Virtual temperature sensor in blade heating system and its validation

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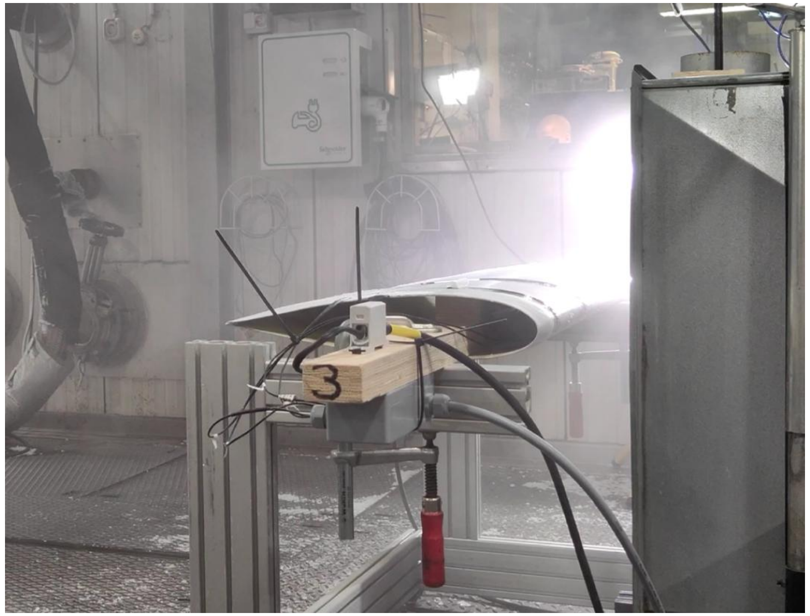

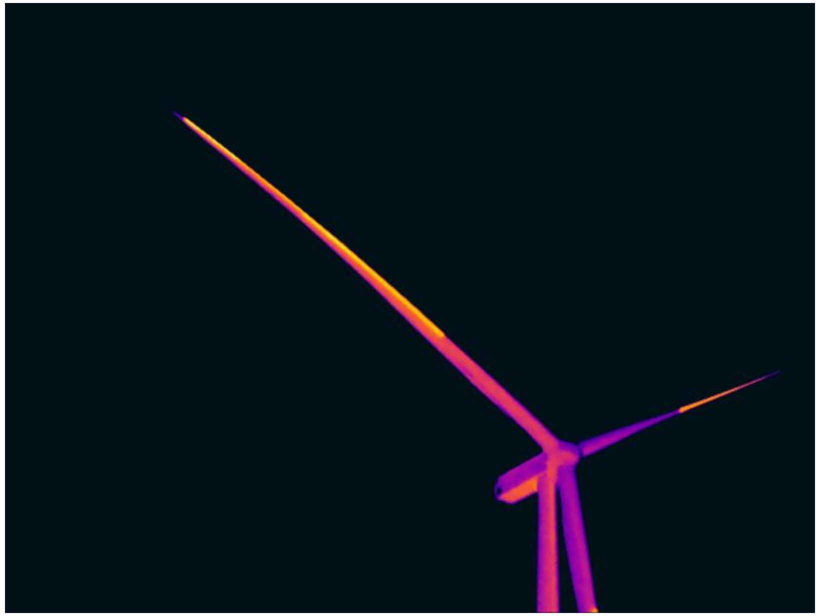

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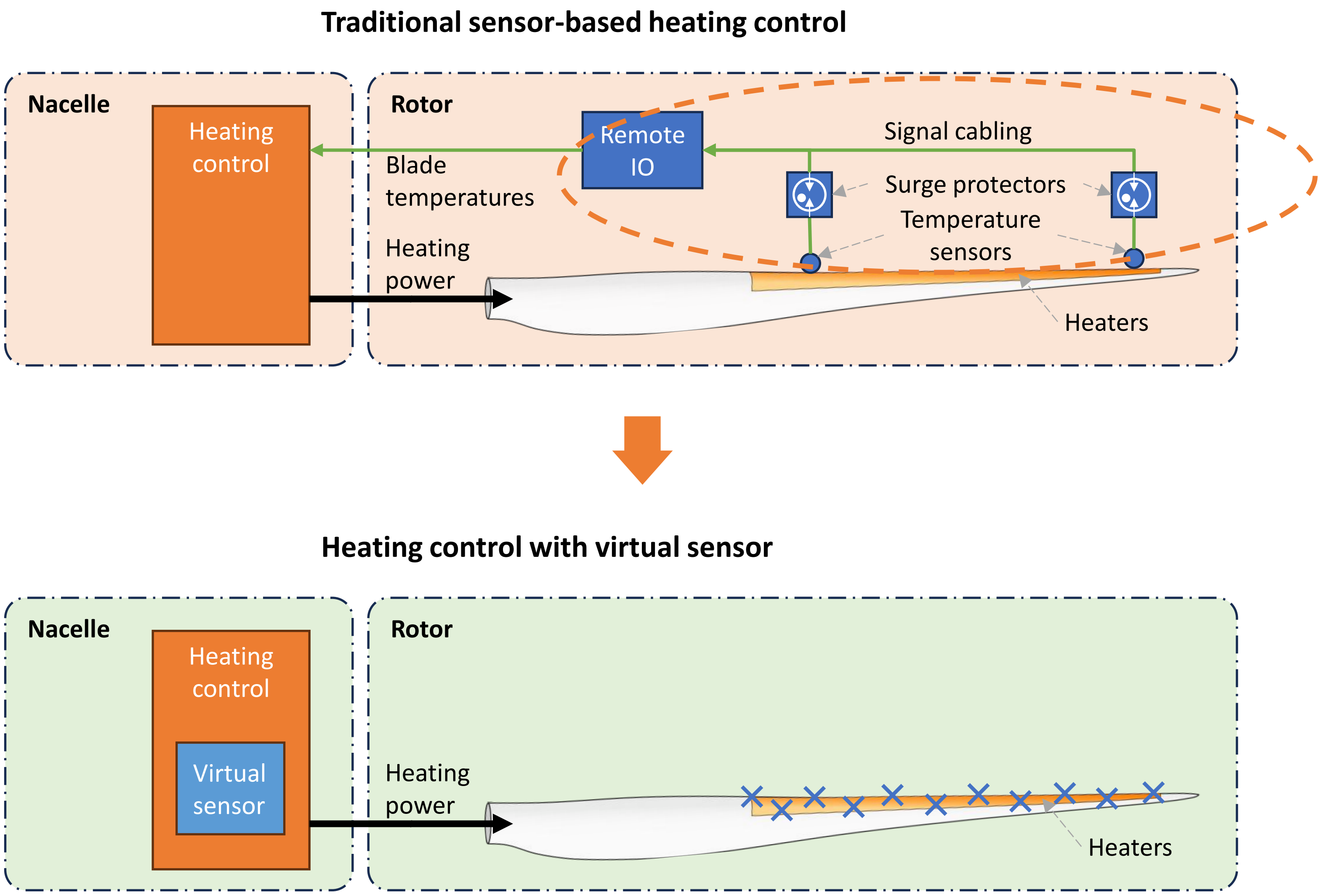
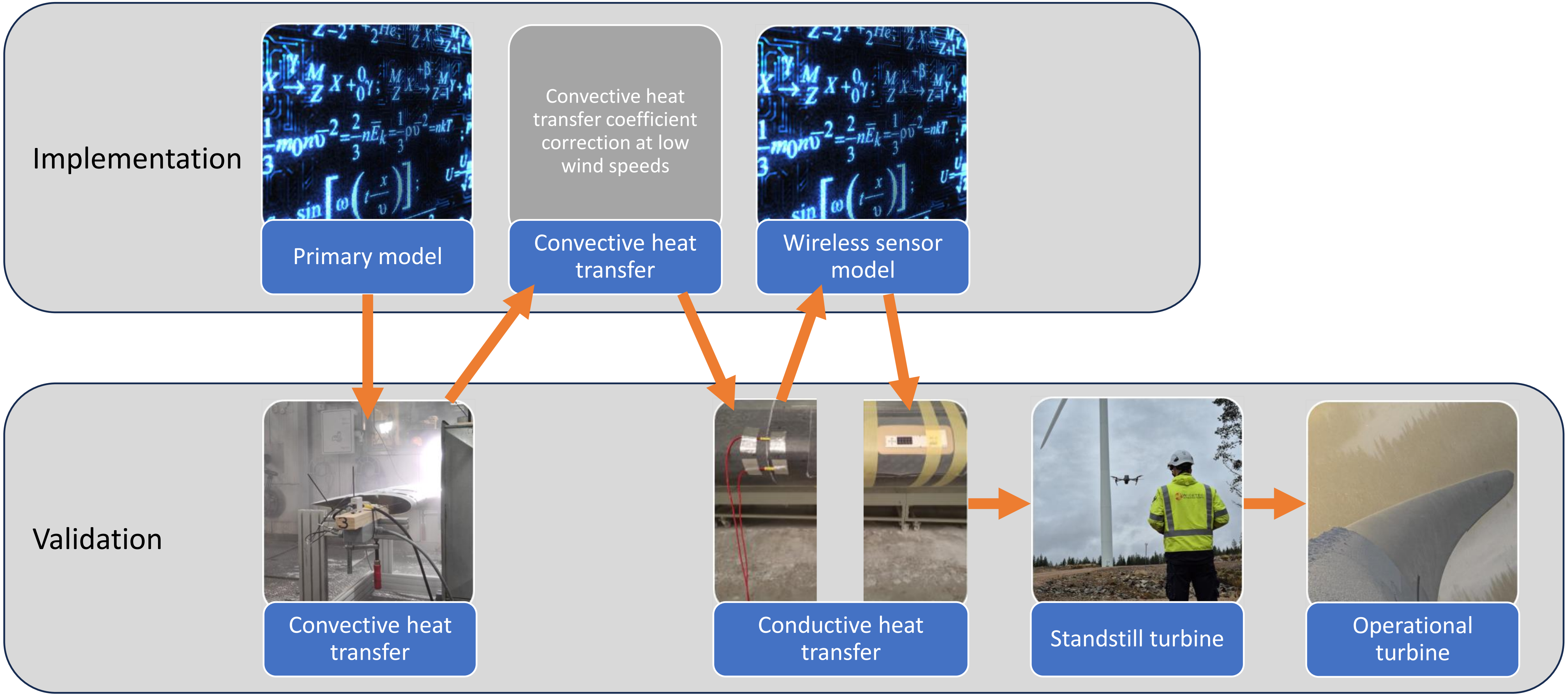
Motivation

- Mathematical algorithm
- Virtual sensors vs physical sensors
  - Lower CAPEX
    - Less hardware
    - Simpler installation
  - Lower OPEX
    - No maintenance
    - No downtime
    - No lightning damage risk
  - More measurement locations

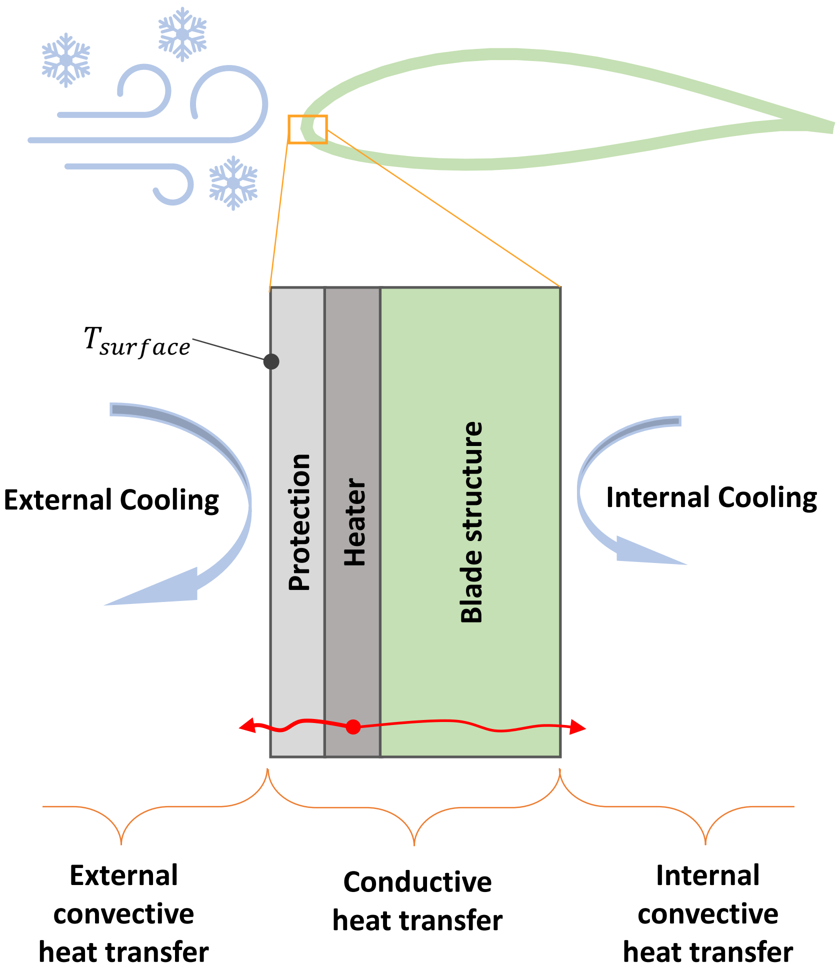


Implementation and validation process



Virtual temperature sensor implementation

- 1-dimensional heat transfer model
- Conductive heat transfer
  - Material properties
  - Heating power
- Convective heat transfer
  - Ambient conditions:
    - Ambient temperature
    - wind speed
    - liquid water content
  - Rotor speed
  - Calculated with Turbice



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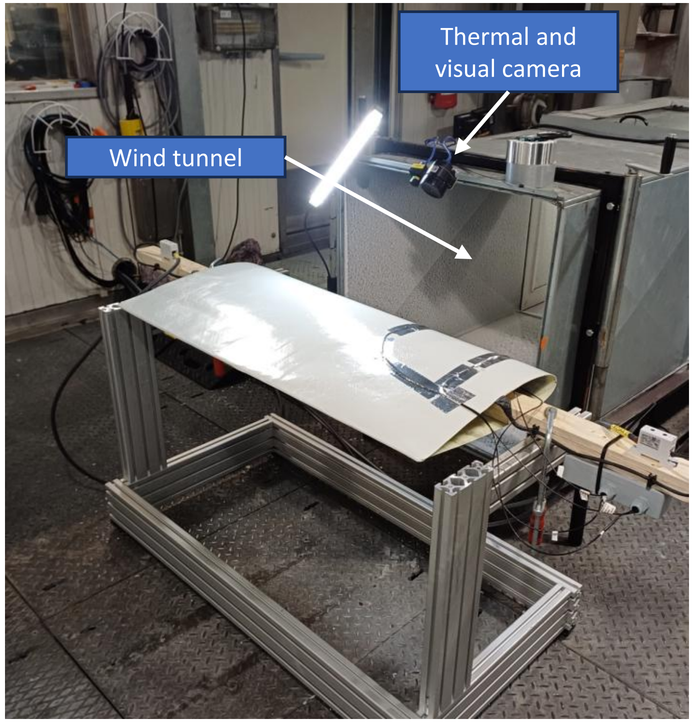
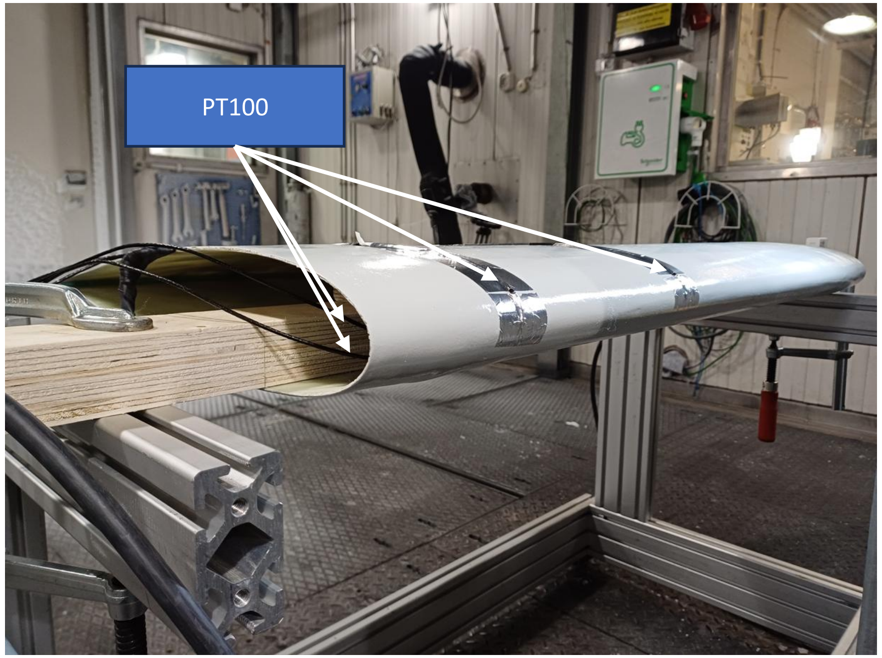
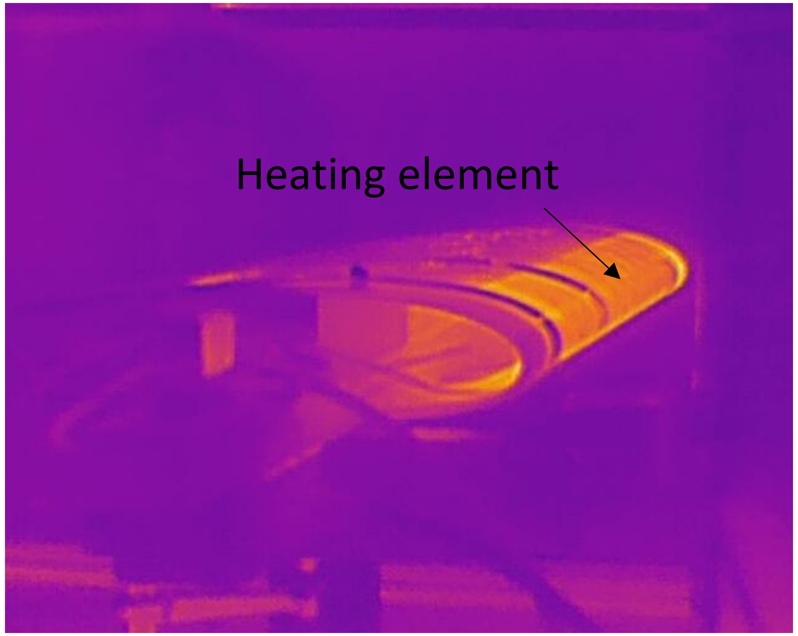
Convective heat transfer validation

- Icing wind tunnel testing at VTT facility in Finland.
- Purpose
  - Validate convective heat transfer coefficients calculated with Turbice

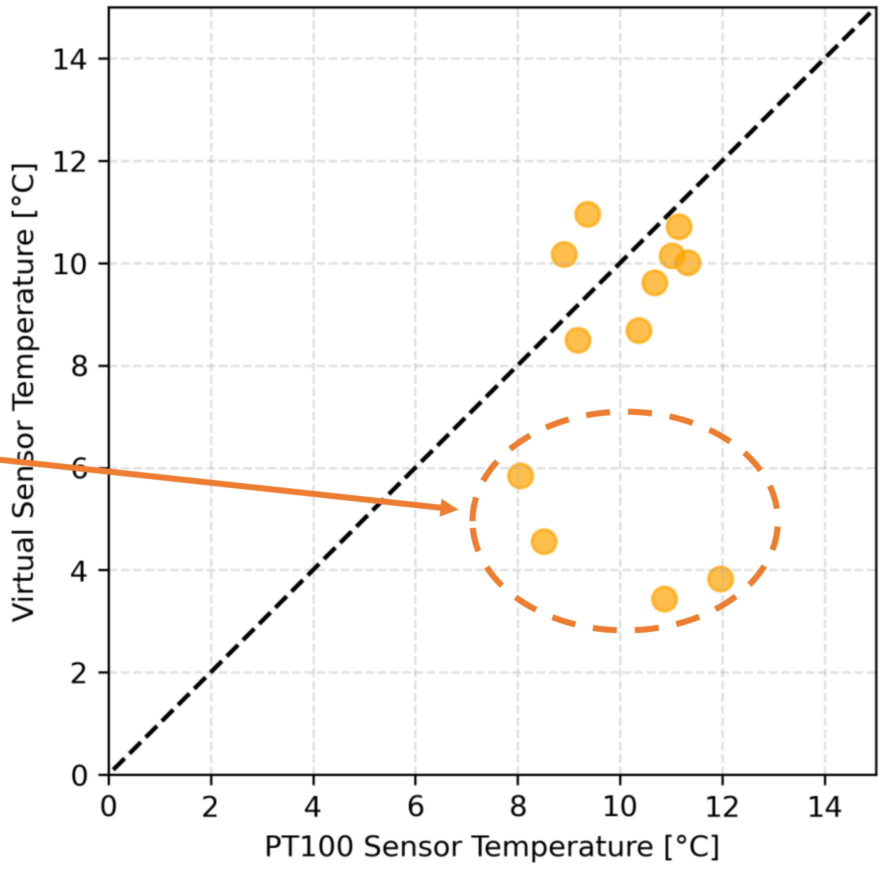






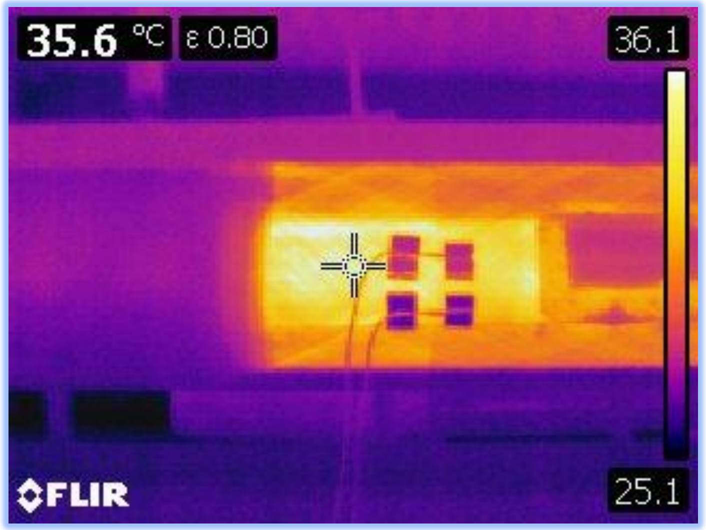
Convective heat transfer validation - results

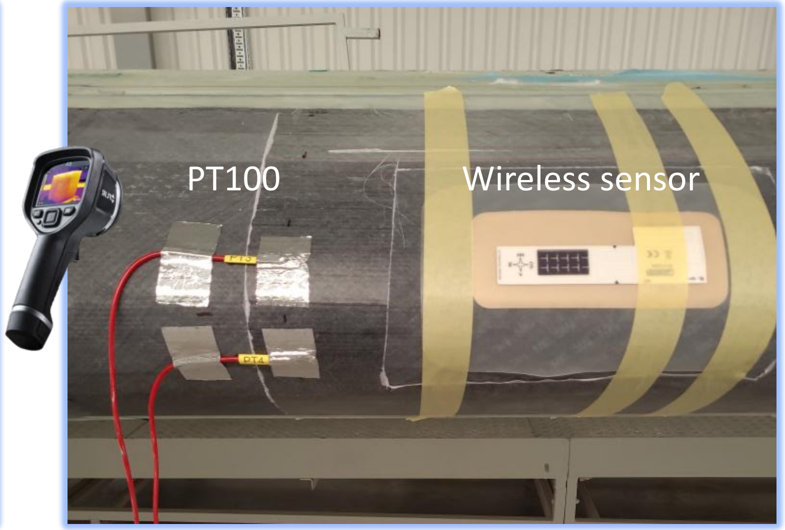
- Ambient conditions:
  - Wind speed 1 – 20m/s
  - LWC 0.4 – 0.6g/m3
  - Ambient temperature -10°C
- Results
  - Model had offset at low wind speeds (1 – 3m/s)



Conductive heat transfer validation

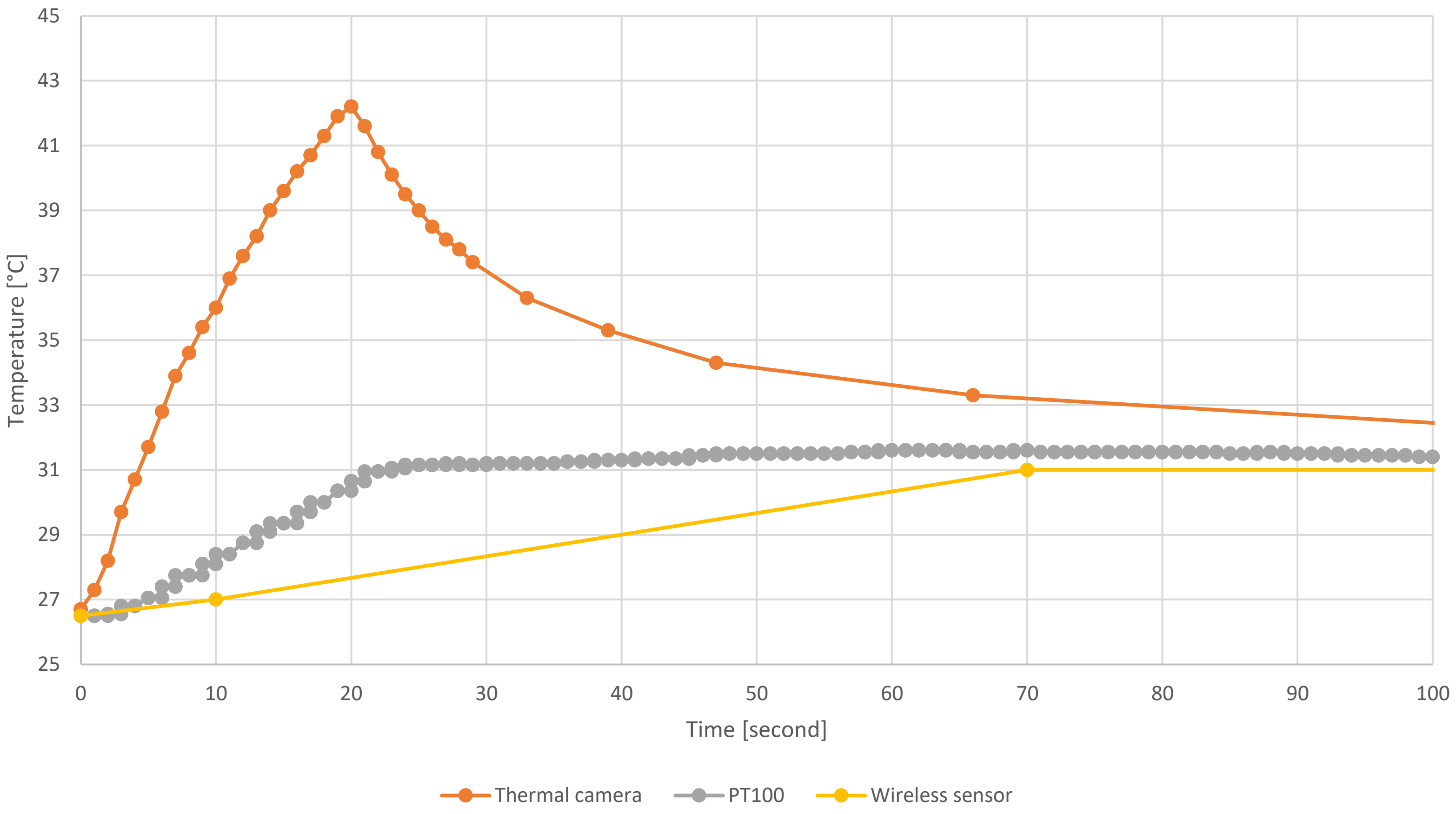
- Testing at blade factory floor
- Purpose
  - Validate material properties
- 3 different temperature measurements
  - Thermal camera
  - PT100 temperature sensors
  - Wireless sensors





Conductive heat transfer validation – first results

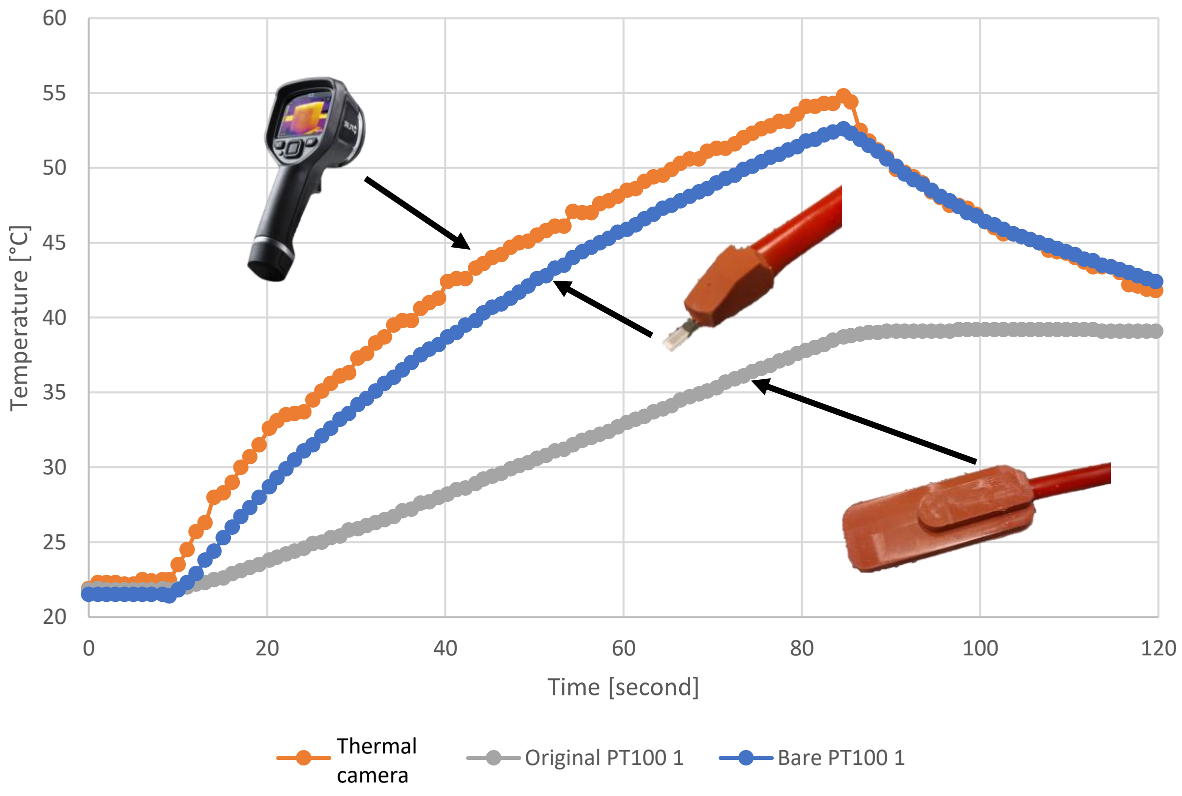
- Big difference in response time between sensors and thermal camera



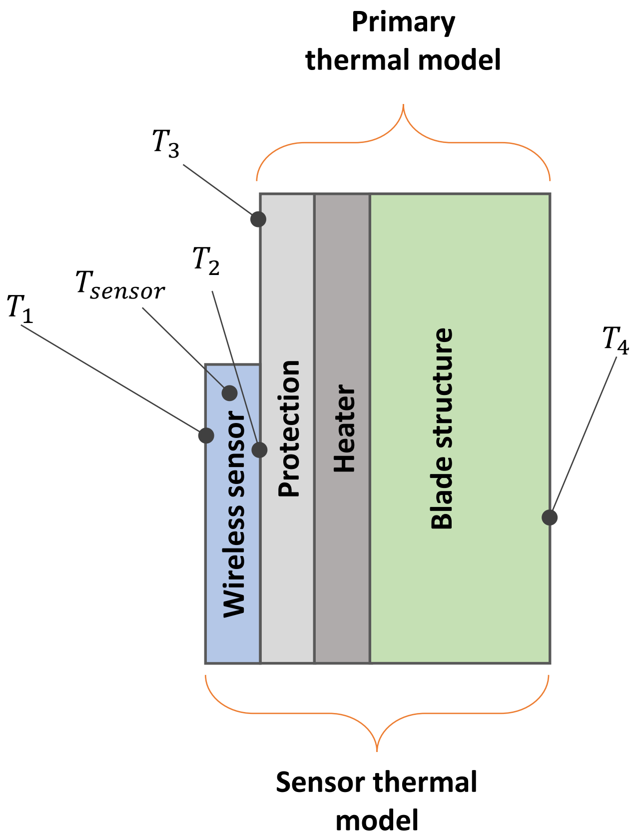
Conductive heat transfer validation – PT100

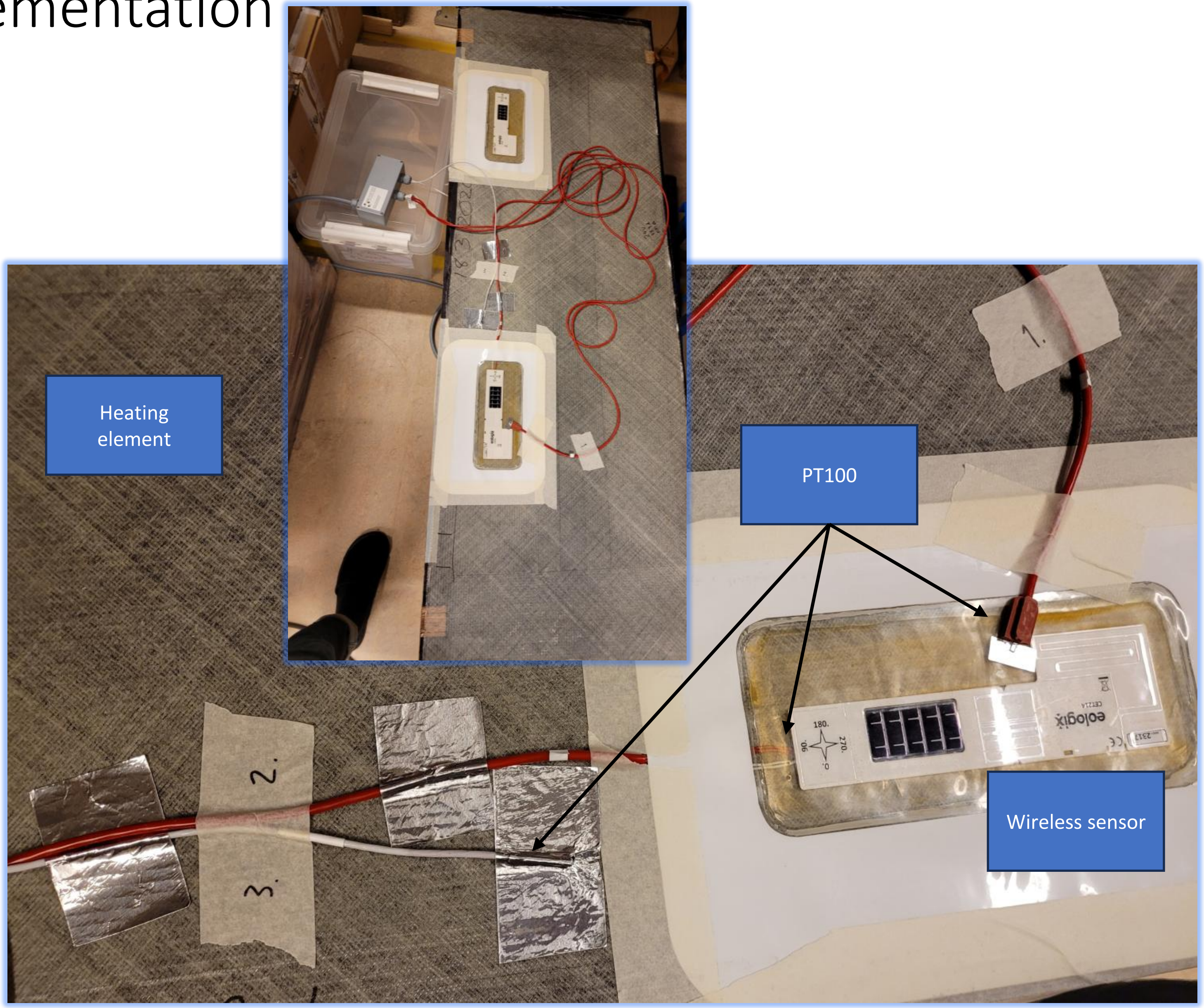
- PT100 sensor element was surrounded with silicone case which increased the response time

- Better results after cutting off the silicon case



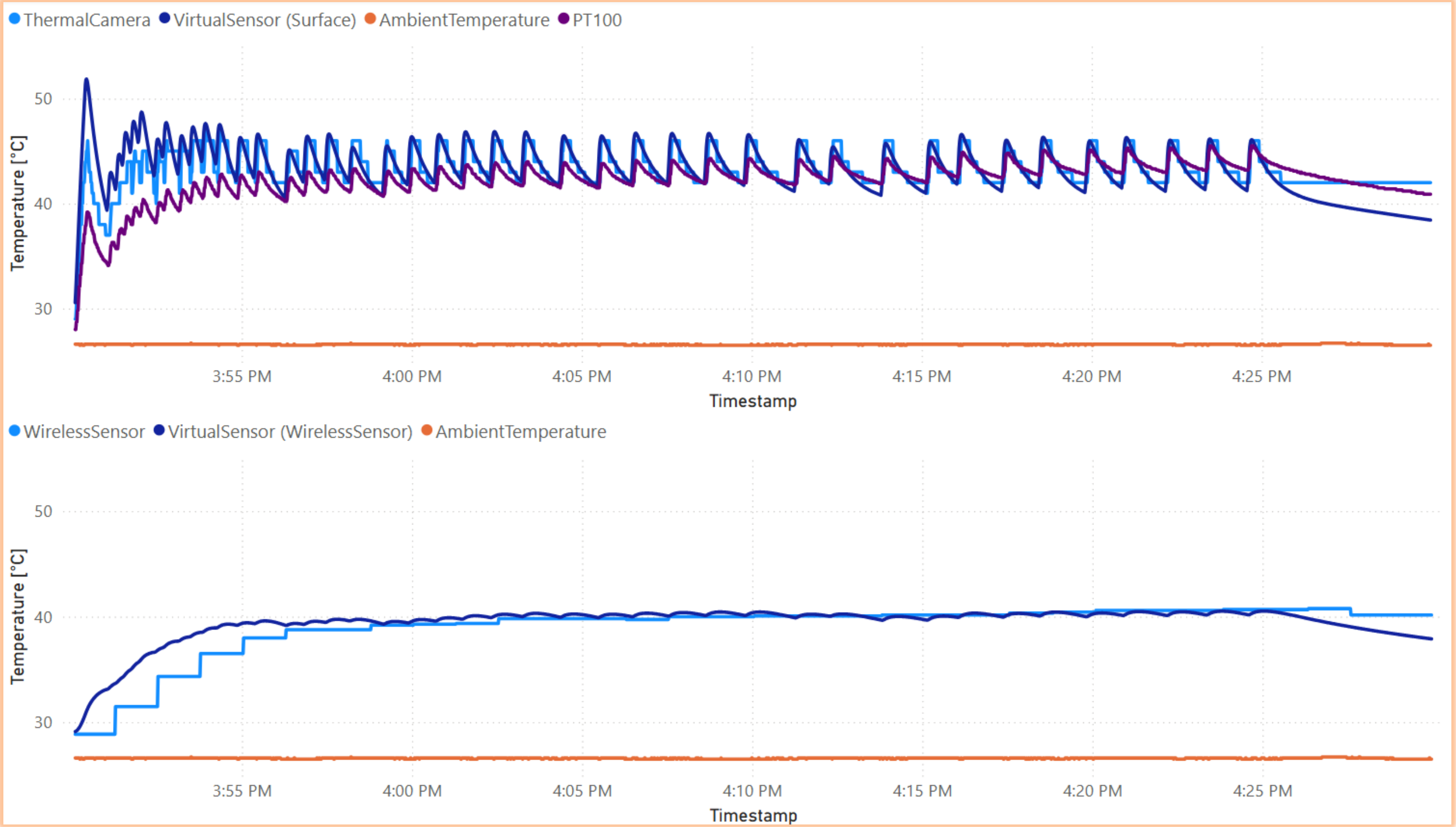
Wireless sensor model implementation for virtual sensor





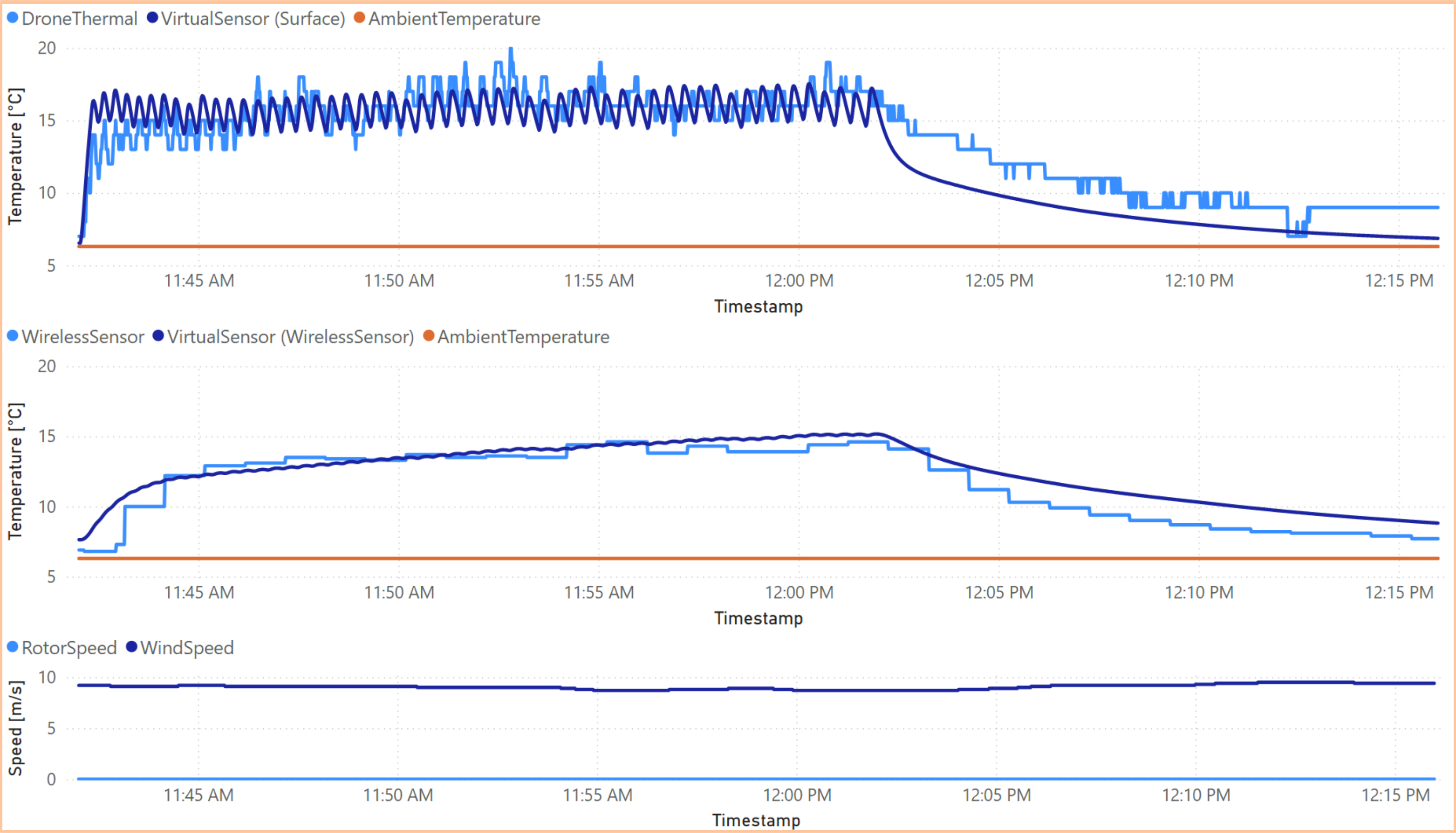
Conductive heat transfer validation – final results

- Surface temperature
  - Good correlation between virtual sensor and thermal camera
  - PT100 still a bit slow but catching up over time
- Wireless sensor temperature
  - Good correlation with virtual sensor



Standstill test

- Testing at wind farm
- Purpose
  - Validate both primary and sensor model at standstill
- 2 different temperature measurements
  - Thermal camera
  - Wireless sensors
- Results
  - Good correlation between virtual sensors and measurements



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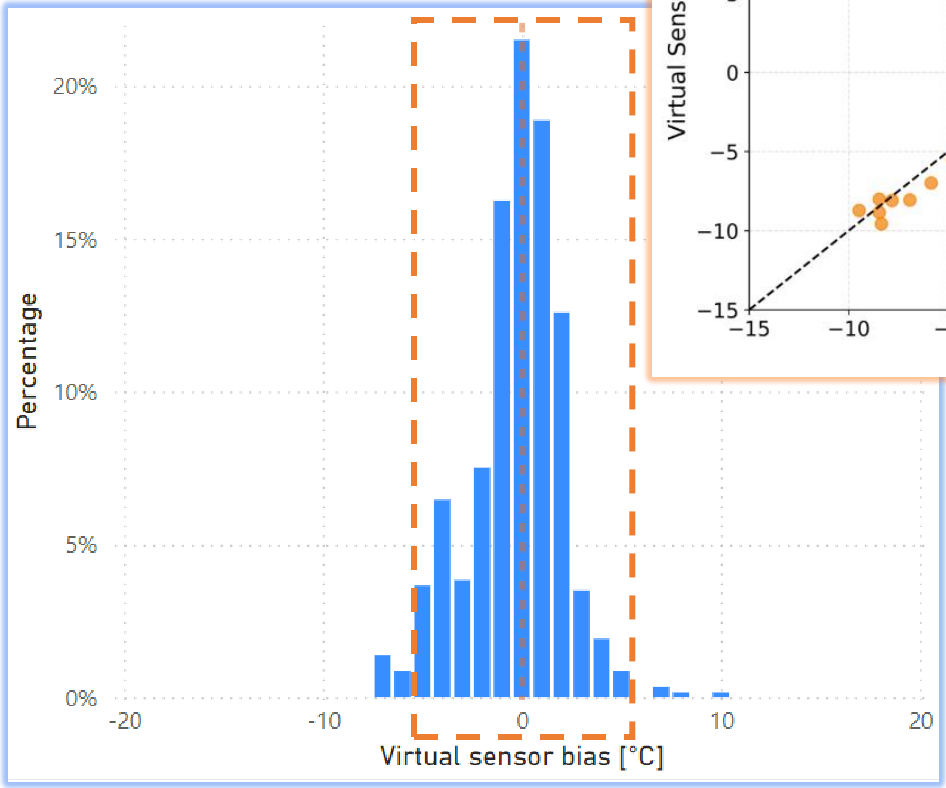
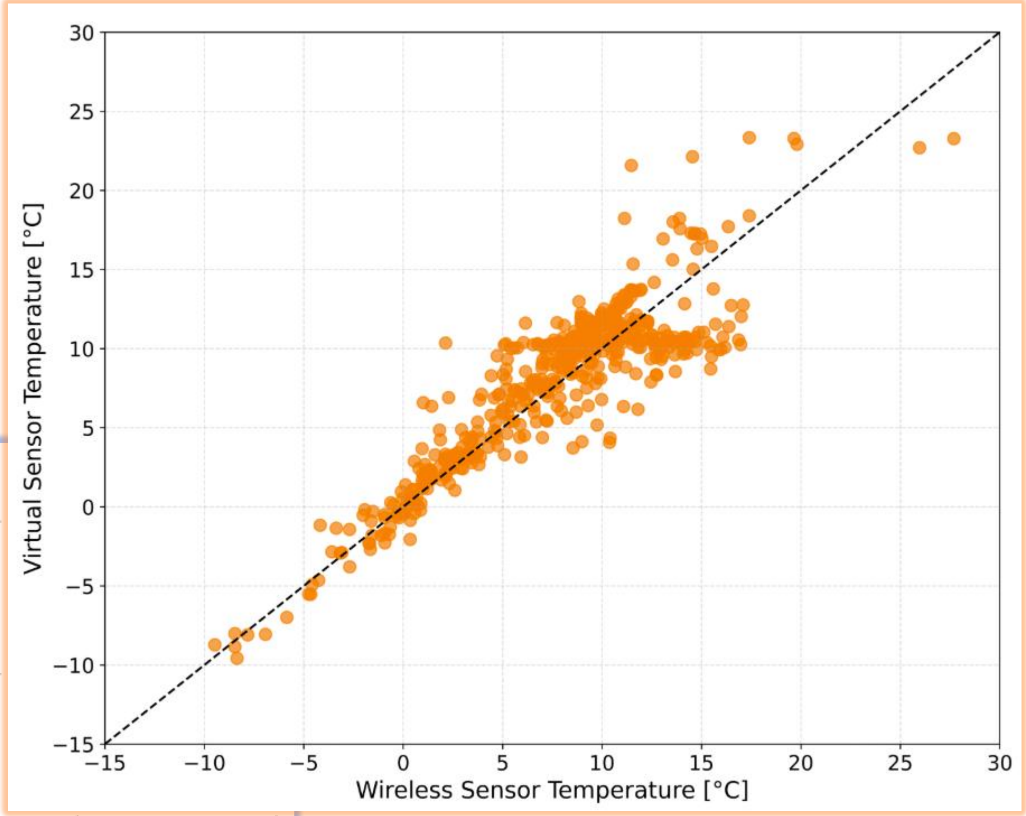
Operating turbine

- Purpose
  - Extensive validation with operating turbine
- Wireless sensors measuring temperatures
- Results
  - Maximum offset = ±10°C
  - **Typical offset (97%) ≤ ±5°C**





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Key points

- Know what you are measuring
  - Surface mounted sensor temperature ≠ surface temperature
  - Thermal cameras for surface measurements
- Know what you are modeling
  - Validation against sensor measurements needs dedicated sensor model

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