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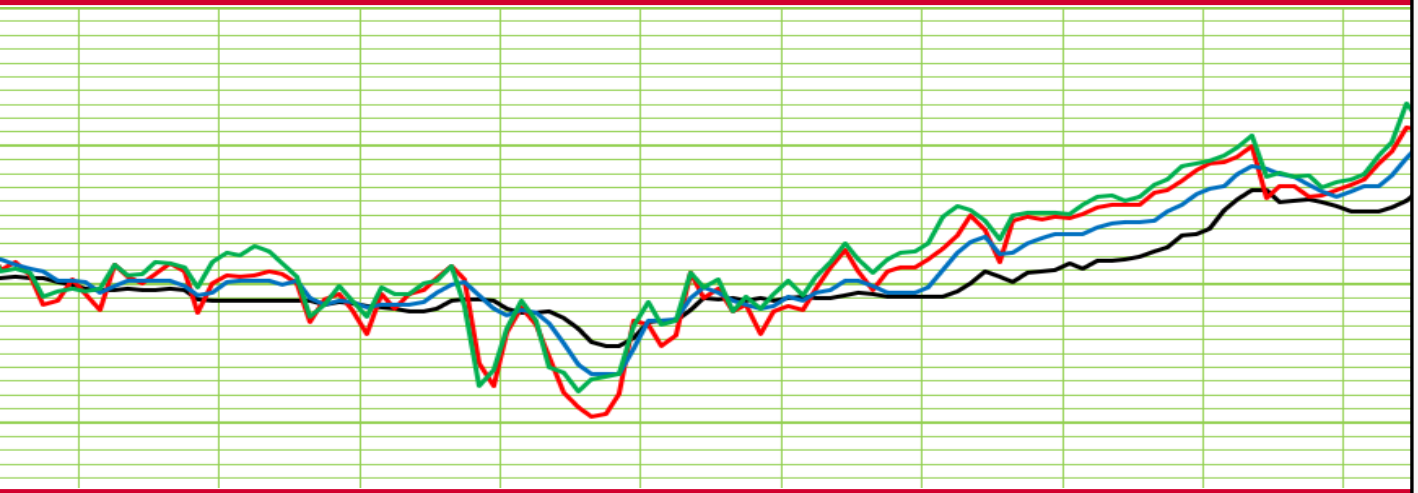
Can commercial PRTs meet WMO CIMO response time specifications?



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WMO TECO Conference
Amsterdam, October 2018

WMO CIMO SPECIFICATION

World Meteorological Organization 2014: *WMO No.8 - Guide to Meteorological Instruments and Methods of Observation (CIMO guide)* (Updated version, May 2017), 1139 pp. WMO, Geneva

2.1.3.3 Response times of thermometers

- For routine meteorological observations there is no advantage in using thermometers with a very small time-constant or lag coefficient, since the temperature of the air continually fluctuates up to one or two degrees within a few seconds. Thus, obtaining a representative reading with such a thermometer would require taking the mean of a number of readings, whereas a thermometer with a larger time-constant tends to smooth out the rapid fluctuations. Too long a time constant, however, may result in errors when long-period changes of temperature occur. It is recommended that the time constant, defined as the time required by the thermometer to register 63.2% of a step change in air temperature, should be 20 s. The time constant depends on the airflow over the sensor.

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RESPONSE TIME THEORY

For a first-order response, the rate of change of the instrument output is proportional to the size of the step change

Considering temperatures, where *T* is the temperature at any instant *t*, and T_a is the final temperature reached

$$\frac{dT}{dt} \alpha (T - T_a)$$

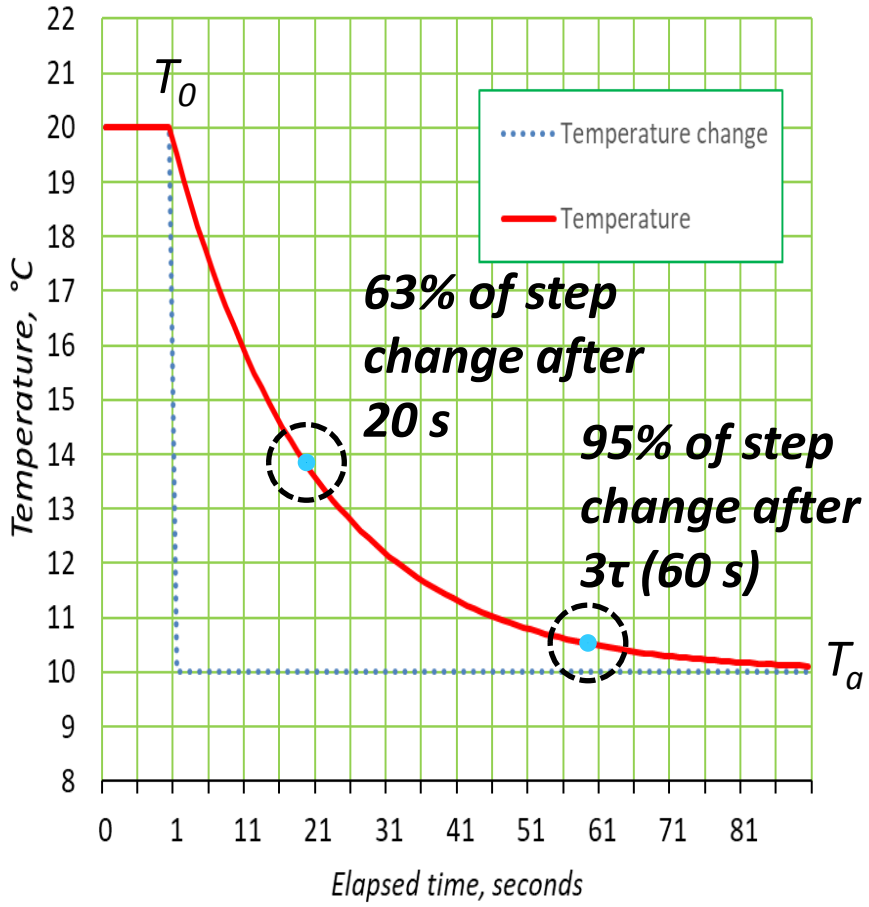
Differentiating wrt *t* for a step change of magnitude ΔT

$$T(t) = T_a + \Delta T \exp(-\frac{t}{\tau})$$

… where τ is the **exponential response time**

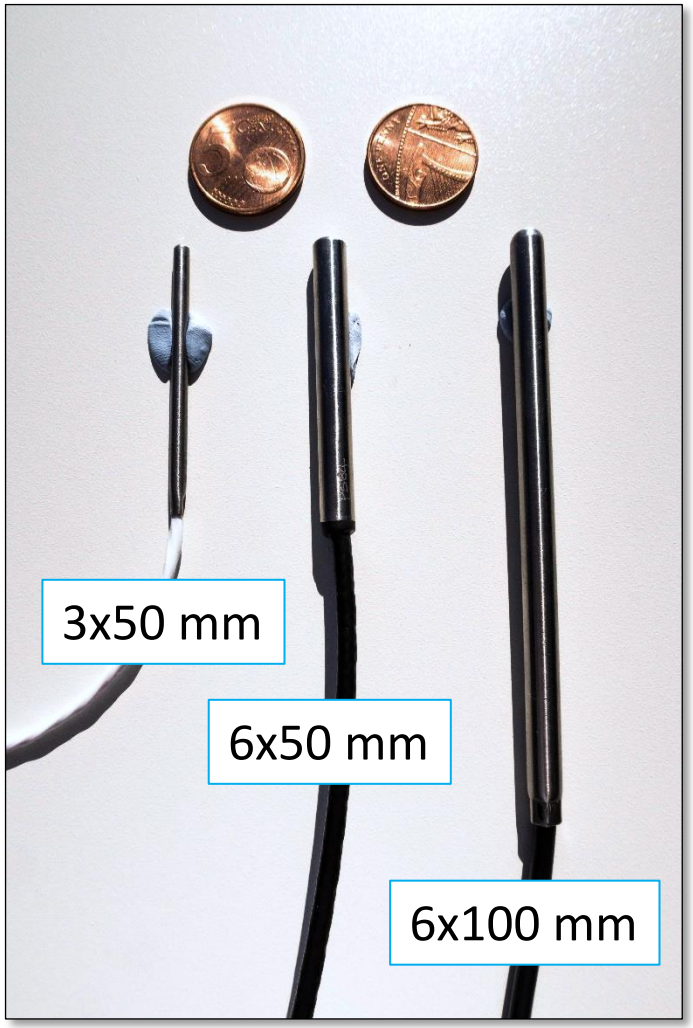
… defined as the time taken for the instrument to respond to 1/e (~63%) of the total change

RESPONSE TIME τ



- $T(t) = T_a + (T_0\text{-}T_a)exp(-t/\tau)$
- **τ = 20 s 63% implies complete response (95%, 3τ) within 60 s averaging period**
  - WMO specification is 60 s averages for air temperature sensors
  - Defines maximum and minimum temperatures
- **Very few manufacturers publish (meteorologically-useful) response time specifications**

COMMERCIAL PRTs



- **20 ‘off the shelf’ commercial 100 Ω PRTs evaluated in laboratory tests**
  - Three manufacturers
  - PRT diameters 3 mm, 4.5 mm and 6 mm
  - PRT length 50 mm to 100 mm
  - 2-3 samples of each unit/type tested to allow for batch variability

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LABORATORY METHOD

- **Cooling response time through controlled ventilation**
  - Heated in aluminium dry block within water bath jacket to ~ 35-40 °C then cooled in wind tunnel
  - Wind tunnel ventilation variable 0.5 to 3.0 m/s ± 5%
  - PRT temperatures logged at 2 Hz
  - 2 x PRT per run, 5 runs per ventilation value 0.5, 1.0, 3.0 m/s
    - 1.0 m/s is thermometer screen ventilation assumed in ISO 17714
    - *ISO 17714 Meteorology — Air temperature measurements — Test methods for comparing the performance of thermometer shields/screens and defining important characteristics.* International Organization for Standardization (ISO).
- **Results averaged over 5-10 runs**
- **427 individual evaluations performed**

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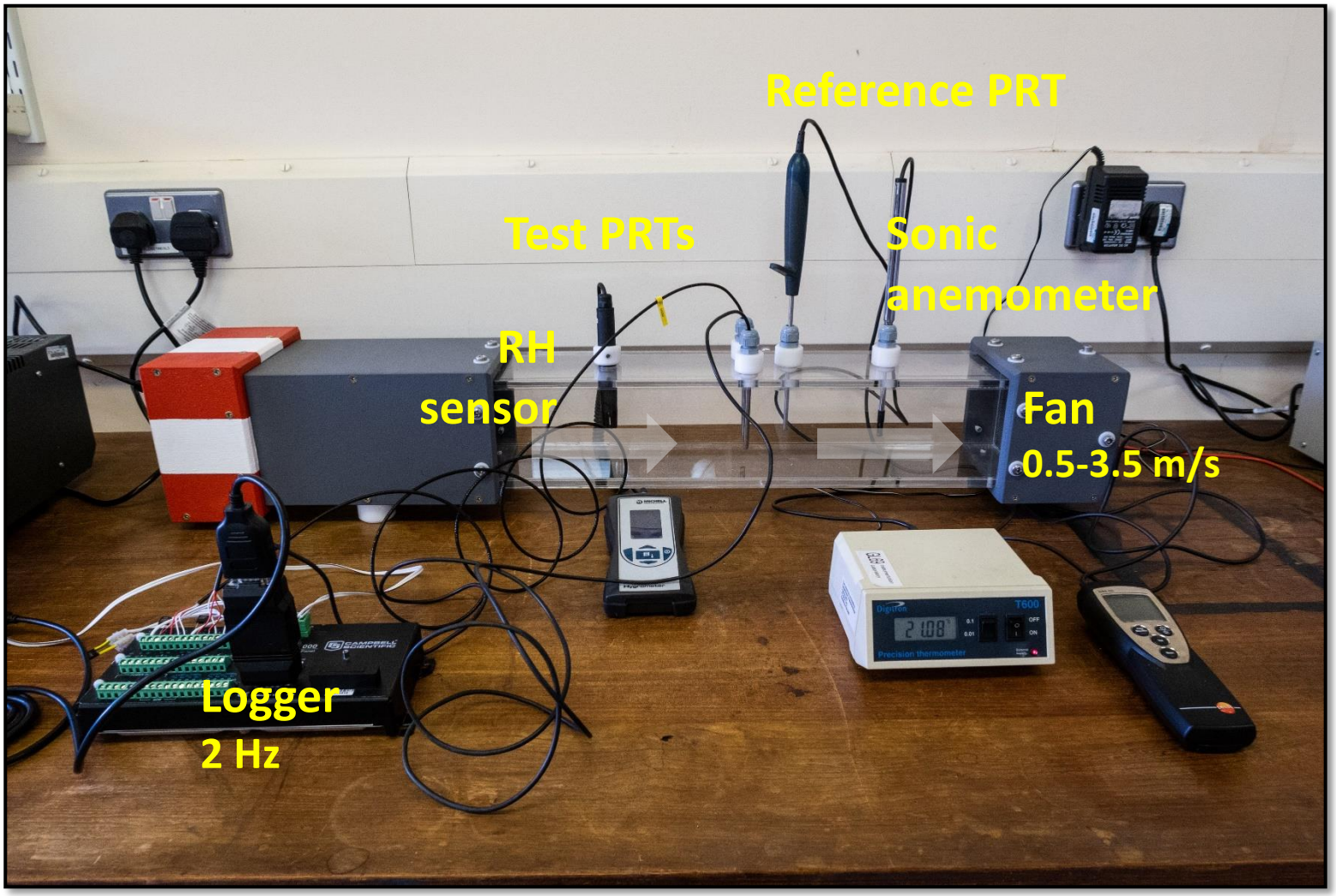
LABORATORY APPARATUS



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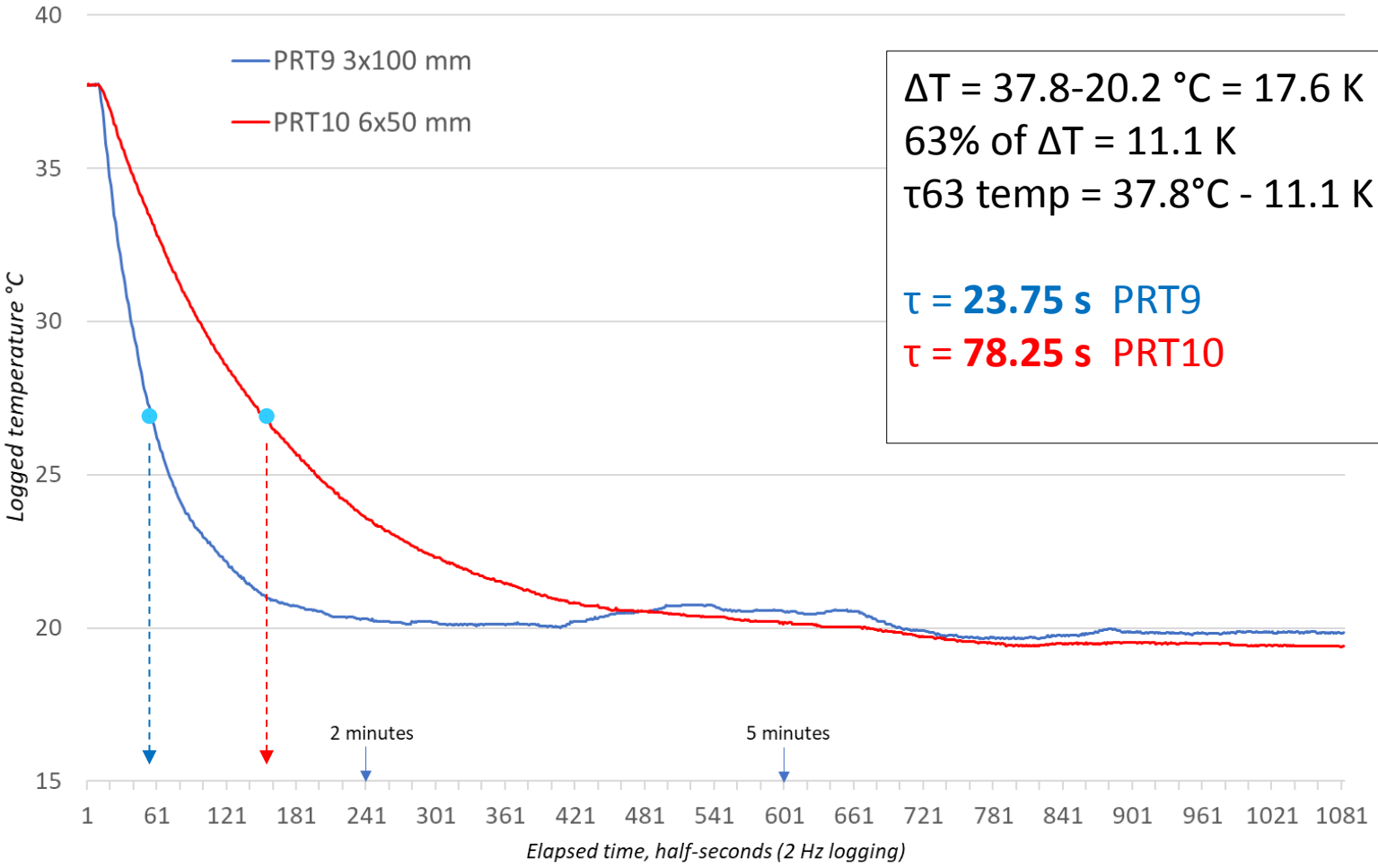
EXAMPLE OUTPUT (2 Hz) *Run 5, v = 1.0 m/s*



ΔT = 37.8-20.2 °C = 17.6 K
63% of ΔT = 11.1 K
τ63 temp = 37.8°C - 11.1 K = 26.7 °C

τ = **23.75 s** PRT9
τ = **78.25 s** PRT10

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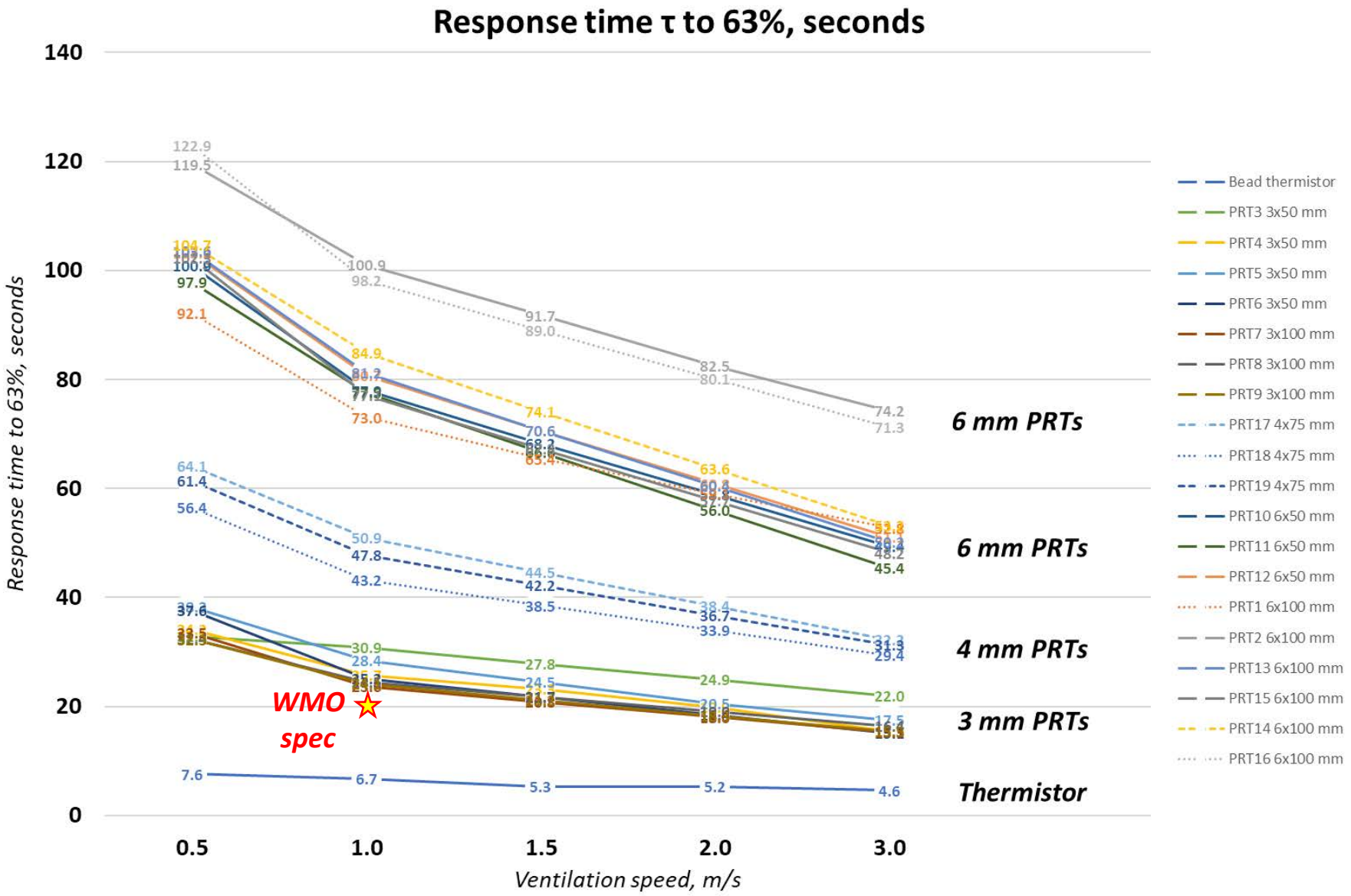
RESULTS



MAJOR DETERMINANTS OF RESPONSE TIME

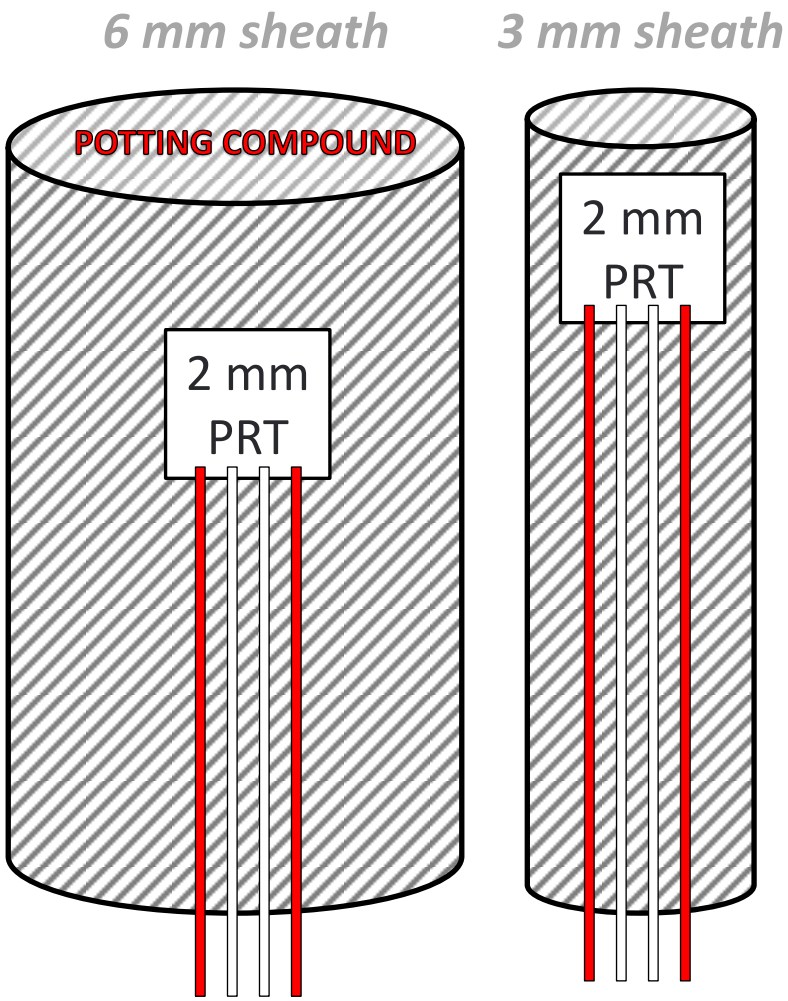
Ventilation speed

- Greater airflow velocity reduces response times owing to increased advective heat transport from sensor surfaces
- Averaged across all PRTs:
  - τ63 **68.0 s** at 0.5 m s^{-1} to **35.4 s** at 3.0 m s^{-1}
  - Huge variation between sensors of different sizes
- **None of the PRTs tested met WMO CIMO response time specification at a 1 m s^{-1} ventilation rate**
  - Even at 3 m s^{-1} airflow, more typical of permanently aspirated systems, only two smaller sensors met WMO CIMO τ63 specification

MAJOR DETERMINANTS OF RESPONSE TIME

Sensor diameter

- Key determinant sensor *diameter*, not length or volume
  - τ63 varied by factor of 3-4
- One 6x100 mm PRT τ63 122.9 s at 0.5 m s^{-1} to 64.4 s at 3 m s^{-1}
  - » Sensor would require > 6 minutes to register 95% change in temperature in light wind conditions



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CONCLUSIONS

- **None of the commercially-available PRTs met the WMO 'desired' response time for air temperature sensors**
- **Response times varied by almost an order of magnitude between sensor diameter and ventilation speed**
  - Fastest: 3 x 50 mm PRT, τ 15.1 s average at 3.0 m/s
    - ✓ Implies (3τ) complete response within 60 s averaging period
  - Slowest: 6 x 100 mm PRT, τ 122.9 s average at 0.5 m/s
    - ☒ Implies (3τ) complete response > 6 minutes
- **Are improvements possible?**

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RECOMMENDATIONS

Are improvements possible?

- **For air temperature measurements, PRTs no larger than 3 mm diameter should be specified in procurement tenders**
  - Particularly where use within passively ventilated thermometer screens is intended
- **Suppliers should be mandated to measure and specify τ63 response times for all PRTs intended for meteorological air temperature measurements**
- **Manufacturers should be encouraged to adapt existing PRT assembly processes to achieve sub-20 s τ63 PRT response time at a ventilation rate of 1 m s^{-1}**
  - Without detriment to robustness and calibration stability of the sensor

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ACKNOWLEDGEMENTS

THANK YOU

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RELEVANT STANDARDS

- **British Standards Institution, 2008: BS EN 60751:2008 -** ***Industrial platinum resistance thermometers and platinum temperature sensors***
- ***ISO 17714 Meteorology — Air temperature measurements — Test methods for comparing the performance of thermometer shields/screens and defining important characteristics*****.** **International Organization for Standardization (ISO)**