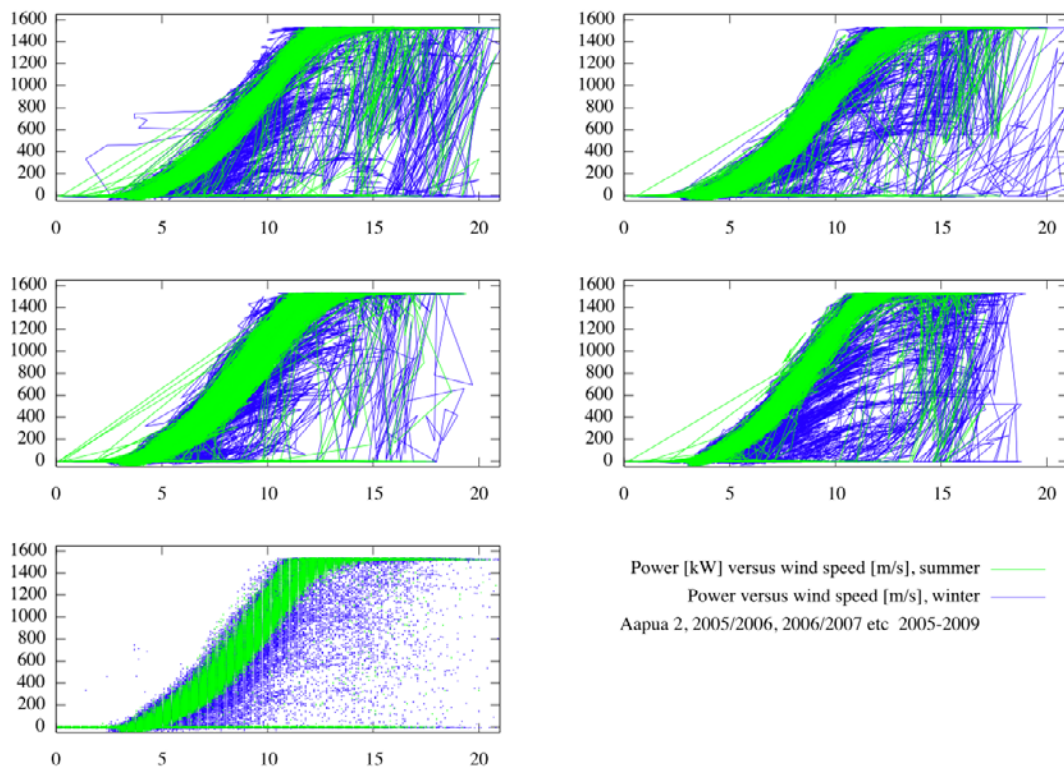


Figure 22: Power performance, 3,5 years for Aapua 2.

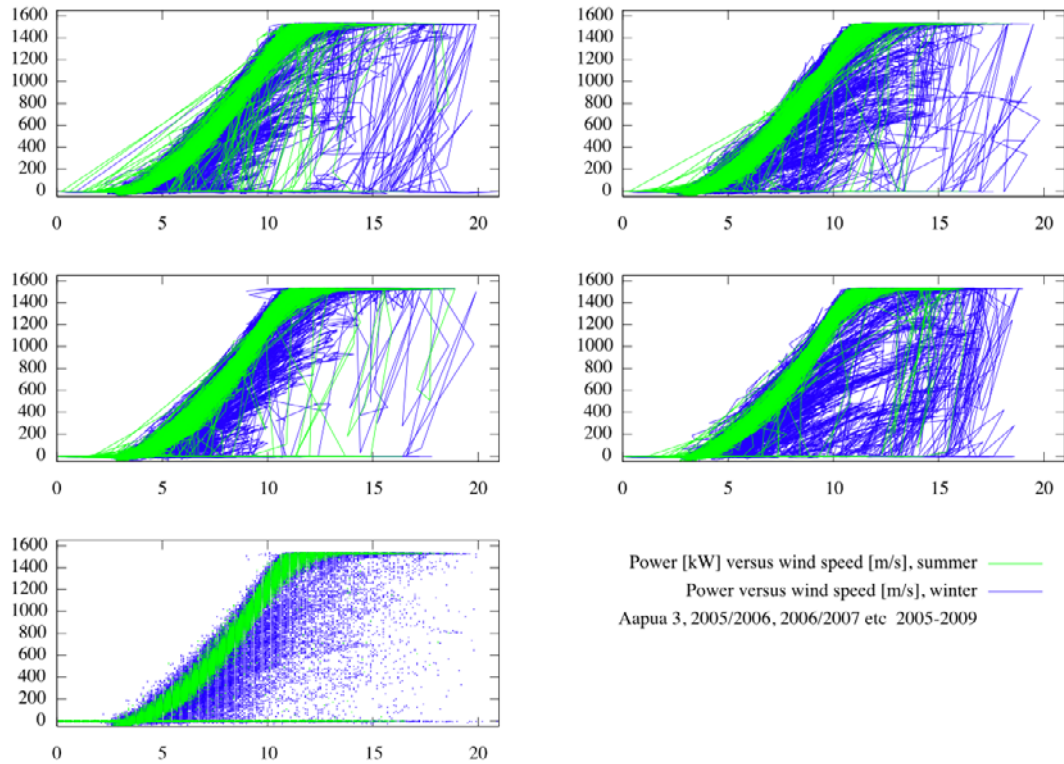


Figure 23: Power performance, 3,5 years for Aapua 3.

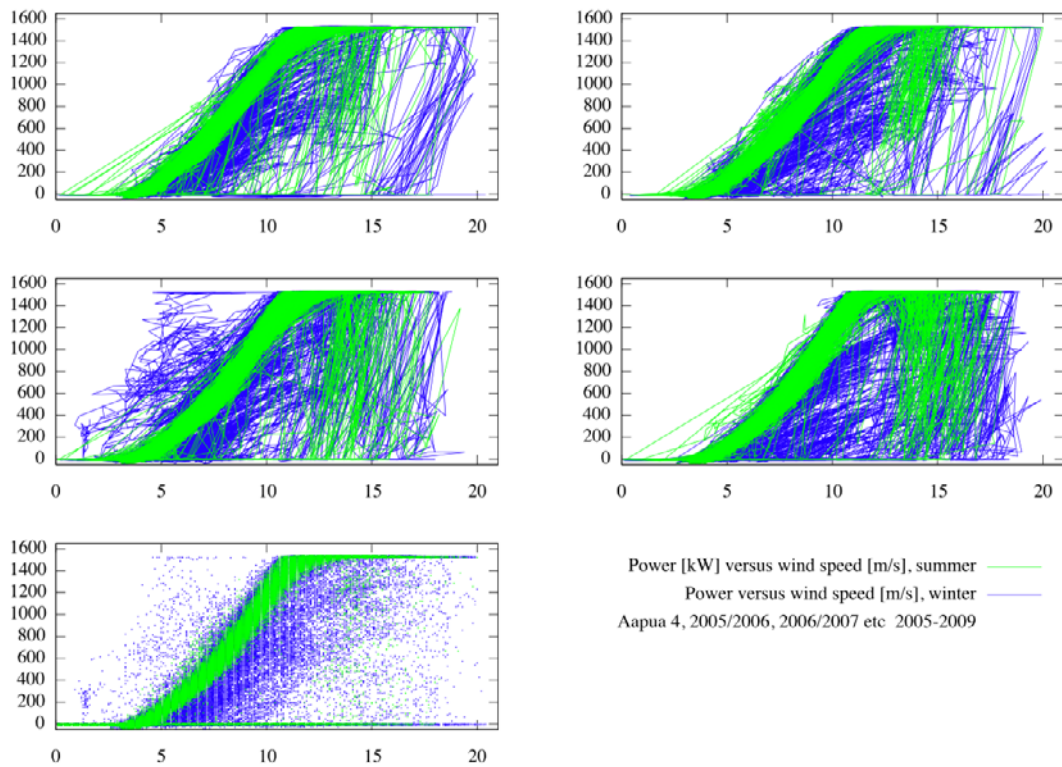


Figure 24: Power performance, 3,5 years for Aapua 4.

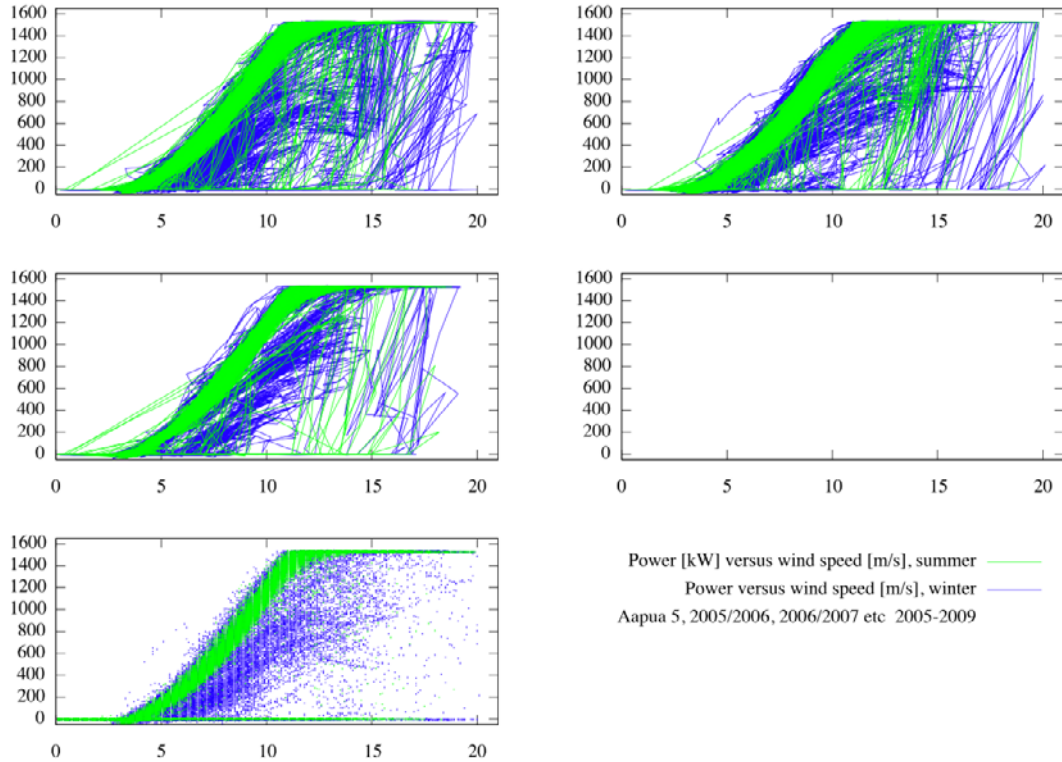


Figure 25: Power performance, 3,5 years for Aapua 5. Data are missing for the whole season of 2008/2009.

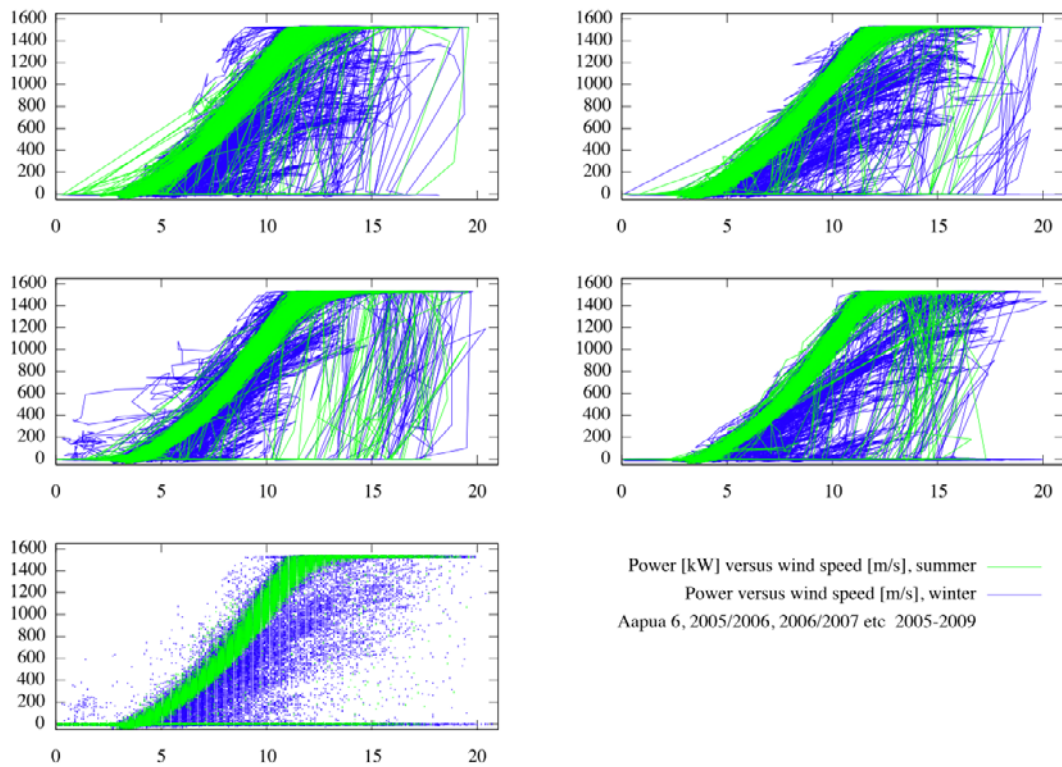


Figure 26: Power performance, 3,5 years for Aapua 6.

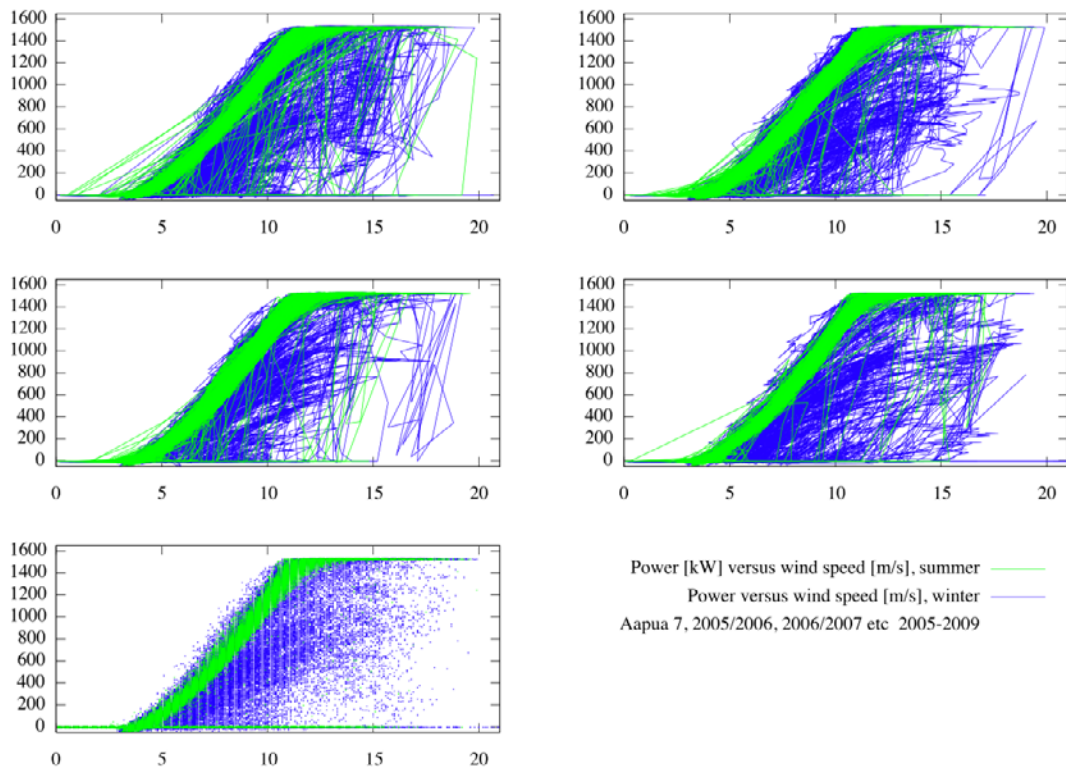


Figure 27: Power performance, 3,5 years for Aapua 7.

9 Appendix 3 - Monthly power, Aapua and Råshön

Figure 28 shows the monthly energy productions from the WT in Aapua.

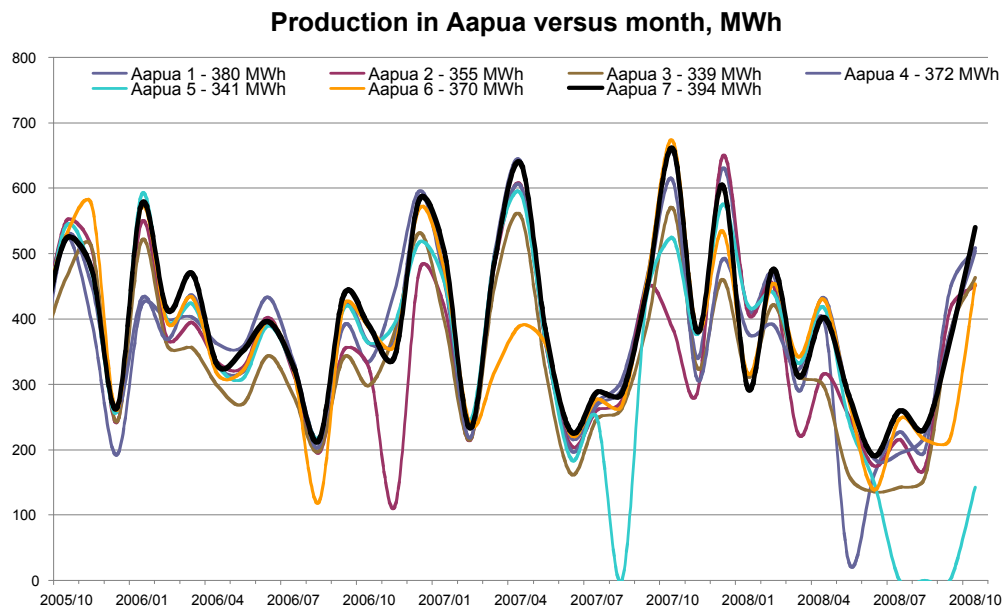


Figure 28: Monthly energy production in Aapua and average production per month. Aapua 7 is generally the best performing WT in the Aapua wind farm.

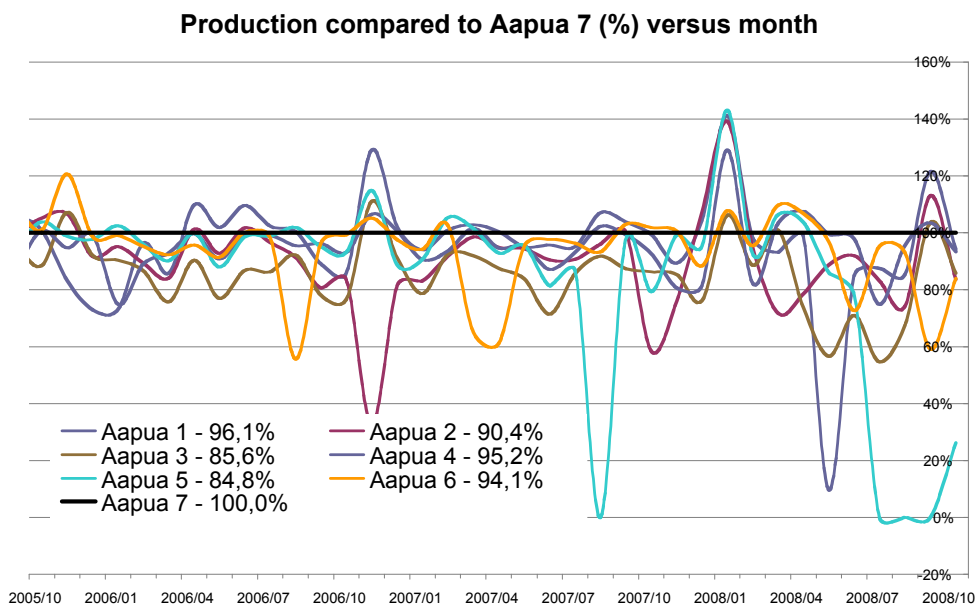


Figure 29: Relative monthly production compared to Aapua 7.

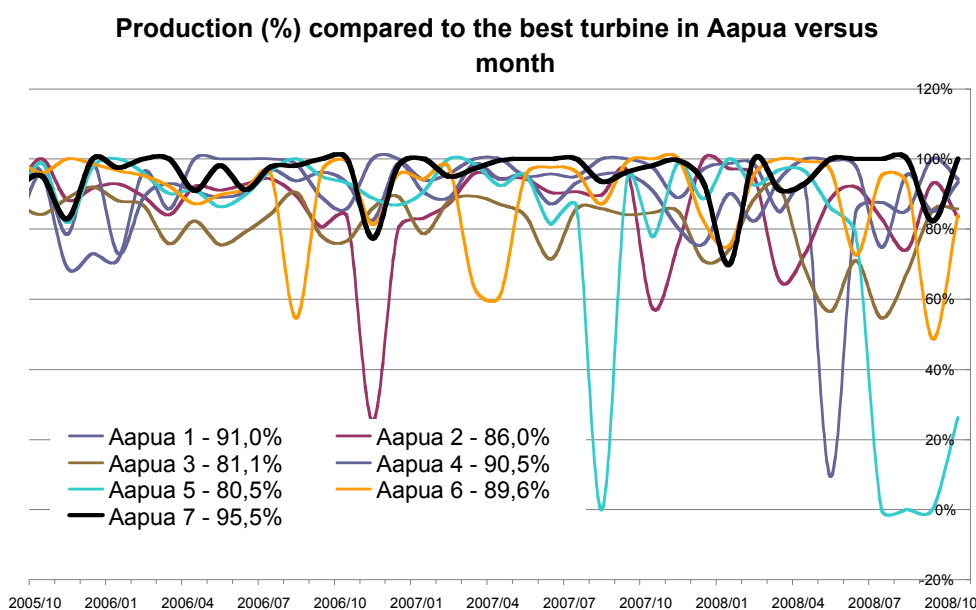


Figure 30: Relative monthly production compared to the best producing turbine each month.

Three of the turbines are owned by Danes whereas four are owned by a majority of Swedes.

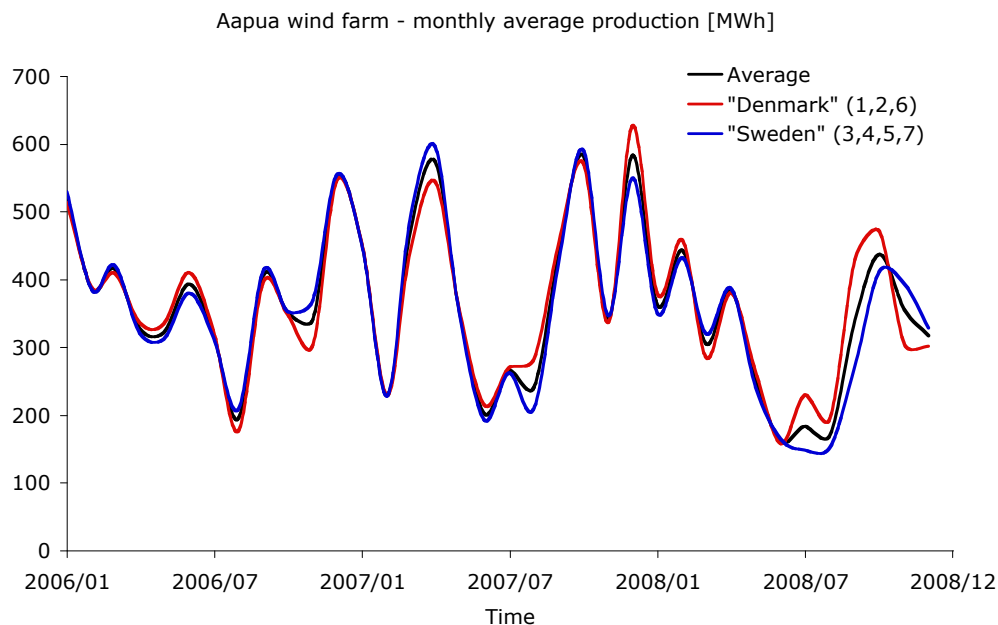


Figure 31: Monthly average energy production per turbine from all seven turbines and the “Danish” and “Swedish” parts.

The monthly production per turbine is quite similar for the two groups.

The equivalent data has been analyzed for Råshön.

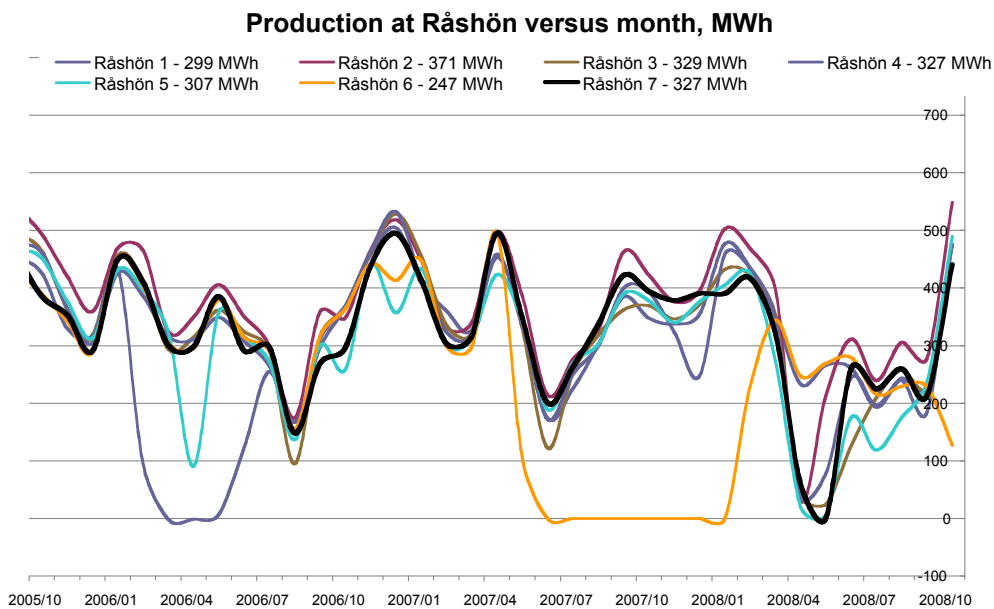


Figure 32: Monthly energy production at Råshön and average production per month.

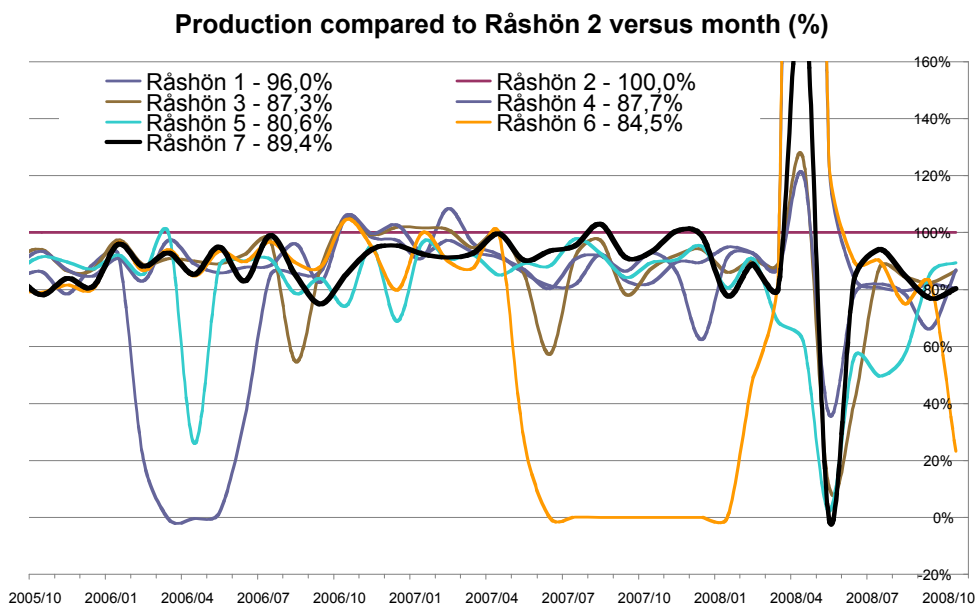


Figure 33: Relative monthly production compared to Råshön 2.

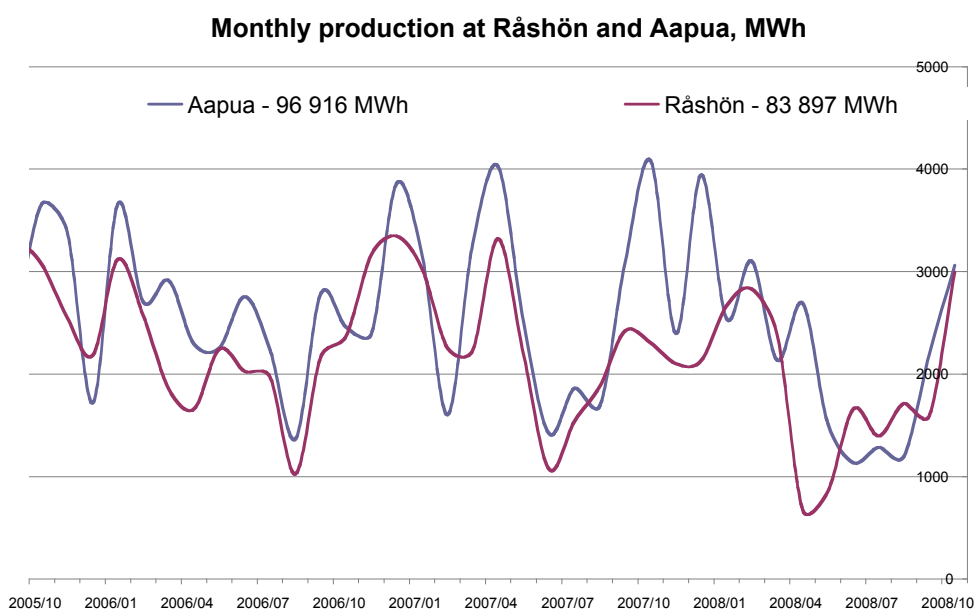
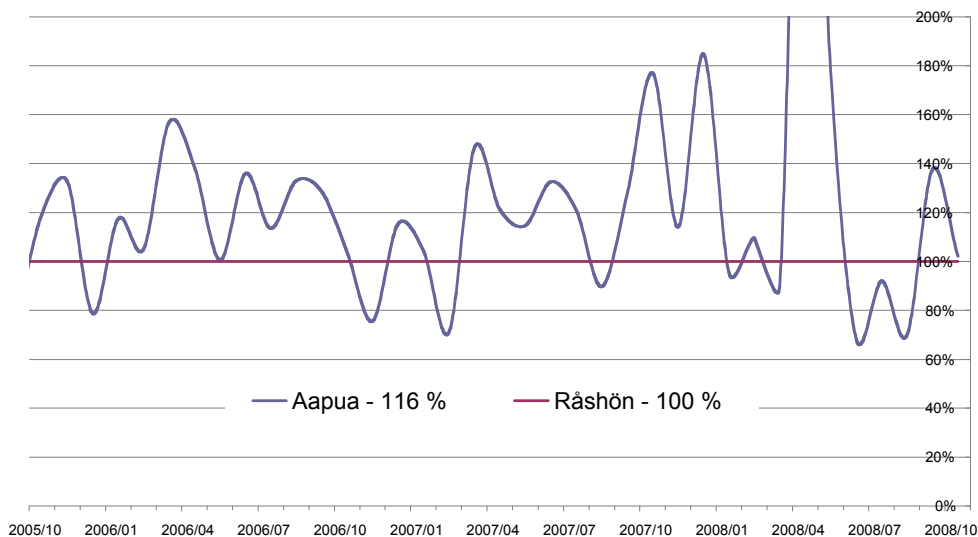


Figure 34: Monthly accumulated energy production at Råshön and Aapua [MWh].

Aapua monthly production ratio based on production at Råshön



Aapua & Råshön: Monthly energy production ratio based on average monthly production

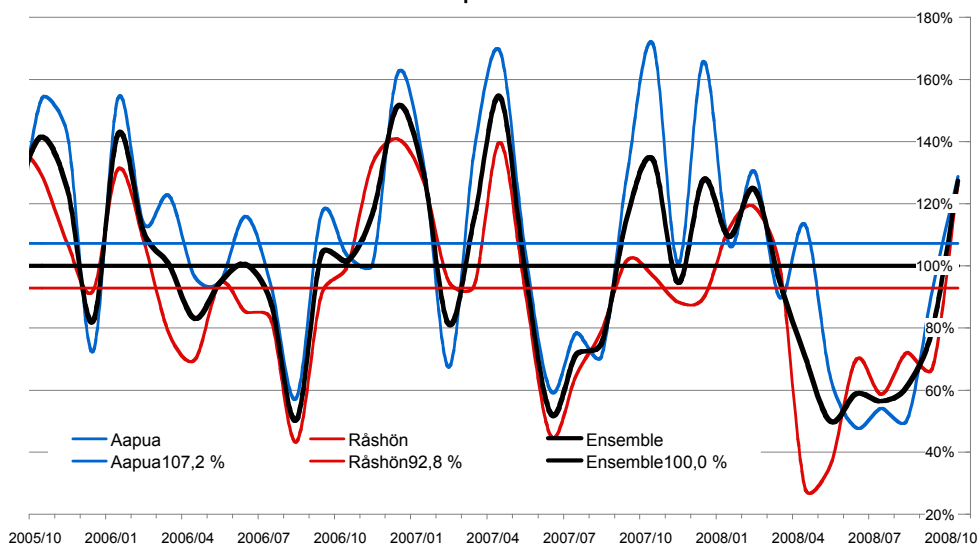


Figure 35: Relative monthly production in Aapua relative ditto at Råshön.

Monthly energy production from Aapua and Råshön have been compared. The production from Aapua has been found to be 16% higher compared to Råshön. The influence of icing on the energy production can not be determined by evaluating the monthly production. We know, however, that both wind farms are effected by icing.

10 Appendix 4 – Air density corrections

This chapter was written as part of the evaluation of the performance of a V90-2MW wind turbine in Sveg⁸.

Air density variations were to be applied on the measured data to enable a comparison with the nominal free stream wind speed and power curve.

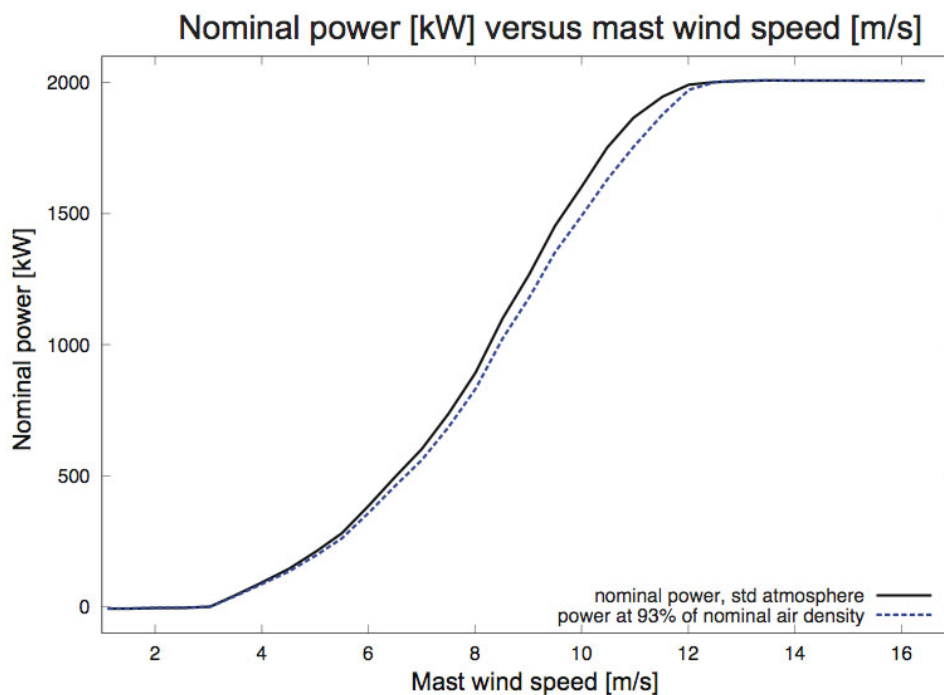


Figure 36: Assumed power performance curve at 93% air density, which happens to be the air density at hub height for the wind turbine in Sveg in the standard atmosphere.

10.1 Atmospheric pressure and temperature

The density corrections are calculated based on analyzed weather data from SMHI's NWP⁹ forecast system HIRLAM¹⁰. Figure 37 shows the atmospheric

⁸ Ronsten G, "Influence of Icing on the Power Performance of a V90-2MW Wind Turbine, Brickan (Brickan), Sveg, Härjedalen, Sweden" as published in an Appendix to Persson P-E, "Mätningar av nedisning i en hög mast", Elforsk rapport 09:24, 2009

⁹ NWP - Numerical Weather Prediction

¹⁰ HIRLAM - High Resolution Limited Area Model

pressure 100 m above the model ground during three and a half winter seasons.

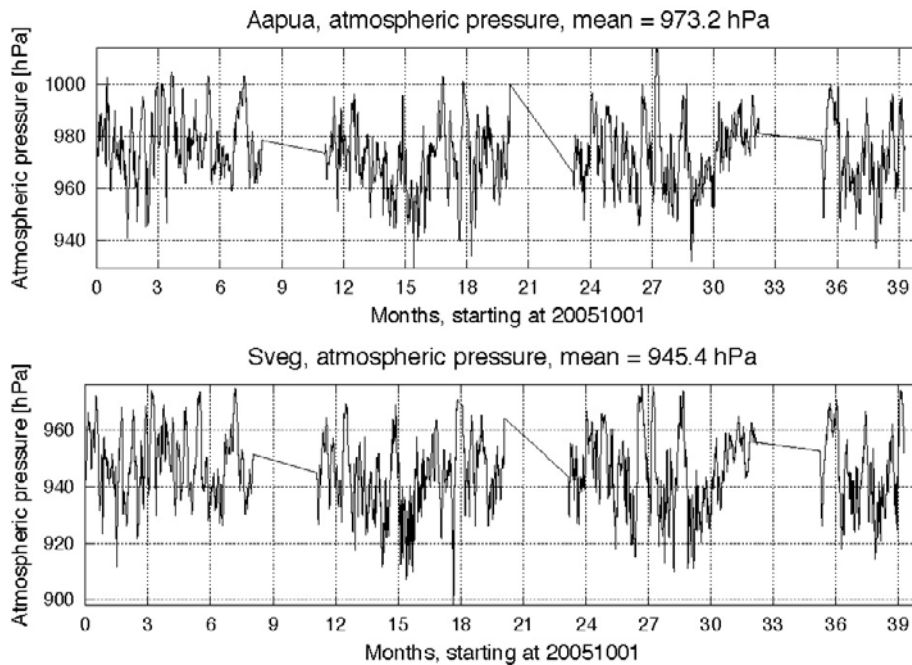


Figure 37: Atmospheric pressure versus time at Aapua and Sveg.

The air pressure is, due to the elevated locations, lower than the standard atmosphere's 1013.25 hPa. The calculated averages are only representative for the winter months when data shown in Figure 37 and Figure 38 are available.

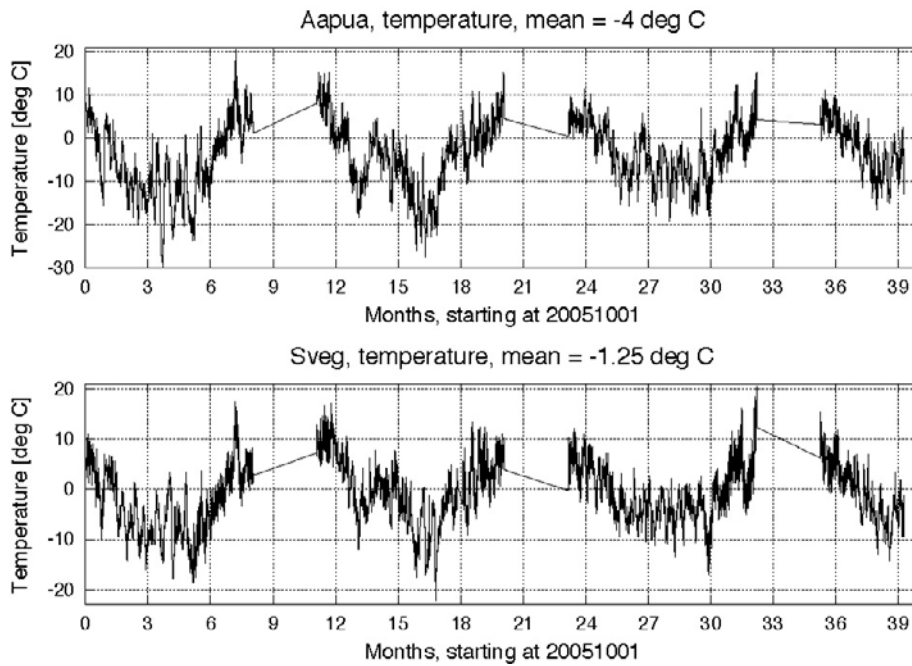


Figure 38: Temperature versus time at Aapua and Sveg.

The average temperature at both locations is significantly lower than the standard atmosphere's 15°C.

10.2 Air density

The corresponding normalized air density is shown in Figure 39.

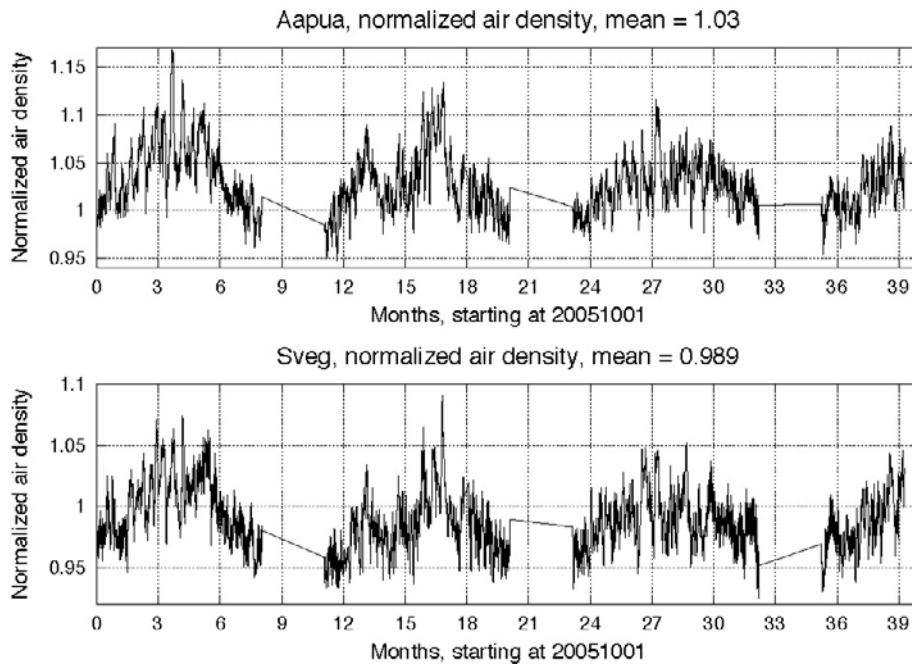


Figure 39: Normalized air density versus time at Aapua and Sveg.

For a wind turbine with active power control, the wind speed is to be adjusted with respect to changes in air density¹¹:

$$V_n = V_{10\min} \left(\frac{\rho_{10\min}}{\rho_0} \right)^{1/3}$$

The density variations in Sveg are close to the standard atmosphere. For variations in normalized air density (the expression within brackets in the equation) between 0.95 and 1.05, the normalized wind speed modification is in the order of less than $\pm 2\%$. The power variation due to this difference can be in the order of 10%.

¹¹ IEC 61400-12-1, Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines, Edition 1.0 2005-12

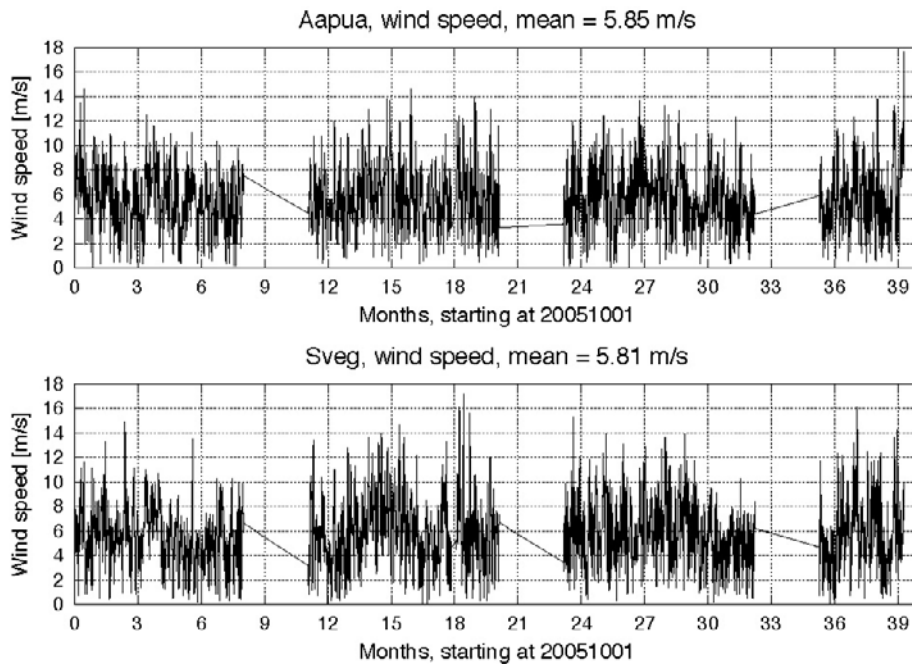


Figure 40: Average wind speeds versus time at Aapua and Sveg.

The calculated wind speeds can be assumed to be significantly too low as the energy production at Aapua is significantly higher than it would have been using the above data. In fact, a number of the wind turbines in Aapua have reached the top-10 list in capacity factor in Sweden both during 2006 and 2007¹².

The density based wind speed correction is not assumed to be affected by a presumably too low wind speed from Hirlam.

10.3 Conclusion regarding air density correction

Icing will in most cases cause a degradation of the power performance of a wind turbine. The issue under investigation is whether density corrections are necessary to detect icing?

As the effect of significant icing can be assumed to be larger than, say 15%, and the influence from density variations have been shown to be in the order of 10%, there's no urgent need to apply density corrections to the measured wind speeds.

A threshold of 85% compared to nominal power is proposed to be used as threshold to detect icing. Icing can also be detected by analyzing the 1P content of the frequency spectra. Either method, or a combination of both, can be used to activate an anti-icing system.

¹² Ny Teknik, <http://nyteknik.se/>, search for Aapua, Dec 19, 2008

11 Appendix 5 - Does a de-icing system help?

The E-70 turbines at Långå were equipped by de-icing systems after the first winter season. The following figures show the normalized energy production from a few neighbouring wind farms and a wind turbine on Digerberget.

Ref. nr.	Turbine	Municipality	Manufacturer	Model	Power [kW]	H [m]	D [m]
699	Digerberget	Härjedalen	NEG Micon	NM72C	1500	62	72
346	Rodovålen1a	Härjedalen	Nordex	600kW	600	46	43
347	Rodovålen 2	Härjedalen	Bonus	Mk IV	600	40	44
348	Rodovålen 3	Härjedalen	NEG Micon	750kW	750	50	44
678	Rodovålen1b	Härjedalen	Vestas	V52-850	850	55	52
821	Långå 1	Härjedalen	Enercon	E-70-2000	2000	85	70
822	Långå 2	Härjedalen	Enercon	E-70-2000	2000	85	70
823	Långå 3	Härjedalen	Enercon	E-70-2000	2000	85	70
824	Långå 4	Härjedalen	Enercon	E-70-2000	2000	85	70
825	Långå 5	Härjedalen	Enercon	E-70-2000	2000	85	70
777	Råshön 1	Krokom	Vestas	V82/1500	1500	78	82
778	Råshön 2	Krokom	Vestas	V82/1500	1500	78	82
779	Råshön 3	Krokom	Vestas	V82/1500	1500	78	82
780	Råshön 4	Krokom	Vestas	V82/1500	1500	78	82
781	Råshön 5	Krokom	Vestas	V82/1500	1500	78	82
782	Råshön 6	Krokom	Vestas	V82/1500	1500	78	82
783	Råshön 7	Krokom	Vestas	V82/1500	1500	78	82

Table 8: Turbines in the neighbourhood of Råshön.

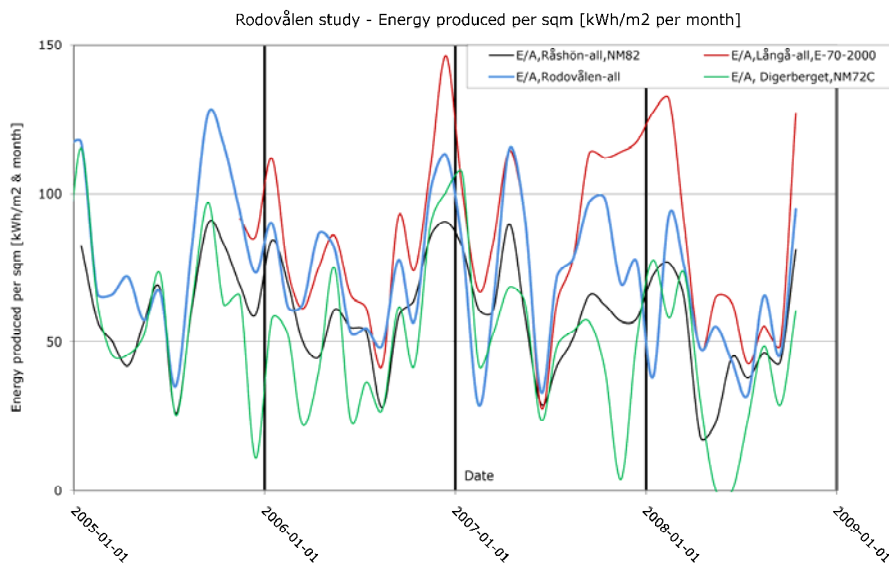


Figure 41: Monthly energy production per sqm at Råshön and three “nearby” locations.

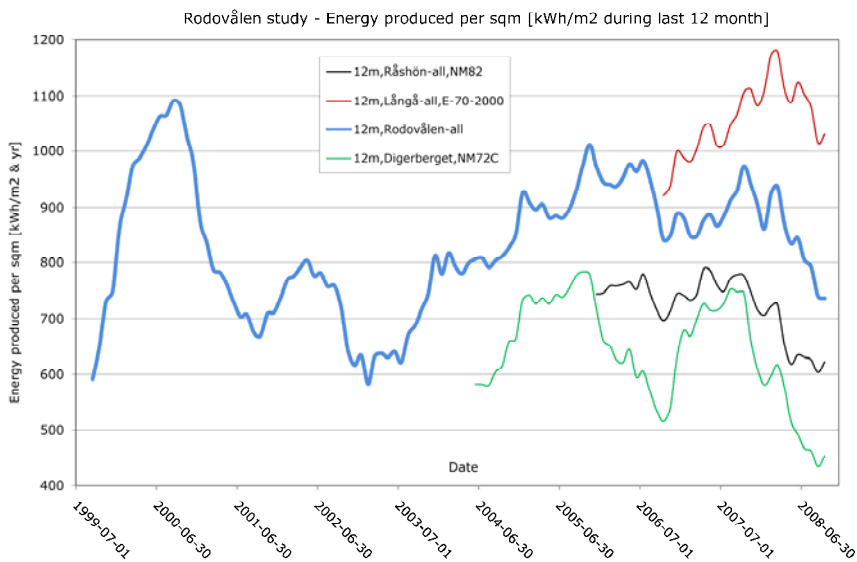


Figure 42: Moving average 12-monthly energy produced per sqm at Råshön and three “nearby” locations.

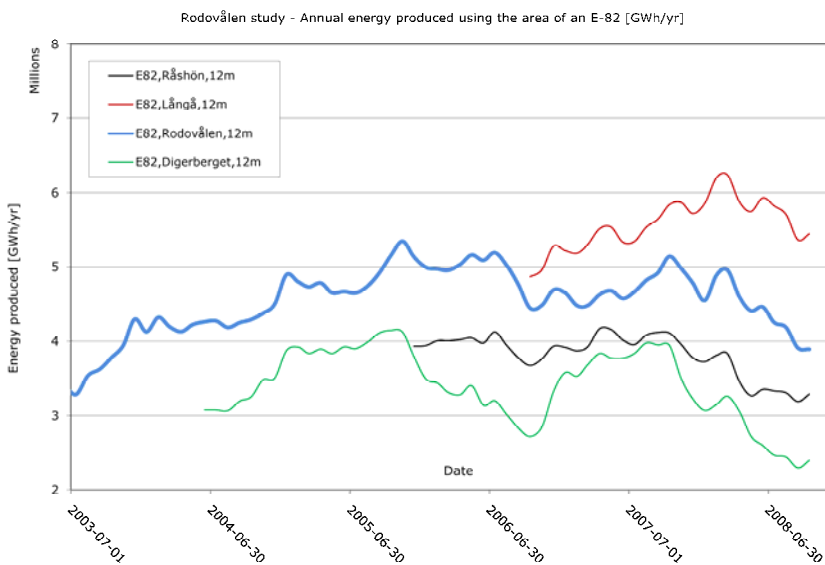


Figure 43: Annual energy moving average using the area of an E-82 at Råshön, Långå, Rodovålen and Digerberget.

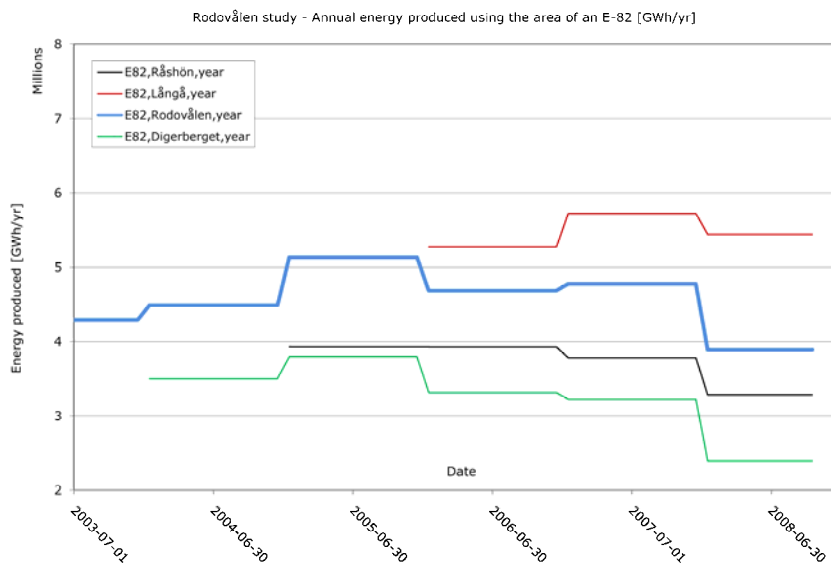


Figure 44: Annual energy produced using the area of an E-82 at Råshön, Långå, Rodovålen and Digerberget.

Figure 44 indicates that the de-icing systems at Långå may increase the energy production.

12 Appendix 6 - Icing measurements in Bliekevare and Sveg

Icing measurements have also been carried out in Bliekevare and Sveg.

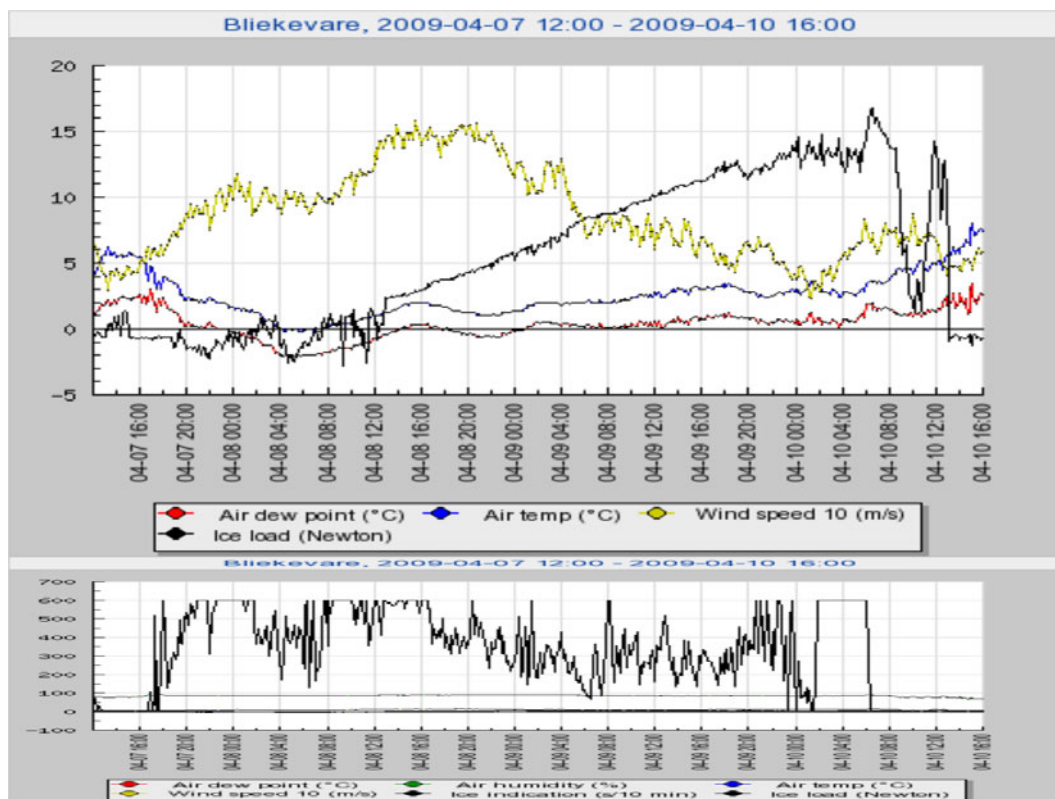


Figure 45: Icing measurements at Bliekevare April 7 to 10, 2009.

In April 2009, a new icing measurement station was installed on turbine #13 in Bliekevare. This turbine is equipped with an anti-icing system from MW-Innovation/Kelly Aerospace Thermawing.

The data shown is from 2009-04-07 to 2009-04-10 when the HoloOptics T23 ice detector indicated icing at an early stage as the temperature was falling. The signal from the ice load sensor; Saab Security's "IceMonitor", was initially unstable and didn't indicate a significant ice load until 18 hours after the first ice detection.

It is assumed that this was a wet snow icing event. On such occasions, the vertical ice load sensor can't be expected to measure icing unless the wind speed is high. The temperature measured is likely to be a few degrees too high, an assumption which has been verified by Saab Security. Another issue with the thermometer used in Bliekevare is, due to the heated sensor, its inability to correctly measure the temperature at wind speeds below 4 m/s.

The icing measurements in Sveg are unique as icing has been measured versus height at several levels. The data has been previously presented at EWEC 2009¹³.

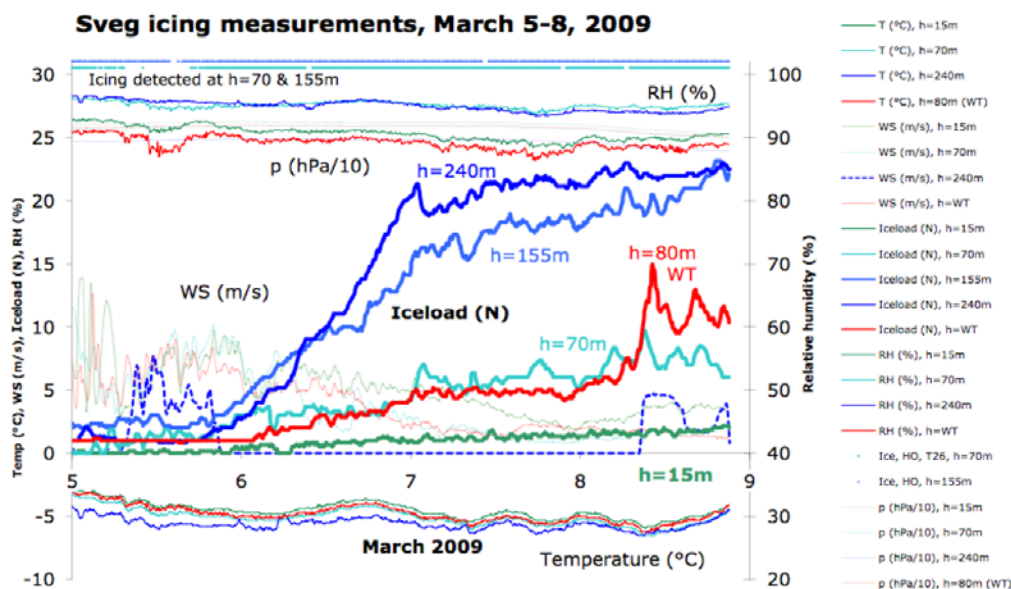


Figure 46: Icing measurements in Teracom's telecommunication mast in Sveg and on the neighbouring V90-2MW wind turbine, March 5 to 8, 2009.

The amount of ice measured at 15 m is significantly lower than the ice measured higher up. The ice loads measured at $h=70\text{m}$ and $h=80\text{m}$ are similar whereas the ice loads measured at $h=155\text{m}$ and $h=240\text{m}$ are significantly higher.

An ice load of 10 N equals 1 kg on the 0.5 m long test cylinder.

A wind turbine will catch icing up to the top of the rotor disk. Consequently, the ice load measured on the nacelle will not always be representative for the icing conditions encountered by the wind turbine blades.

These truly unique icing measurements will be used for comparisons with icing model calculations carried out within COST Action 727 to be presented at IWAIS 2009 in Andermatt, Switzerland on Sep 8-11.

¹³ Ronsten G., Dierer S., Nygaard B.E.K., Makkonen L., Homola M., "Measures needed for the successful development of wind energy in icing climates", EWEC 2009, March 2009.

13 Appendix 7 – List of reports and papers from IEA Task 19

[1] Laakso T. et al, "Expert Group Study on Recommendations for Wind Energy Projects in Cold Climates, Edition 2009". To be published in June 2009 on <http://arcticwind.vtt.fi/>.

[2] Laakso T. et al, "State-of-the-art of wind energy in cold climates, Edition 2009", To be published in June 2009 on <http://arcticwind.vtt.fi/>.

[3] Laakso T. et al, "Task 19 - Wind Energy in Cold Climates, Final Report 2.4.2009", Submitted to and accepted by The Executive Committee of the International Energy Agency Programme for Research, Development and Deployment of Wind Energy Conversion Systems. (Administrative, not intended to be published)

[4] Ronsten G., "Mapping of Icing for Wind Turbine Applications. A Feasibility Study", Vindforsk, report V-158, Sweden, November 2008

http://www.vindenergi.org/Vindforskrappporter/elforsk%20rapport%2008_40%20V-158%20feasibility%20study.pdf (6 MB)

[5] Laakso T., IEA RD&D Wind Task 19 – Wind Energy in Cold Climates, Task Extension Proposal, 2.4.2009. Submitted to and accepted by The Executive Committee of the International Energy Agency Programme for Research, Development and Deployment of Wind Energy Conversion Systems. (Administrative, not intended to be published)

[6] Laakso T. et al, "Wind Energy in Cold Climates IEA Task 19 – Outlook 2010, abstract submitted to IWAIS-2009, COST-727 Action Final Workshop, available at <http://iwais.org/>.

[7] Ronsten G., "Influence of Icing on the Power Performance of NM82-1.5 MW Wind Turbines, Aapua, Övertorneå, Sweden, October 2005 – March 2009", Elforsk report V-XXX to be published in June 2009, <http://www.vindenergi.org/rapporter.htm>

[8] Baring Gould I. et al, IEA WIND RD&D Task 19 - Wind Energy in Cold Climates, EWEC 2009, Marseille, March 2009, <http://www.ewec2009.info/index.php?id=73> (abstract, access to the report and poster requires non-public URL)

IEA Task 19 and COST 727 posters submitted to EWEC 2009:

http://windren.se/DIV/EWEC2009_Task19_PO98_v3.pdf (1.1 MB)

http://windren.se/DIV/EWEC2009_COST727_PO130_v3.pdf (1.6 MB)

IEA Task 19 and COST 727 papers submitted to EWEC 2009:

http://windren.se/DIV/IEAT19_EWEC2009_paper_v1.pdf (0.6 MB)

http://windren.se/DIV/EWEC2009_COST727_Paper_v1.pdf (1.0 MB)

[9] Baring Gould I. et al, "Wind Turbines in Cold and Icing Climates, an R&D and Market Review", DEWEK 2008, Bremen, Germany, November 2008

- [10] Wallenius T., "The Effect Of Icing On Energy Production Losses Of Wind Turbines With Different Control Strategies", VTT Technical Research Centre Of Finland, Finland, DEWEK 2008, Bremen, Germany, November 2008
- [11] Cattin R., "An Improved Approach For The Determination Of In-Cloud Icing At Wind Turbine Sites", Meteotest, Switzerland, DEWEK 2008, Bremen, Germany, November 2008
- [12] Homola M., "Experiences With Icing From Nygårdsfjell Wind Park", Narvik University College, Norway, DEWEK 2008, Bremen, Germany, November 2008
- [13] A Cost Action 727 Study Of How To Increase The Profitability Of Wind Energy In Icing Climates Göran Ronsten, WindREN AB, Sweden, DEWEK 2008, Bremen, Germany, November 2008
- [14] Peltola E. et al, "R&D and Market Review of Wind Turbines in Cold and Icing Climates. A Report from the IEA Wind Task 19, Wind Energy in Cold Climates", presentation at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/06_Peltola_Winterwind_2008.pdf
- [15] Durstewitz M., Wind power forecast accuracy under icing conditions. General approach, practical applications and options for considering effects of wind turbine icing, ISET, Kassel, presentation at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/17_Durstewitz_Winterwind_2008.pdf
- [16] Baring-Gould I. et al, "Wind-Diesel Power Systems, Experiences and Applications", presentation at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/18_BaringG_Winterwind_2008.pdf
- [17] Cattin R. et al, Alpine Test Site Gu.tsch, presentation at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/21_Cattin_Winterwind_2008.pdf
- [18] Lacroix A., "Cold Climate Issues and Related R&D Regarding Wind Energy in Canada", NRCan, Wind Energy R&D Group Ottawa, Ontario, presentation at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/24_Lacroix_WinterWind_2008.pdf
- [19] Ronsten G., Wind Energy in Cold Climates as a Bridge Between Onshore and Offshore", WindREN AB, poster at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/P09_Ronsten_Winterwind_2008.pdf
- [20] Laakso T. et al, "Wind energy production in cold climate -15 years ahead -part 1", VTT Technical Research Centre of Finland, poster at Winterwind 2008, Norrköping, Sweden, December 2008
http://www.winterwind.se/Winterwind2008/P10_Laakso_Winterwind_2008.pdf
- [21] Horbaty R., "Wind Power Development in the Swiss alps 10 years of experiences, lessons learned and new projects", ENCO Energie-Consulting AG, Switzerland, poster at Winterwind 2008, Norrköping, Sweden, December 2008

http://www.winterwind.se/Winterwind2008/P11_Horbaty_Winterwind_2008.pdf

[22] Peltola E., Huuhtanen R., "Existerande och framtida lösningar", VTT Technical Research Centre of Finland, presentation at Vintervind 2008, Åsele, Sweden, March 2008

<http://www.winterwind.se/Vintervind2008/Esa%20Peltola%20-%20Existerande%20och%20framtida%20l%3%b6sningar%20-%20Vintervind2008.pdf>

[23] Peltola E., Huuhtanen R., "Wind energy production in cold climate some international activities & experience", VTT Technical Research Centre of Finland, presentation at Vintervind 2008, Åsele, Sweden, March 2008

<http://www.winterwind.se/Vintervind2008/Esa%20Peltola%20-%20Wind%20energy%20production%20in%20cold%20climate%20-%20Vintervind2008.pdf>

[24] Ronsten G., Vindkraft i kallt klimat - Internationella erfarenheter och forskningsläget, WindREN AB, presentation at Vintervind 2008, Åsele, Sweden, March 2008

http://www.winterwind.se/Vintervind2008/G%3%b6ran%20Ronsten_WindREN.pdf

[25] Durstewitz M., Wind power forecast in Germany. General approach, practical applications and options for considering effects of wind turbine icing, ISET, Kassel, Germany, presentation at Vintervind 2008, Åsele, Sweden, March 2008

http://www.winterwind.se/Vintervind2008/Michael%20Durstewitz_forecast_icing.pdf