Borealis Wind

Determining Heating Power for Blade Heating System

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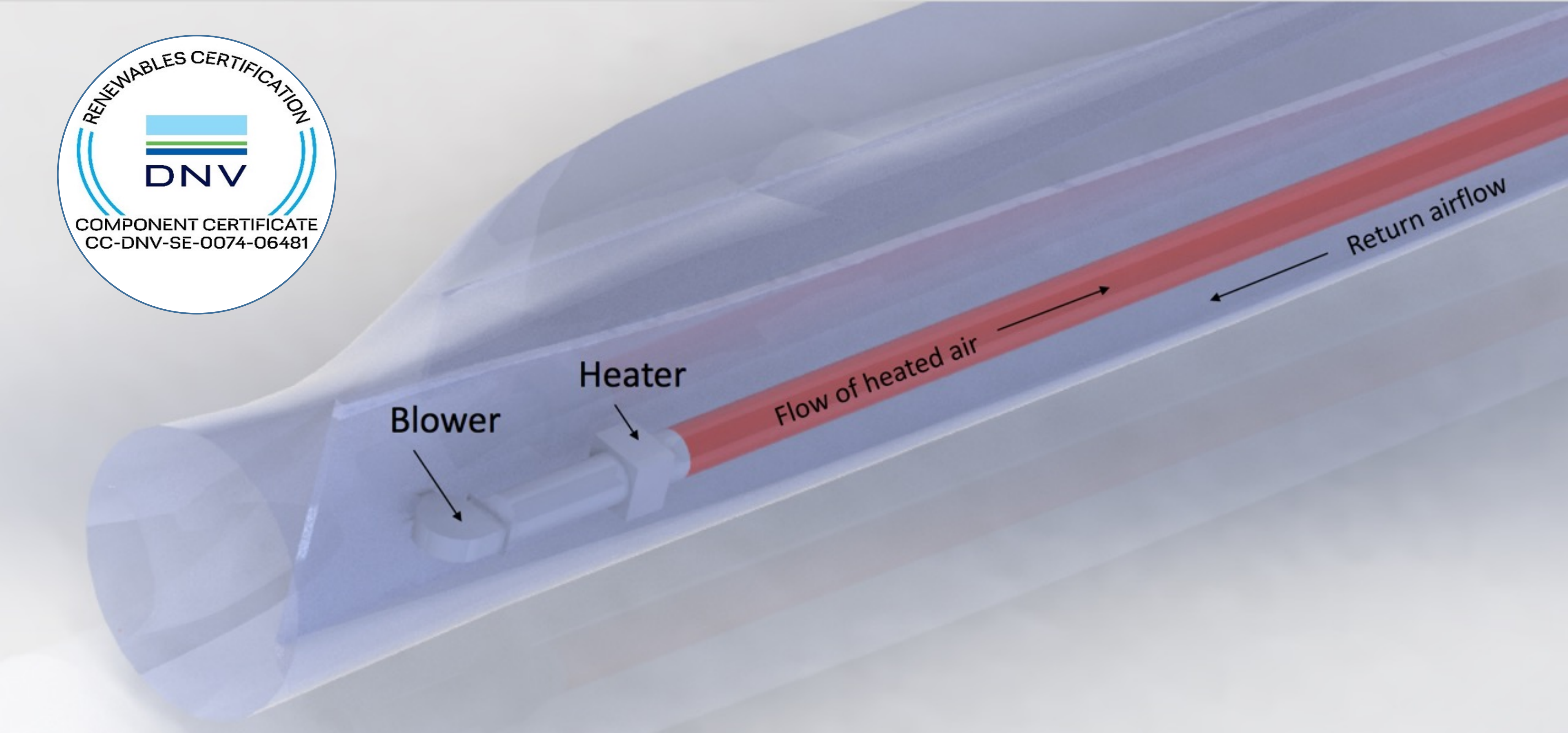
Our Goal:
Provide a simple retrofit system that can reduce icing loss by at least 70%, is robust, reliable and maintainable

RENEWABLES CERTIFICATION

DNV

COMPONENT CERTIFICATE
CC-DNV-SE-0074-06481



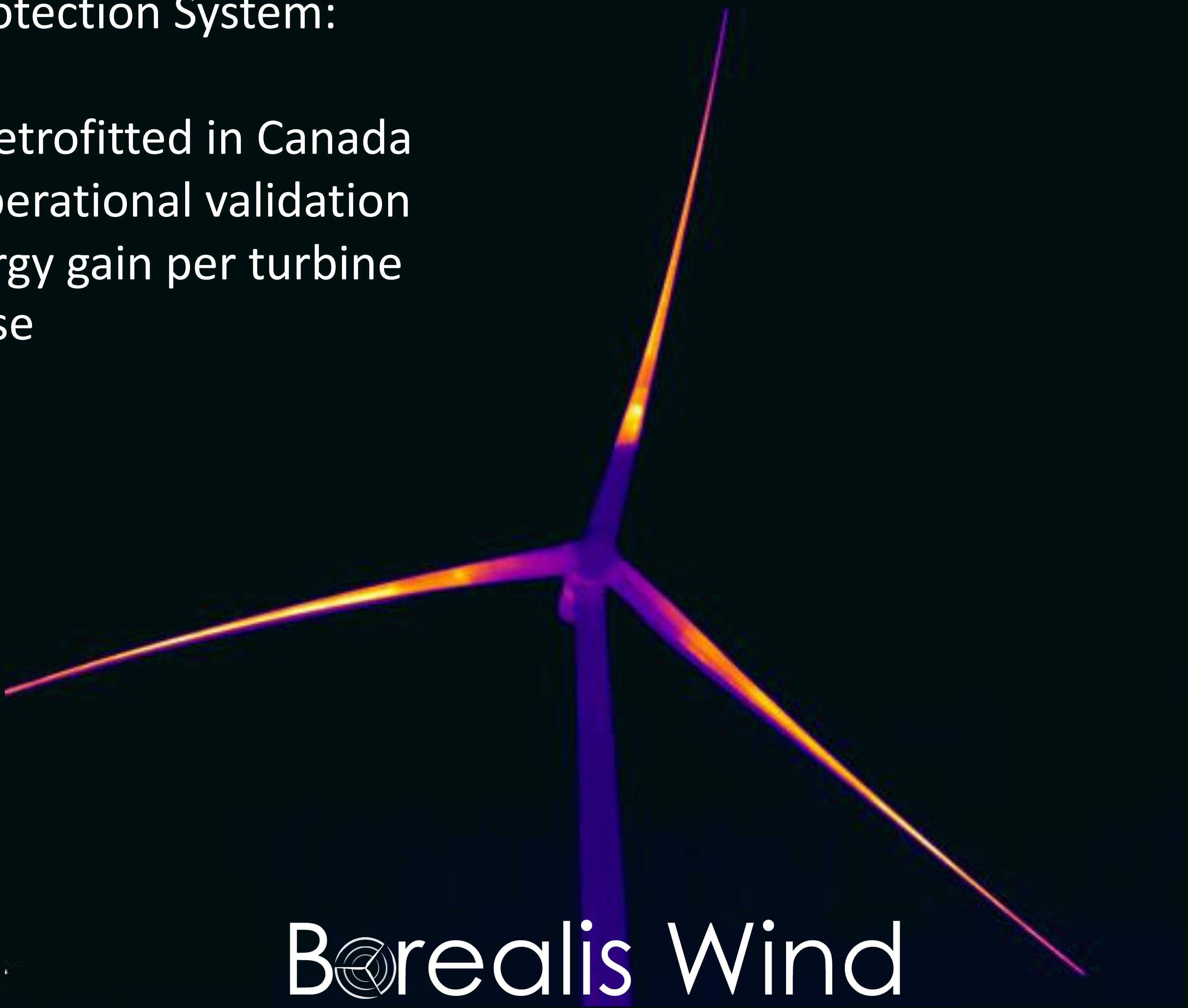
Borealis Ice Protection System

Retrofit Installation

- 3 days to retrofit the Borealis System prior to turbine construction
- 7 days to retrofit the Borealis System into a constructed turbine
- Schedule is designed to have the turbine operational overnight
- All materials are sized so they can be easily passed into the blade
    - Less than 50 cm x 50cm in cross section
    - Less than 70 lbs.

Borealis Ice Protection System:

5 wind farms retrofitted in Canada
5 winters of operational validation
500 MWh energy gain per turbine
8% AEP increase



Borealis Wind

Thermodynamic Model - High Level

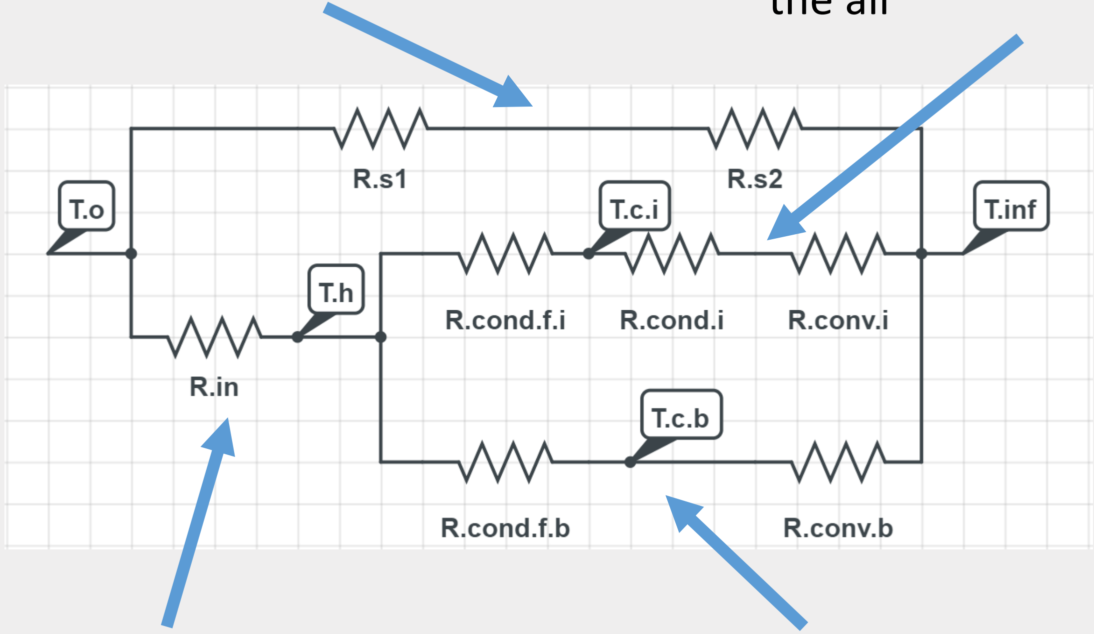
- Heat exchanger inside the blade, to heat the leading edge cavity
- Heat loss to the trailing edge
- Conduction through the leading edge
- Conduction through ice
- Convection to outside air
- Assuming rime ice is present, LWC = 0, Tambient = -7C, Wind = 7 m/s

Thermodynamic Model – Part 1

Symbol	Description
T_o	Temperature of the air inside the leading-edge cavity of the blade
T_h	Temperature of the internal blade surface on the leading-edge
$T_{c.i}$	Temperature of the external blade surface in contact with ice
$T_{c.b}$	Temperature of the external blade surface in contact with the ambient air
T_{inf}	Ambient air temperature

Heat loss to the trailing edge

Heat loss through the leading edge and ice to the air



Convection to the leading edge

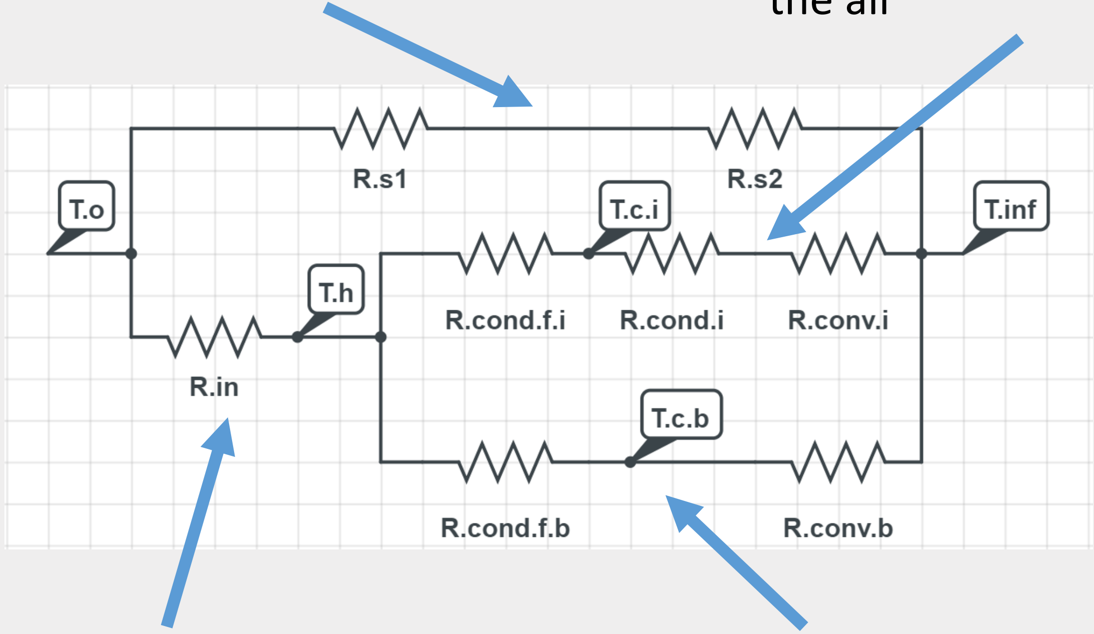
Heat loss through the leading edge to the air

Thermodynamic Model – Part 2

	Symbol	Equation	Description
R_s	R_{s1}	$\frac{1}{h_{in} * A_{shear\ web}}$	Resistance for heat to transfer from the air inside the leading edge to the shear web
R_s	R_{s2}	$\frac{t_{spar}}{k_{fiberglass} * A_{shear\ web}}$	Resistance for heat to travel through the shear web
R_l	R_{in}	$\frac{1}{h_{in} * A_{leading\ edge}}$	Resistance for heat to transfer from the air inside the leading edge cavity to the leading edge airfoil
R_l	$R_{cond.f.i}$	$\frac{t_{leading\ edge}}{k_{fiberglass} * A_{iced}}$	Resistance for heat to travel through the leading edge airfoil in areas covered in ice
R_l	$R_{cond.i}$	$\frac{t_{ice}}{k_{ice} * A_{iced}}$	Resistance for heat to travel through the layer of ice
R_l	$R_{conv.i}$	$\frac{1}{h_{ext} * A_{iced}}$	Resistance for heat to transfer from the external surface of the ice to the ambient air
R_l	$R_{cond.f.b}$	$\frac{t_{leading\ edge}}{k_{fiberglass} * A_{bare}}$	Resistance for heat to travel through the leading edge airfoil in areas not covered in ice
R_l	$R_{conv.b}$	$\frac{1}{h_{ext} * A_{bare}}$	Resistance for heat to transfer from the external surface of the leading edge to the ambient air

Heat loss to the trailing edge

Heat loss through the leading edge and ice to the air

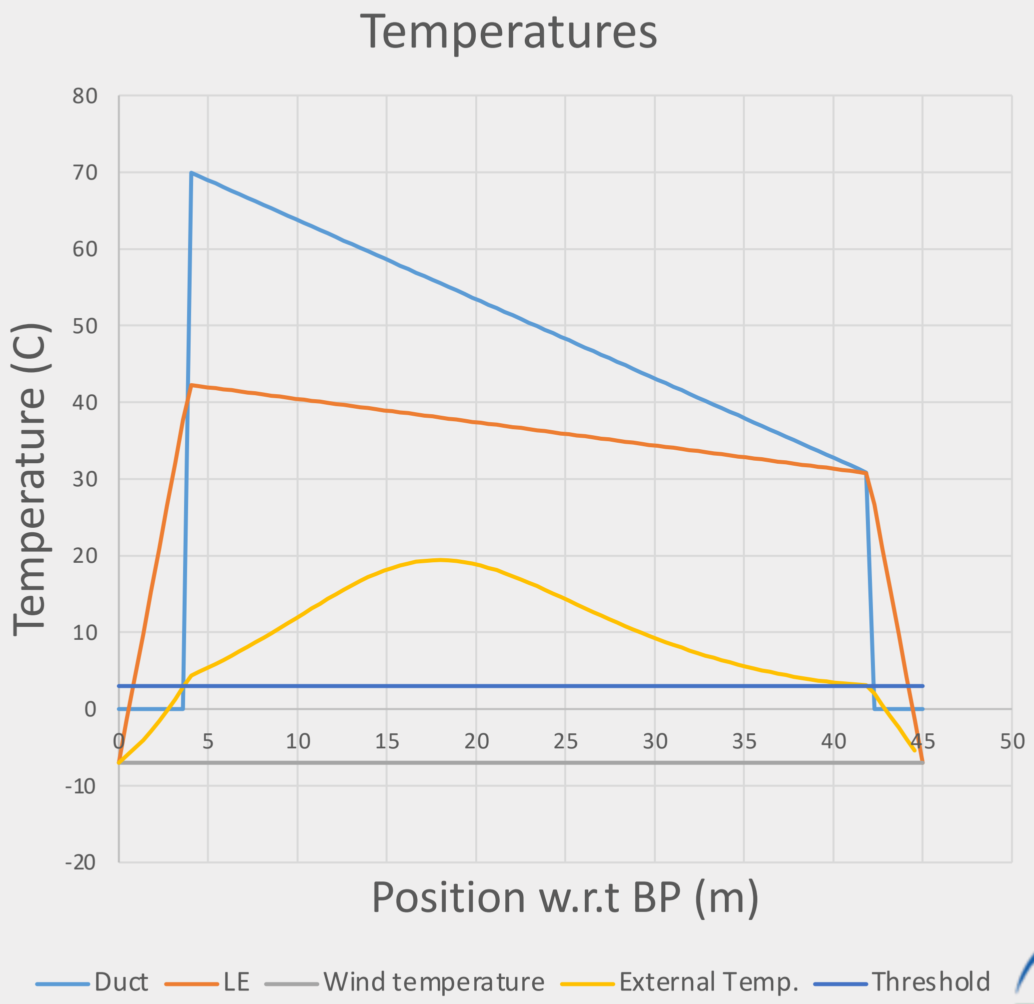


Convection to the leading edge

Heat loss through the leading edge to the air

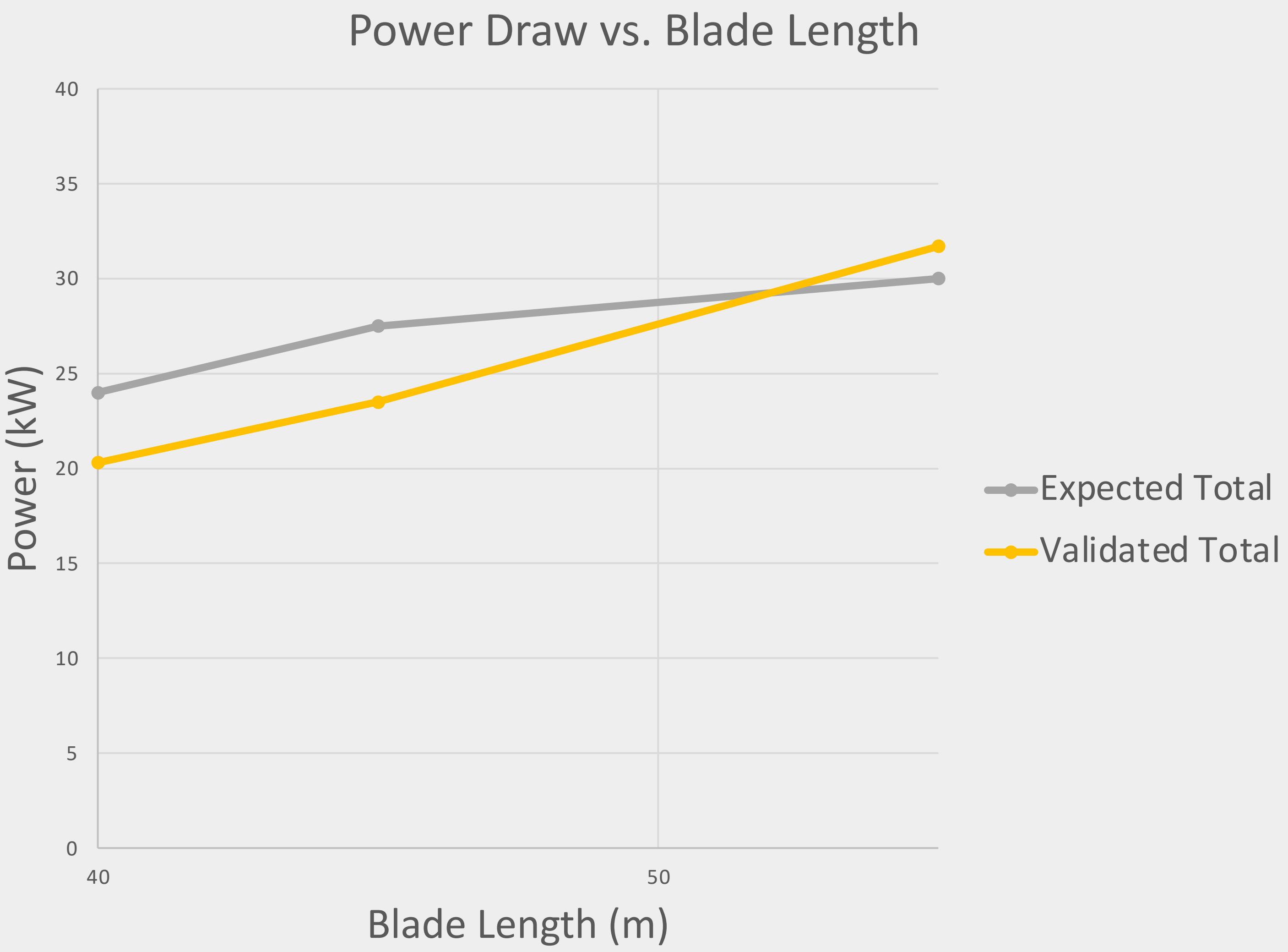
Thermodynamic Model – Part 3

- This allows us to determine a rate of heat transfer (Q) that can be passed through the blade
  - *Rtotal = 1/(1/Rs + 1/Rl)*
  - *Q = (To-Tinf)/Rtotal*
  - Calculcated at each 0.5m section
- We are limited in temperature, by the material of the blade
- The critical factor is the airflow, to be able to deliver that heat to the critical area, without exceeding the maximum allowable temperature



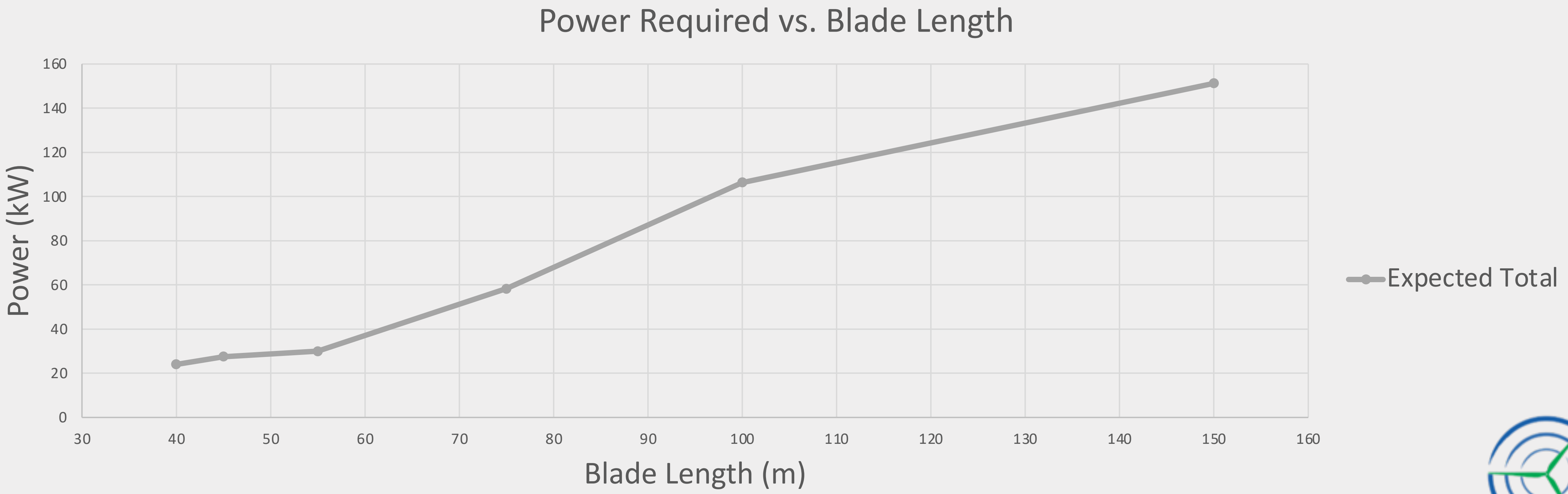
Results

- The graph shows the calculated and measured power consumption for the heating systems we have installed



Heating Requirements for Larger Blades

- The graph shows the validated heating requirements, and the calculated requirements for larger blades



Summary

Borealis Ice Protection System:

Internal hot air heating system

3-7 day retrofit

8% AEP increase achieved

Heat Requirement by Blade Length:

Heating power is determined with a thermo-model

Determine heat transfer, Q, through the blade

Validated to 55m blades, calculated up to 150m blades

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