# Can commercial PRTs meet WMO CIMO response time specifications?

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## Introduction

WMO CIMO guidelines ( [1] 2014 edition, revised 2017, section 2.1.3.3, *Response times of thermometers*) recommend that the 63% response time $\tau$ for an air temperature sensor be 20 seconds. (A 63% response time $\tau = 20$ s implies that 95% of the change be registered within $3\tau$ or 60 s, the recommended averaging interval for air temperature.) To assess whether this was feasible, or even possible, laboratory wind tunnel tests were undertaken to quantify 63% and 95% response times on 20 'off the shelf' commercial platinum resistance thermometers (PRTs) of various sizes (length and sheath diameter) from several manufacturers.

## Methods

PRTs under test were mounted in a small laboratory wind tunnel. Ventilation within the wind tunnel could be adjusted to provide steady measured airflow at speeds between 0.5 and 3.0 m $s^{-1}$ (± 5%). Two steel-sheathed PRTs were connected to a Campbell Scientific logger and their temperature logged at 2 Hz. Both were then fitted into dry close-fitting holes drilled within a substantial block of aluminium and warmed to 35-40 °C by placing the aluminium block within a beaker of warm water. Both PRTs were allowed to reach a steady temperature, and then quickly inserted into the airflow of the wind tunnel using insulated mountings. The temperature of each PRT was logged until it fell close to the ambient laboratory temperature. The process was repeated for different airflow velocities, initially at 0.5 m $s^{-1}$ increments from 0.5 m $s^{-1}$ to 3.0 m $s^{-1}$ (later streamlined to 0.5, 1.0 and 3.0 m $s^{-1}$, with intermediate results linearly interpolated) for 20 commercial PRTs of varying diameters and lengths. From the logged output, the time to reach 63% and 95% of the difference between the start temperature and steady-state room temperature was evaluated objectively for each sensor. Each test was repeated between five and ten times at each airflow velocity for each sensor, and the results averaged to provide a representative sample; in all, 427 individual evaluations were carried out.

## Results and discussion

Results are summarised in Table 1. Manufacturers have been anonymised. For brevity, only the 63% response times (hereafter $\tau 63$) are shown; 95% response times were, as expected, around 3 x $\tau 63$.

The major determinants of response time were (i) ventilation speed $v$ and (ii) sensor size.

### *Effect of ventilation*

Greater airflow velocity results in shorter response times owing to increased advective heat transport from sensor surfaces. Averaged across all PRTs, $\tau 63$ varied from 68.0 s at 0.5 m $s^{-1}$ ventilation to 35.4 s at 3.0 m $s^{-1}$, with very considerable variation between sensors of different sizes (see below). None of the PRTs tested was capable of meeting the WMO CIMO response time specification at a 1 m $s^{-1}$ ventilation rate, approximately that found within a Stevenson-type radiation screen assuming an external wind speed of 2 m $s^{-1}$. A minority of the smaller PRTs could do so when ventilated at 2 m $s^{-1}$, but even at 3 m $s^{-1}$ airflow, more typical of the minimum ventilation rate in permanently aspirated systems, only two of the smaller sensors were reliably able to meet the WMO CIMO $\tau 63$ specification.

### *Effect of sensor size*

Sensor size was investigated as a function of diameter and length of the PRT sheath, and thus volume, although the diameter of the sensor sheath was found to be the most influential parameter. Table 1 gives the average response times for the sensors in the test (multiple units of the same manufacturer and size have been combined for brevity). From Table 1 it can be seen that *τ63* for the 6 x 100 mm PRTs sampled from manufacturer A were a factor of 3-4 greater than the 3 x 50 mm sensors from manufacturer B. Informal discussions with suppliers suggested that the discrepancy was almost certainly due to differences in the amount of potting compound introduced around the actual sensor unit within the sheath during the manufacturing process. A typical sensor unit is only about 2 mm square, fitting snugly within a 3 mm sheath but interred within a greater thickness of potting compound within a larger sheath: the insulation of the potting compound is greater than that of the steel sheath and would thus slow the response time of the PRT compared with the 'raw' sensor. Average *τ63* for one of the 6 x 100 mm PRTs ranged from 109.7 s at 0.5 m $s^{-1}$ to 64.4 s at 3 m $s^{-1}$, implying this particular sensor would be incapable of registering a 95% change in temperature in under 5 minutes in light wind conditions.

## Summary and conclusions

The results of this experiment showed conclusively that huge variations exist in response times of commercial PRTs. The two most important factors were found to be ventilation rate and sensor diameter, the combination accounting for almost an order of magnitude difference in *τ63*. **None of the PRTs tested were capable of meeting the CIMO *τ63* 20 s response time specification** at a ventilation speed of 1 m $s^{-1}$ typical of passively-ventilated thermometer shields such as Stevenson-type thermometer screens, where sensor airflow depends upon ambient wind speed. It was found that sub-20 s *τ63* response times were attainable only with small diameter (3 mm) PRT probes ventilated at > 2 m $s^{-1}$, an airflow rate more typical of permanently aspirated systems.

Based upon these findings, the following recommendations are suggested:

1. 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.
2. Suppliers should be mandated to measure and specify *τ63* response times for all PRTs intended for meteorological air temperature measurements.
3. Manufacturers should be encouraged to adapt existing PRT assembly processes with a view to attaining a 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.

Table 1. PRT response times for 63% change (*τ63,* s) by size (sheath diameter x length) and for different ventilation rates *v*, m $s^{-1}$. The number of tests performed for each type (multiple units tested) is also shown. Results in *italic* are interpolated. Only the results shown in bold meet WMO TECO specification for air temperature sensors.

| | | | | **τ63 (s) for airflow *v* , m $s^{-1}$** | | | |
|---|---|---|---|---|---|---|---|
| *Sensor type and size* | *Mfr* | *Samples* | | *0.5* | *1.0* | *2.0* | *3.0* |
| **PRT** *3 x 50 mm* | A | 4 | Mean | 32.8 | 30.9 | *26.4* | 22.0 |
| | | | SD | 1.4 | 0.7 | | 0.5 |
| | | | Max | 34.3 | 31.5 | | 22.3 |
| | | | Min | 31.0 | 29.8 | | 21.0 |
| **PRT** *3 x 50 mm* | B | 19 | Mean | 36.1 | 26.1 | 20.1 | **15.9** |
| | | | SD | 2.7 | 1.7 | 1.1 | 1.1 |
| | | | Max | 40.5 | 29.0 | 22.5 | 18.3 |
| | | | Min | 28.8 | 23.8 | 18.5 | 14.5 |
| **PRT 3** *x 100 mm* | B | 15 | Mean | 32.7 | 24.1 | ***19.9*** | **15.7** |
| | | | SD | 1.2 | 1.5 | | 0.7 |
| | | | Max | 35.3 | 27.3 | | 17.8 |
| | | | Min | 30.8 | 20.8 | | 14.8 |
| **PRT** *4 x 75 mm* | C | 15 | Mean | 60.6 | 45.3 | *38.1* | 30.9 |
| | | | SD | 3.7 | 8.5 | | 2.0 |
| | | | Max | 66.8 | 52.8 | | 34.3 |
| | | | Min | 54.5 | 41.8 | | 26.8 |
| **PRT** *6 x 50 mm* | B | 15 | Mean | 100.6 | 78.8 | *63.7* | 48.6 |
| | | | SD | 2.9 | 2.2 | | 2.8 |
| | | | Max | 107.3 | 81.8 | | 53.3 |
| | | | Min | 94.3 | 75.3 | | 43.0 |
| **PRT** *6 x 100 mm* | A | 22 | Mean | 109.7 | 88.5 | 67.9 | 64.4 |
| | | | SD | 13.9 | 13.4 | 11.0 | 9.8 |
| | | | Max | 125.8 | 107.3 | 85.0 | 77.3 |
| | | | Min | 88.3 | 70.3 | 53.0 | 50.8 |
| **PRT** *6 x 100 mm* | B | 15 | Mean | 103.5 | 81.0 | *65.8* | 50.5 |
| | | | SD | 2.6 | 3.6 | | 2.2 |
| | | | Max | 108.3 | 86.8 | | 54.3 |
| | | | Min | 99.3 | 74.8 | | 46.8 |

REFERENCE 1. World Meteorological Organization (WMO), 2014. *WMO No.8 - Guide to Meteorological Instruments and Methods of Observation (CIMO guide) (Updated version, May 2017)*: WMO, Geneva