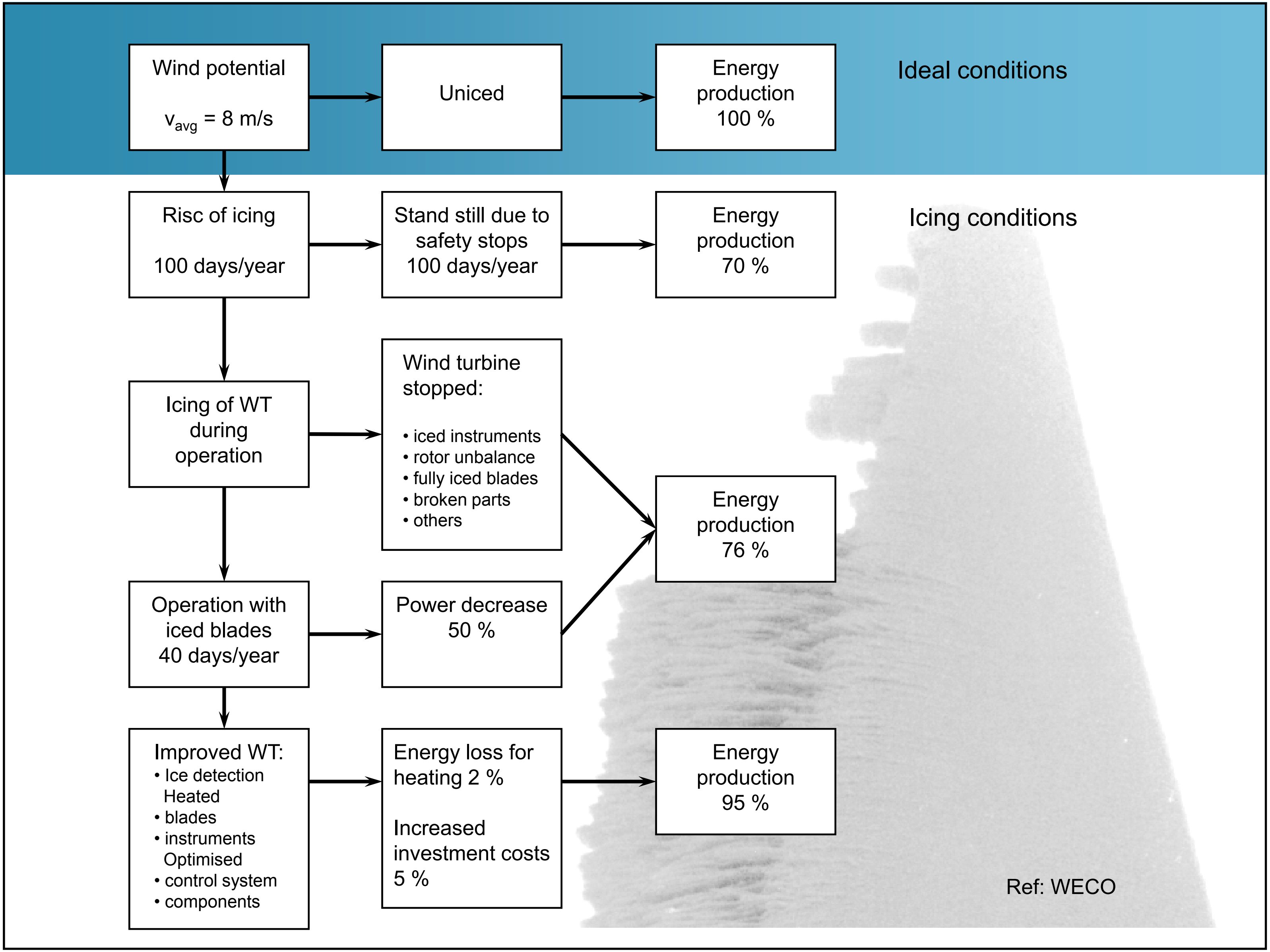
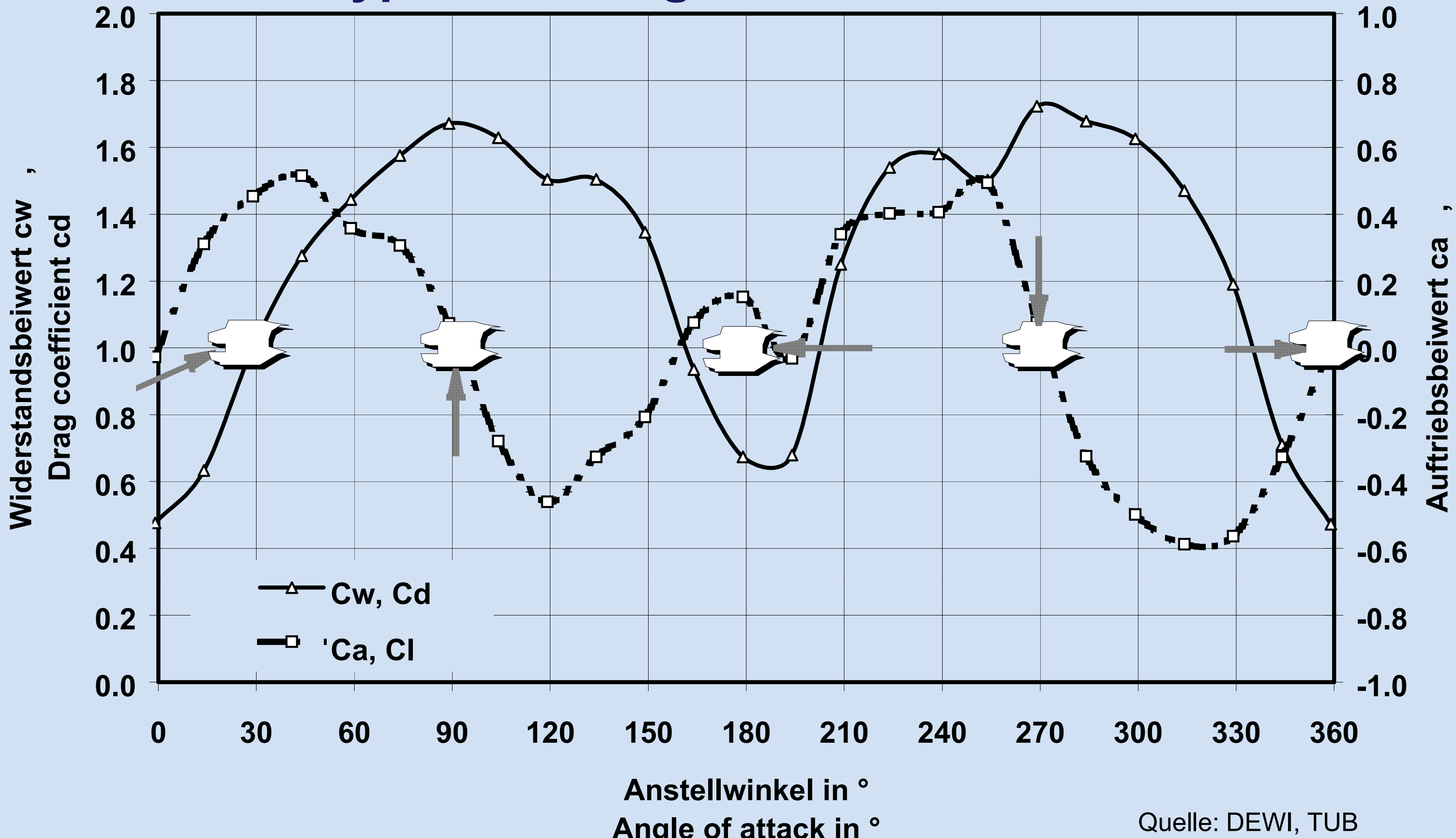

Wind potential
v_{avg} = 8 m/s
Uniced
Energy production 100 %
Ideal conditions
Risc of icing
100 days/year
Stand still due to safety stops 100 days/year
Energy production 70 %
Icing conditions
Icing of WT during operation
Wind turbine stopped:
• iced instruments
• rotor unbalance
• fully iced blades
• broken parts
• others
Energy production 76 %
Operation with iced blades 40 days/year
Power decrease 50 %
Improved WT:
• Ice detection
Heated
• blades
• instruments
Optimised
• control system
• components
Energy loss for heating 2 %
Increased investment costs 5 %
Energy production 95 %
Ref: WECO

Measurements of the aerodynamic coefficients of typical ice fragments of rotor blades



Quelle: DEWI, TUB

Also affecting the cold climate operation:

Turbine type

pitch control
stall control
active stall control

variable speed vs fixed speed

with or without gearbox

Strategies

stop operation
- standstill
- idle
- yaw

operate
- without or
- with heating

Technical equipment

ice - sensors
vibration sensors
cameras

active or passiv
- anti - icing
- de - icing systems

control software

Strategies

Duration of icing:

- no icing ⇨ no strategy necessary
- rare icing ⇨ no heating necessary, ice free instruments and/or ice detectors recommended

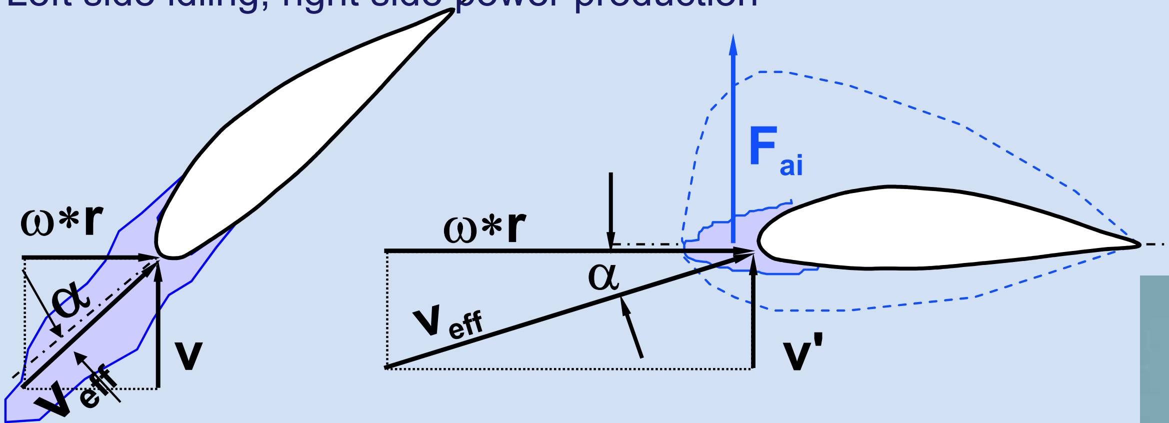
  during icing condition ⇨ stop, idle, or operate WT
- frequent icing ⇨ passive or active de - icing, anti - icing during operation recommended

During icing conditions

keep the wind turbine in operation or cut off automatically?

Icing at leading edge at different modes of operation

Left side idling, right side power production



- v = wind speed
- v' = reduced velocity in the rotor area
- r = local radius
- ω = angular velocity of the rotor
- v_{eff} = effective inflow velocity at the cross section
- α = angle of attack
- F_{ai} = aerodynamic force acting on the ice accretion

Rotor blade iced during idling

Removing ice from the rotor blade

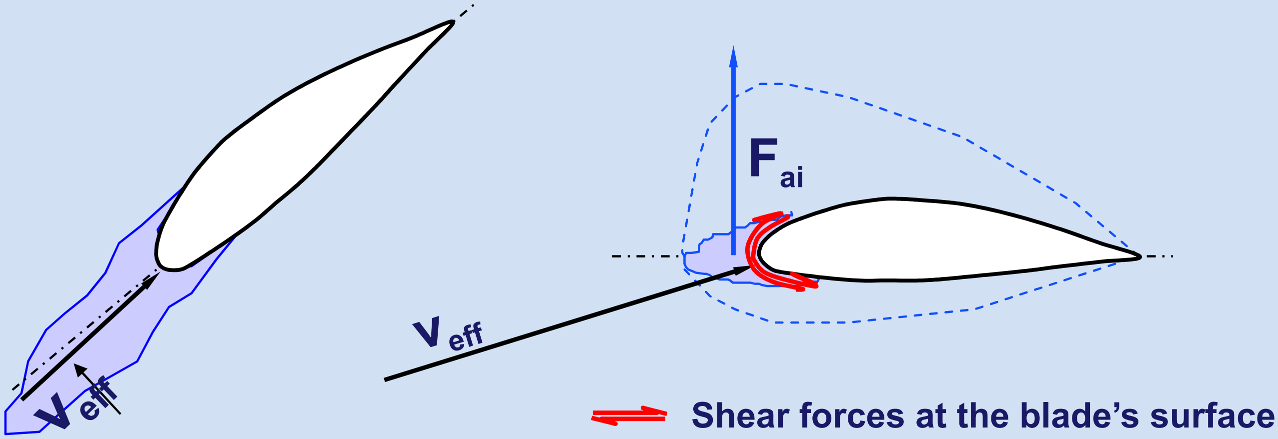
passive systems

special coatings

active systems

heating systems at leading edge
rubber boots at leading edge
heating of the inner part of the blade

Passive systems: e.g. special coating



Advantages

relatively low costs

lightning protection

simple to maintain

complete surface protected

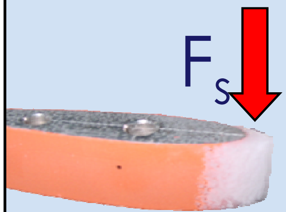
Disadvantages

ice throw during operation

no cleaning at idling

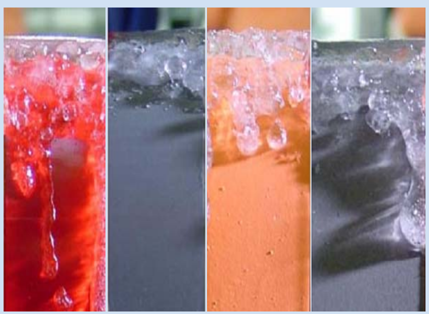
unsymmetrical ice accretion possible

Passive Systems: e.g. special coatings



Air velocity : 18m/s

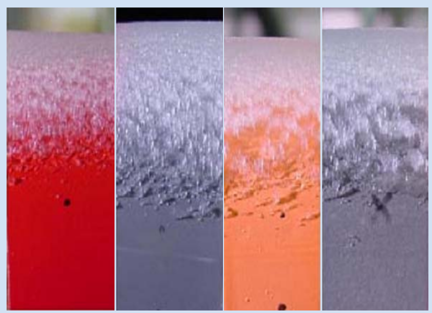
T = -2°



UR WR SWR-A SWR-B

Glaze
transparent

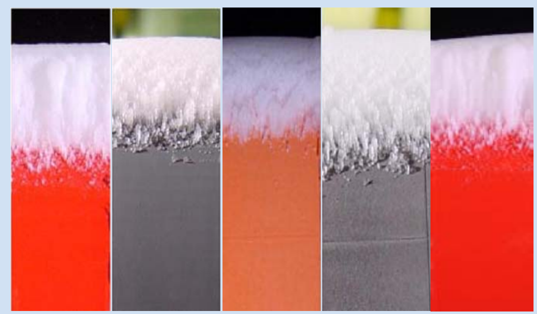
T = -6°



UR WR SWR-A SWR-B

Clear ice
translucent

T = -15°



UR WR SWR-A SWR-B AI

Rime
white opacity

Ref.: Shigeo Kimura

Removing ice from the rotor blade

passive systems

special coatings

active systems

heating systems at leading edge
rubber boots at leading edge
heating of the inner part of the blade

Removing ice from the rotor blade

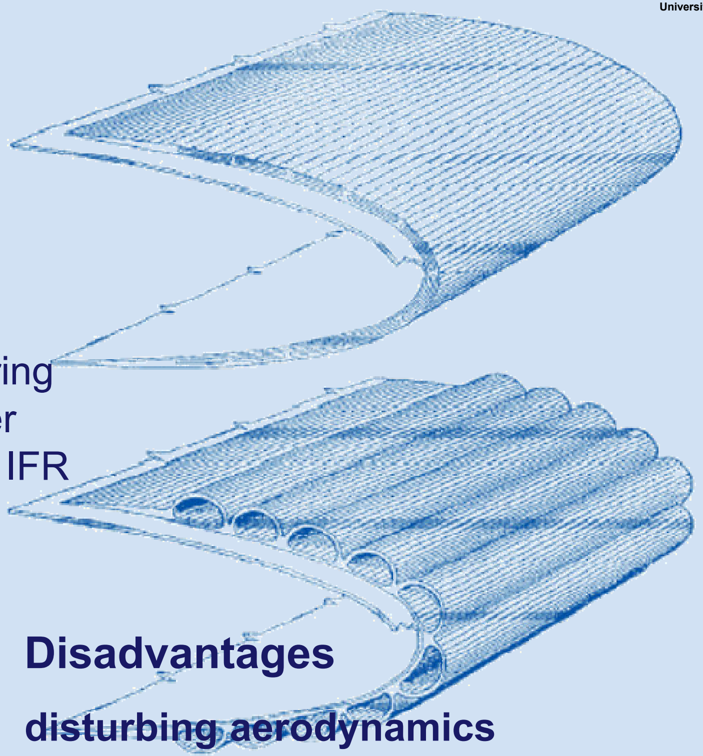
De-icing

Remove collected ice accretion during operation or idling

Anti-icing

Avoid collecting ice accretion during operation or idling

Removing ice from the rotor blade



Mechanical De-icing

Remove collected ice accretion during operation or idling by inflated rubber boots at leading edge (like at small IFR permitted aircrafts)

Advantages

lightning protection

Disadvantages

disturbing aerodynamics

intensive maintenance required

pneumatic systems under centrifugal loads

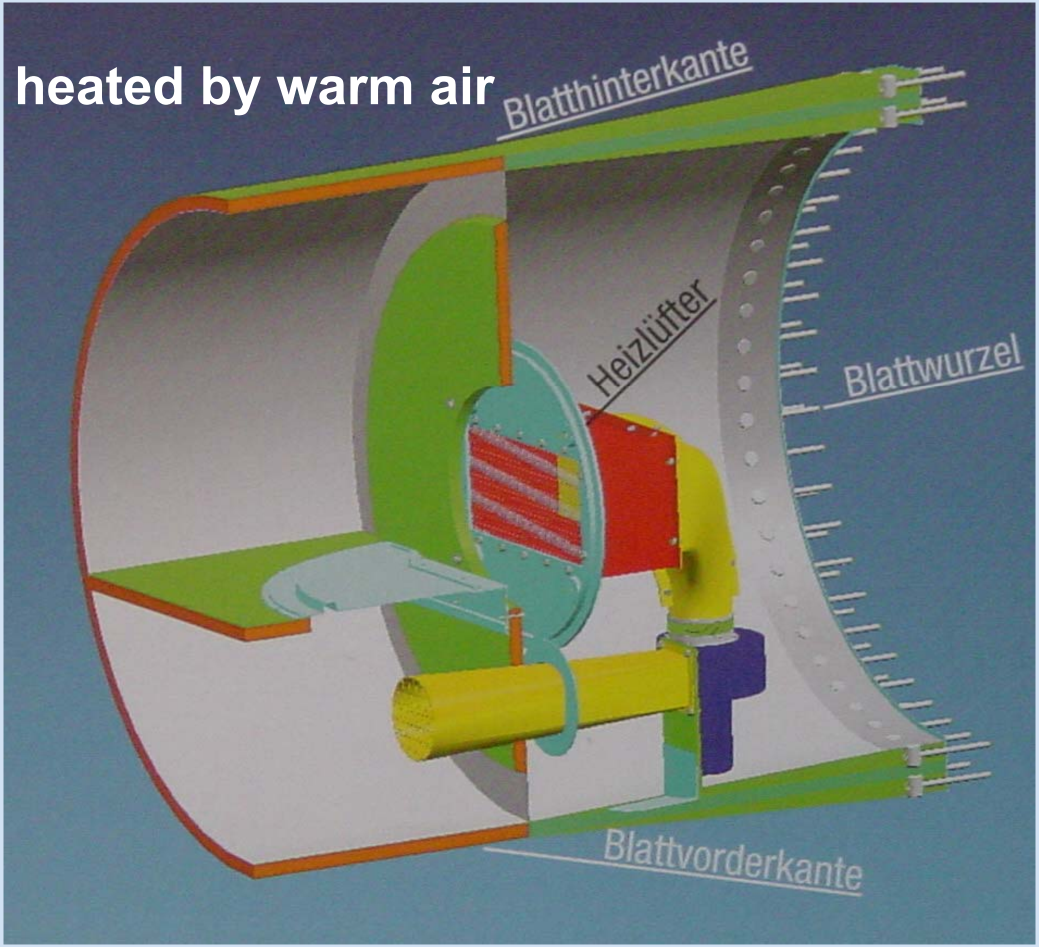
Electrical de-icing
Rotor blade heating

Technical solutions

Electrical heated foils at the leading edge (wires or carbon fibres)

Blowing warm air into the rotor blade at standstill

Rotor blade heated by warm air



Ref.: Enercon, Windblatt

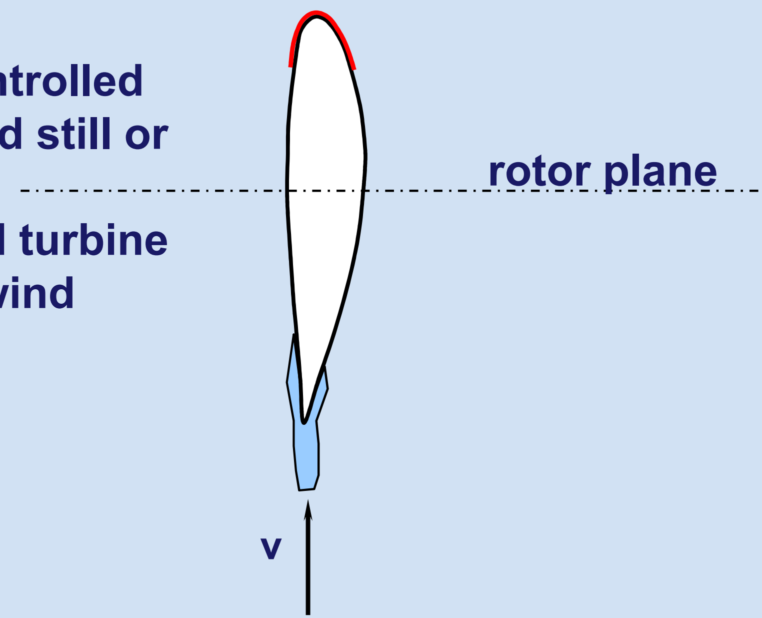
Rotor blade heated by warm air

Advantages	Disadvantages
leading edge surface not affected	GRP material is a good isolator
lightning protection OK	only for de-icing at standstill high energy demand during standstill high energy prices without production
for all control systems	ice throw during de-icing at standstill
complete surface can be de-iced	

Electrical leading edge heating

active stall controlled turbine at stand still or

stall controlled turbine yawed out of wind



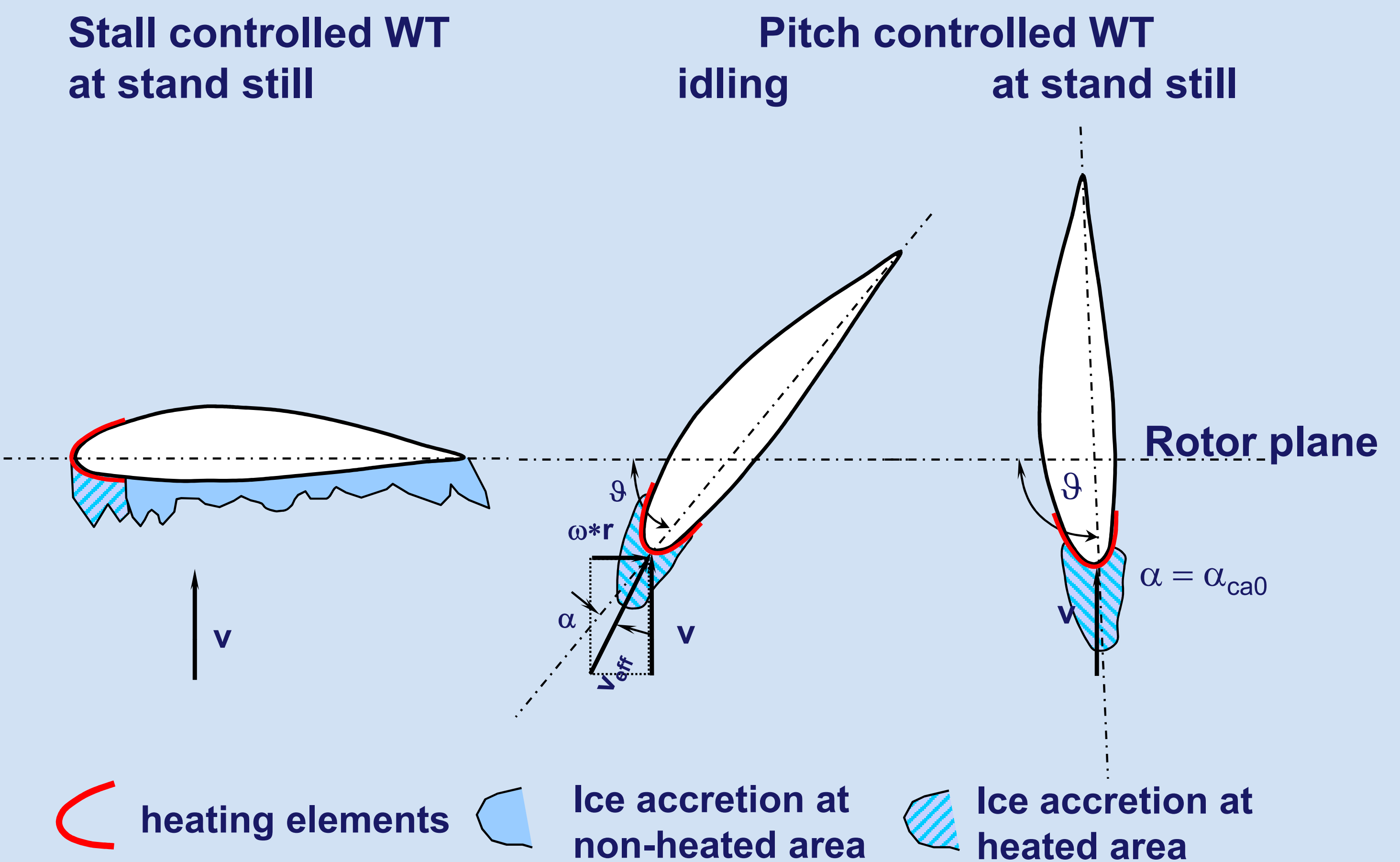
heating elements

Ice accretion at non-heated area

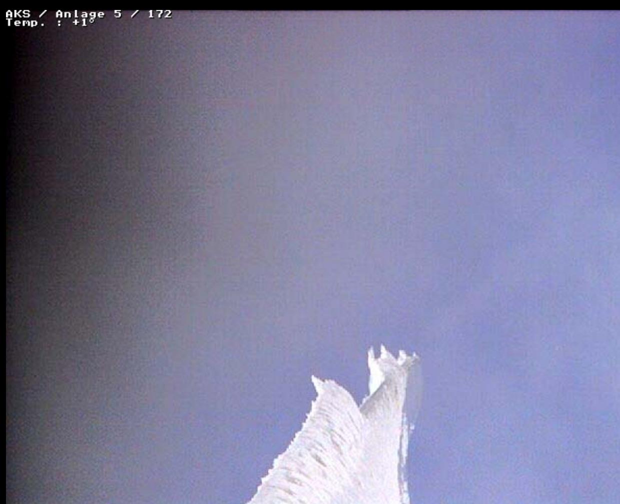
Ice accretion at heated area


Trailing edge icing

Electrical leading edge heating

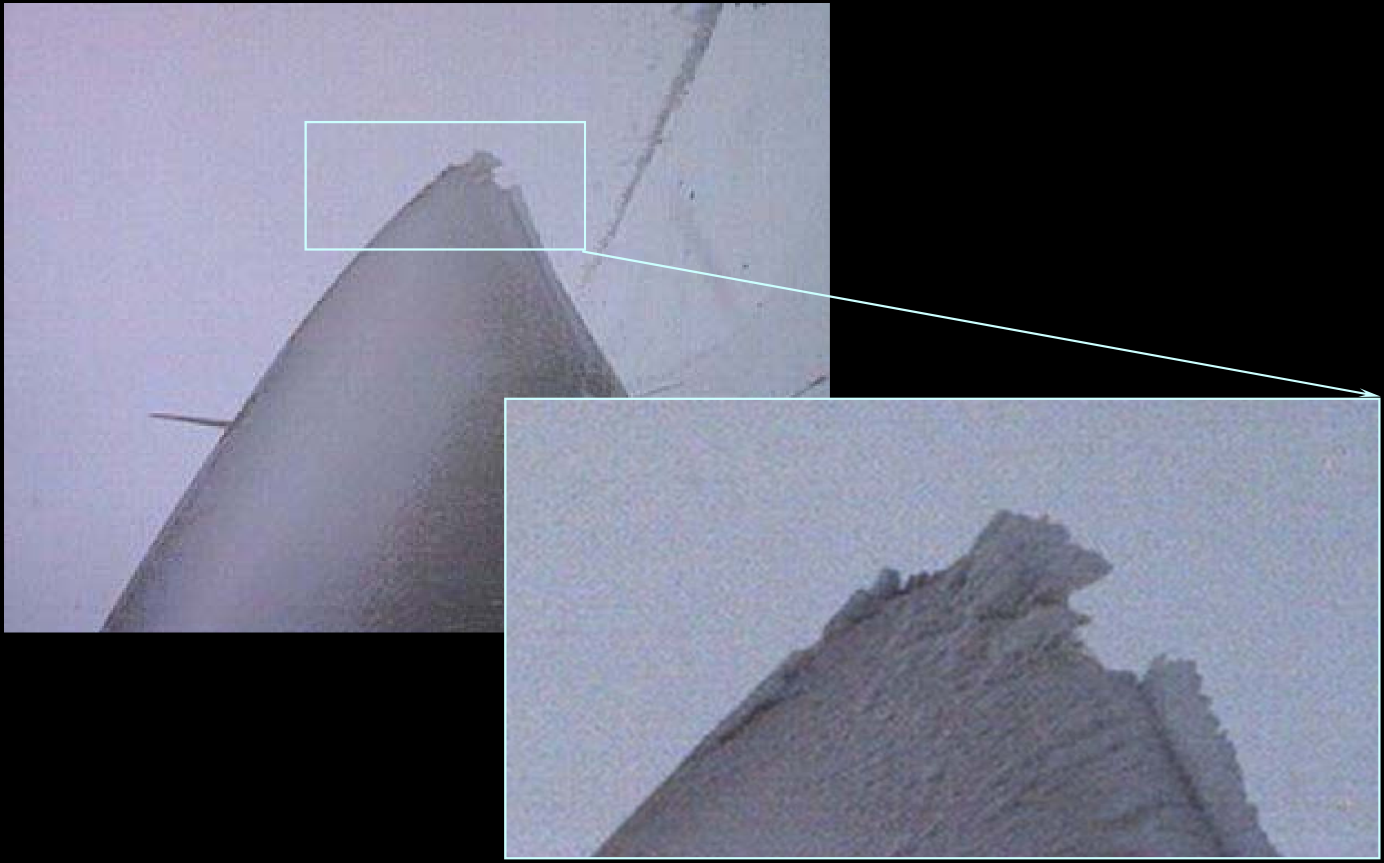


Monitoring by WEBcam

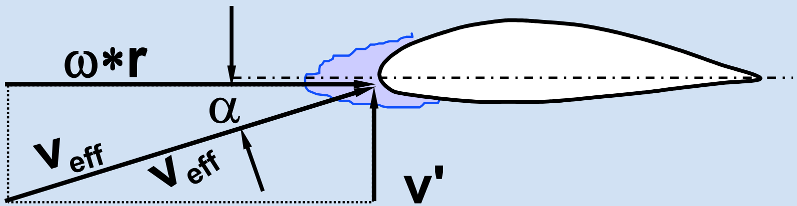


Ref.: Tauernwind

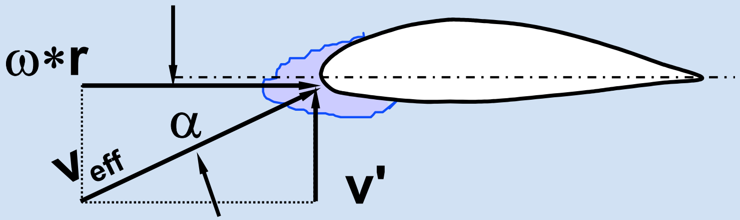
Variable speed control & icing conditions



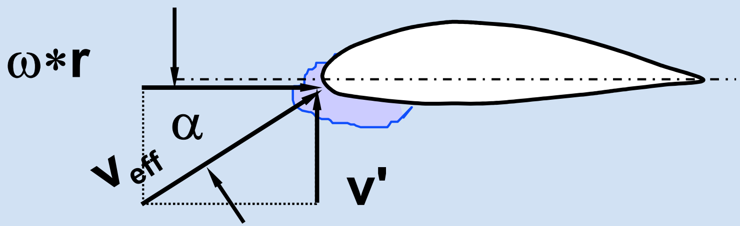
Variable speed control & icing conditions



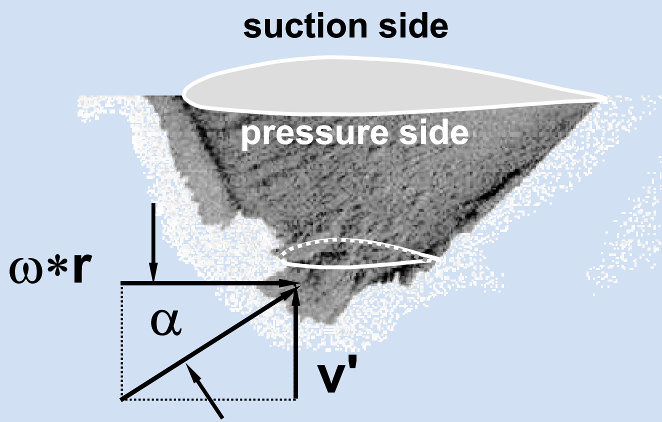
Variable speed control & icing conditions



Variable speed control & icing conditions

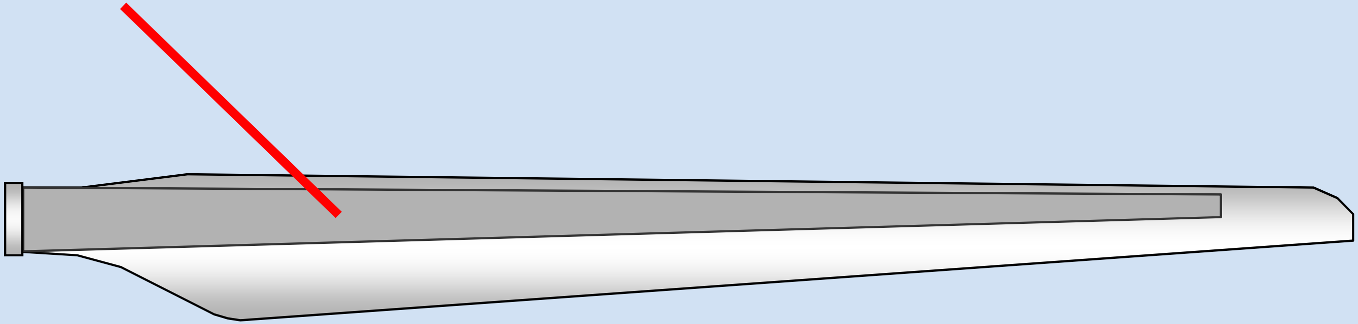


Variable speed control & icing conditions

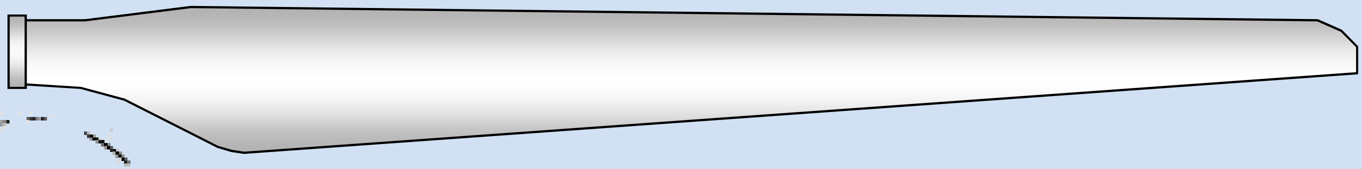


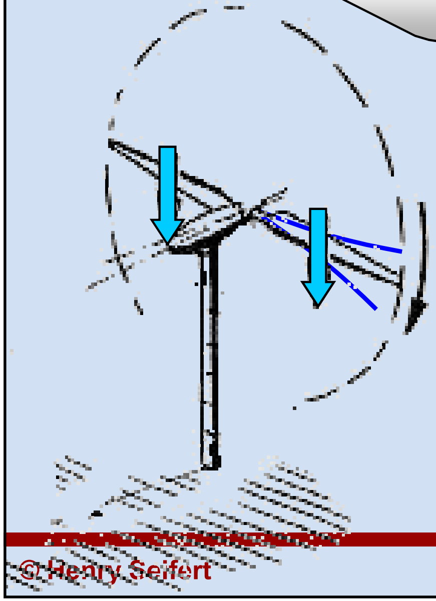
Mechanical effects on leading edge heating elements

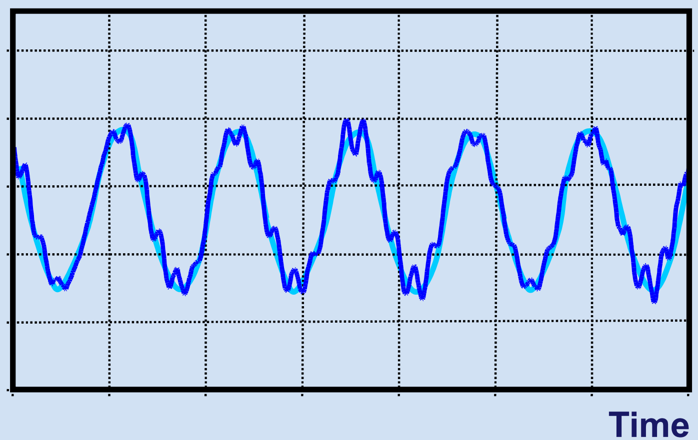
Load carrying structure of the rotor blade in edgewise direction

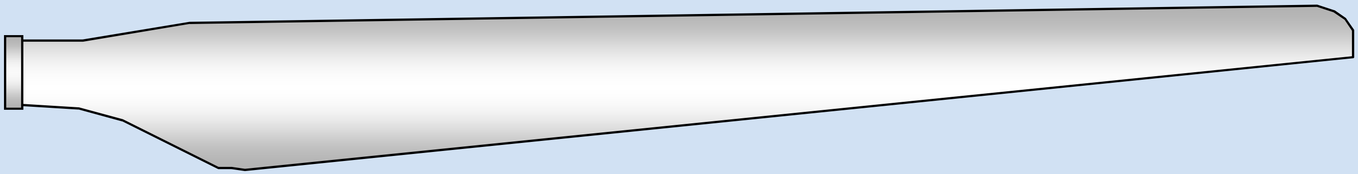


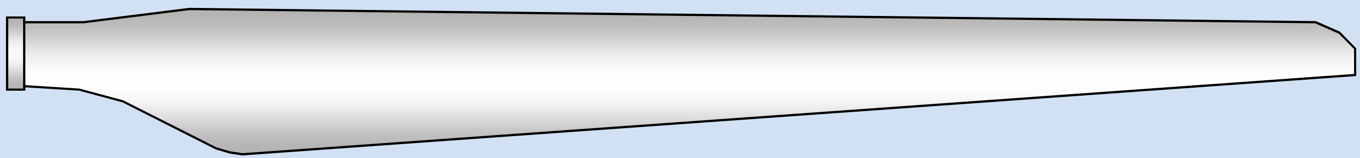
Rotor blade loaded edgewise during operation

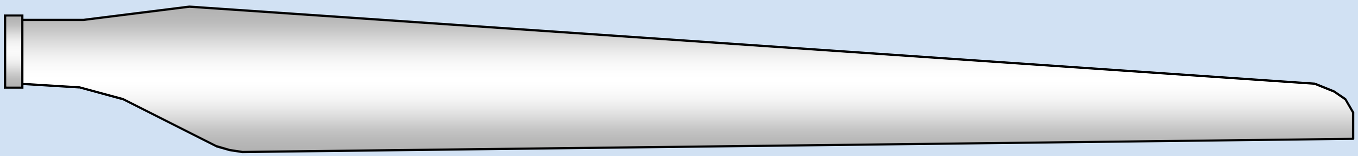


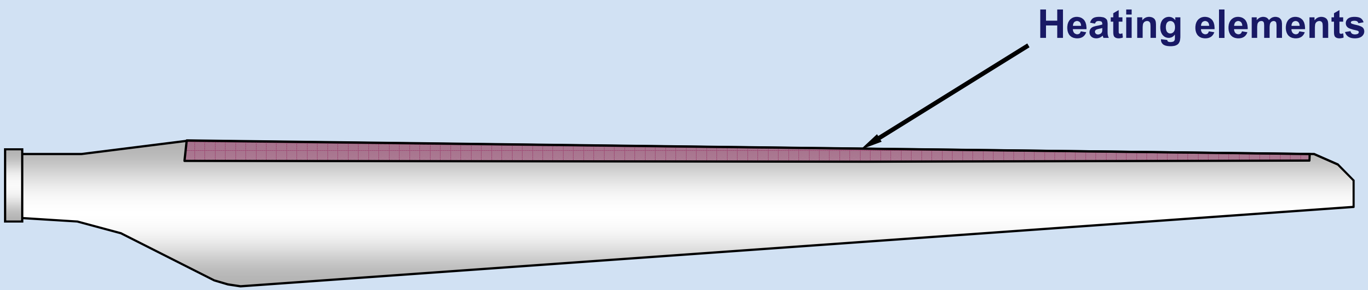


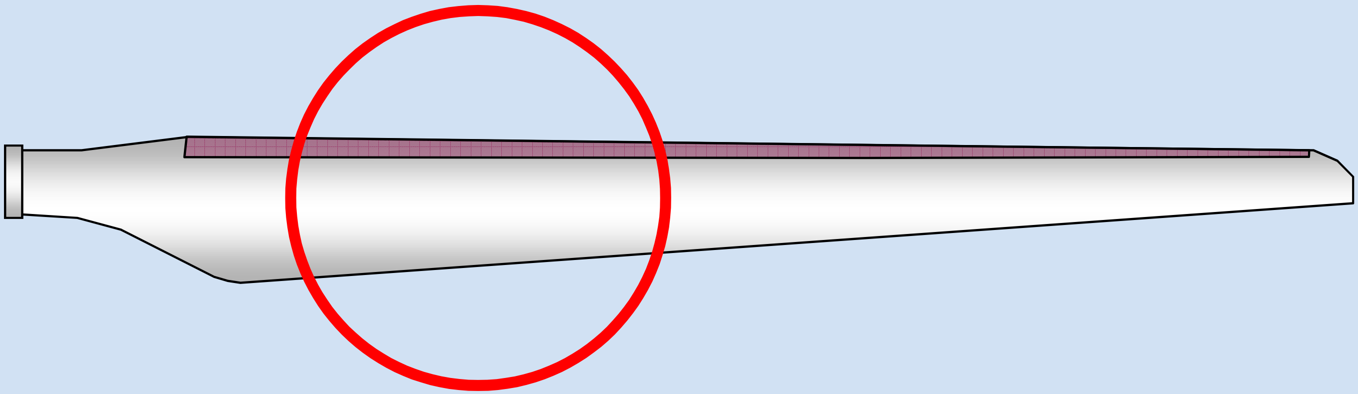




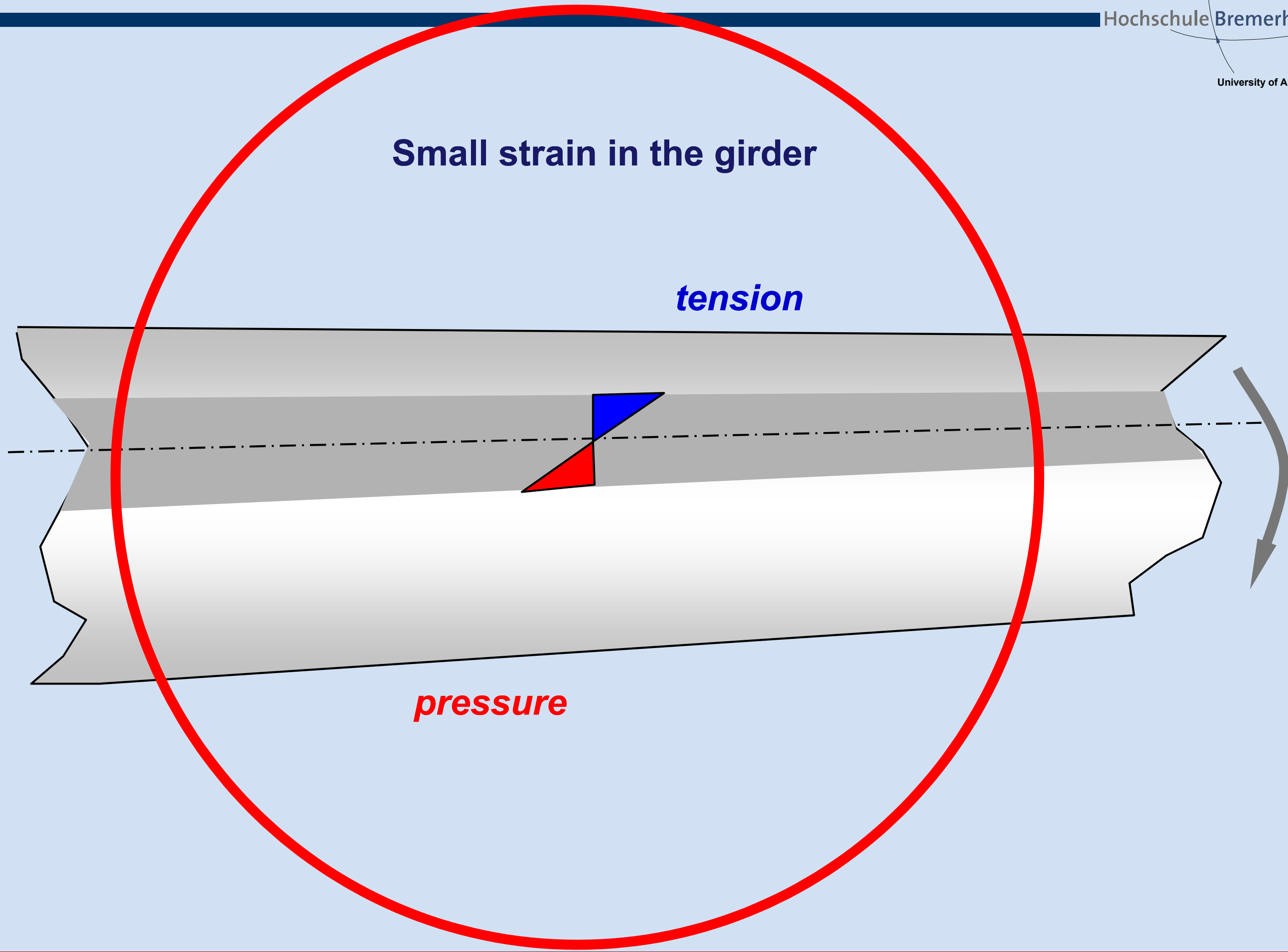


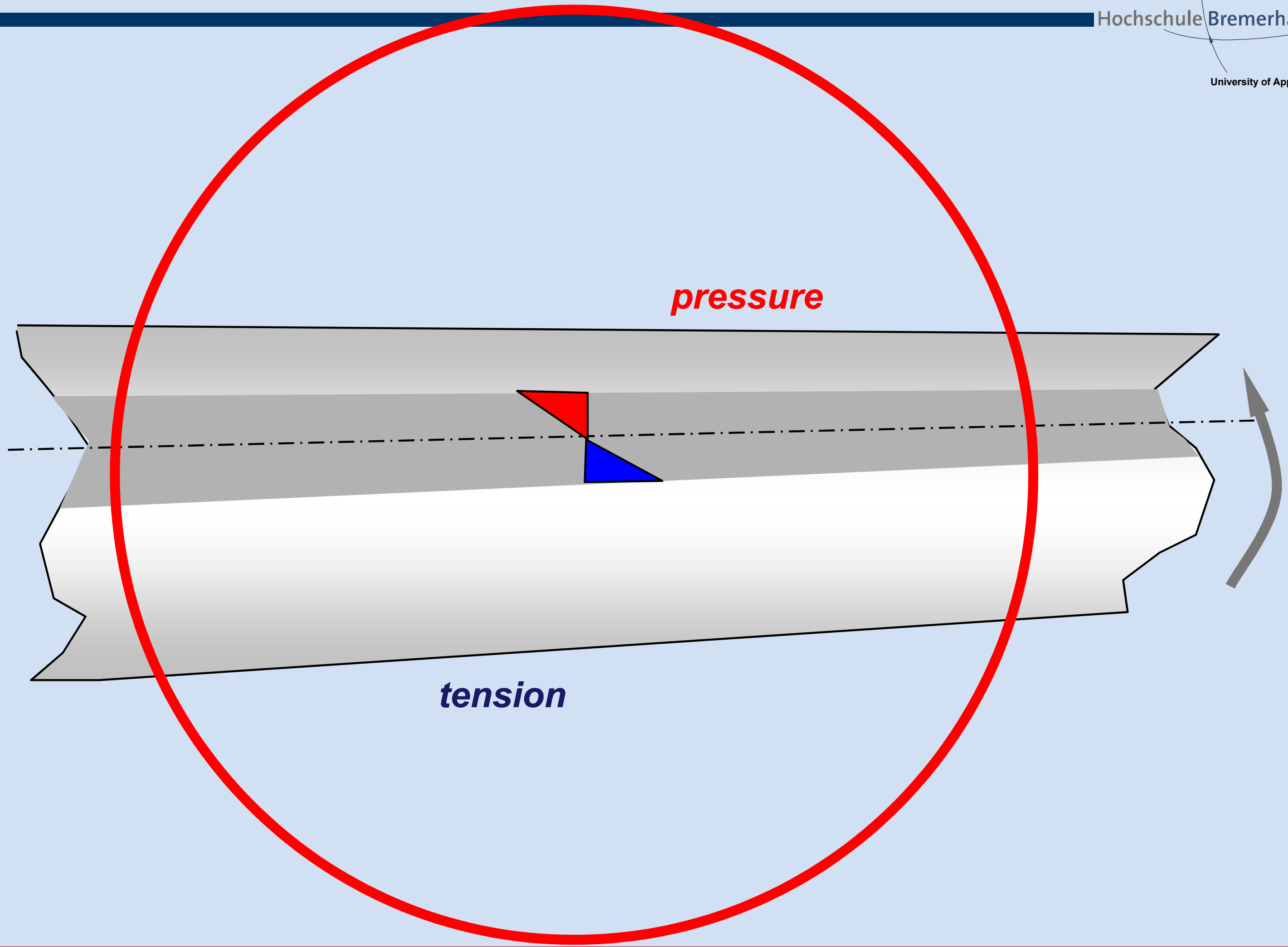



Heating elements

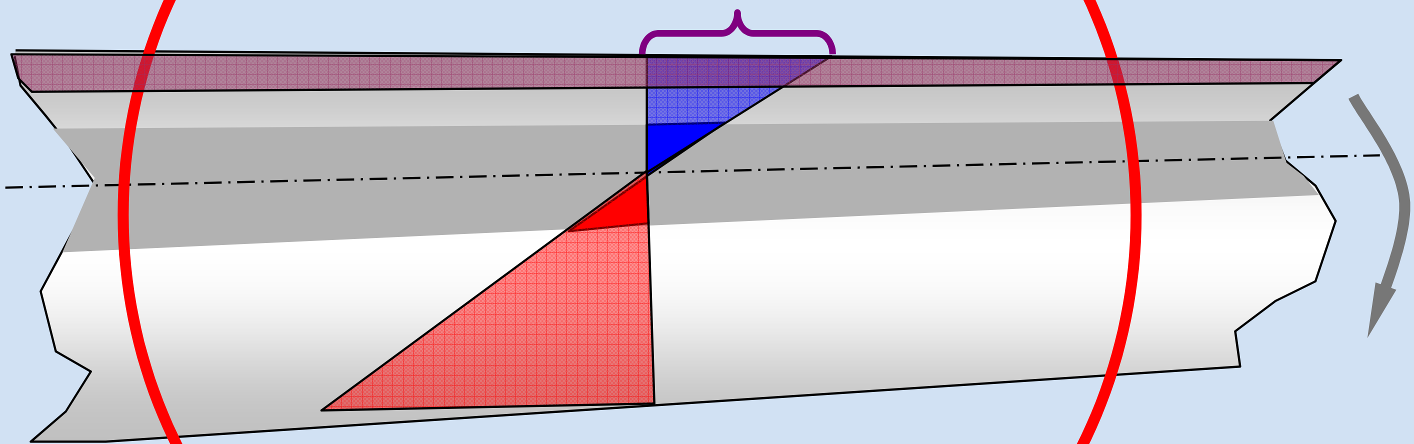


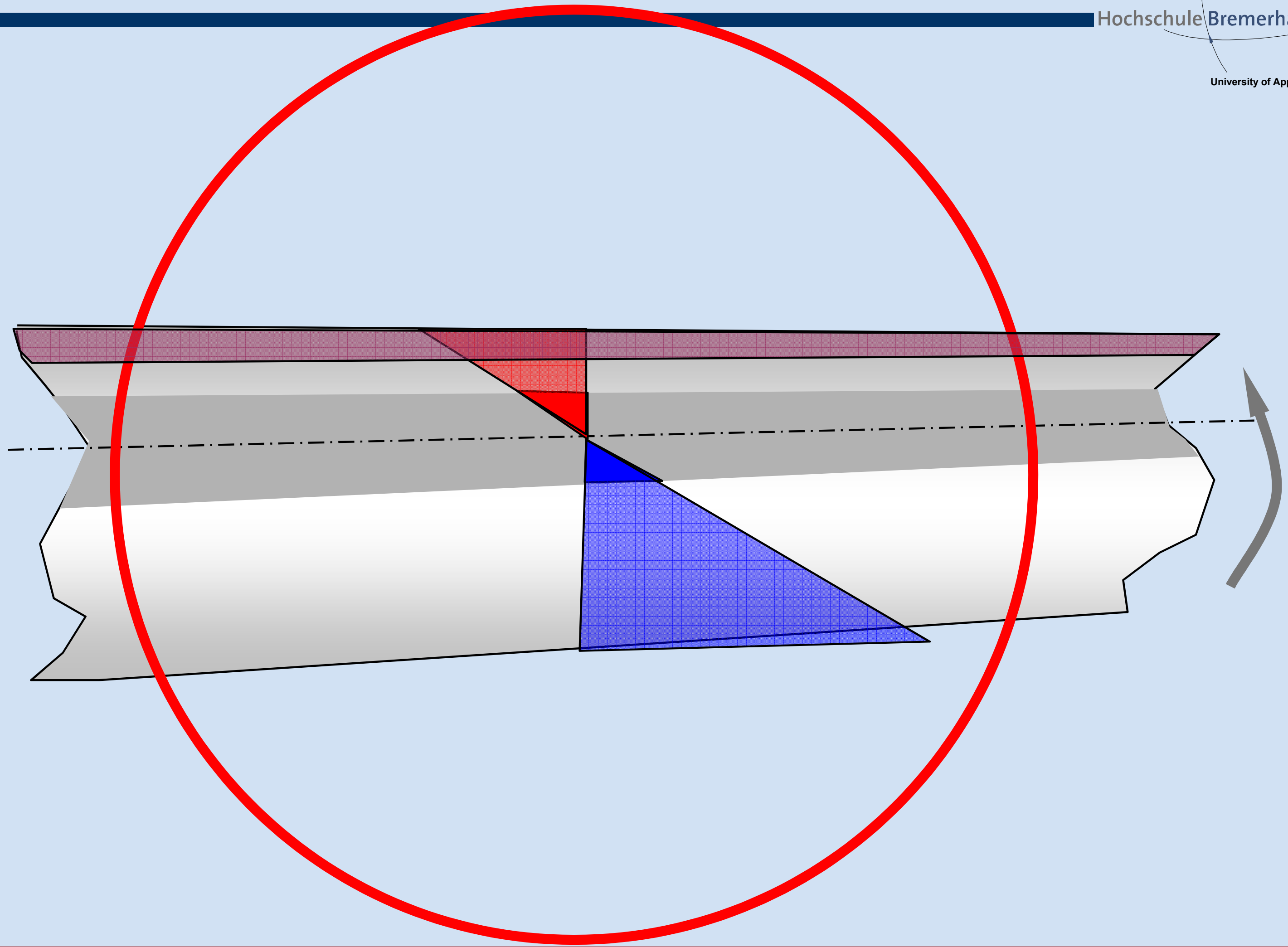
Small strain in the girder




pressure
tension

Large strain in the heating elements





Rotor blade heating by LE heating elements

Advantages

effective anti icing during operation

for pitch controlled WT also at idling or stand still

reduced ice throw

foils easy to applicable

Disadvantages

leading edge surface affected

during operation compensation of heating energy

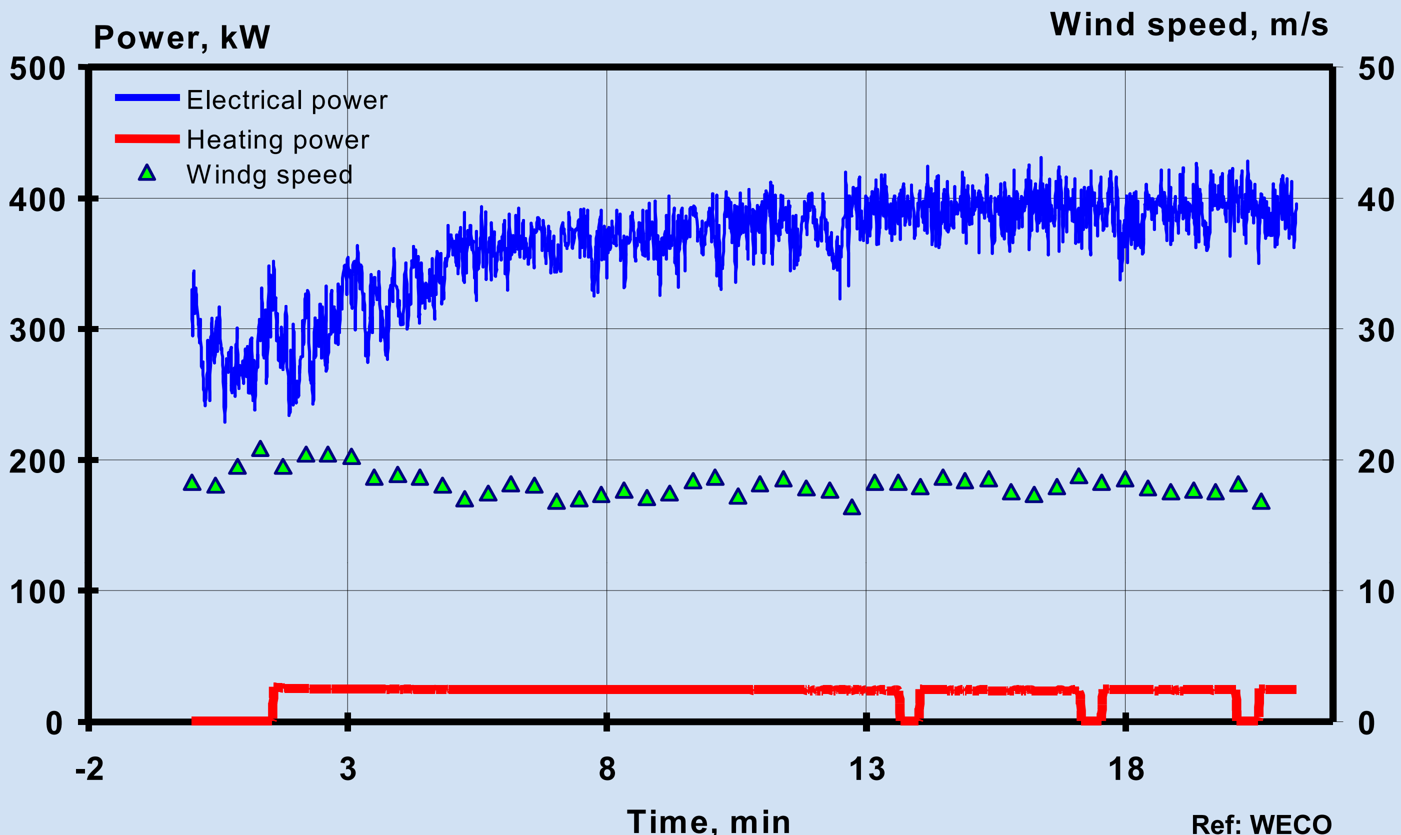
lightning protection ? conductive or semi-conductive

only LE surface heated

high strains at LE require special solutions

high stiffness of carbon fibres may cause even higher problems

Rotor blade heating during icing conditions



Ref: WECO

Influence of operation under icing conditions on the lifetime of WT components

Increasing of fatigue loads

Additional ice masses will cause higher deterministic loads

Asymmetric masses causes unbalance

Higher amplitudes of edgewise vibrations have been observed (3 WECO WT)

Ice accretion affects the control system. Amplified vibrations of the controller have been observed

Oblique inflow due to frozen wind vane

Pitch controlled WT run as stall controlled

Changed natural frequencies of iced components such as rotor blades

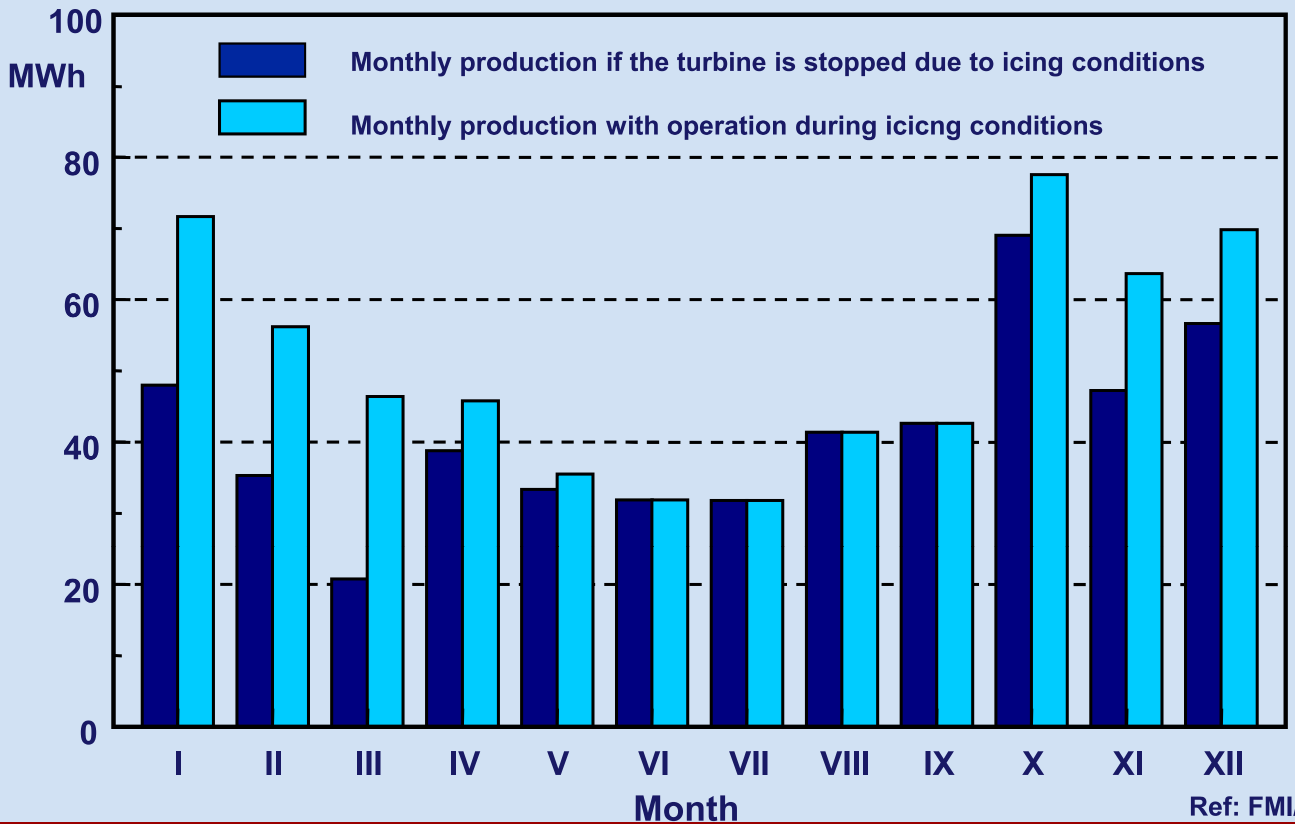
Decreasing of fatigue loads

Ice accretion can enlarge the aerodynamic damping and thus, reduce the excitation of components

Shut downs due to icing of rotor and/or control instruments and stand still during icing conditions reduces the number of load cycles

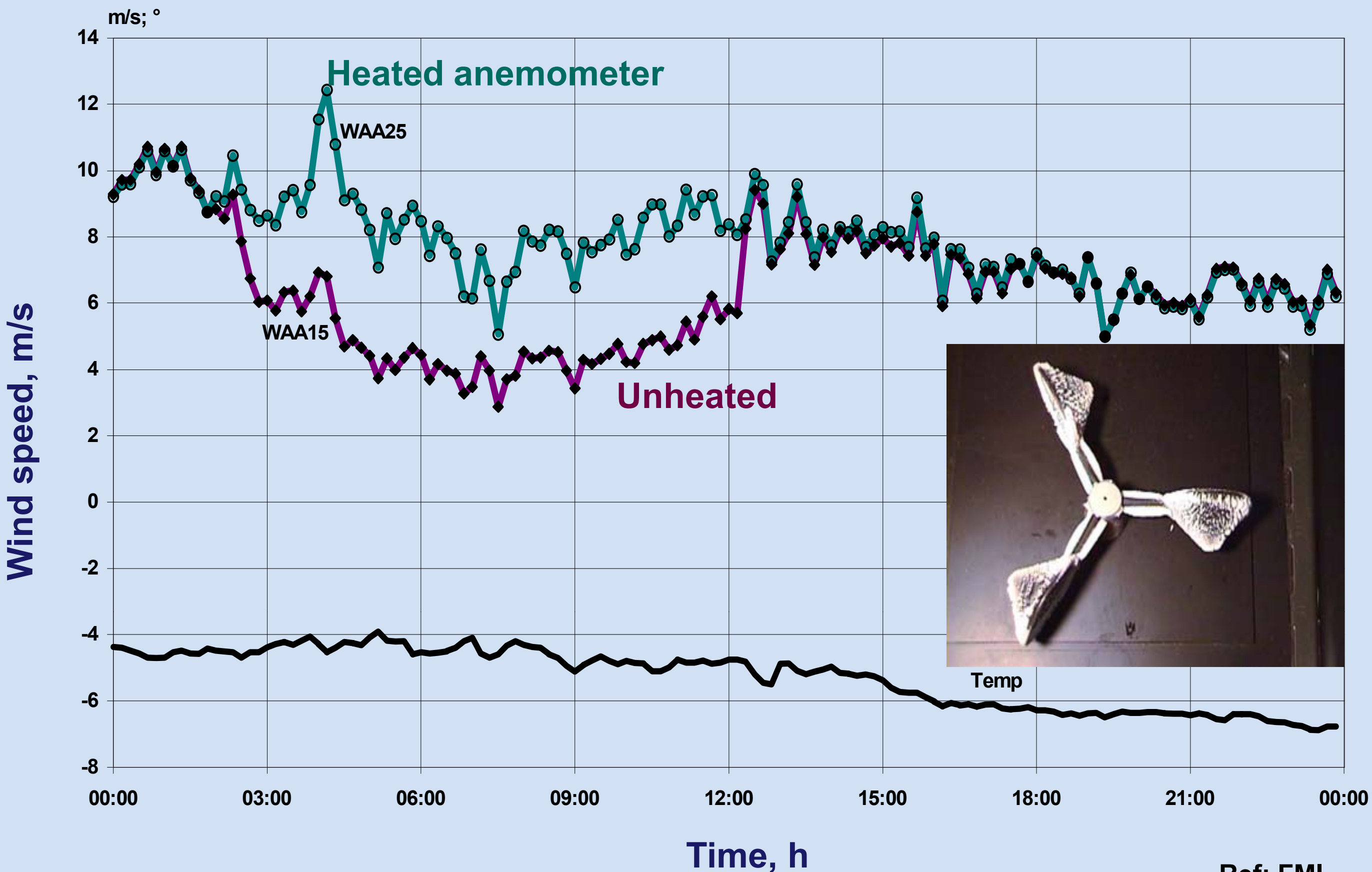
The operation at lower rotor speed (two speed generator or variable speed) due to icing reduces the number of loads cycles. However, the load amplitudes can be increased

Calculated monthly energy production of a 200 kW turbine at Sodankylä, Finland



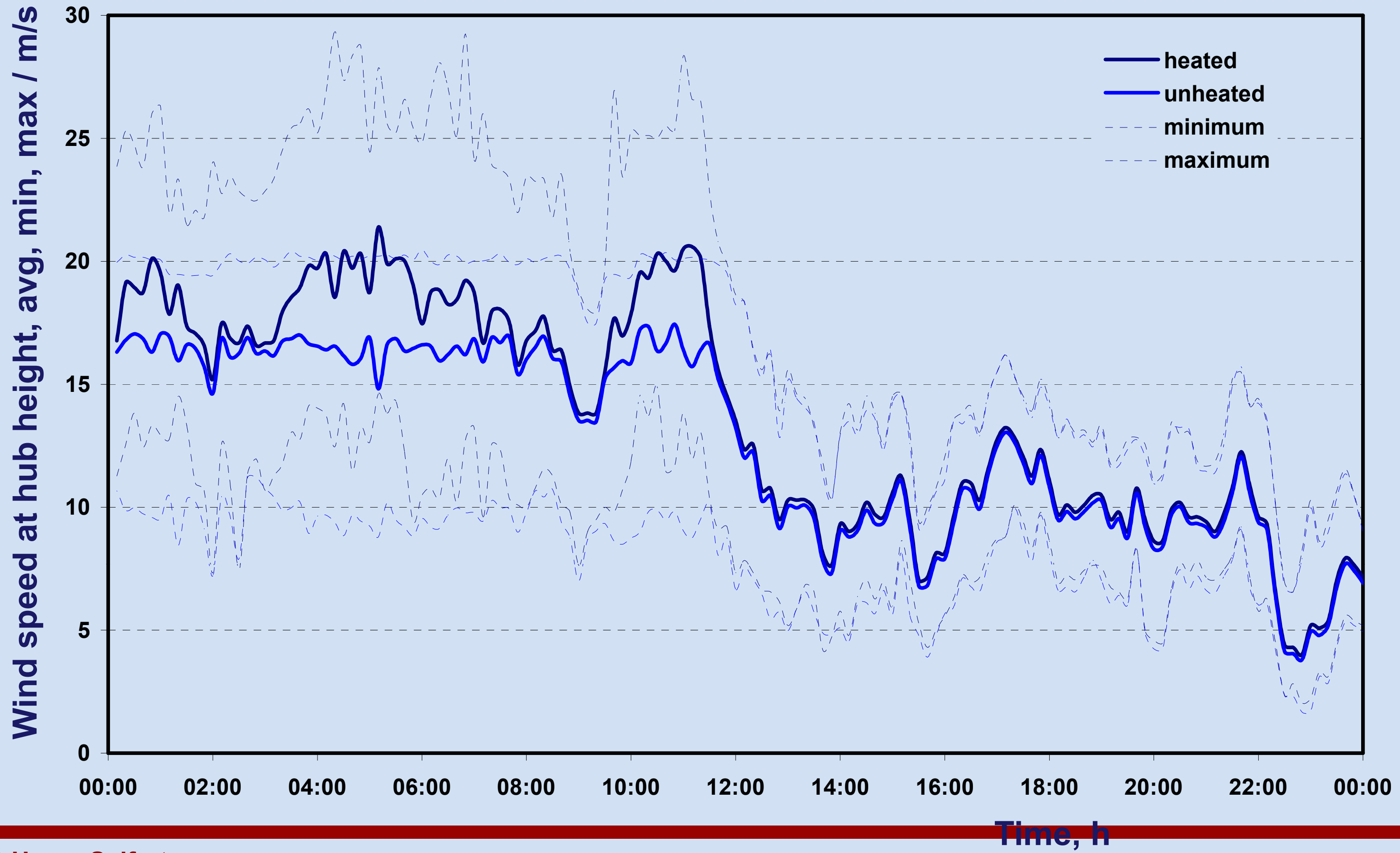
Ref: FMI/VTT

Wind measurements with heated anemometers

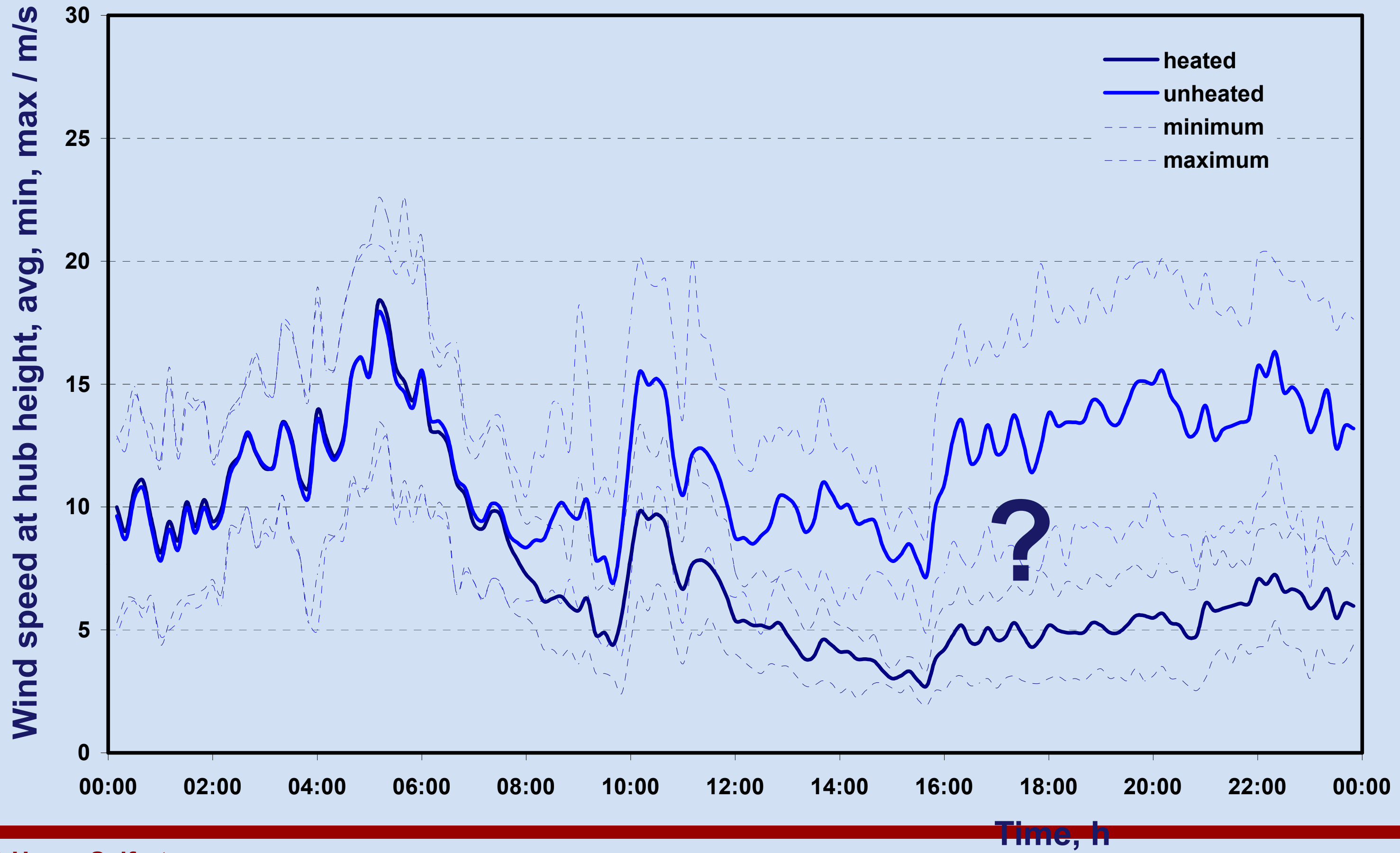


Ref: FMI

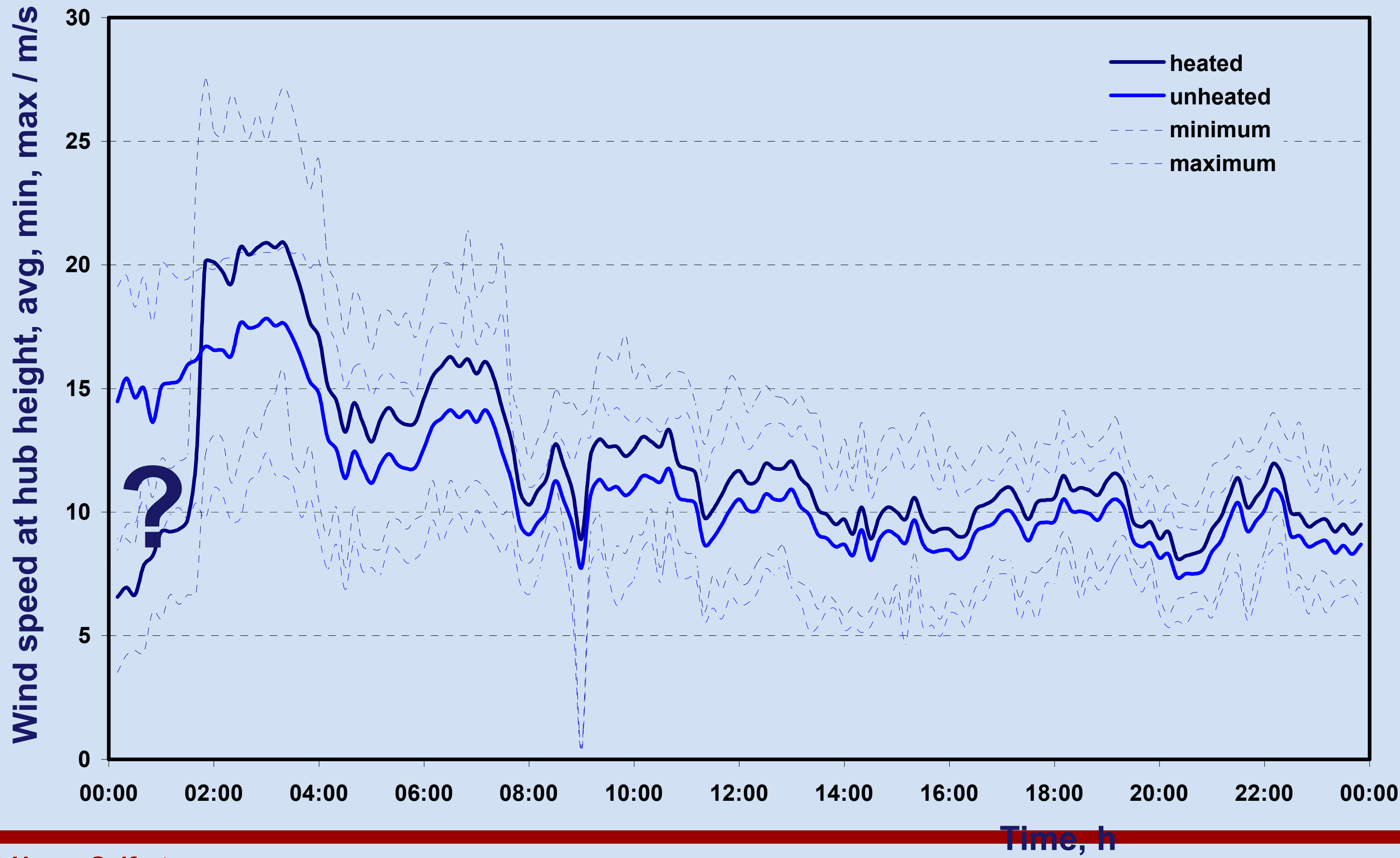
Heated vs unheated anemometer



Heated vs unheated anemometer



Heated vs unheated anemometer



Anemometer

Heated anemometer combined with:

low temperature

precipitation (eg. heavy snow fall)

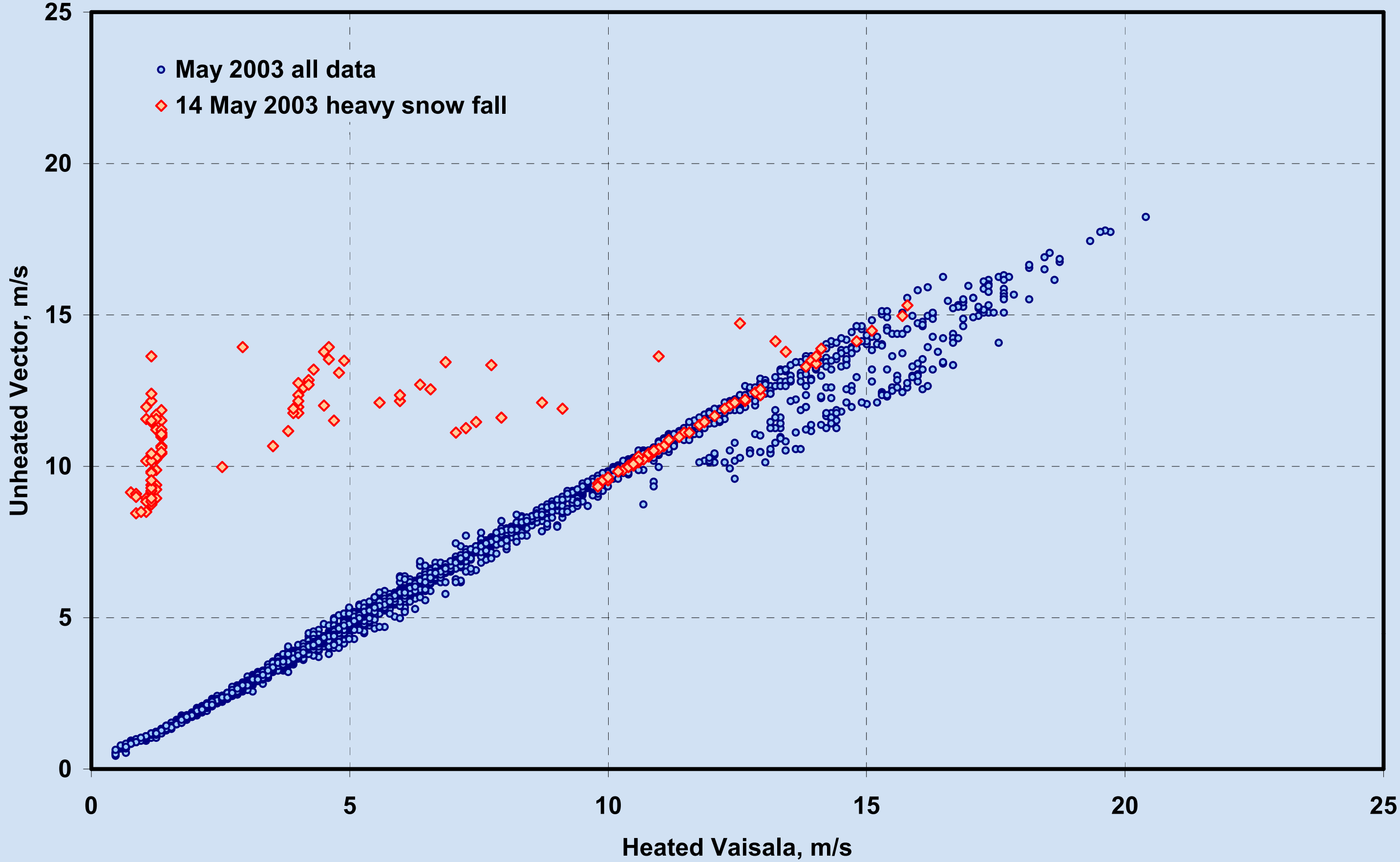
snow melts at the hot cups

forced convection at low temps and high winds cause immediate "re-freezing" of water, causing ice at the outer cups

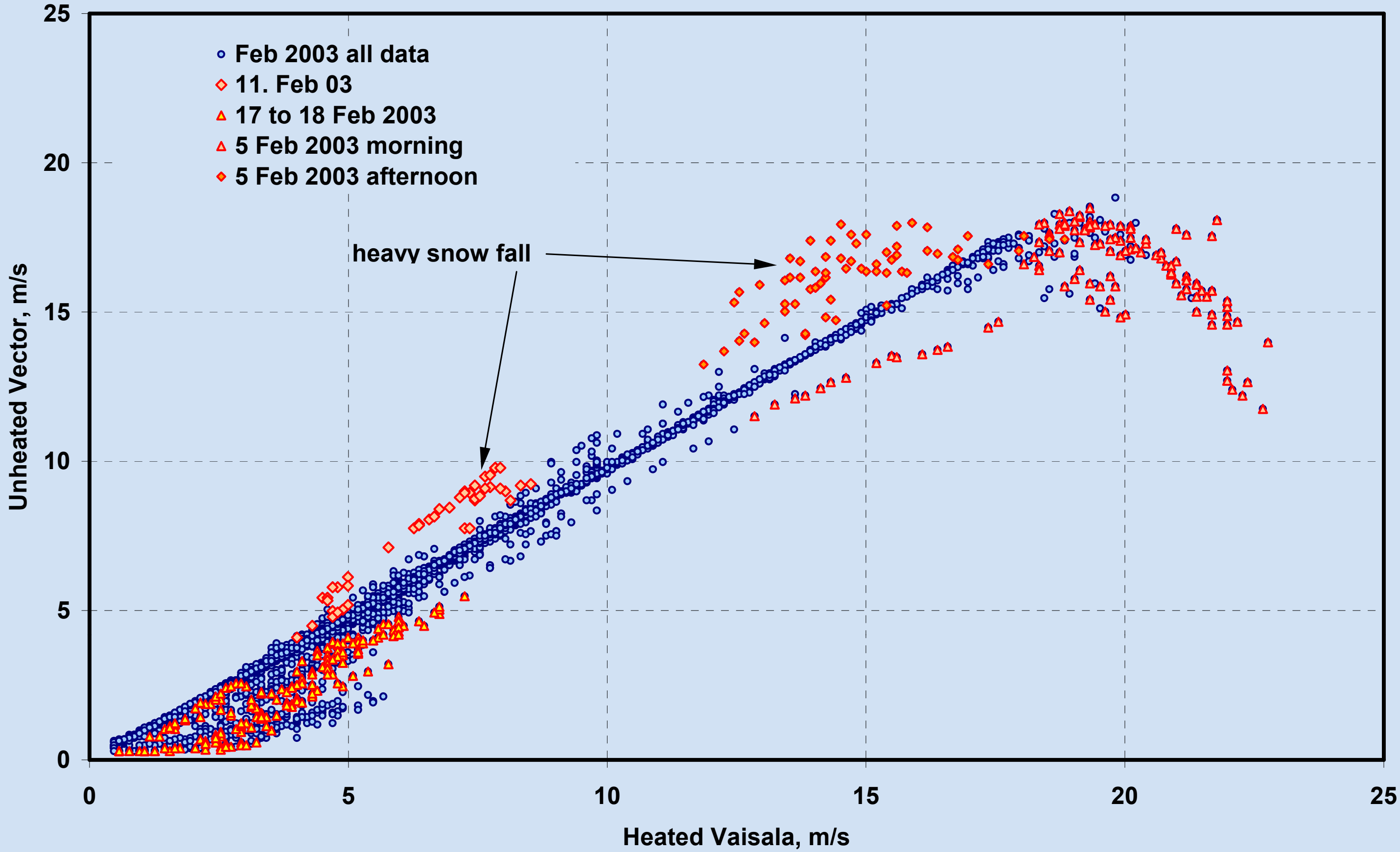
higher inertia and drag cause wrong results

The unheated anemometer remains cold:
Snow does not melt and is reflected.
Thus, no big effect on the measurement

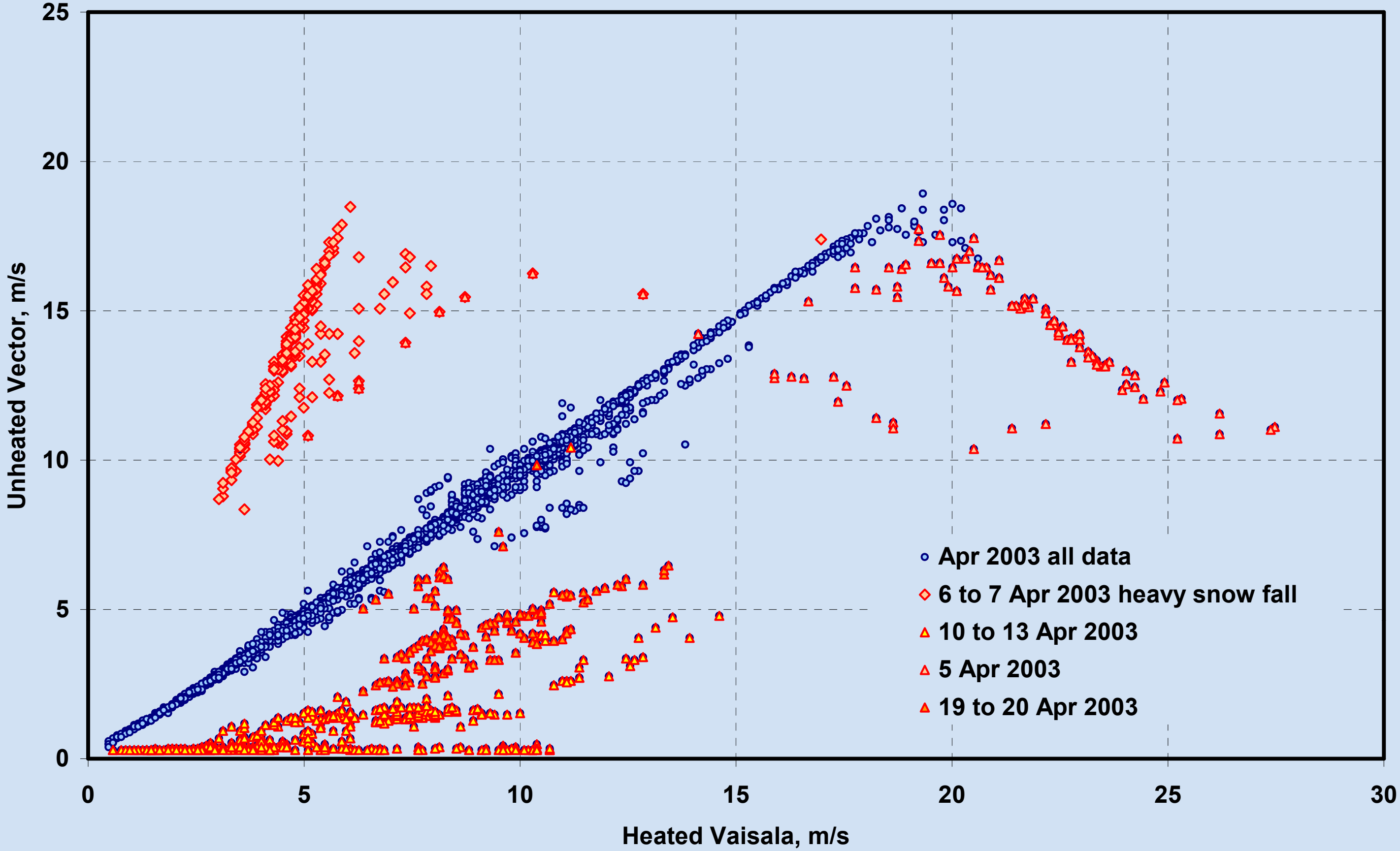
Tauernwind: Heated vs unheated anemometer



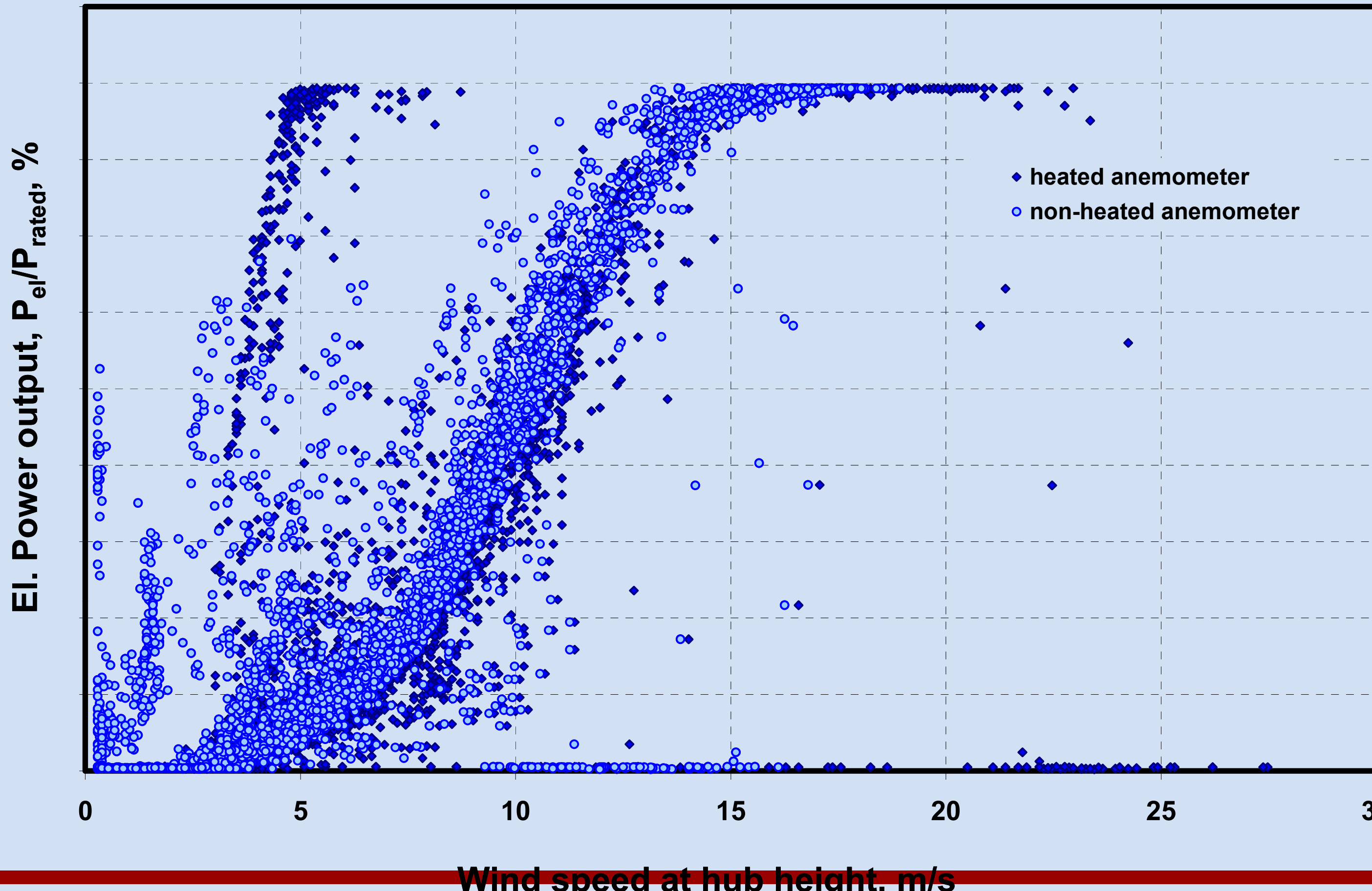
Tauernwind: Heated vs unheated anemometer



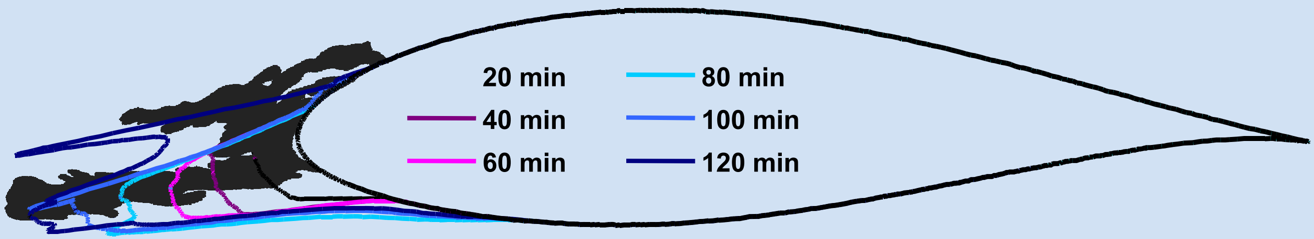
Tauernwind: Heated vs unheated anemometer



Check of power curve



Comparison "TURBICE" simulation vs experiments



Conclusions

Still no standard solutions available on the markets today

Prototypes and 0-series of heated blades still under development

Only small experience with anti-icing and de-icing systems available

Market for inland turbines and thus, for cold climate WT increases

What to do?

Research and demonstration projects on a pre-competitive basis

Improve theoretical background

Bring both together

Take profit from synergy with aircraft technology

The future ?

The optimised cold climate wind turbine