The Effects of Black Blades on Surface Temperatures for Wind Turbines

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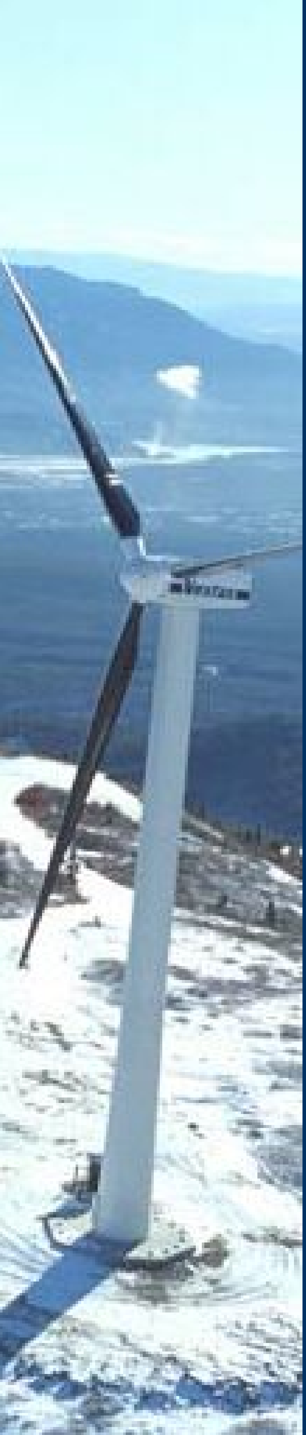
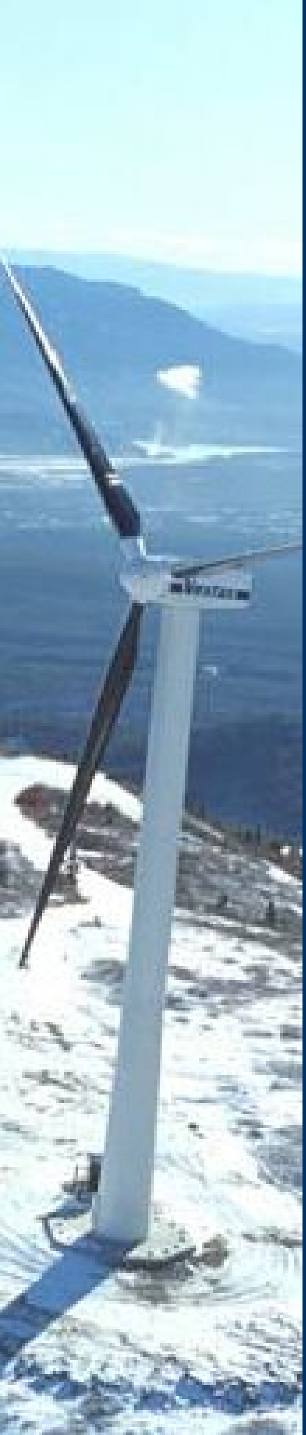


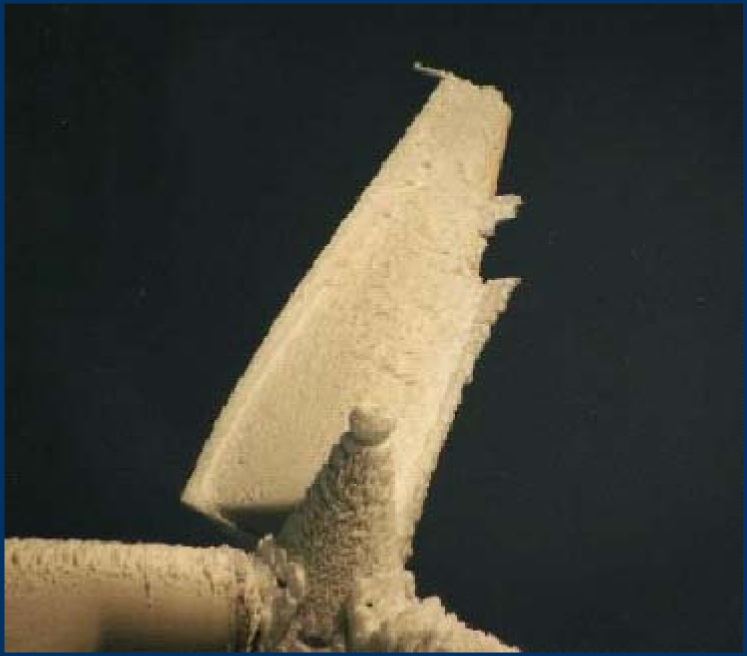
Presentation Outline

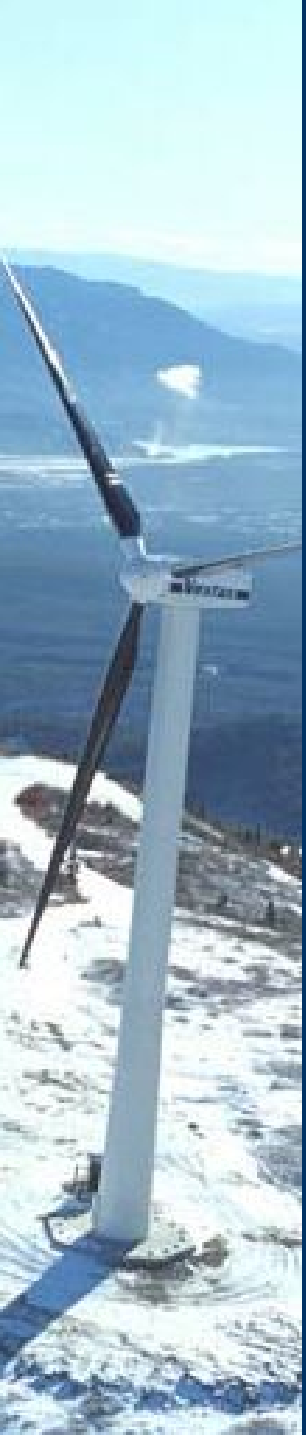
- Introduction: Rime Ice and Wind Energy
- Experimental Setup
- Goals
- Results



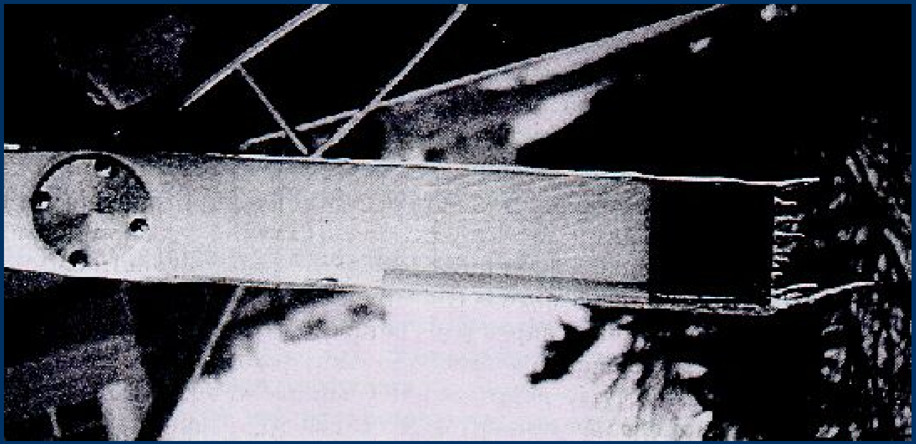
Problems with Ice Accretion

- Altered Aerodynamics
- Ice Shedding
- Control



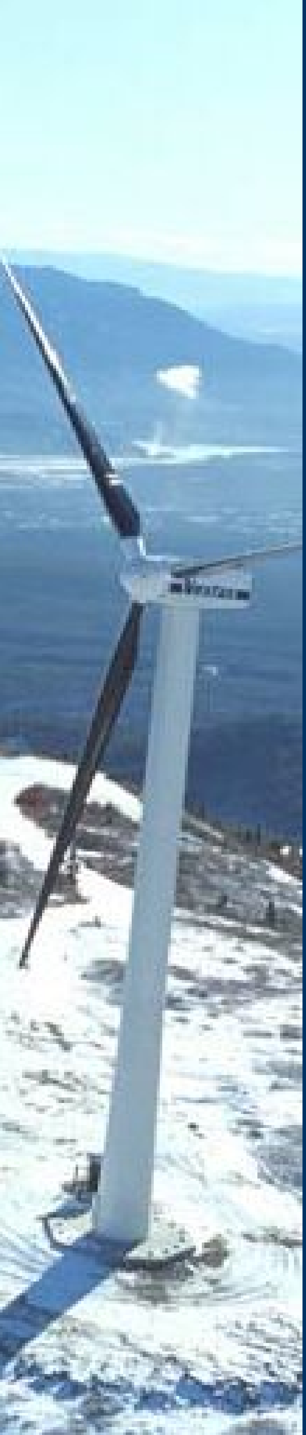


Types of Ice Accretion



Glaze Ice ↑

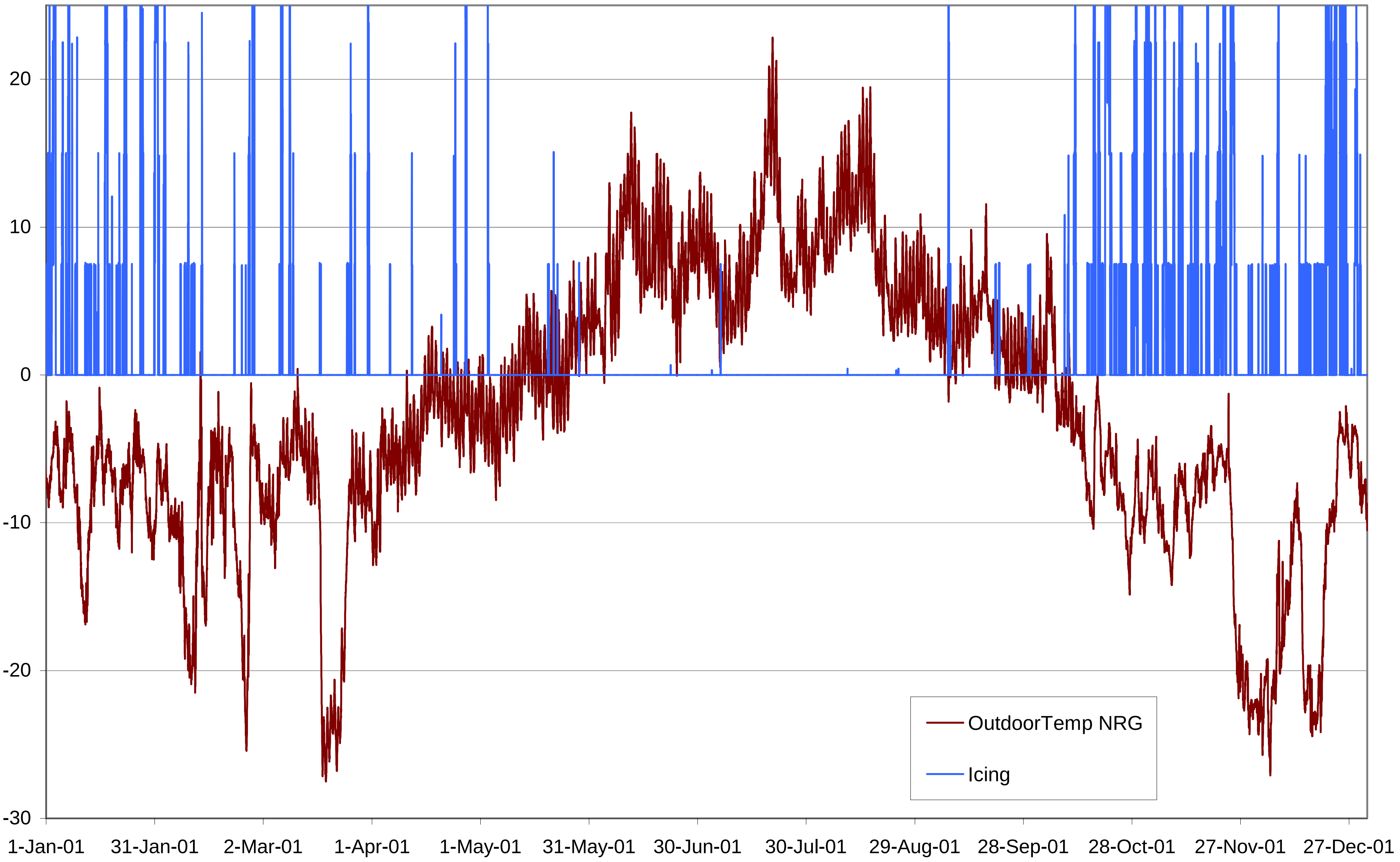
Rime Ice →



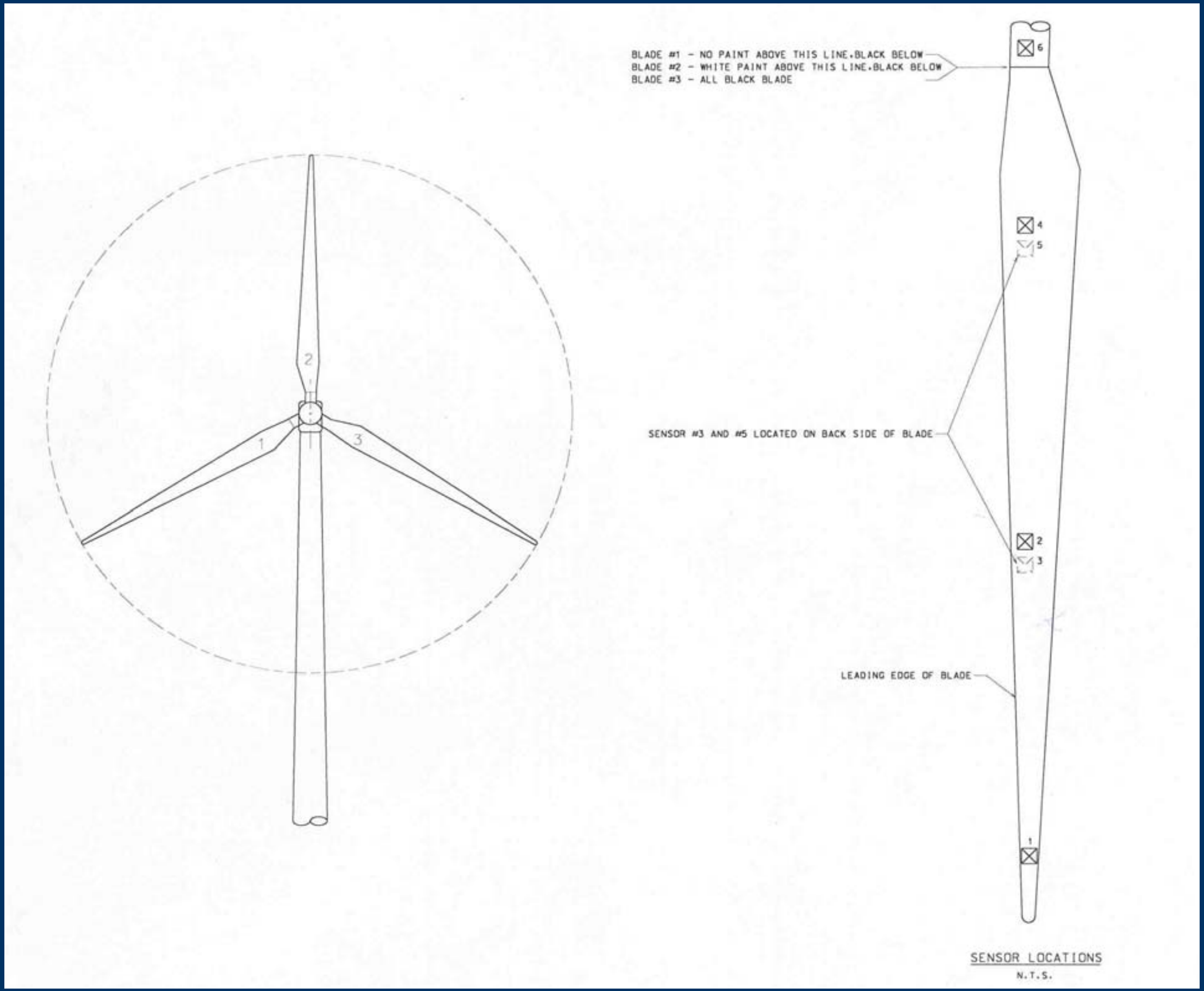
YEC's Icing Treatments

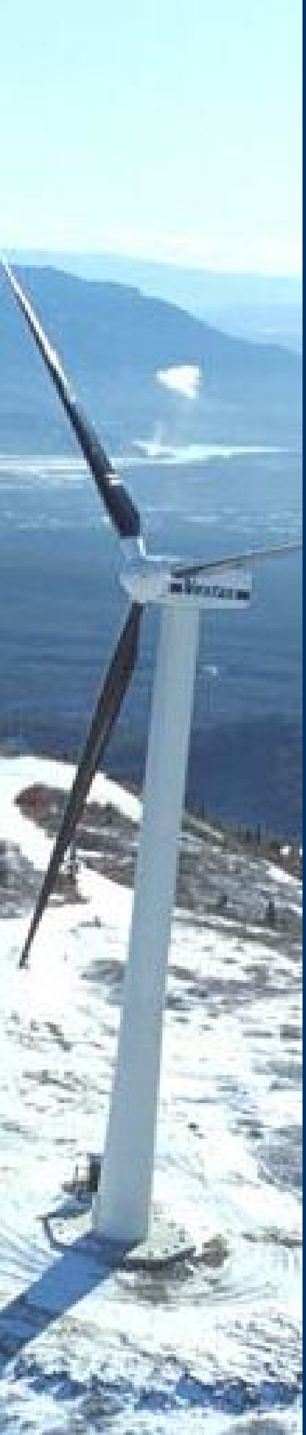
- Leading Edge Heaters

- StaClean (Black) Coated Blades


20
10
0
-10
-20
-30
1-Jan-01
31-Jan-01
2-Mar-01
1-Apr-01
1-May-01
31-May-01
30-Jun-01
30-Jul-01
29-Aug-01
28-Sep-01
28-Oct-01
27-Nov-01
27-Dec-01
OutdoorTemp NRG
Icing

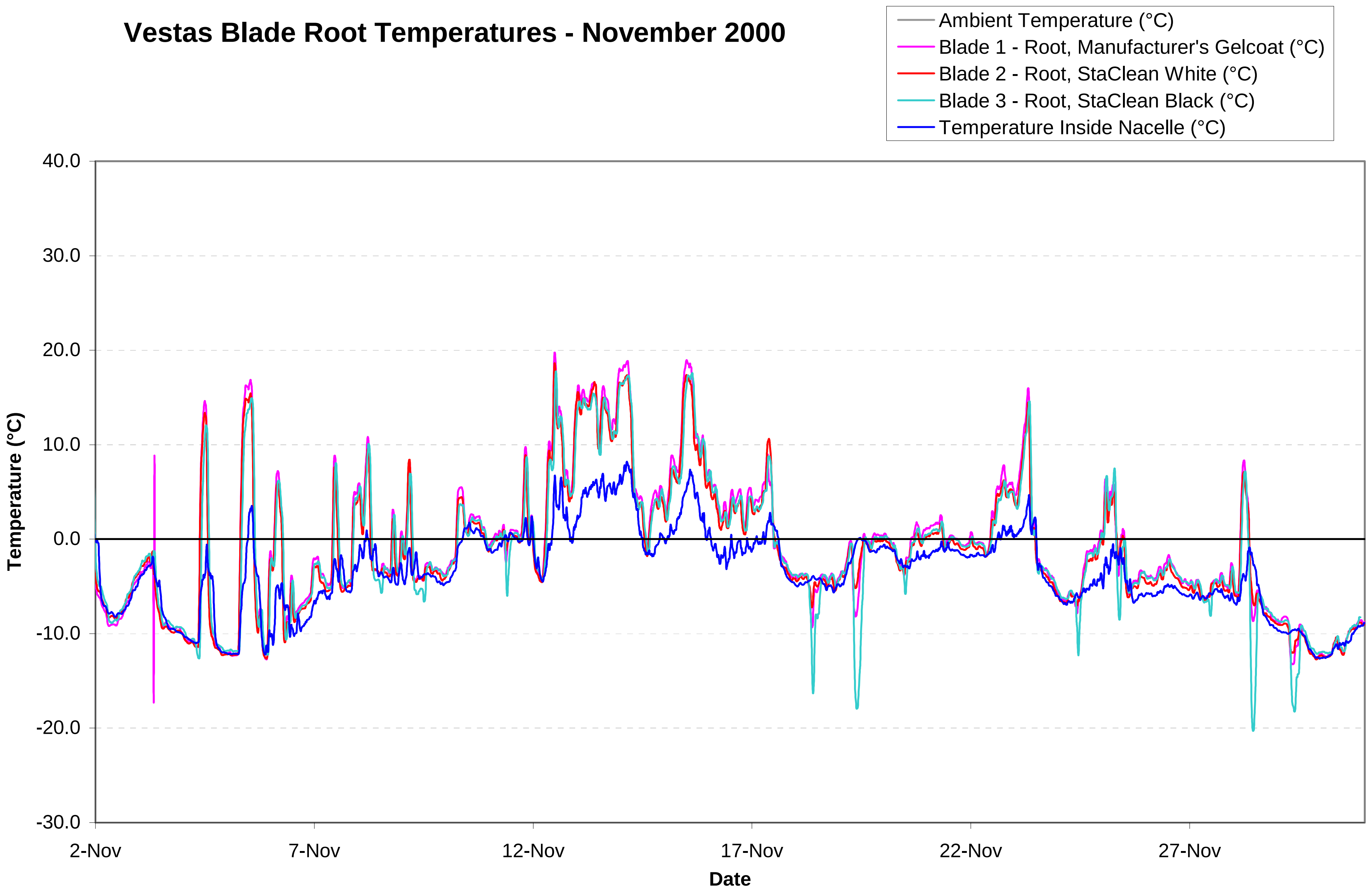
Experimental Setup

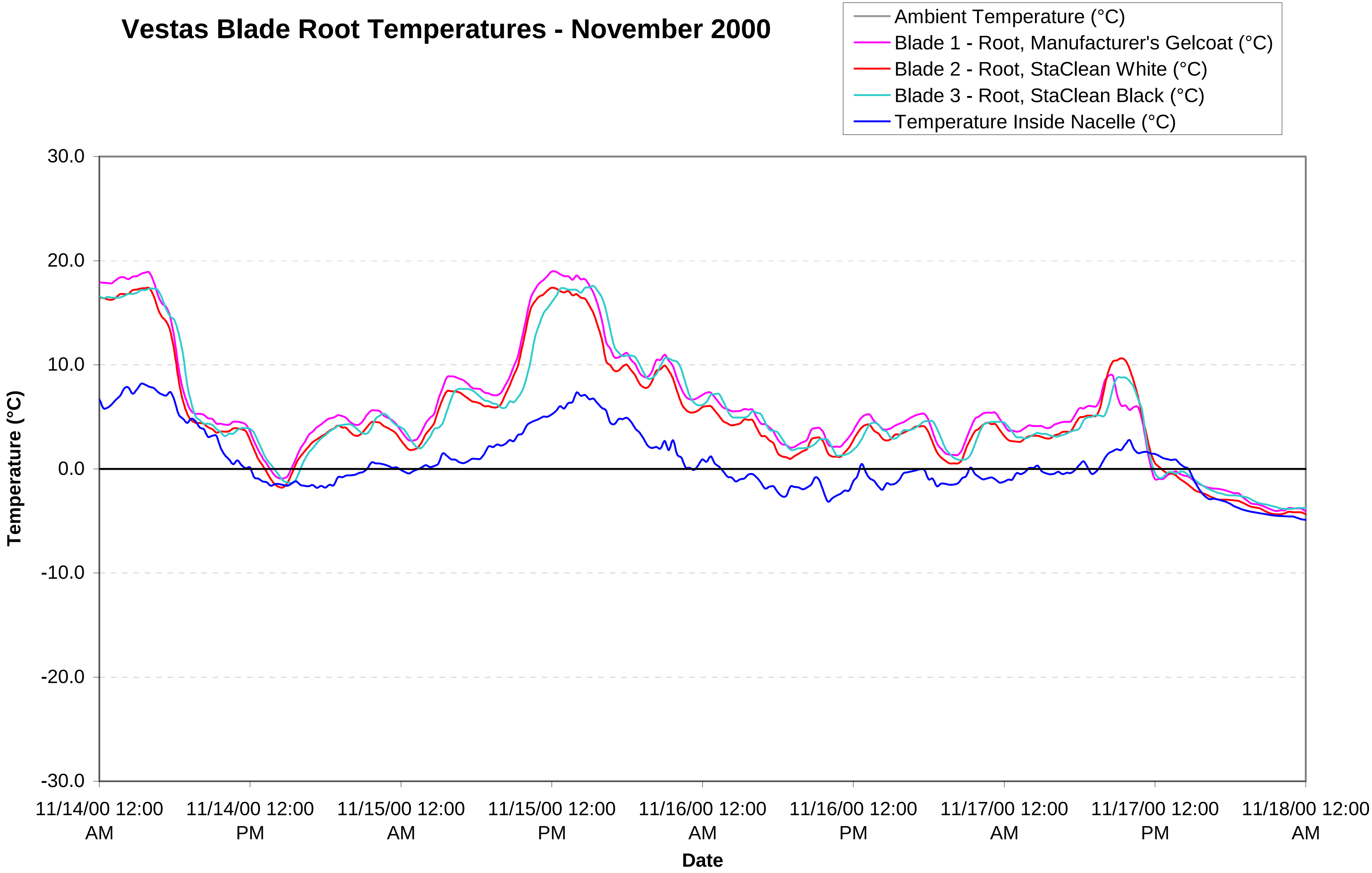


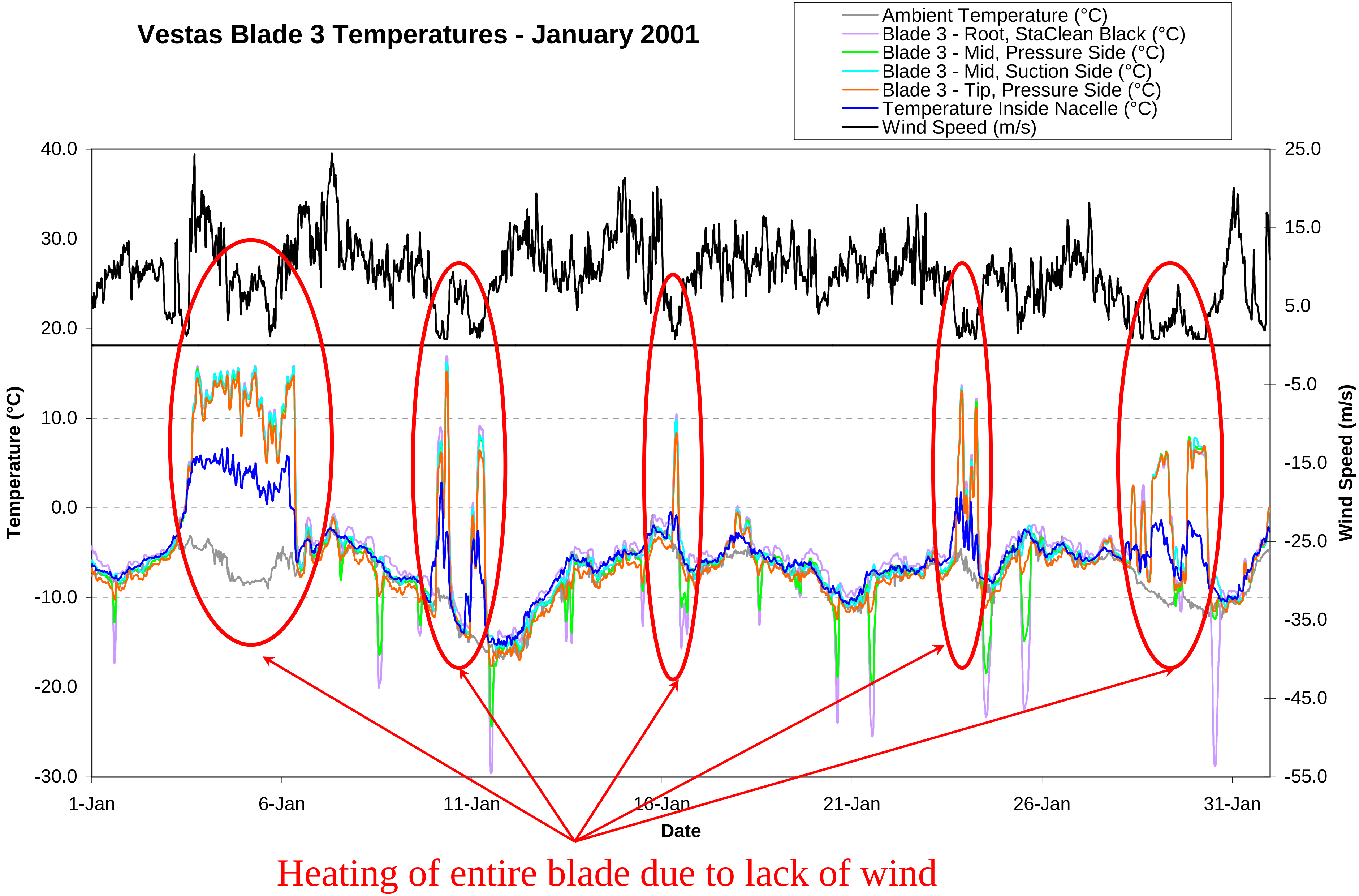


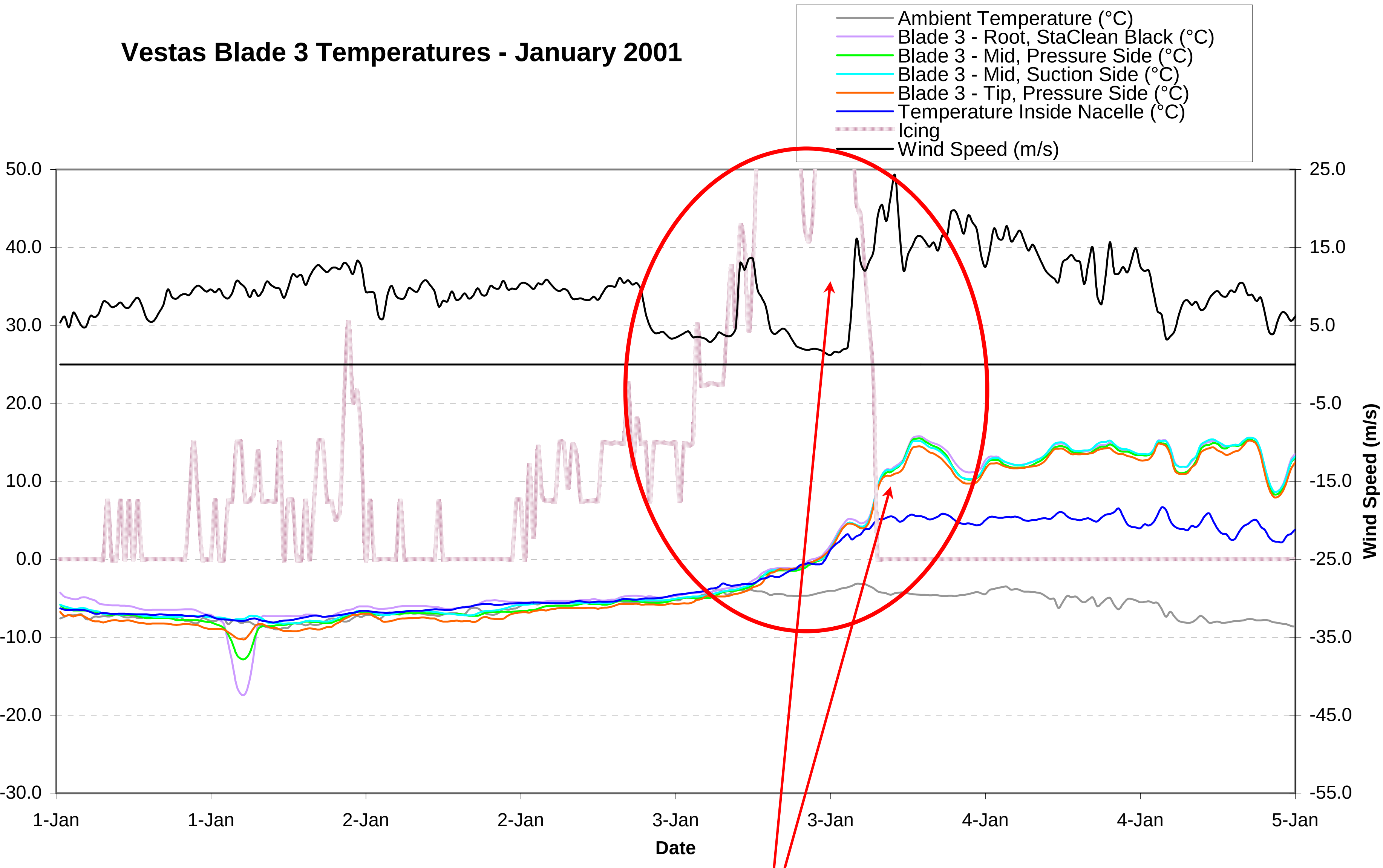
Experimental Setup

- Two Sets of Data
  - Comparing 3 <u>root</u> temperatures:
    - Manufacturer's Blade Coating (White)
    - StaClean White
    - StaClean Black
  - Temperatures along length of Black Blade
    - Tip Temperature
    - Root Temperature

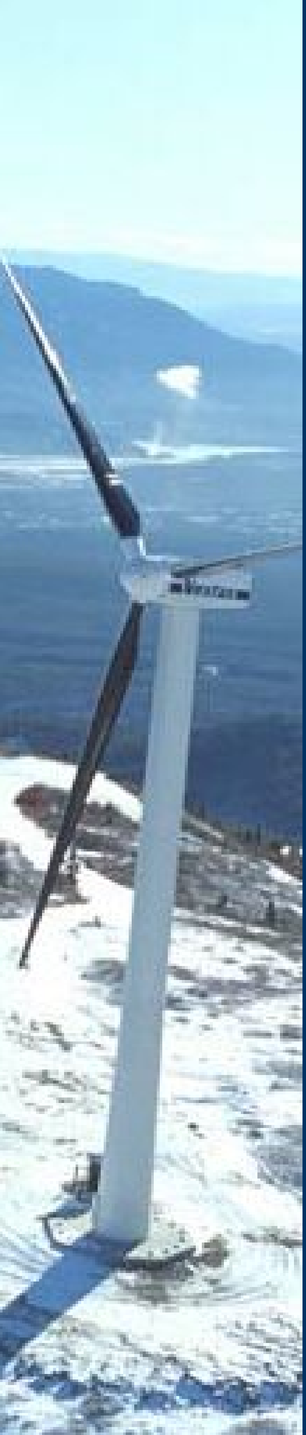

Vestas Blade Root Temperatures - November 2000
Ambient Temperature (°C)
Blade 1 - Root, Manufacturer's Gelcoat (°C)
Blade 2 - Root, StaClean White (°C)
Blade 3 - Root, StaClean Black (°C)
Temperature Inside Nacelle (°C)
Temperature (°C)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
2-Nov
7-Nov
12-Nov
17-Nov
22-Nov
27-Nov
Date


Vestas Blade Root Temperatures - November 2000
Ambient Temperature (°C)
Blade 1 - Root, Manufacturer's Gelcoat (°C)
Blade 2 - Root, StaClean White (°C)
Blade 3 - Root, StaClean Black (°C)
Temperature Inside Nacelle (°C)
Temperature (°C)
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
11/14/00 12:00 AM
11/14/00 12:00 PM
11/15/00 12:00 AM
11/15/00 12:00 PM
11/16/00 12:00 AM
11/16/00 12:00 PM
11/17/00 12:00 AM
11/17/00 12:00 PM
11/18/00 12:00 AM
Date

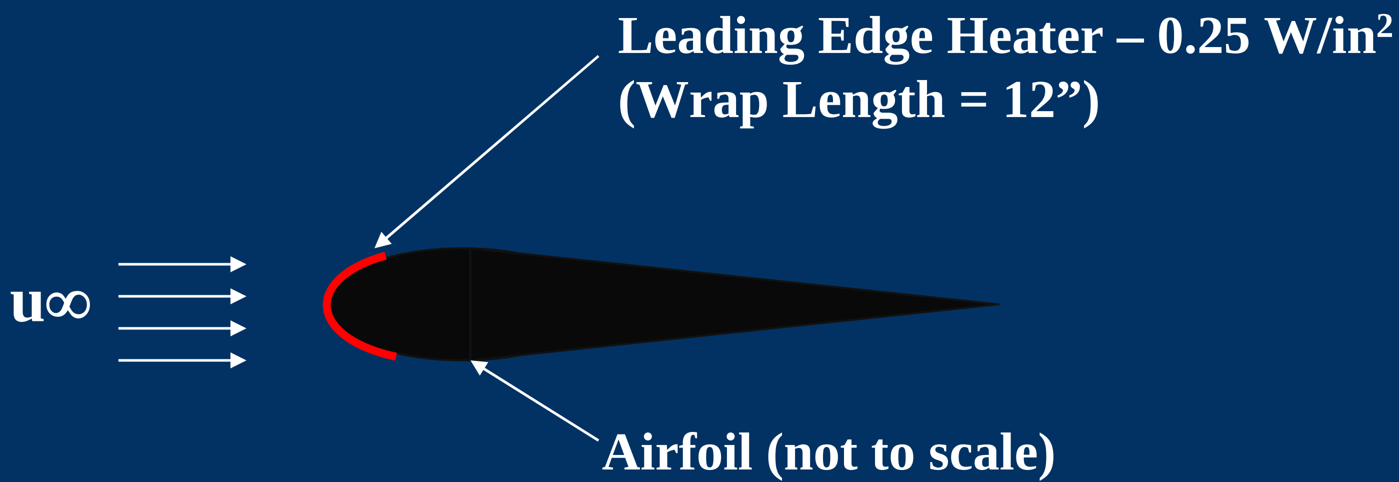

Vestas Blade 3 Temperatures - January 2001
Ambient Temperature (°C)
Blade 3 - Root, StaClean Black (°C)
Blade 3 - Mid, Pressure Side (°C)
Blade 3 - Mid, Suction Side (°C)
Blade 3 - Tip, Pressure Side (°C)
Temperature Inside Nacelle (°C)
Wind Speed (m/s)
Temperature (°C)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
Wind Speed (m/s)
25.0
15.0
5.0
-5.0
-15.0
-25.0
-35.0
-45.0
-55.0
1-Jan
6-Jan
11-Jan
16-Jan
21-Jan
26-Jan
31-Jan
Date
Heating of entire blade due to lack of wind

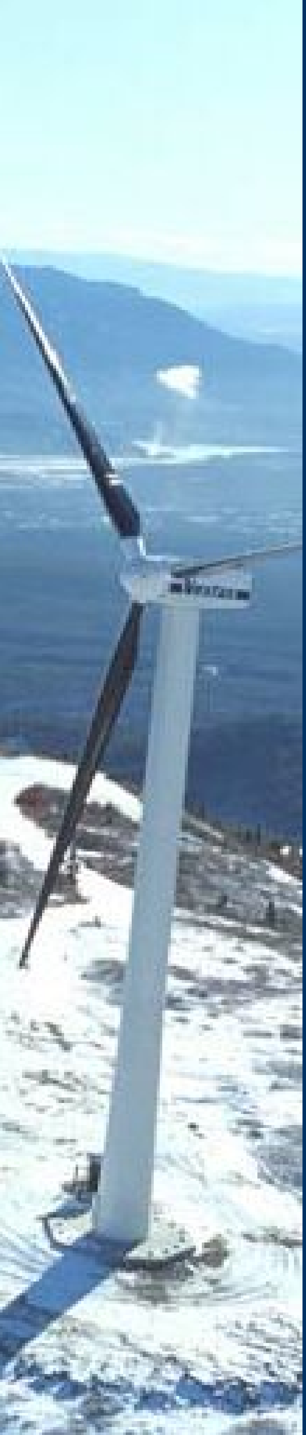


Ice acts as an insulator after an icing event

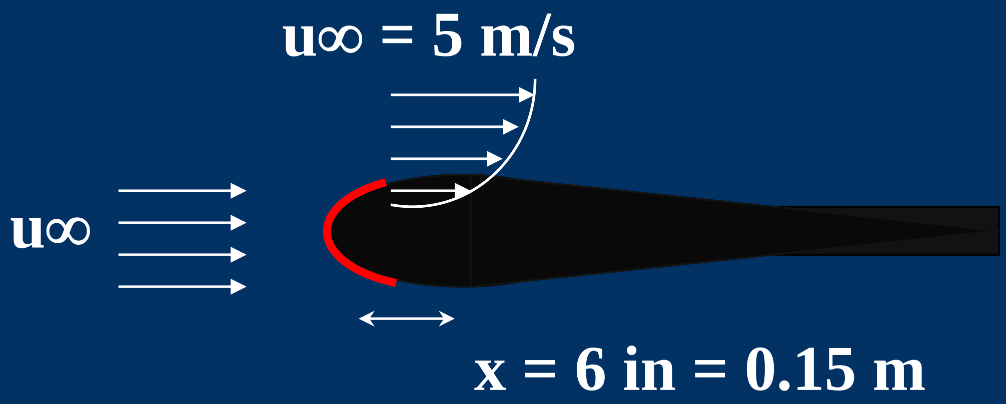


Heat Transfer



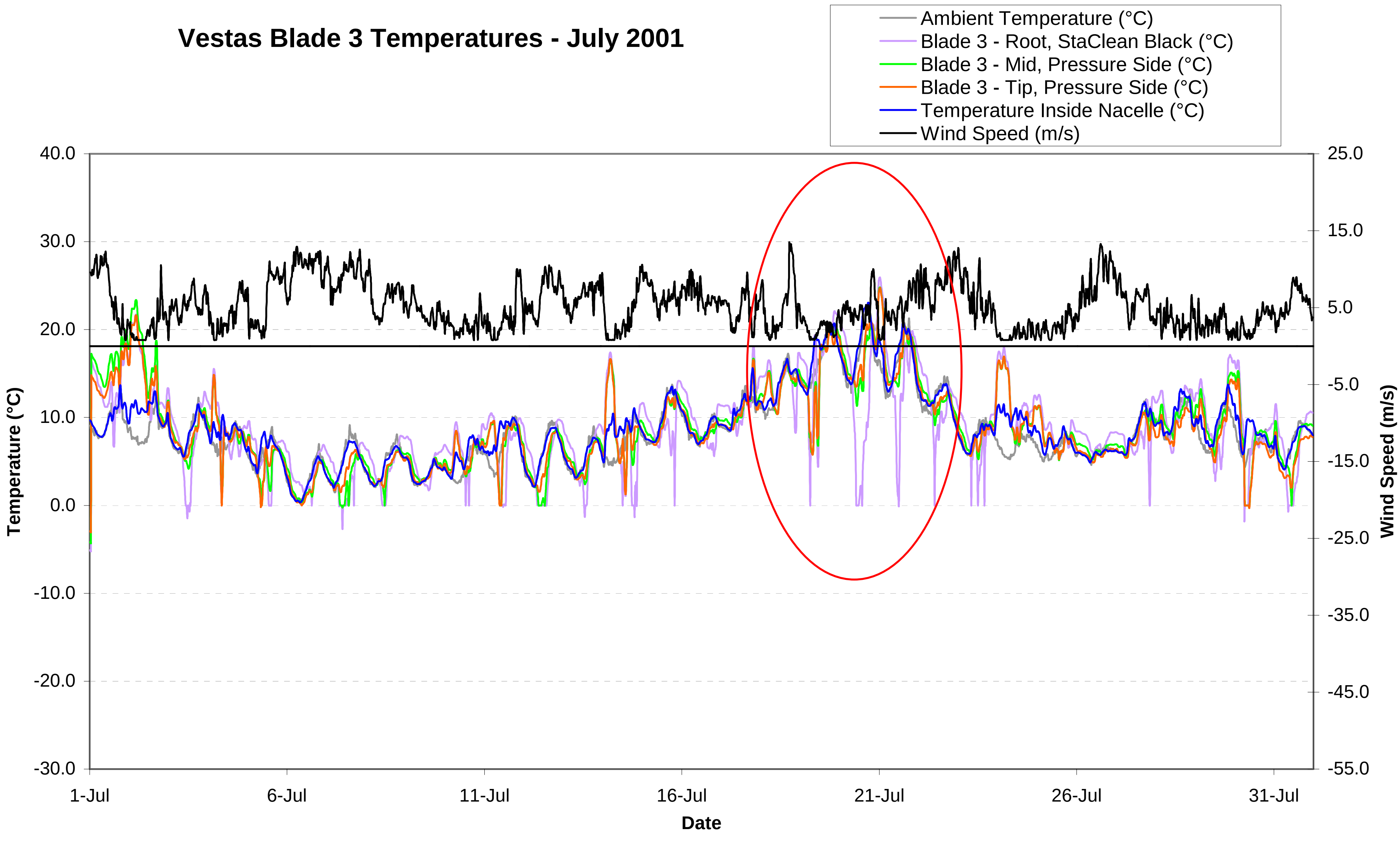


Heat Transfer

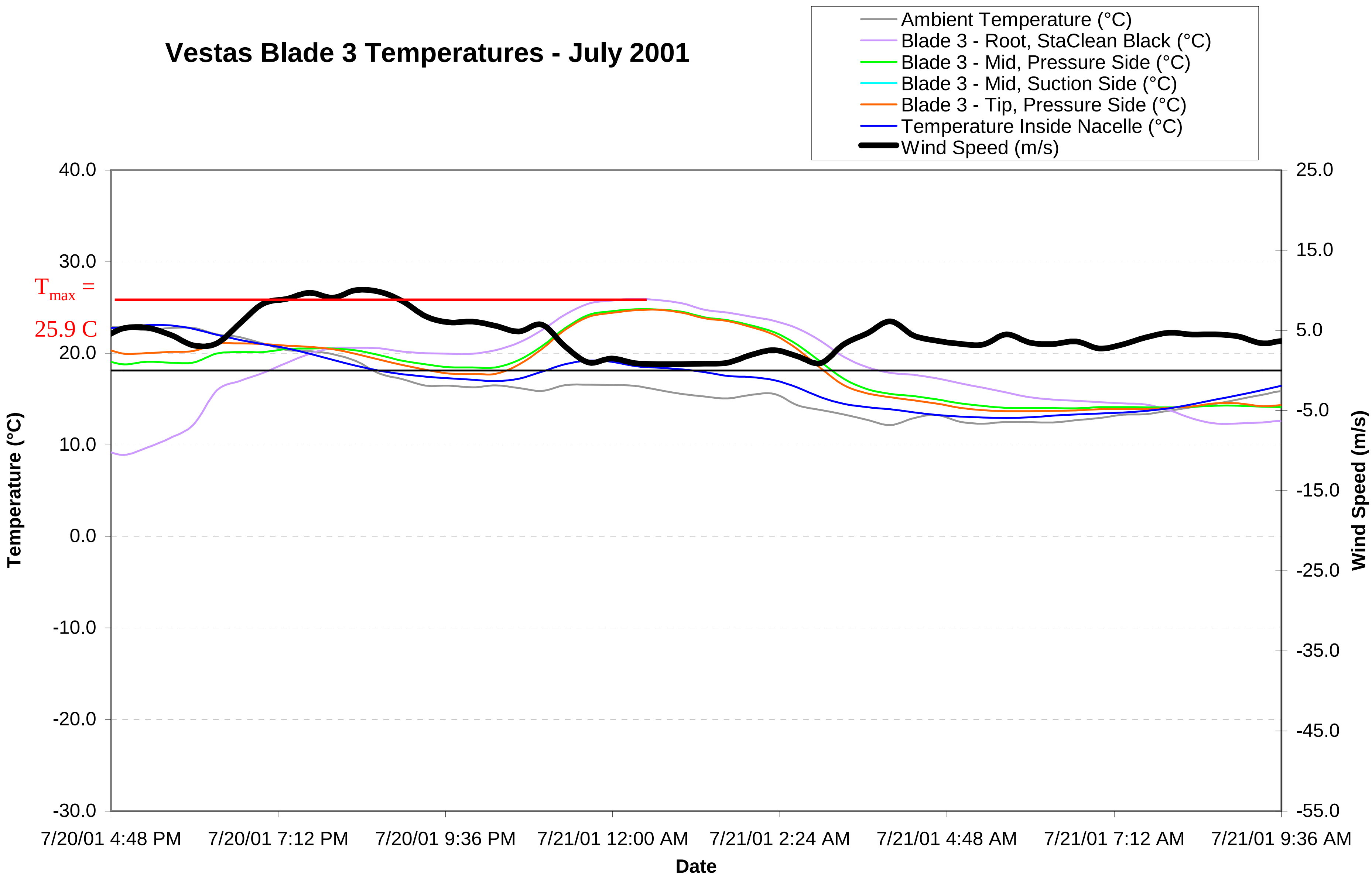


$$\overline{Nu_x} = \frac{\overline{h}_x\, x}{k} = 0.664\, Re_x^{1/2}\, Pr^{1/3}, \quad Pr > 0.6$$

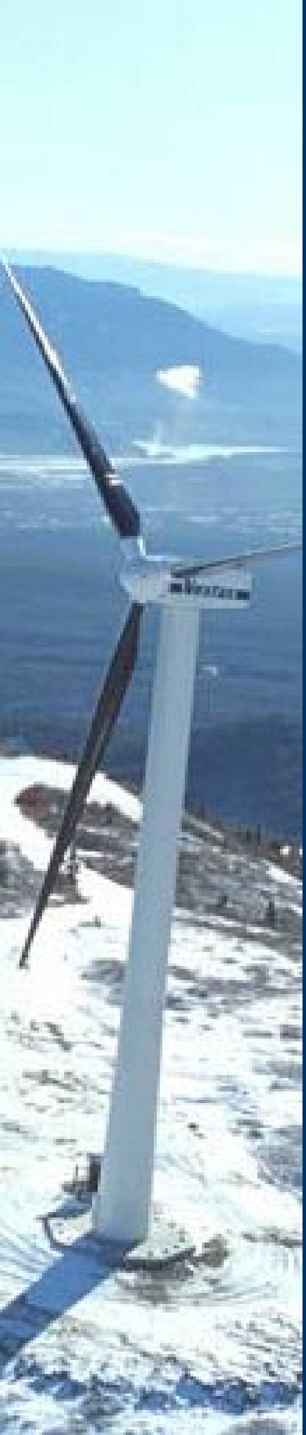
$$q'' = \overline{h}\, \Delta T = 300\ W/m^2 = .2\ W/in^2$$



Vestas Blade 3 Temperatures - July 2001
Ambient Temperature (°C)
Blade 3 - Root, StaClean Black (°C)
Blade 3 - Mid, Pressure Side (°C)
Blade 3 - Tip, Pressure Side (°C)
Temperature Inside Nacelle (°C)
Wind Speed (m/s)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
25.0
15.0
5.0
-5.0
-15.0
-25.0
-35.0
-45.0
-55.0
Temperature (°C)
Wind Speed (m/s)
1-Jul
6-Jul
11-Jul
16-Jul
21-Jul
26-Jul
31-Jul
Date



Vestas Blade 3 Temperatures - July 2001
Ambient Temperature (°C)
Blade 3 - Root, StaClean Black (°C)
Blade 3 - Mid, Pressure Side (°C)
Blade 3 - Mid, Suction Side (°C)
Blade 3 - Tip, Pressure Side (°C)
Temperature Inside Nacelle (°C)
Wind Speed (m/s)
T_{max} =
25.9 C
Temperature (°C)
Wind Speed (m/s)
Date
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
25.0
15.0
5.0
-5.0
-15.0
-25.0
-35.0
-45.0
-55.0
7/20/01 4:48 PM
7/20/01 7:12 PM
7/20/01 9:36 PM
7/21/01 12:00 AM
7/21/01 2:24 AM
7/21/01 4:48 AM
7/21/01 7:12 AM
7/21/01 9:36 AM



Discussion & Conclusions

- Heaters are not able to heat blades beyond themselves even in modest winds (>5 m/s)
- Black blades appear to add minimal solar gain in windy areas, in neither summer nor winter
- Black blades do not overheat in the summer