More than 20 years of experience

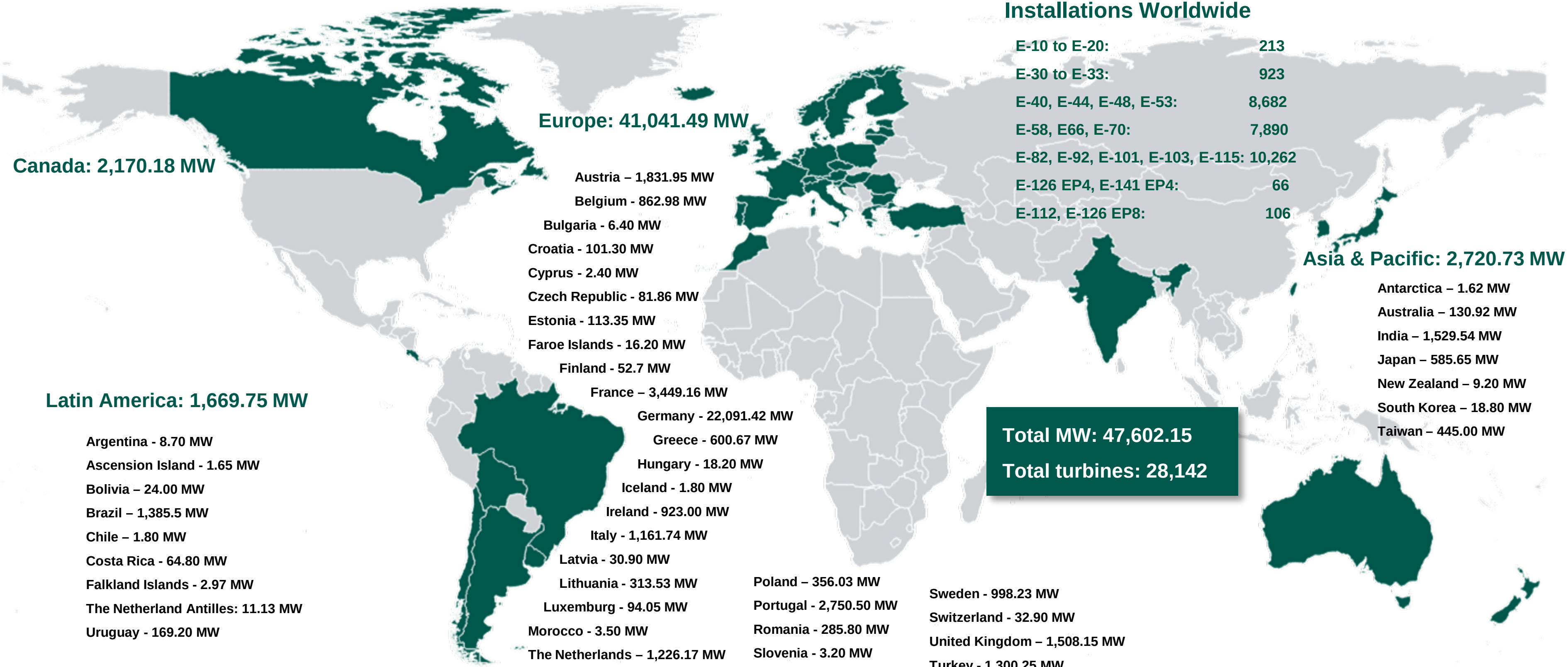
Retrospect and outlook of ENERCON’s cold climate technologies

Winterwind Åre, February 6th, 2018

Sten Barup

ENERCON
ENERGY FOR THE WORLD

ENERCON Installed capacity in December 2017



Installations Worldwide

E-10 to E-20:	213
E-30 to E-33:	923
E-40, E-44, E-48, E-53:	8,682
E-58, E66, E-70:	7,890
E-82, E-92, E-101, E-103, E-115:	10,262
E-126 EP4, E-141 EP4:	66
E-112, E-126 EP8:	106

Canada: 2,170.18 MW

Europe: 41,041.49 MW

Austria – 1,831.95 MW
Belgium - 862.98 MW
Bulgaria - 6.40 MW
Croatia - 101.30 MW
Cyprus - 2.40 MW
Czech Republic - 81.86 MW
Estonia - 113.35 MW
Faroe Islands - 16.20 MW
Finland - 52.7 MW
France – 3,449.16 MW
Germany - 22,091.42 MW
Greece - 600.67 MW
Hungary - 18.20 MW
Iceland - 1.80 MW
Ireland - 923.00 MW
Italy - 1,161.74 MW
Latvia - 30.90 MW
Lithuania - 313.53 MW
Luxemburg - 94.05 MW
Morocco - 3.50 MW
The Netherlands – 1,226.17 MW
Norway - 142.90 MW
Poland – 356.03 MW
Portugal - 2,750.50 MW
Romania - 285.80 MW
Slovenia - 3.20 MW
Spain - 680.25 MW
Sweden - 998.23 MW
Switzerland - 32.90 MW
United Kingdom – 1,508.15 MW
Turkey - 1,300.25 MW

Latin America: 1,669.75 MW

Argentina - 8.70 MW
Ascension Island - 1.65 MW
Bolivia – 24.00 MW
Brazil – 1,385.5 MW
Chile – 1.80 MW
Costa Rica - 64.80 MW
Falkland Islands - 2.97 MW
The Netherland Antilles: 11.13 MW
Uruguay - 169.20 MW

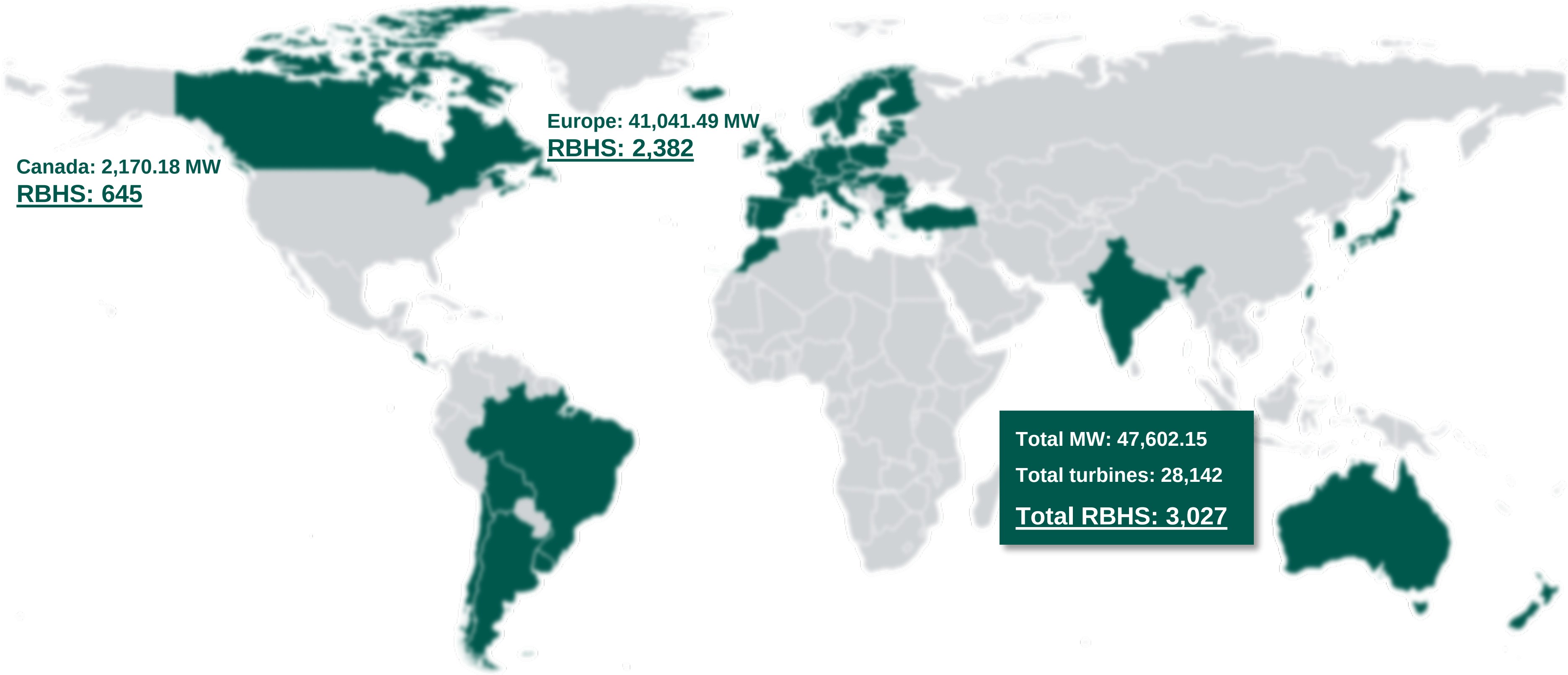
Asia & Pacific: 2,720.73 MW

Antarctica – 1.62 MW
Australia – 130.92 MW
India – 1,529.54 MW
Japan – 585.65 MW
New Zealand – 9.20 MW
South Korea – 18.80 MW
Taiwan – 445.00 MW

Total MW: 47,602.15

Total turbines: 28,142

ENERCON Installed Rotor Blade Heating Systems January 2018



AGENDA

1 Rotor Blade Heating System

Continuous Developments | Important features

2 Ice Detection

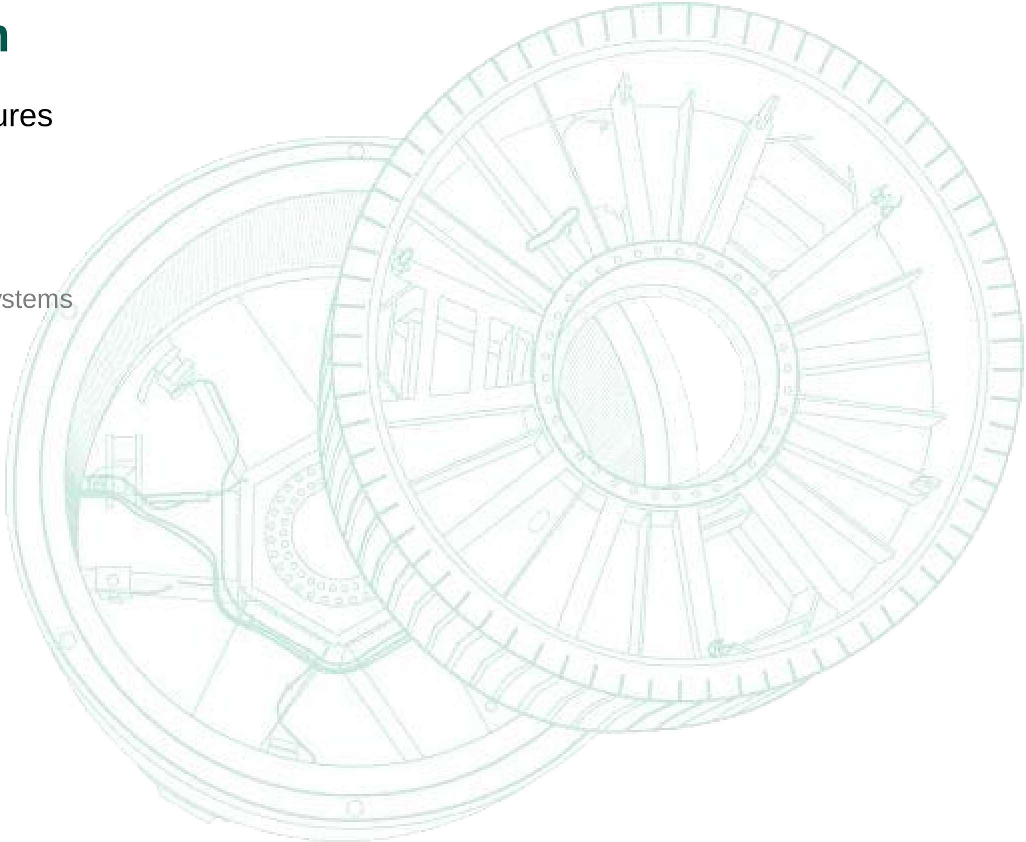
Characteristic Curves | Additional Ice Detection Systems

3 Cold Climate Package

Low Temperature Operation | Mine Raglan

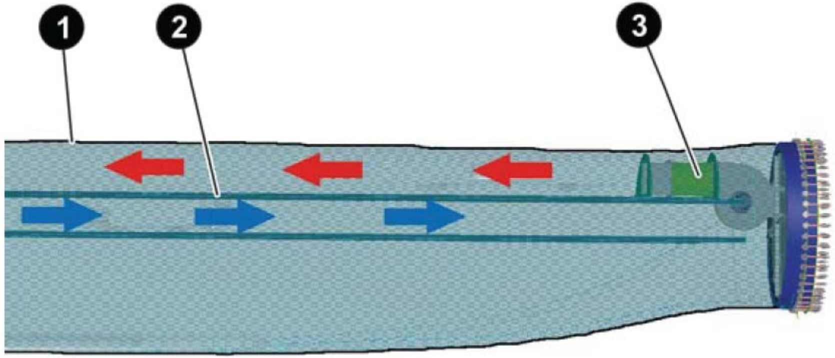
4 Site Assessment and Optimization

Ice Fall/Throw Assessments | Icing Losses



1 I ROTOR BLADE HEATING SYSTEM - Since 1996

- **FIRST PROTOTYPE:** 1996 on an E-40 turbine



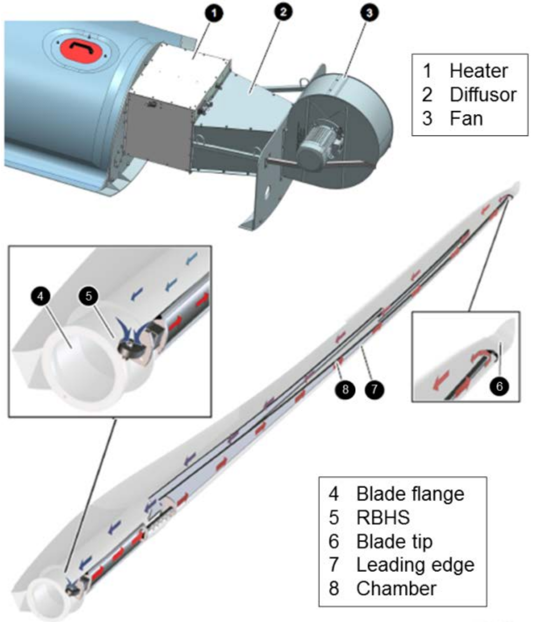
1. Leading edge
2. Main web
3. Heating element with fan

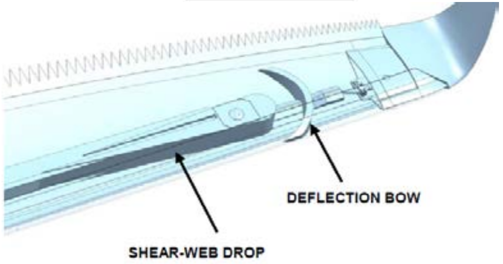
The Rotor Blade Heating System (RBHS) consists of two main parts, a heater and a fan which are both located at the blade flange. The heating elements heat up the air to a maximum of 72°C inside the leading edge chamber and the fan distributes it down to the blade tip.

1 I ENERCON RBHS – Continuous Development

HISTORIC DEVELOPMENTS

- Automated on/off
- New operational modes
- Increased heating power
- Internal flow dynamics
- Sectioned blade
- Integrated heating mat (E-126 EP8)





TURBINE TYPE	WEC RATED POWER	STANDARD NOMINAL POWER RBHS
E-44, E-48, E-53	900, 800, 800 kW	46 kW
E-70 E4	2 / 2.3 MW	70 kW
E-82 E2 - E4	2 / 2.3 / 3 MW	85 kW
E-92	2.35 MW	129 kW
E-103 EP2	2.35 MW	175 kW*
E-101, E-101 E2	3 MW / 3.5 MW	225 kW
E-115, E-115 E2	3 MW / 3.2 MW	225 kW
E-126 EP4	4.2 MW	225 kW
E-141 EP4	4.2 MW	225 kW

* subject to validation

1 I ENERCON RBHS – Features

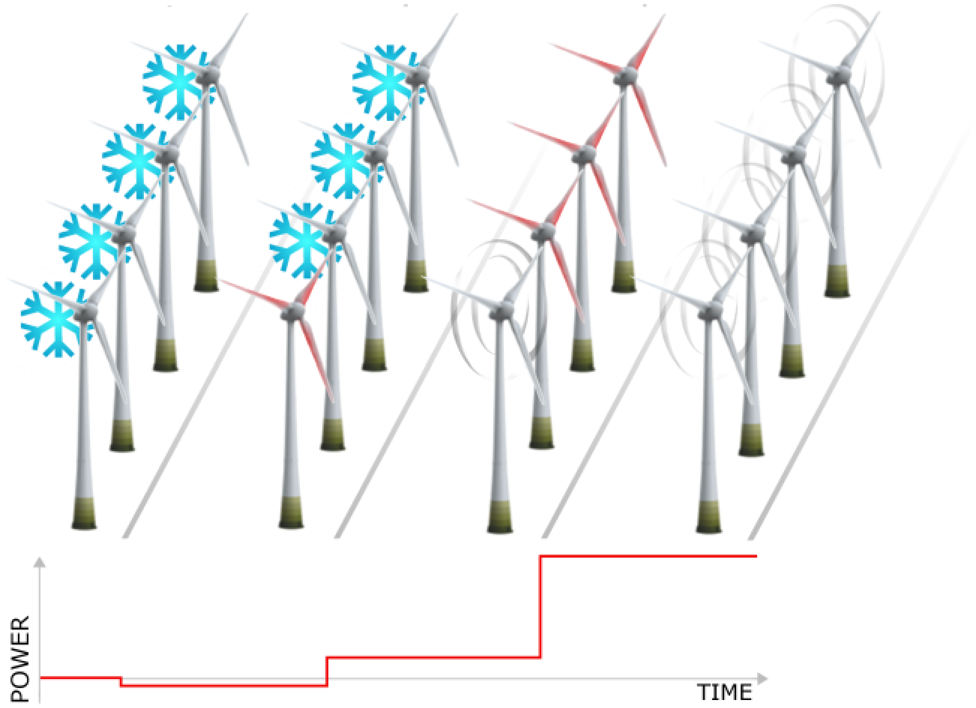
Facing the cold: Griessee (CH) ↑ and Beaupré (CA) ↓

FEATURES

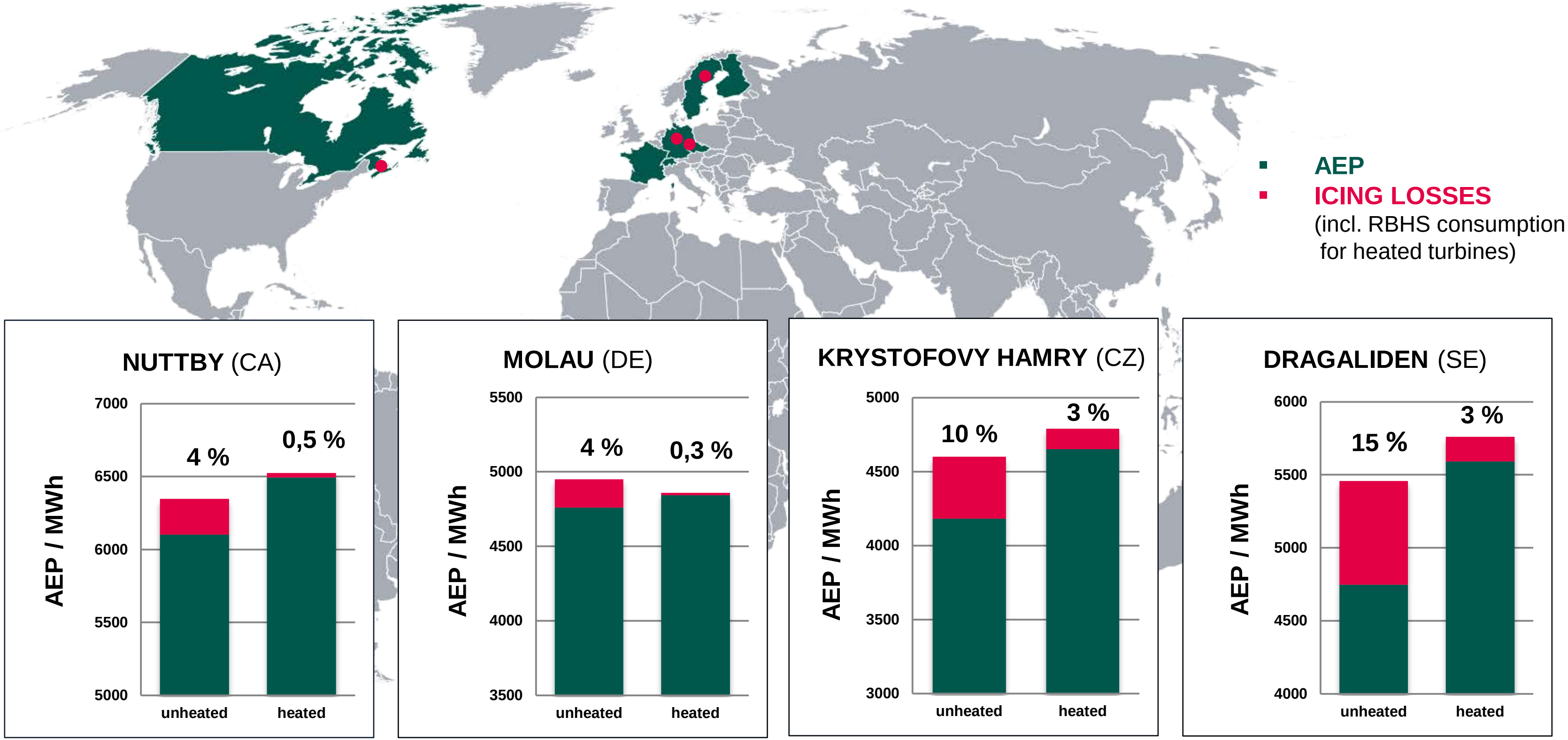
- Proven slip-ring power supply
- Heating all blades in operation or idling
- Favorable blade structure
- All blades designed to make RBHS possible
- No additional lightning risks
- No additional installations in the blade shell
- Easily accessible for maintenance
- Compatible with new anti-erosion layer
- Proven fans, heaters and auxiliaries

LIMIT POWER CONSUMPTION FROM GRID

- Predefine maximum power
- Sequential heating
- Avoid grid penalties
- Grid stability



1 I ENERCON RBHS – Efficiency



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2 I DETECTING ICE USING CHARACTERISTIC CURVES

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For detecting ice on ENERCON turbines, deviations from characteristic curves are monitored for temperatures below 2°C.

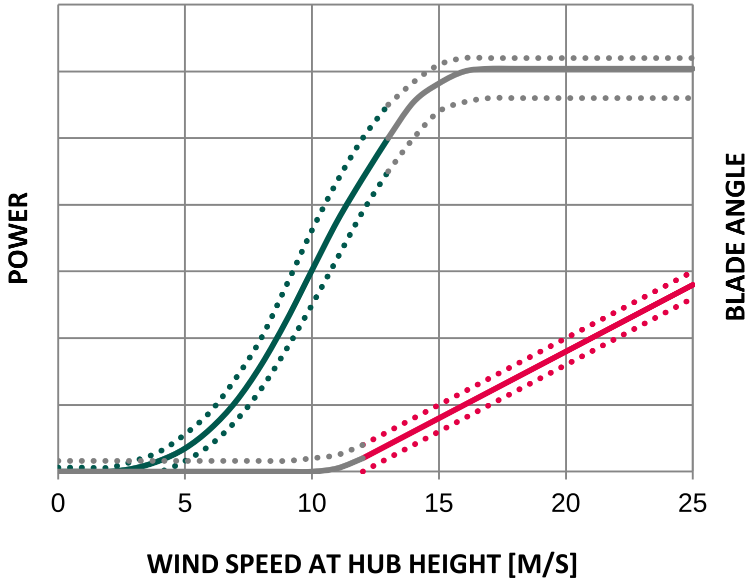
GREEN GRAPH – POWER CURVE METHOD

Deviations from the power curve compared to the current wind speed are detected and registered as ice on the rotor blades.

PINK GRAPH – BLADE ANGLE METHOD

Deviations from the blade angle curve compared to the current wind speed are detected and registered as ice.

<u>Standard for all ENERCON WECs</u>



European patent specification
EP 1 642 026 B1
© 2004 - 2024

2 I ADDITIONAL LABKOTEC® ICE DETECTION – Since 2006

The combination of the Labkotec® ice detector and the ENERCON power curve method extends the working range of the ice detection system because

- Ensures a reliable ice detection during low wind speeds or standstill of the turbine
- Ice throw risk is decreased if the turbine needs to restart after a standstill
- Provides the additional measurement of meteorological icing in order to identify periods when ice growth in hub height is possible
- Potential requirements of authorities to offer an independent and redundant system can be fulfilled

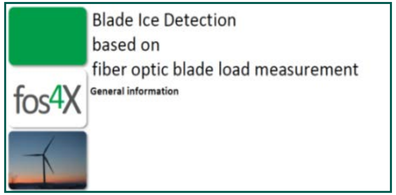
2 I TESTING INNOVATIVE ICE DETECTION SYSTEMS

ENERCON strikes new paths to serve customer requests and requirements from authorities.

EOLOGIX
IMPEDANCE
MEASUREMENT

- Bonding of tags on blade
- Impedance measurement with a planar capacitor
- Self support by solar panel
- Two configurations under development:
  1) Ice detection during operation
  2) Automatic restart

FOS4X
EIGENFREQUENCY
MEASUREMENT



- Measurement with acceleration sensor in the blade
- Transmission via fiber-optic cables
- *Warnings* and *Alarms* with site specific ice mass thresholds optimize the turbine operation under icing conditions

WÖLFEL
EIGENFREQUENCY
MEASUREMENT

- Installation of a structural noise sensor in the blade
- Transmission via screened electric cables
- *Warnings* and *Alarms* with site specific ice mass thresholds optimize the turbine operation under icing conditions

ONGOING VERIFICATION CAMPAIGN!

UNDER DEVELOPMENT!

2 I WIND FARM ICE DETECTION

ADDITIONAL OPTION FOR WIND FARMS :

- Ice detection of predefined percentage of WECs triggers the entire wind farm
- Possible to define the percentage necessary to trigger ice detection of all WECs
- Can be used as additional safety measure at sensitive sites

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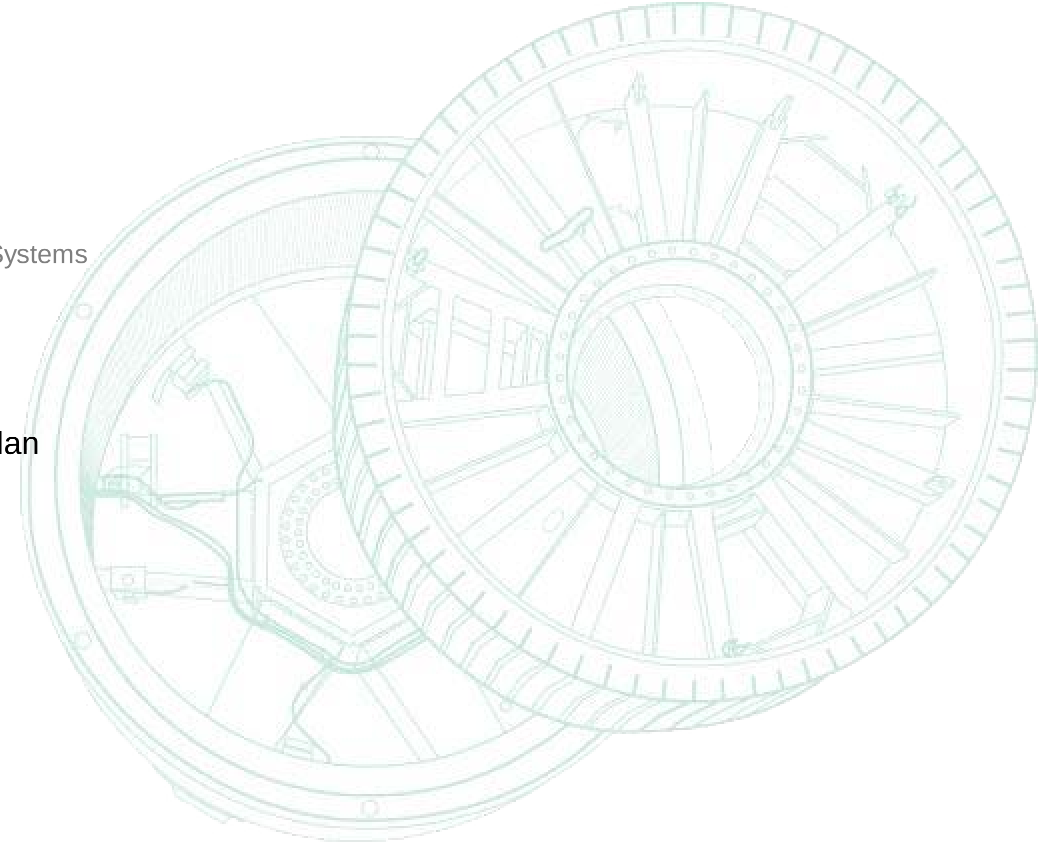

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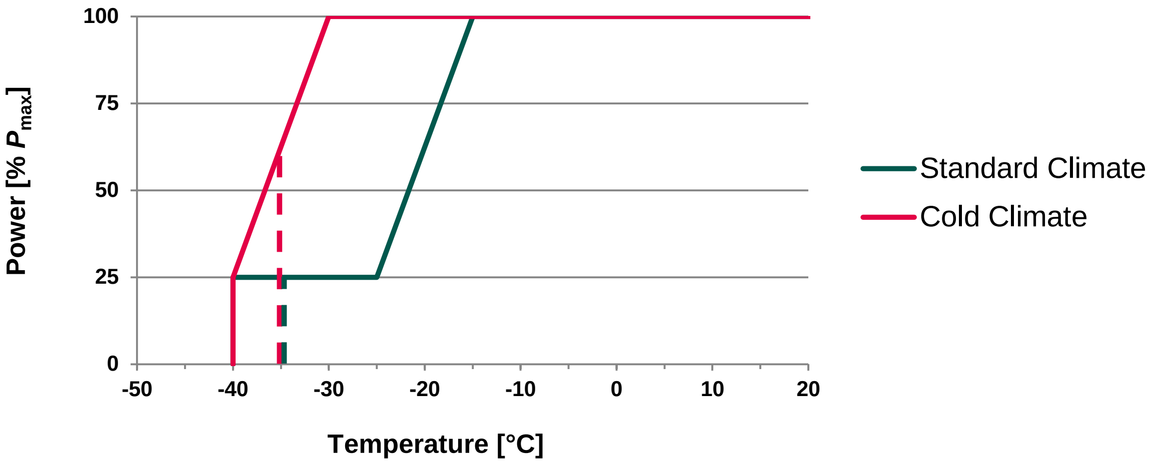
- ENERCON turbines are able to produce energy down to temperatures of -40°C
- Turbines in "Standard Climate" version have a decreased maximum power P for temperatures below -15°C.
- With "Cold Climate" adjustments the rated power P_{max} can be reached until -30°C.

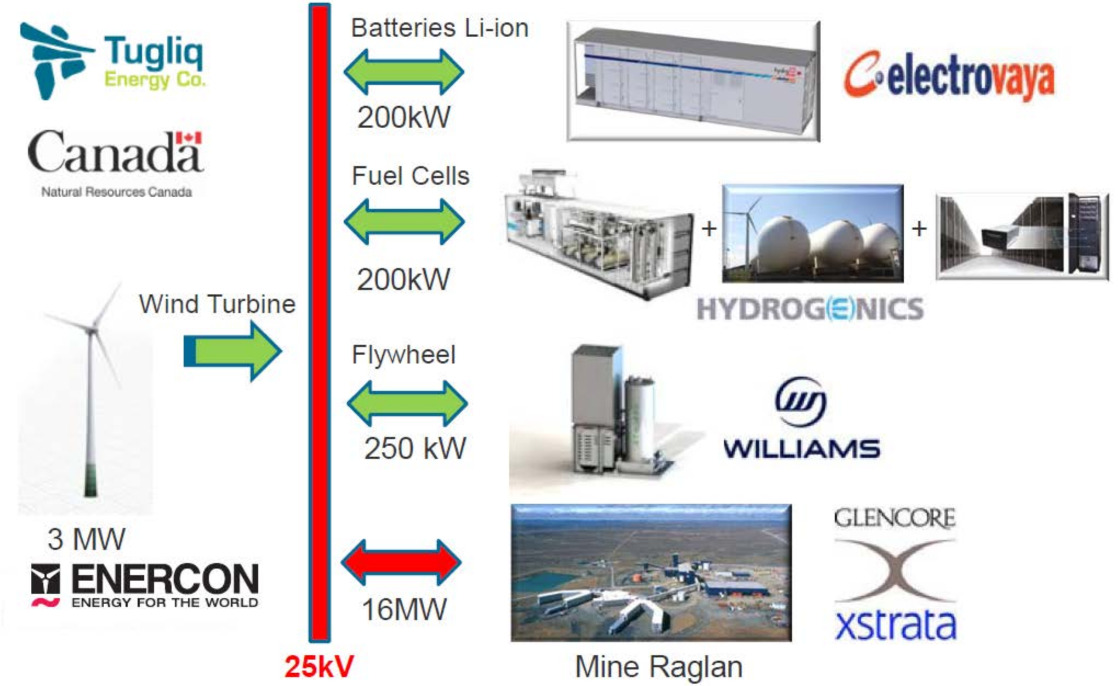


COLD CLIMATE SITE

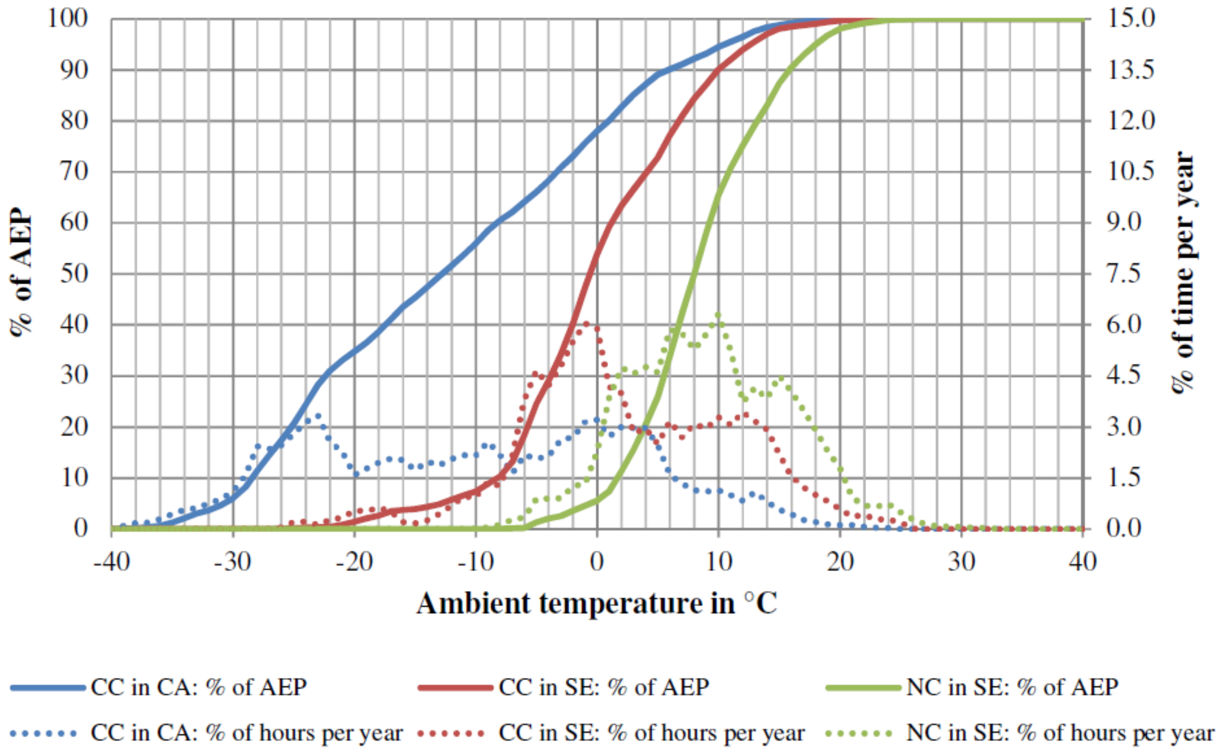
Site with more than nine days per year with temperatures below -20°C for at least one hour

or

yearly average temperature below 0°C



Pictures taken from *ecoENERGY Innovation Initiative Demonstration Component, Project: GC 128296, Public Report*



Production reduction from -15°C without the cold climate package

Maximum production down to -30°C with the cold climate package

The site in CANADA produces **45 % of AEP** at temperatures below -15°C.

Godin, P. and Ogiewa, R. (2016). Operational Experiences with Electricity Generation from Wind Turbines in Challenging Cold Climate Conditions

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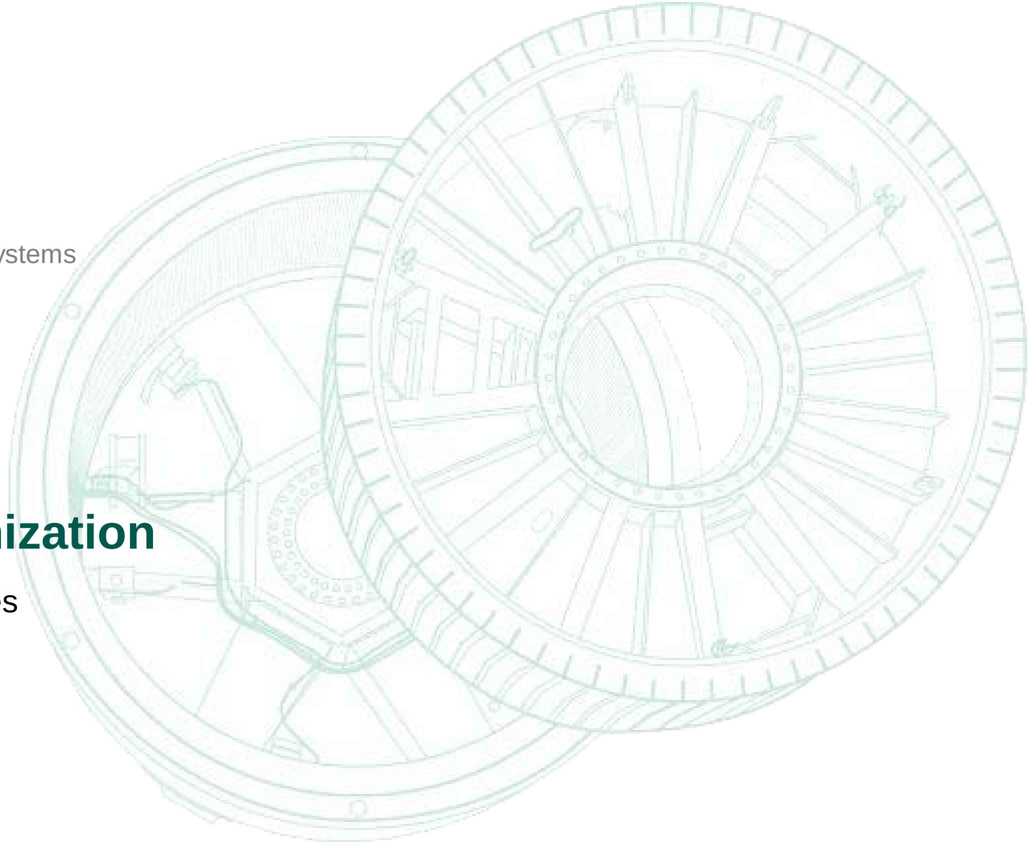


Site Assessment

- Wind measurements in cold climates
- Ice fall/throw risk assessment
- CCP-evaluation
- IEA t19 table – extended with RBHS
- IEA T19IceLossMethod
- Upcoming: Site specific icing losses

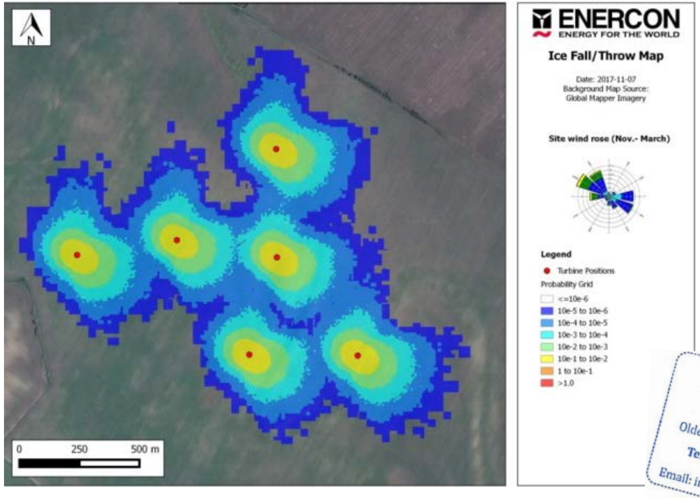
OPTIMIZED SOLUTION FOR YOUR SITE!

IEA ICE CLASS (no.)	MET. ICING (% of year)	INSTR. ICING (% of year)	PRODUCTION LOSS (WITHOUT RBHS) (% of AEP)	PRODUCTION LOSS (WITH RBHS, CONSUMPTION INCL.) (% of AEP)	VALIDATION (Site)
5	> 10	> 20	> 20	> 4	-
4	5 - 10	10 - 30	10 - 25	1.5 - 5	Krystofovy Hamry (CZ)* Dragaliden (SE)* Gabrielsberget (SE)
3	3 - 5	6 - 15	3 - 12	0.5 - 3	St. Brais (CH) Nuttby (CA)
2	0,5 - 3	1 - 9	0.5 - 5	0 - 1.5	Molau (DE)*
1	0 - 0.5	< 1.5	0 - 0.5	< 0.5	-

*** Proved by Meteotest, external consultant from Switzerland**

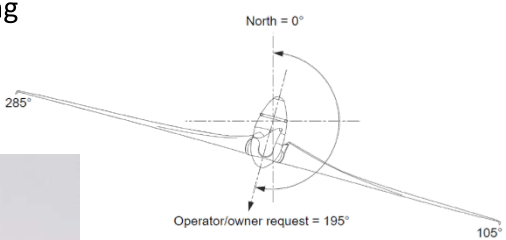
ICE RISK ASSESSMENT

- Model certified model by WindGuard Certification GmbH
- Based on largest ice piece collection campaign



ICE RISK MITIGATION SYSTEMS

- Ice detection and restart strategies
- Nacelle positioning
- Warning lights



TAKING HOME MESSAGES

ROTOR BLADE HEATING

- The ENERCON RBHS uses a hot air system since 1996
- Multiple modes and settings to suit all demands
- The RBHS can lead to significant energy yield gains for IEA class ≥3 sites.
- More than 3,000 RBHS installed

Korpiranta (FI) ↑ and Koskenkylä (FI) ↓

ICE DETECTION

- Proven ENERCON ice detection system using operating characteristics
- Several ice detection alternatives available

SITE ASSESSMENT

- Validated and certified ice fall/throw assessments
- IEA t19 – table extension with losses incl. RBHS

THANK YOU FOR YOUR ATTENTION

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LEGAL NOTICE

Document details

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Note	

Date	**Language**	**DCC**	**Plant / Department**
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Revisions

Rev.	**Date**	**Change**
0	2018-02-02	Document created