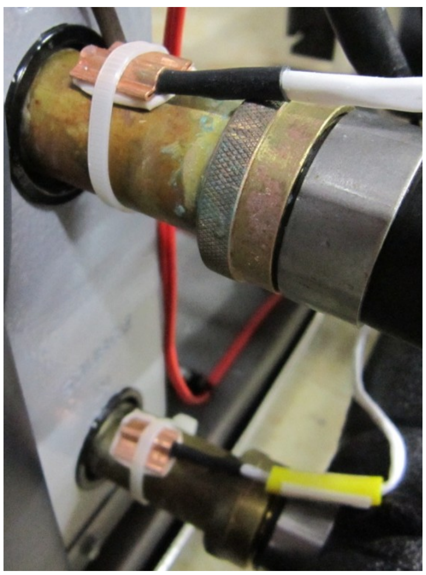
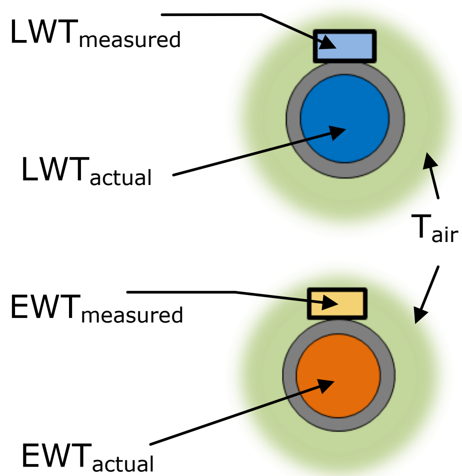
GxTracker™ On-Pipe Measurement of ΔT

Error and Bias Correction: Sources (p. 1)

Introduction: Quantifying the thermal energy transferred by ground source heat pumps (GSHP) requires knowledge of the fluid thermal properties, fluid flow rate and the difference between the entering and leaving fluid temperatures (ΔT). Because the ΔT of GSHP systems is relatively small (~3-6 ºC), measurement errors on the order of 0.5 ºC can significantly affect the calculated heat production and measured system efficiency. Introduction of thermal wells into a system can be costly and their mass can delay temperature response, creating another source of error. Non-invasive on-pipe temperature sensors that provide good thermal connection between the sensor and pipe and have a very low thermal mass provide a potentially attractive means for measuring fluid temperature. However, when using on-pipe sensors, care must be taken to properly calibrate and correct for measurement bias.

On-Pipe Measurement Bias:



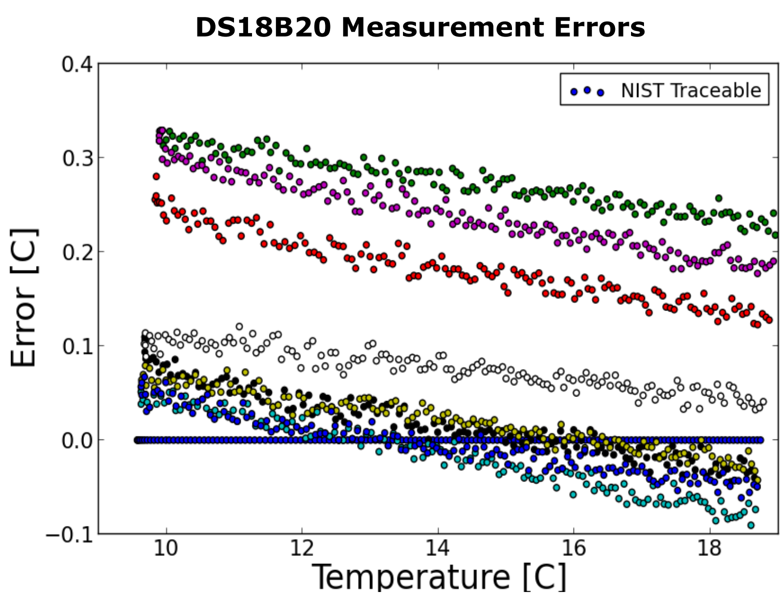


NOTE: Insulation not shown in photos so that mounted sensors are visible.

On Pipe Measurements of fluid temperatures are biased towards the ambient air temperature (Tair). Good insulation around the sensor is essential to minimize the influence of the ambient temperature. However, it is generally not sufficient to remove the bias. We show that this bias does not contribute a significant error in the measurement of ΔT. However it does limit the effectiveness of using in-pipe temperature probes as a method for calibrating the temperature sensor.

Sensor Calibration:

The DS18B20 temperature sensor that is commonly used in web-based monitoring systems has a factory-rated accuracy of ±0.5 ºC over a temperature range −10 to 85 ºC. While the error over the range of most GSHP applications is less for an individual measurement, the errors in measuring ΔT can be significant. In addition, because the error depends on temperature, proper calibration requires characterization of both the offset and its dependence on temperature. Because of the measurement bias note above, calibration should not be done using in-pipe temperature probes as the standard.



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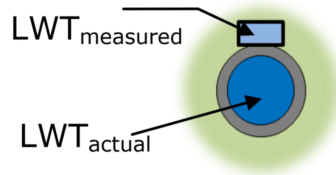
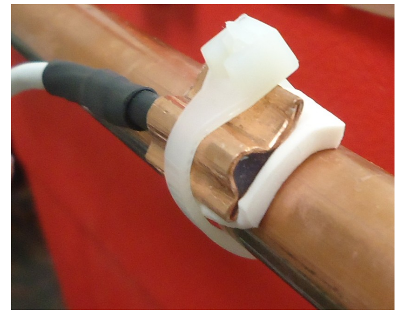
Method for Error and Bias Correction (p.2)

Measurement Bias is inherent to on-pipe temperature measurements and can be represented using a thermal resistance between the fluid and sensor. A thermally conductive interface diminishes the magnitude of bias (it decreases thermal resistance and the influence of Tair).

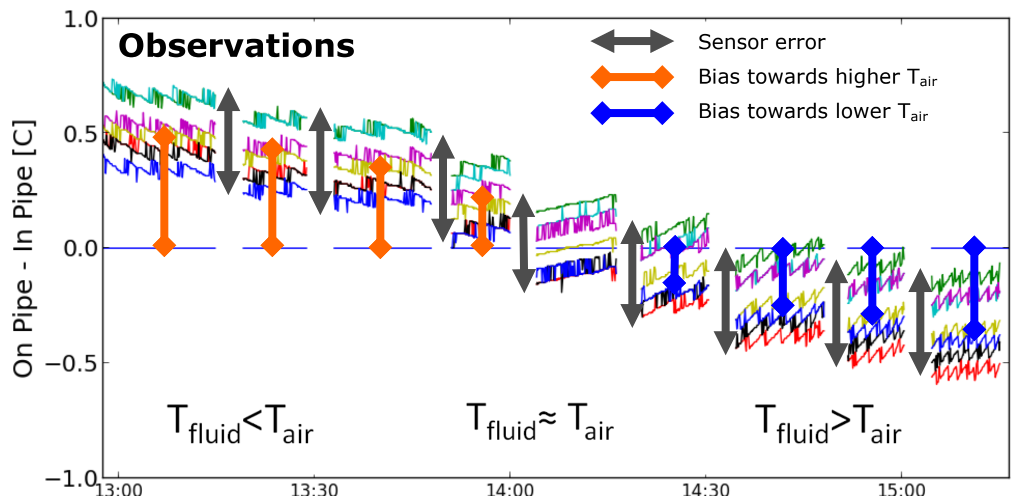
$$LWT_{measured} = LWT_{actual} + \lambda(T_{air} - LWT_{actual})$$

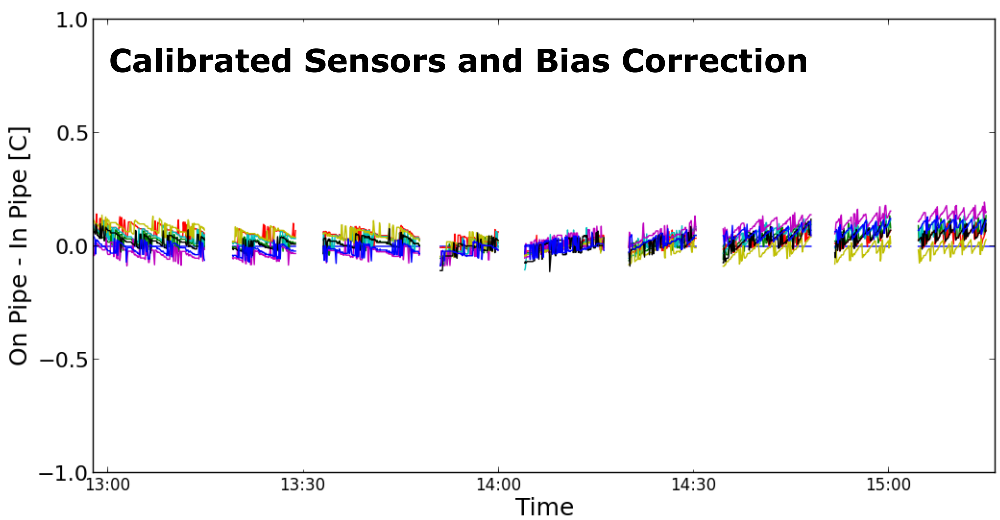


NOTE: Insulation not shown in photos so that mounted sensor is visible.



Experimental Analysis: To assess the effects of measurement error and bias and test a methodology for correcting for both, an experiment was conducted where seven on-pipe temperature sensors were placed on a 1/2" copper pipe connected to a re-circulating water bath. The in-pipe temperature was measured using a NIST-Traceable Digital Thermometer (0.1 ºC accuracy). Measurements were collected on 2-second intervals over a period of 2.5 hours. Water temperature ranged from 6 ºC to 35 ºC and was increased (by approximately 3.5 ºC) incrementally eight times. Each step ran for 15 minutes.





Results: The difference between On-Pipe and In-Pipe temperatures (left) ranged from approximately 0.5 to −0.5 degrees C. Sensor error and measurement bias contribute approximately equal amounts at the warmest and coldest in-pipe temperatures.

Calibrating the sensors to the 0.1 ºC standard reduces of the sensor error to 0.1 ºC. This enables estimation of λ and the removal of bias.

If the measurement conditions (λ and T_{air}) are the same for both EWT and LWT, the effect of the bias on ΔT is small and can be easily removed.