Thermal response time of a DS 27.5 mm temperature sensor

Experimental determination in different set-ups and consequences in a real installation

Lasse Sloth Harbo, John Domino, Christian Bombis, and Mads Wraa Hyttel

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Agenda

Thermal response time $t_{0.5}$ of a temperature sensor

Determination in production – ASP2

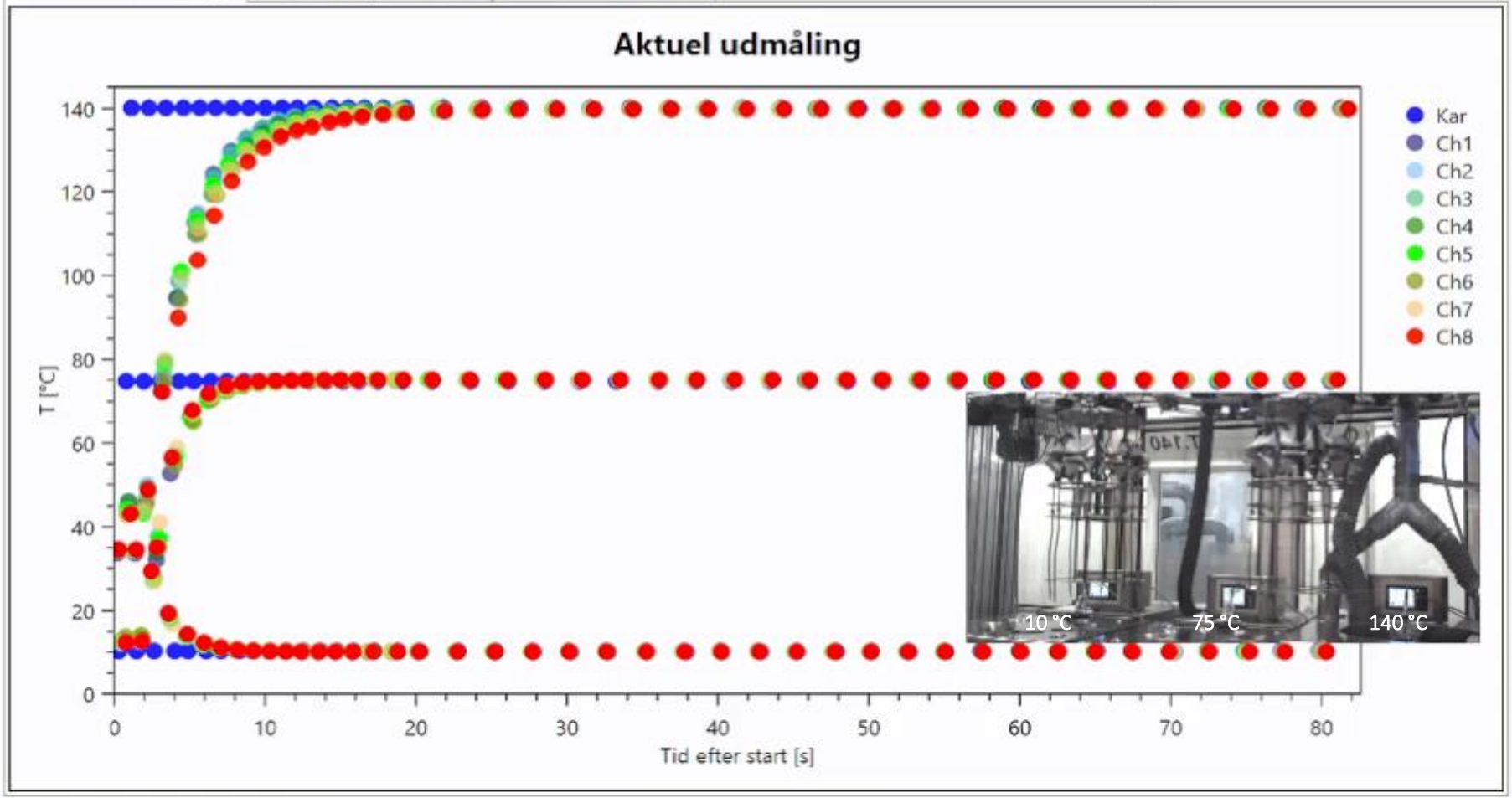
Determination in laboratory

Consequences for the measurement
of thermal energy in dynamic installations

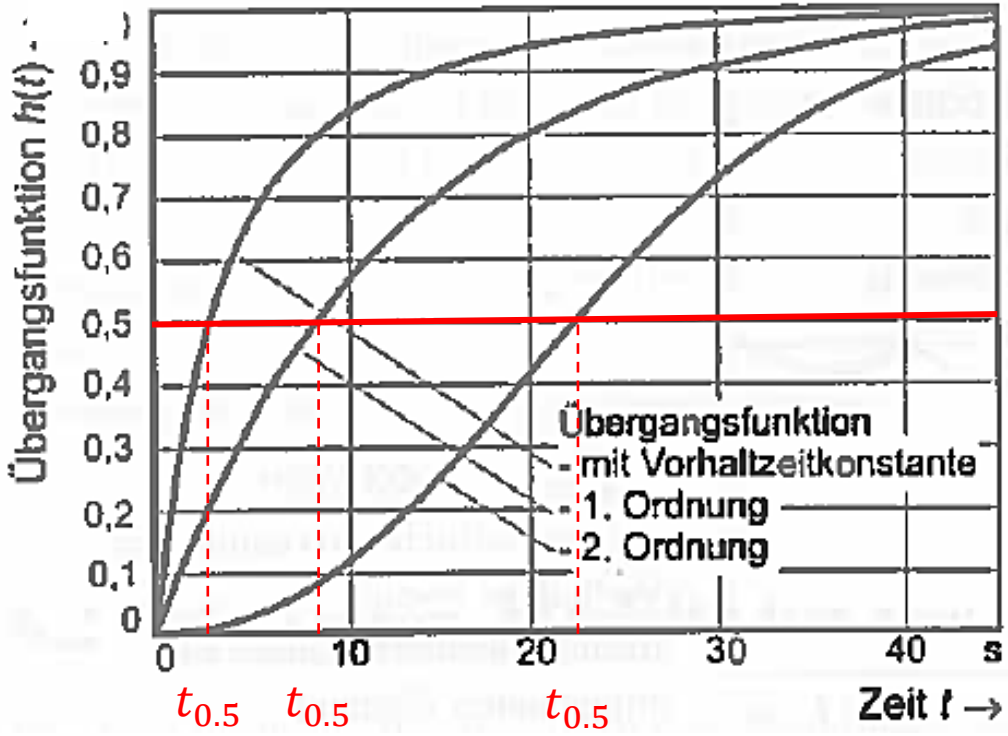
Udmåling

Aktuel måling | Kartemperatur | Væskeniveau

Status: Idle



Introduction – Response function



$$h_1(t) = 1 - e^{-t/\tau}$$

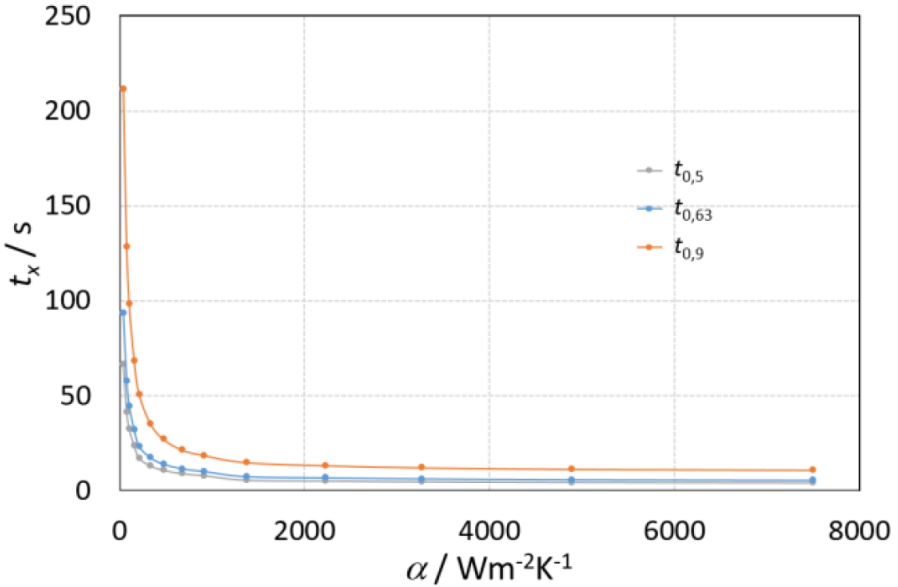
$$h_2(t) = 1 - \frac{\tau_1}{\tau_1 - \tau_2} e^{-t/\tau_1} - \frac{\tau_2}{\tau_2 - \tau_1} e^{-t/\tau_2}$$

$$h_{2V}(t) = 1 - \frac{\tau_1 - \tau_V}{\tau_1 - \tau_2} e^{-t/\tau_1} - \frac{\tau_2 - \tau_V}{\tau_2 - \tau_1} e^{-t/\tau_2}$$

Literature:
Figure 6.2 from F. Bernhard, Handbuch der Technischen Temperaturmessung, 2. Auflage; Springer 2014
Equations from A. Brethauer, PhD thesis TU Ilmenau (see Entwicklung einer Methode zur Temperaturbestimmung von Fluiden mithilfe von Berührungsthermometern bei niedrigen Eintauchtiefen – Digitale Bibliothek Thüringen (db-thueringen.de); Link checked 2024-08-20)

Introduction – Heat coefficients α

	Strömungsbedingung	Wärmeübergangskoeffizient in $W \cdot m^{-2} \cdot K^{-1}$
air	Luft 25 °C v = 1 m/s	44
	Luft 25 °C v = 3 m/s	81
	Luft 25 °C v = 5 m/s	108
	Luft 25 °C v = 10 m/s	161
water	Wasser, 50 °C, v = 0,02 m/s	1374
	Wasser, 50 °C, v = 0,05 m/s	2229
	Wasser, 50 °C, v = 0,1 m/s	3268
	Wasser, 50 °C, v = 0,2 m/s	4888
	Wasser, 50 °C, v = 0,4 m/s	7496
oil	Wacker AK10, 50 °C v = 0,1 m/s	479
	Wacker AK10, 50 °C v = 0,2 m/s	683
	Wacker AK10, 50 °C v = 0,4 m/s	981



Marc Schalles, Joseph Beerel, and Silke Augustin; Untersuchungen von Thermometern mittels eines neuartigen Prüfstandes zur Bestimmung dynamischer Kennwerte; manusricpt from Institut für Prozessmess- und Sensortechnik, TU Ilmenau; see also conference contribution at Temperatur 2024 (Startseite - Temperatur (ptb.de) and VDI/VDE 3522 Blatt 1 – Dynamisches Verhalten von Berührungsthermometern – Experimentelle Bestimmung der Zeitprozentkennwerte. VdI-Verlag, 2014)

Introduction – Standardisation

from DS/EN 1434-1:2022, Annex C

Fast response meters

A meter or sub-assembly defined as “Fast response meter” shall have at least the following additional specifications:

— response time ($\tau_{0,5}$): max. 6 s for direct long temperature sensors; max. 2,5 s for direct short temperature sensors;

⚠ $\tau_{0,5} \equiv t_{0.5}$

from DS/EN 1434-4:2022

7.4.4.2 Thermal response time

The temperature sensors shall be tested according to EN 60751:2008, 6.5.2. For sensors designed to be mounted in pockets the test should be made with pockets. The response time shall not exceed the manufacturer's specification.

Introduction – Standardisation

from DS/EN 60751:2008 (IEC 60751:2008)

6.5.2 Thermal response time

The thermal response time $\tau_{0.5}$ in flowing water with a velocity >0.2 m/s and/or in flowing air with a velocity (3 ± 0.3) m/s shall be recorded. If requested the response times $\tau_{0.9}$ and/or $\tau_{0.1}$ may also be recorded.

from DS/EN IEC 60751:2022 (IEC 60751:2008)

6.5.5 Thermal response time

The thermal response time T in flowing water with a velocity (0,3 ± 0,1) m/s or in flowing air with a velocity (3 ± 0,3) m/s shall be recorded. To specify the response time it is necessary to declare the percentage of response, usually $T_{0,9}$, $T_{0,63}$, $T_{0,5}$, or $T_{0,1}$, which gives the time until the thermometer reading reaches 90 %, 63,2 %, 50 % or 10 % of the temperature step change, respectively. The test medium and its flow conditions shall be specified (usually flowing water or flowing air).

Design of DS 27.5 mm (EN 1434) temperature sensor

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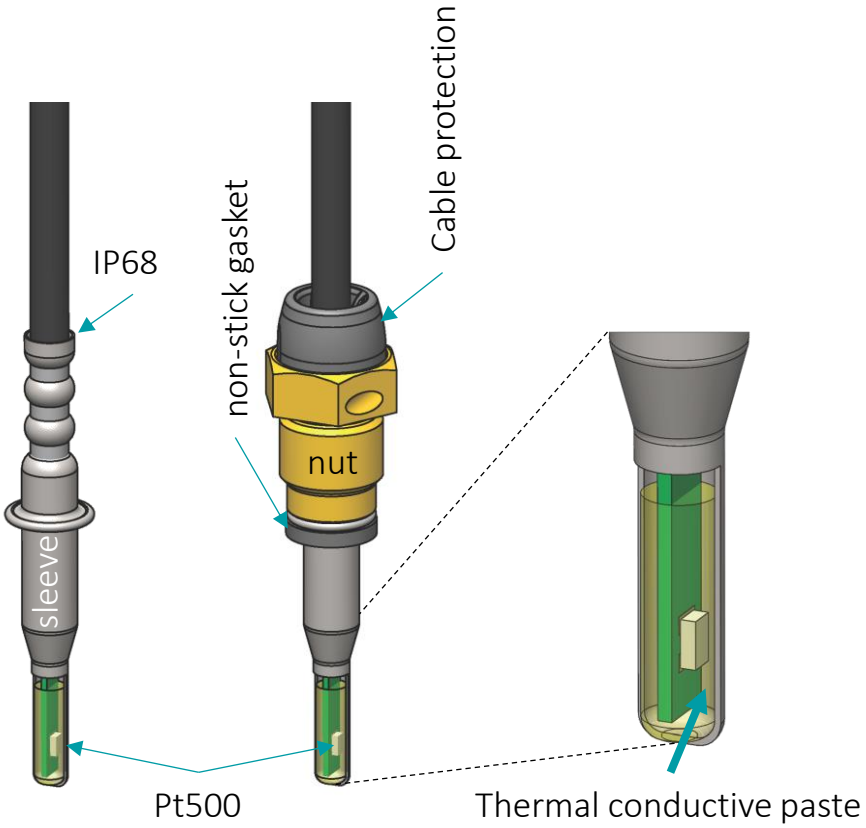

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Agenda

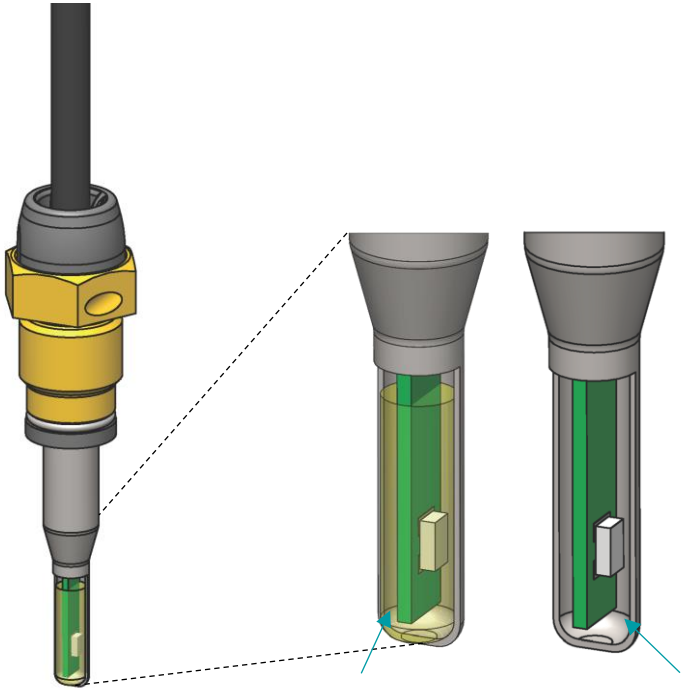
Thermal response time $\tau_{0.5}$ of a temperature sensor

Determination in production – ASP2

Determination in laboratory

Consequences for the measurement
of thermal energy in dynamic installations

QA of temperature sensors in ASP2



TemperatureSensor 63 (DS 27.5 mm, Pt500)

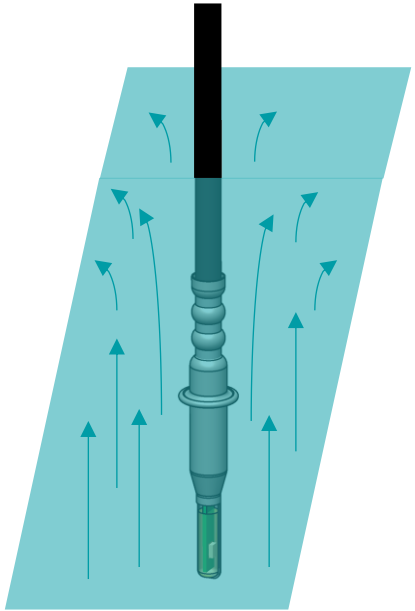
Response time $t_{0.5}$ fast*: (1.12±0.11) s

Accept criterium*: $t_{0.5}$ < 2 s

Response time $t_{0.5}$ slow*: (6.20±0.71) s

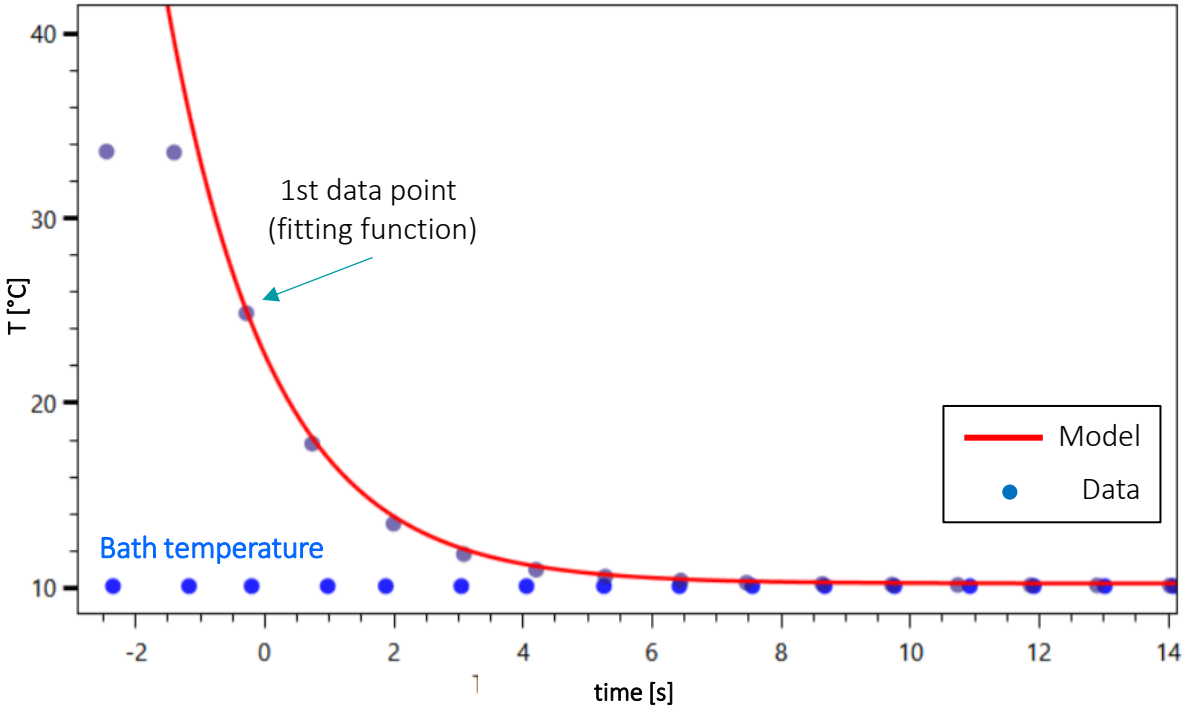
*Data from ASP2. Terminology “fast” and “slow” is related to these investigations. The fast temperature sensors are from standard production.

Determination of thermal response time $t_{0.5}$ – ASP2



Medium:	water (10 °C, 75 °C) and glycerin (140 °C)
Velocity:	not defined
Approach:	upstream overflow
Immersion depth:	> 100 mm (fully immersed, including parts of cable)
DS 27,5 mm:	without gasket, nut and cable protection

Determination of thermal response time $t_{0.5}$ – ASP2

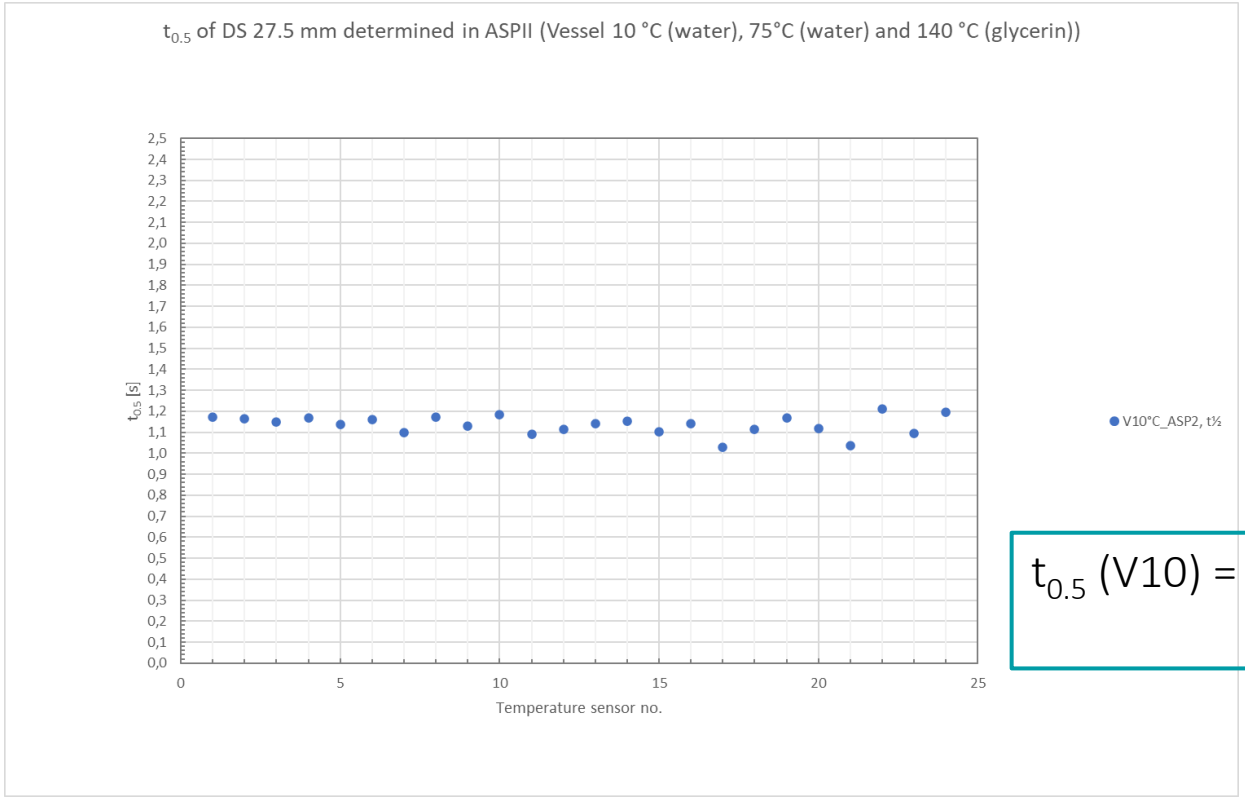


Model equation:

$$h(t) = 1 - e^{-\frac{t}{\tau 1}}$$

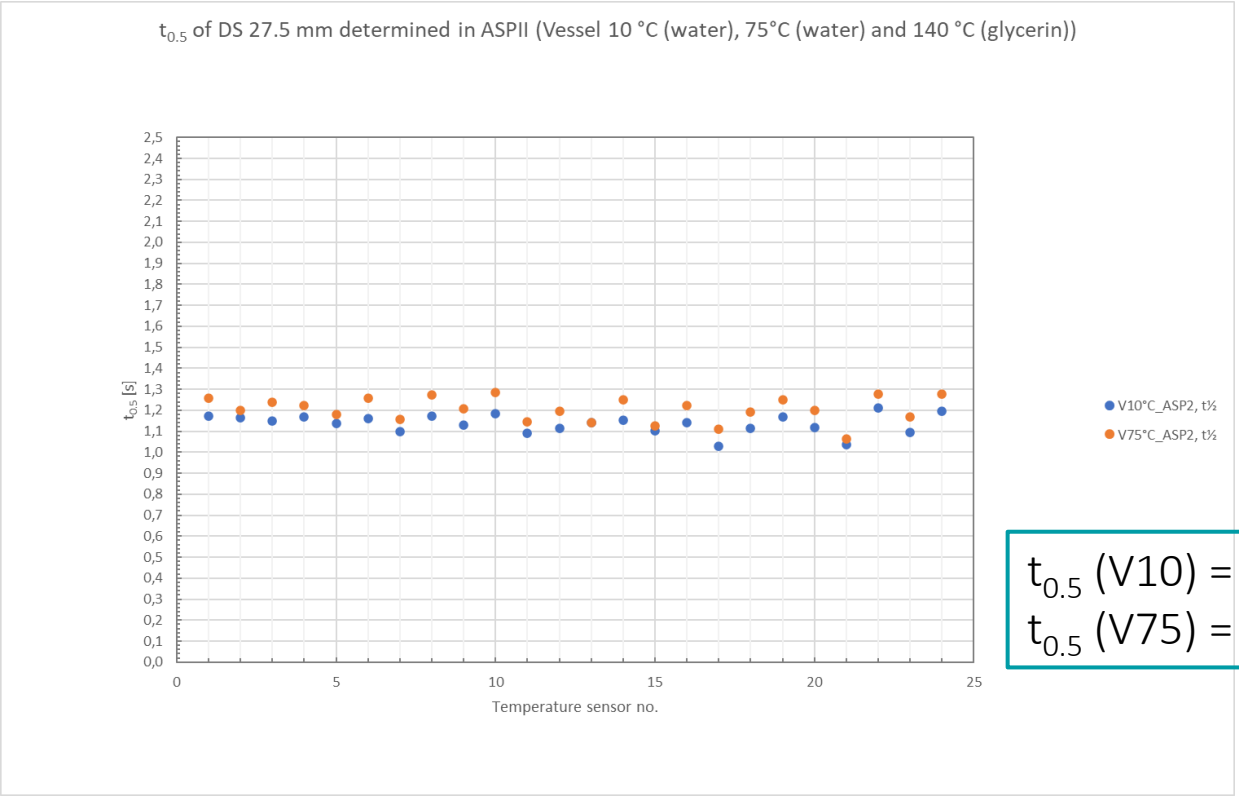
$$t_{0.5} = \tau_1 \cdot \ln(2)$$

Determination of thermal response time $t_{0.5}$ – ASP2



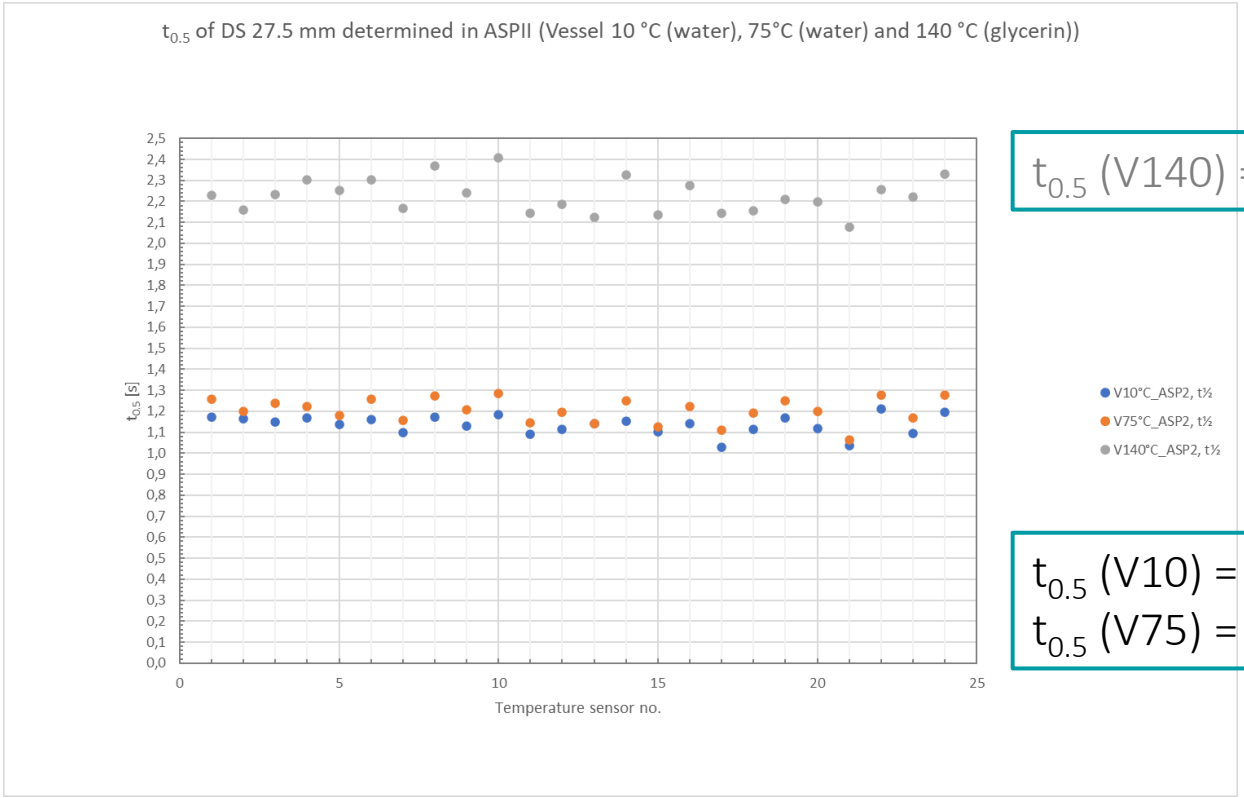
$t_{0.5}$ (V10) = (1.14±0.05) s

Determination of thermal response time $t_{0.5}$ – ASP2



$t_{0.5}$ (V10) = (1.14±0.05) s
$t_{0.5}$ (V75) = (1.20±0.06) s

Determination of thermal response time $t_{0.5}$ – ASP2



$t_{0.5}$ (V140) = (2.23±0.08) s

$t_{0.5}$ (V10) = (1.14±0.05) s
$t_{0.5}$ (V75) = (1.20±0.06) s

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Agenda

Thermal response time $t_{0.5}$ of a temperature sensor

Determination in production – ASP2

Determination in laboratory

Consequences for the measurement
of thermal energy in dynamic installations

Determination of thermal response time $t_{0.5}$ – TECHNISCHE UNIVERSITÄT ILMENAU

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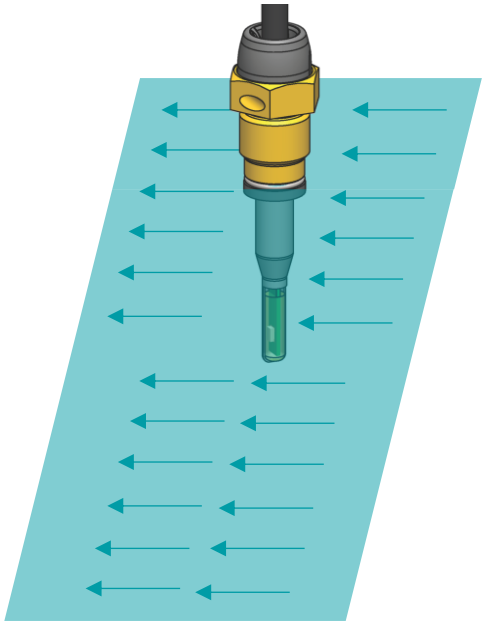
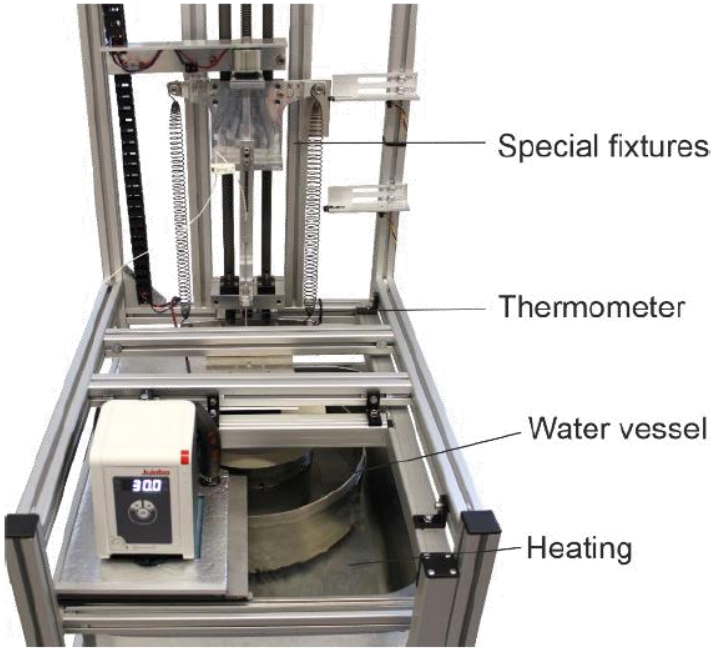
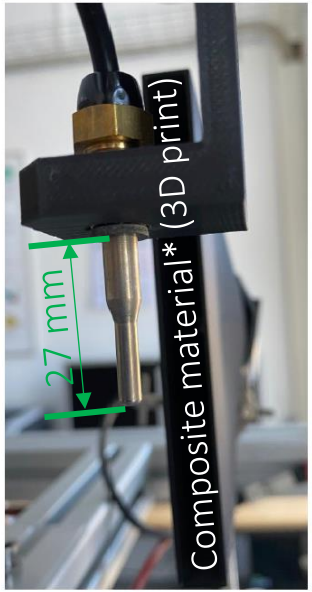


Medium:	water (50 °C)
Velocity:	(0.3±0.1) m/s
Approach:	H(orizontal), laminar flow
Immersion depth:	27 mm (fully immersed as installed)
DS 27,5 mm:	complete temperature sensor

Determination of thermal response time $t_{0.5}$ –

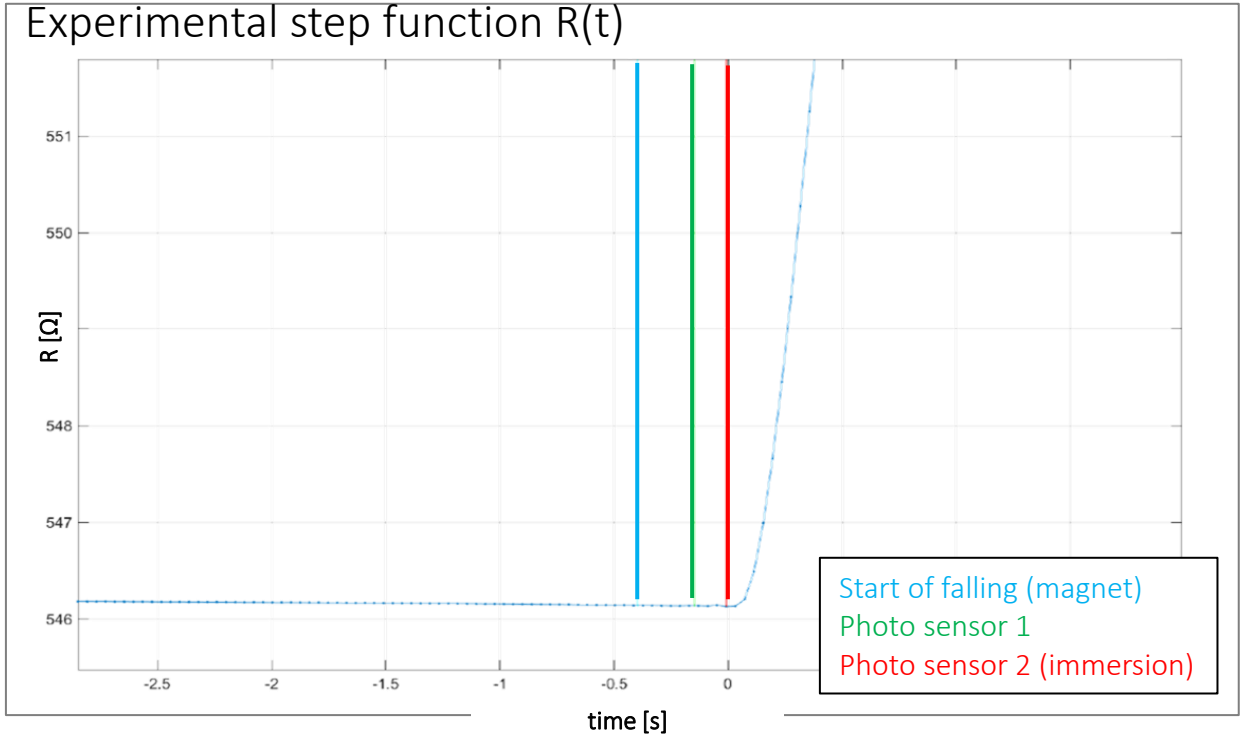




*composite material due to low thermal conductivity

see e. g. Temperaturmesstechnik | Technische Universität Ilmenau (tu-ilmenau.de) and H. Mammen, S. Augustin, T. Fröhlich: Prüfeinrichtung zur Untersuchung des dynamischen Verhaltens von Berührungsthermometern in Wasser, Conference: Sensoren und Messsysteme - 19. ITG/GMA-Fachtagung, 06/26/2018 - 06/27/2018, Nürnberg, Deutschland, Proceedings; J. Beerel, C. Hilpert: Versuchseinrichtung zur Untersuchung des dynamischen Verhaltens von Thermometern in Öl, Projektseminar, TU Ilmenau, 2021

Determination of thermal response time $t_{0.5}$ –

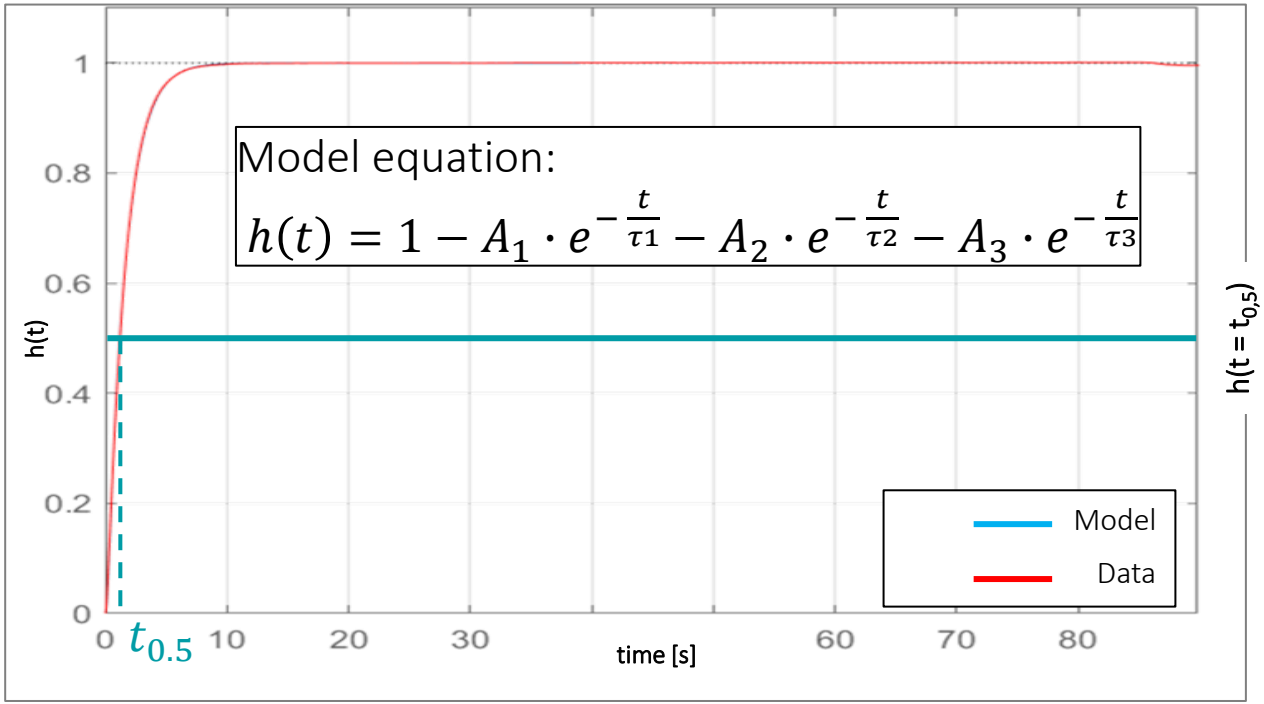


Analysis:

- Determine starting point (photo sensor 2)
- Select data to fit

Determination of thermal response time $t_{0.5}$ –

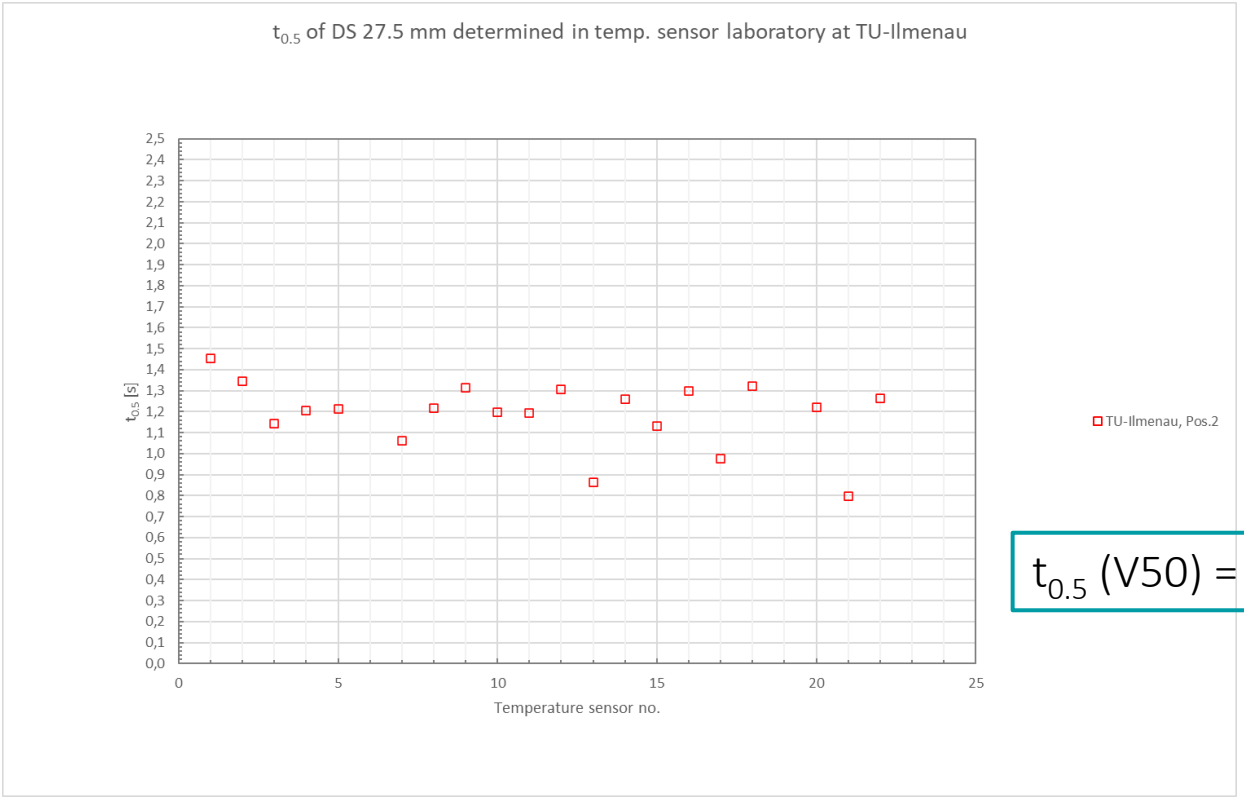
Calculated (normalized) step function h(t)



Analysis:

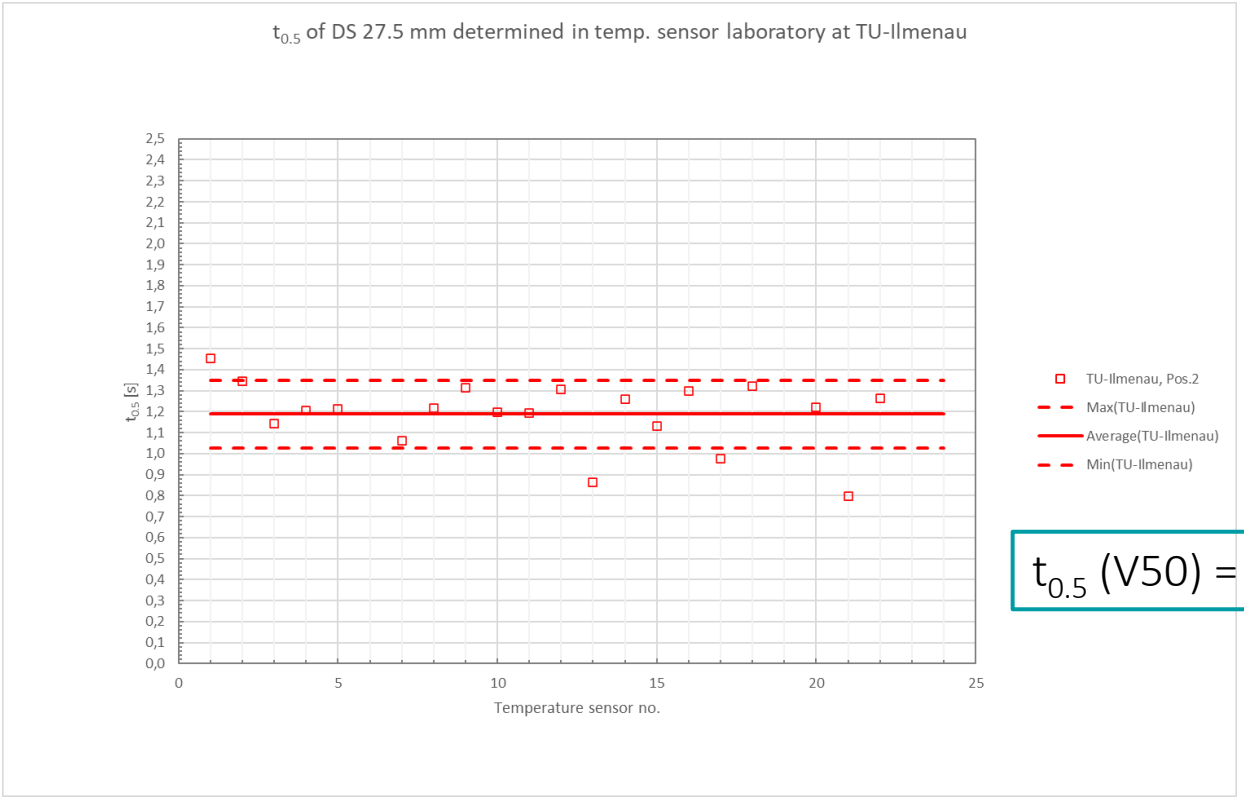
- Determine immersion (photo sensor 2)
- Select data to fit
- calculate h(t) and use 3rd order fit-function as model equation
- Calculate $t_{0.5}$

Determination of thermal response time $t_{0.5}$ –



$t_{0.5}$ (V50) = (1.19±0.16) s

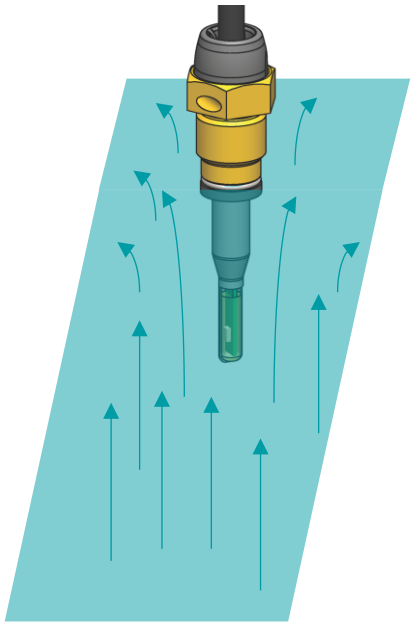
Determination of thermal response time $t_{0.5}$ – TECHNISCHE UNIVERSITÄT ILMENAU



$t_{0.5}$ (V50) = (1.19±0.16) s

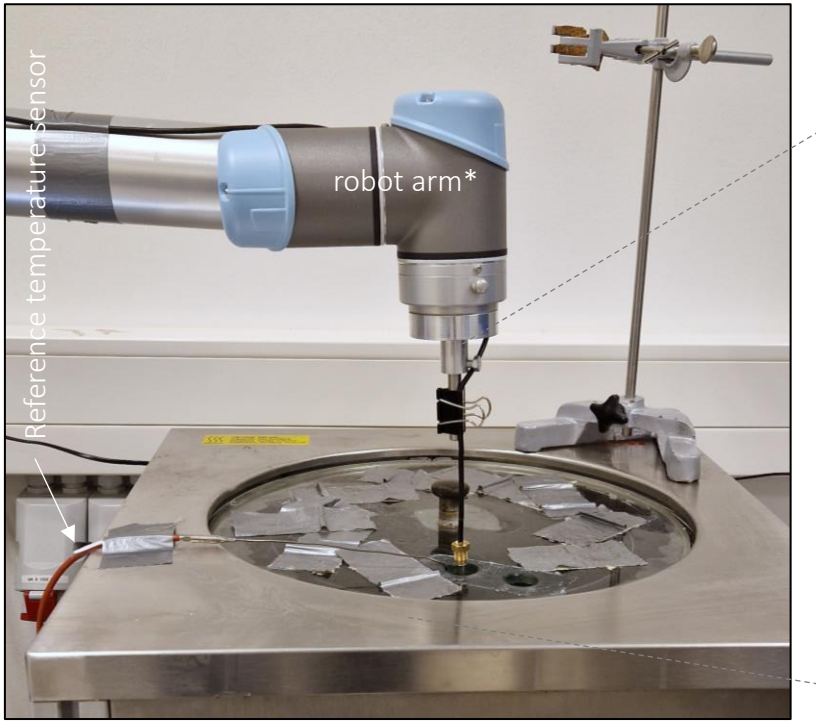
Determination of thermal response time $t_{0.5}$ – Temp. lab.

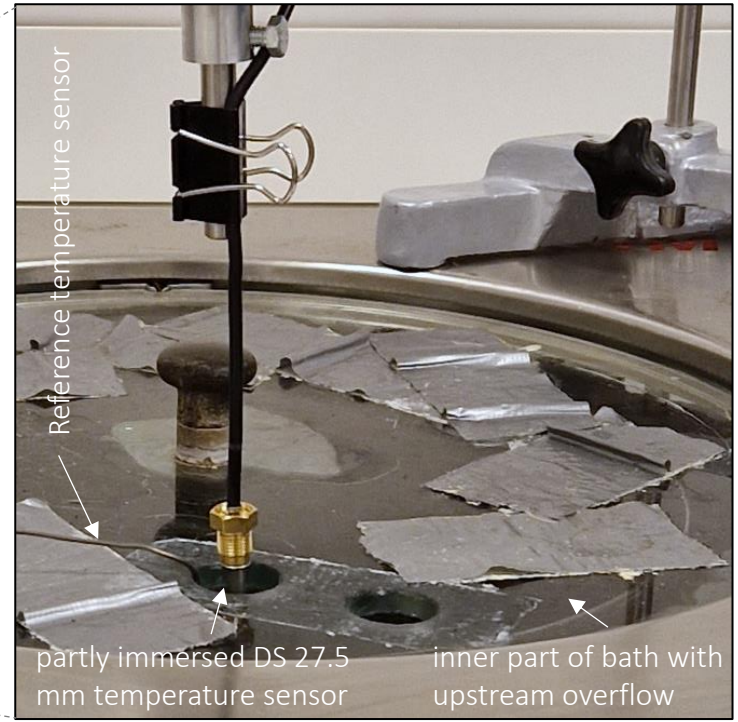
Temp. lab.



Medium:	water (≈34 °C)
Velocity:	not defined
Approach:	upstream overflow
Immersion depth:	27 mm (fully immersed as installed)
DS 27.5 mm:	complete temperature sensor

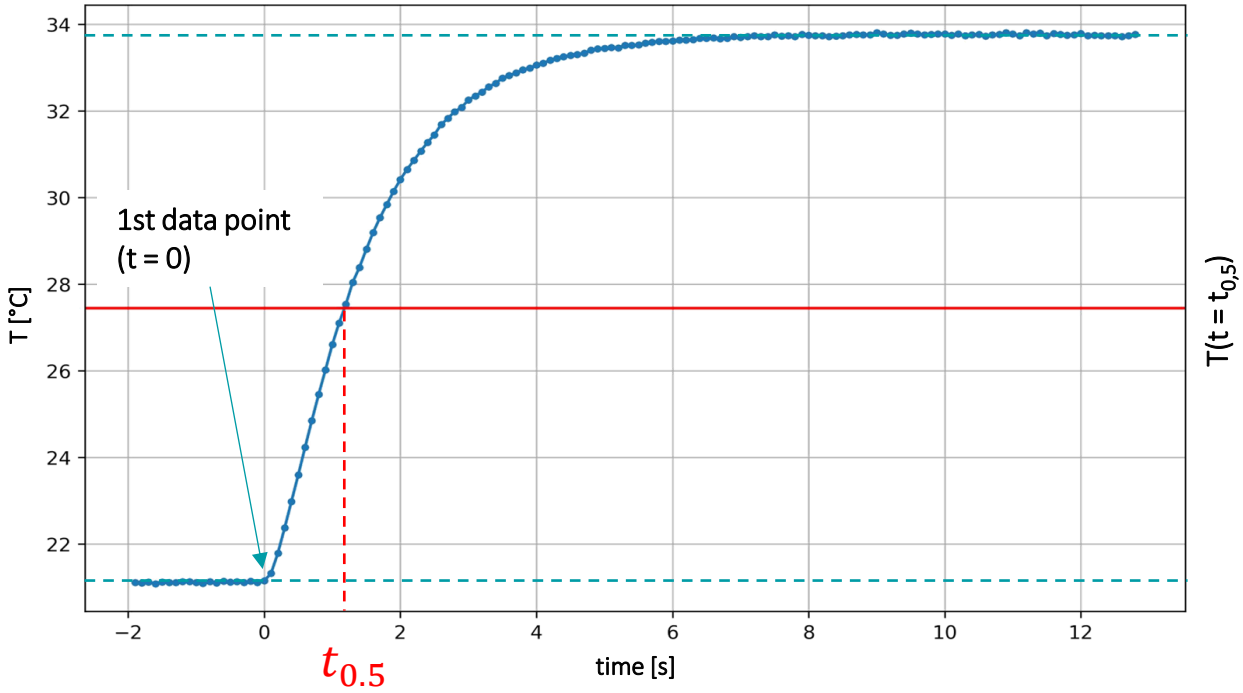
Determination of thermal response time $t_{0.5}$ – Temp. lab.





*see e. g. EMATEM Summer school 2016 EMATEM_2016_MWH_sent to PTB (Link checked 2024-08-14)

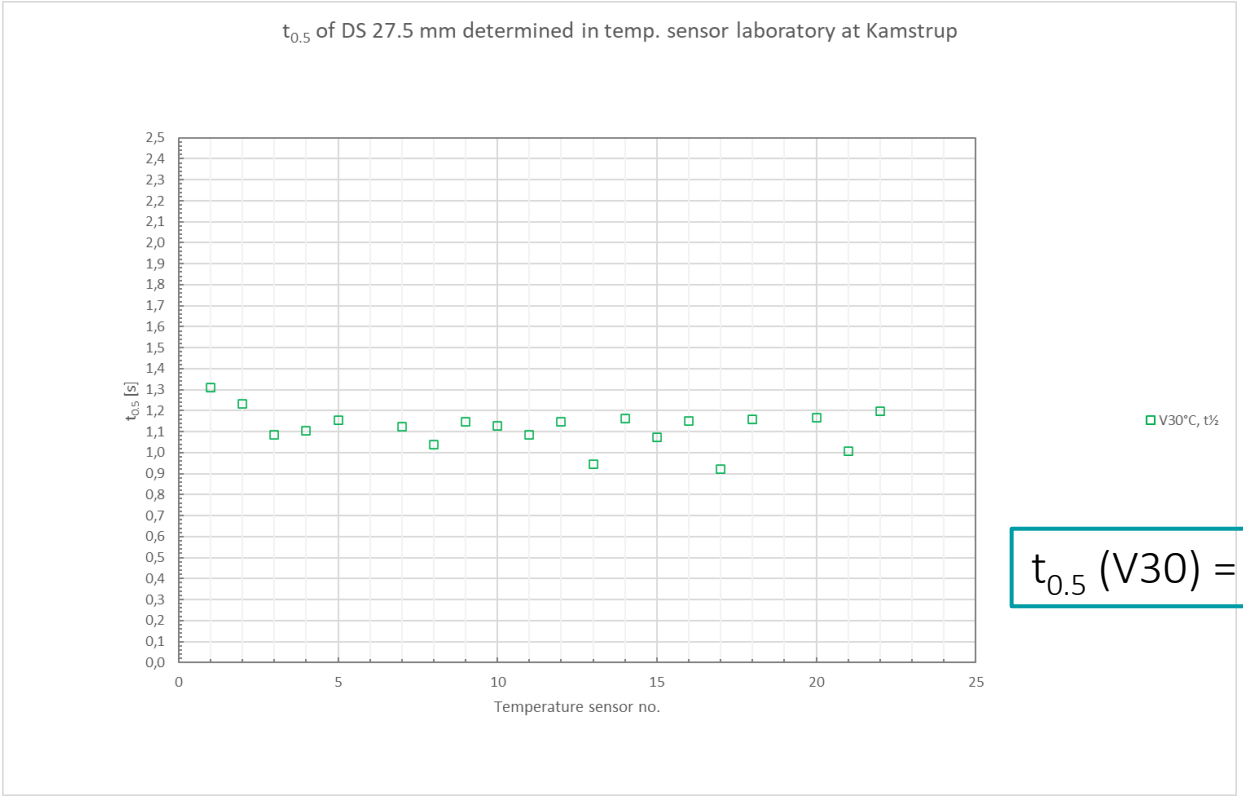
Determination of thermal response time $t_{0.5}$ – Temp. lab.



empirical analysis:

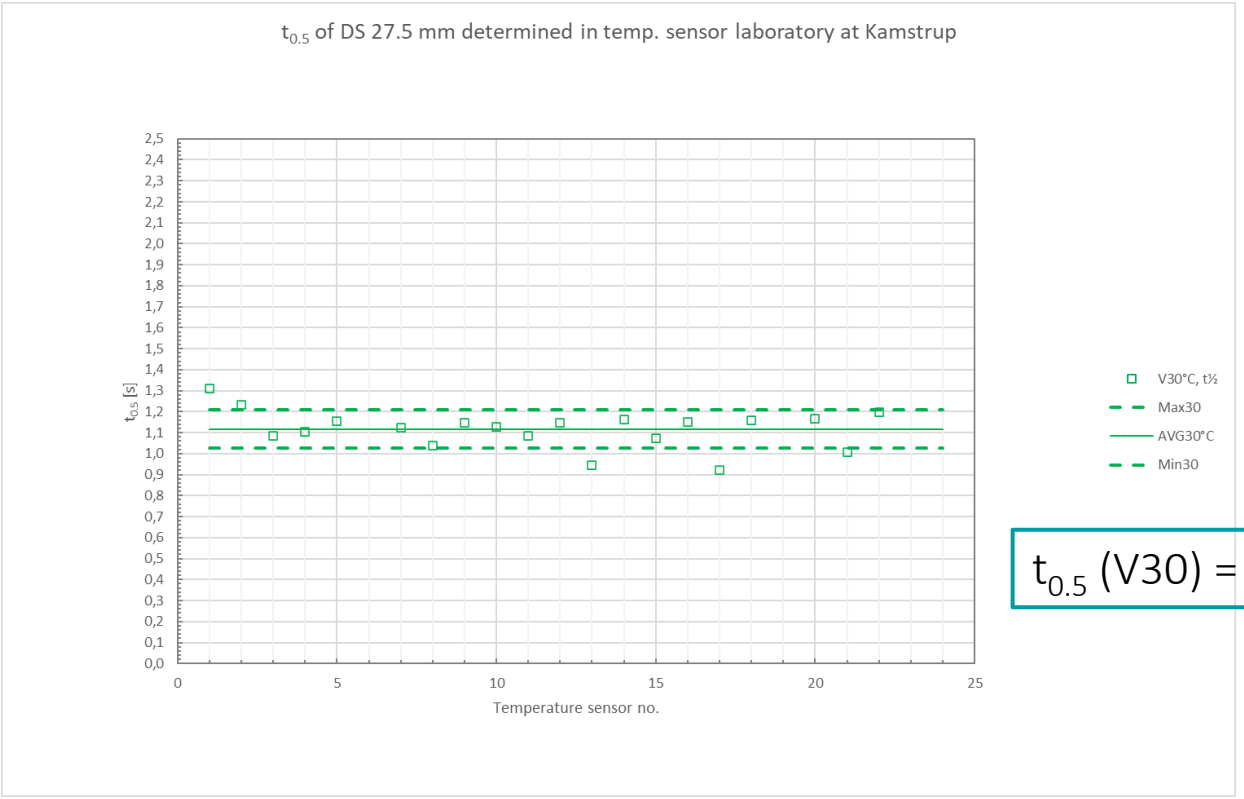
- 1st data point (t = 0)
- start/end temperature
- $T(t = t_{0.5})$

Determination of thermal response time $t_{0.5}$ – Temp. lab.



$t_{0.5}$ (V30) = (1.12±0.09) s

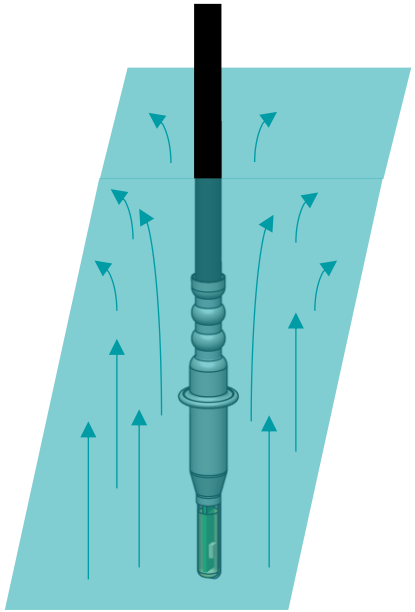
Determination of thermal response time $t_{0.5}$ – Temp. lab.



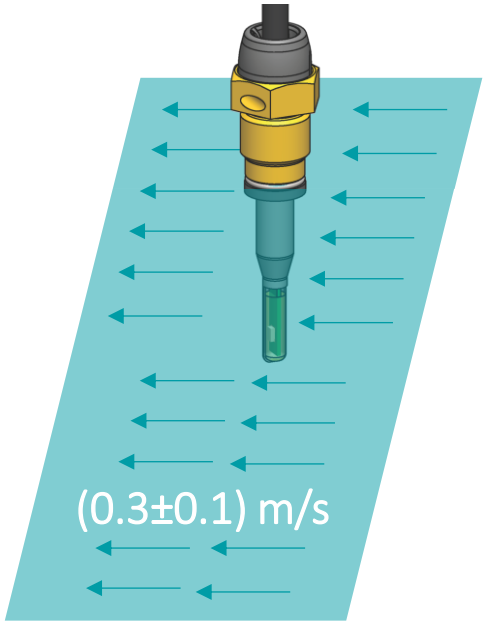
$t_{0.5}$ (V30) = (1.12±0.09) s

Comparison of response time $t_{0.5}$

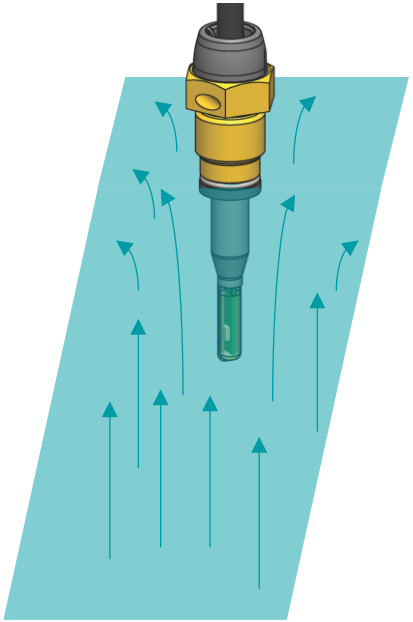
ASP2



TECHNISCHE UNIVERSITÄT ILMENAU



Temp. lab.

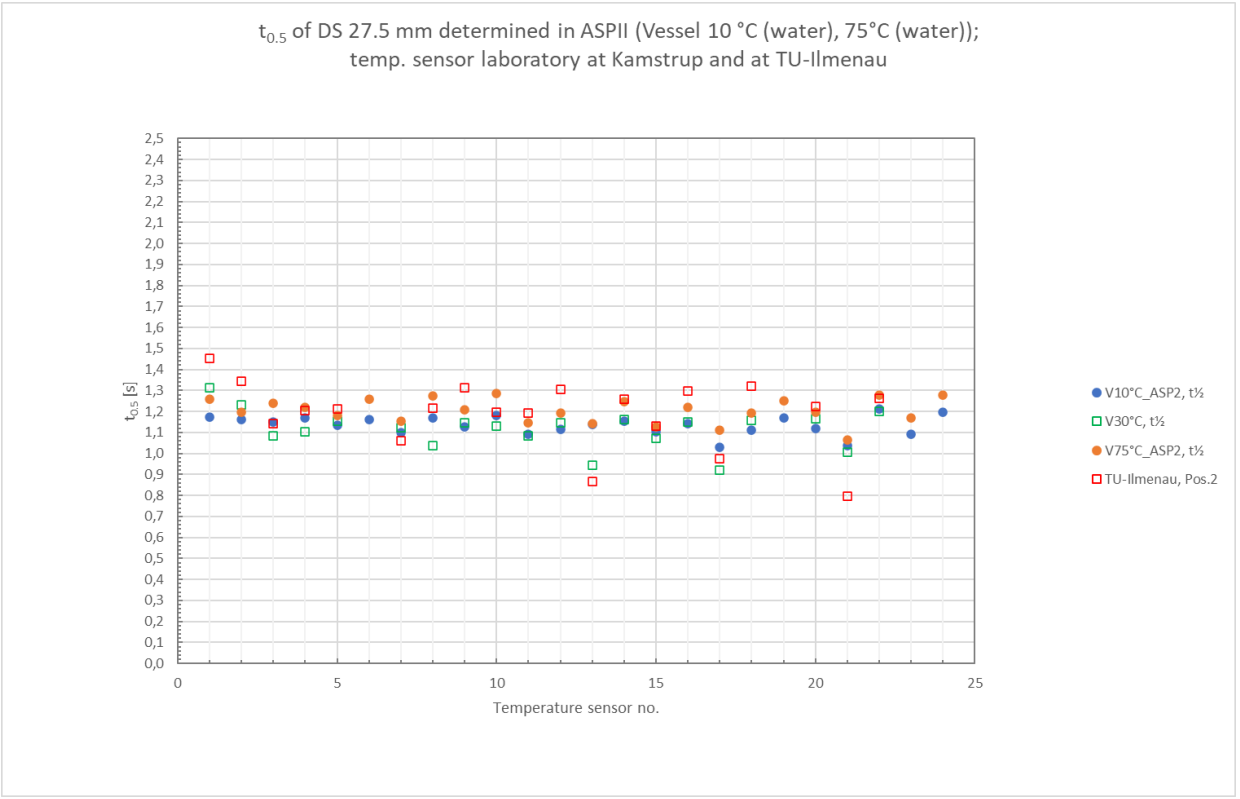


Comparison of response time $t_{0.5}$

	ASP2	TECHNISCHE UNIVERSITÄT ILMENAU	Temp. lab.
temp. jump	RT (≈ (30…35) °C) to 10°C; RT (≈ (15…35) °C) to 75°C	RT (≈23 °C) to 50 °C	RT (≈22 °C) to 34 °C;
fixture	clamped on cable	screwed in 3D print (composite)	clamped on cable
Data analysis	model equation, single fit	model equation, 3rd degree fit	empirical start/stop, read-out $t_{0.5}$
Results*	$t_{0.5}$ (V10) = (1.14±0.05) s $t_{0.5}$ (V75) = (1.20±0.06) s	$t_{0.5}$ (V50) = (1.19±0.16) s	$t_{0.5}$ (V30) = (1.12±0.09) s
	$t_{0.5}$ (V10; V75; V50; V30) = (1.16±0.20) s		

*Results are stated as arithmetic averages from N = 20 temperature sensors. The result for single temperature sensors is based on N ≈ 10 (ASP2), N = 3 (TU-Ilmenau) and N = 5 (Temp. Lab.) measurements. Uncertainties are stated as simple standard deviations from measurements with N = 20 temperature sensors or as a combined uncertainty based on the stated standard deviations.

Comparison of response time $t_{0.5}$



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Agenda

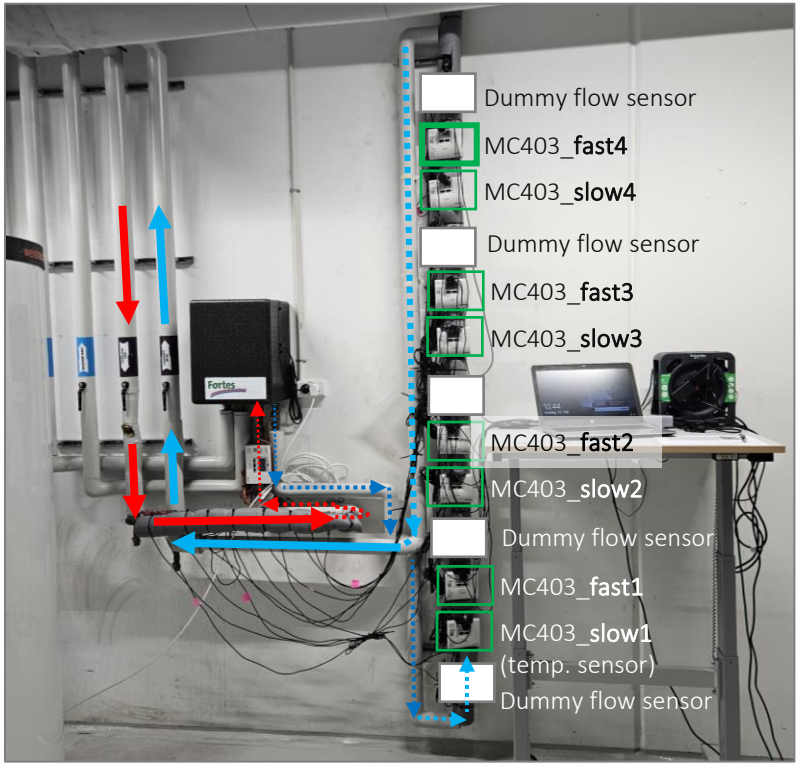
Thermal response time $\tau_{0.5}$ of a temperature sensor

Determination in production

Determination in laboratory

Consequences for the measurement
of thermal energy in dynamic installations

Influence of response time on thermal energy measurement

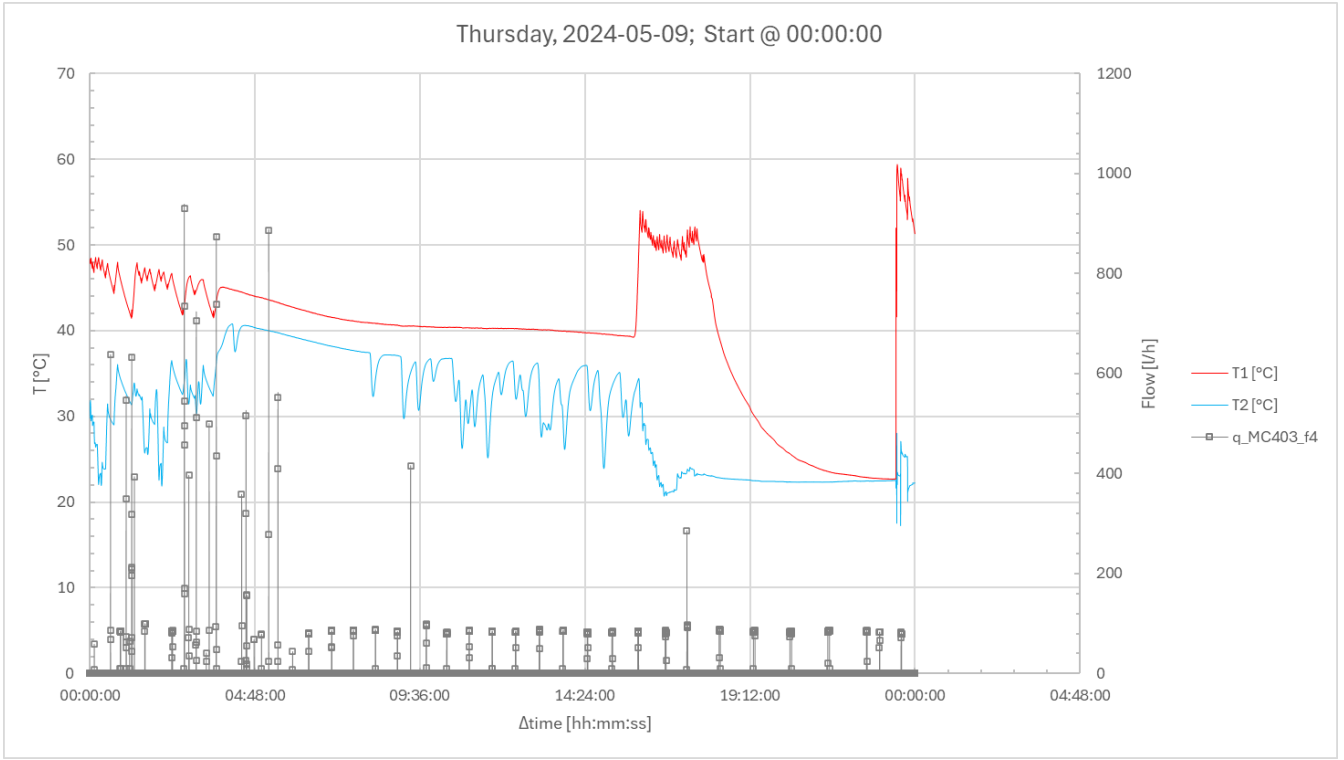


MULTICAL® 403
qp 0.6 m^3/h; G¾ x 110 mm; (L =3; fast mode)
Temperature sampling interval: 4 s
Volume sampling interval: 1 s
Integration time: 4 s

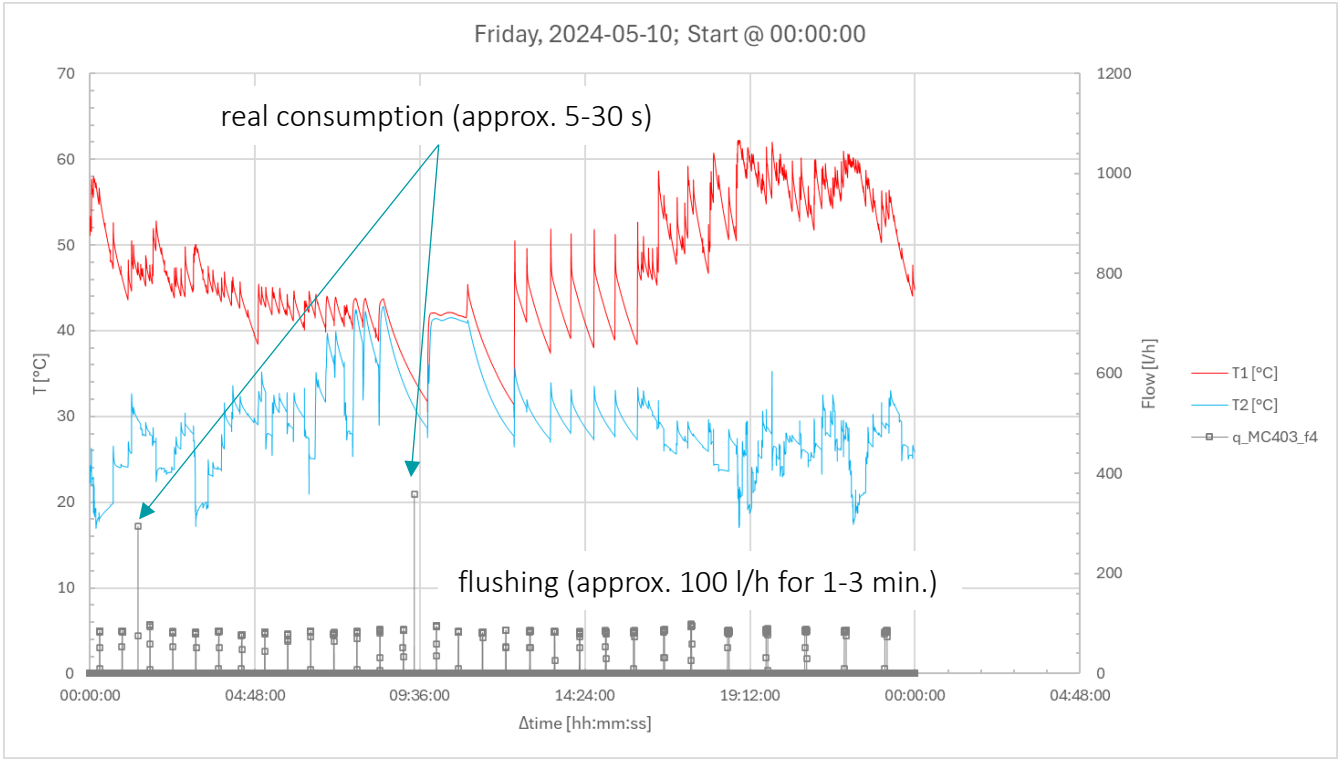
TemperatureSensor 63 (DS 27.5 mm, Pt500)
Response time $t_{0.5}$ fast*: (1.12±0.11) s
Accept criterium*: $t_{0.5}$ < 2 s

Response time $t_{0.5}$ slow*: (6.20±0.71) s
*Data from ASP2. Terminology “fast” and “slow” is related to these investigations. The fast temperature sensors are from standard production.

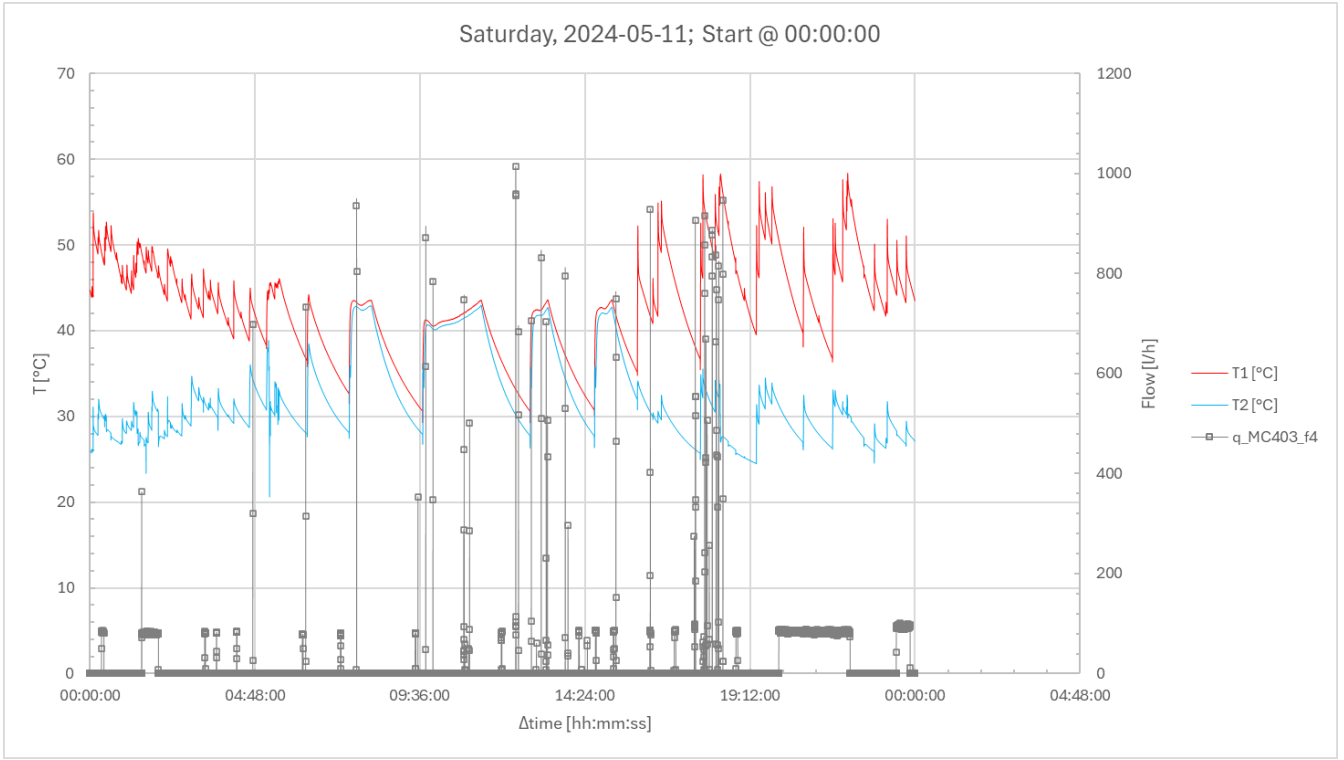
Characterization of district heating unit



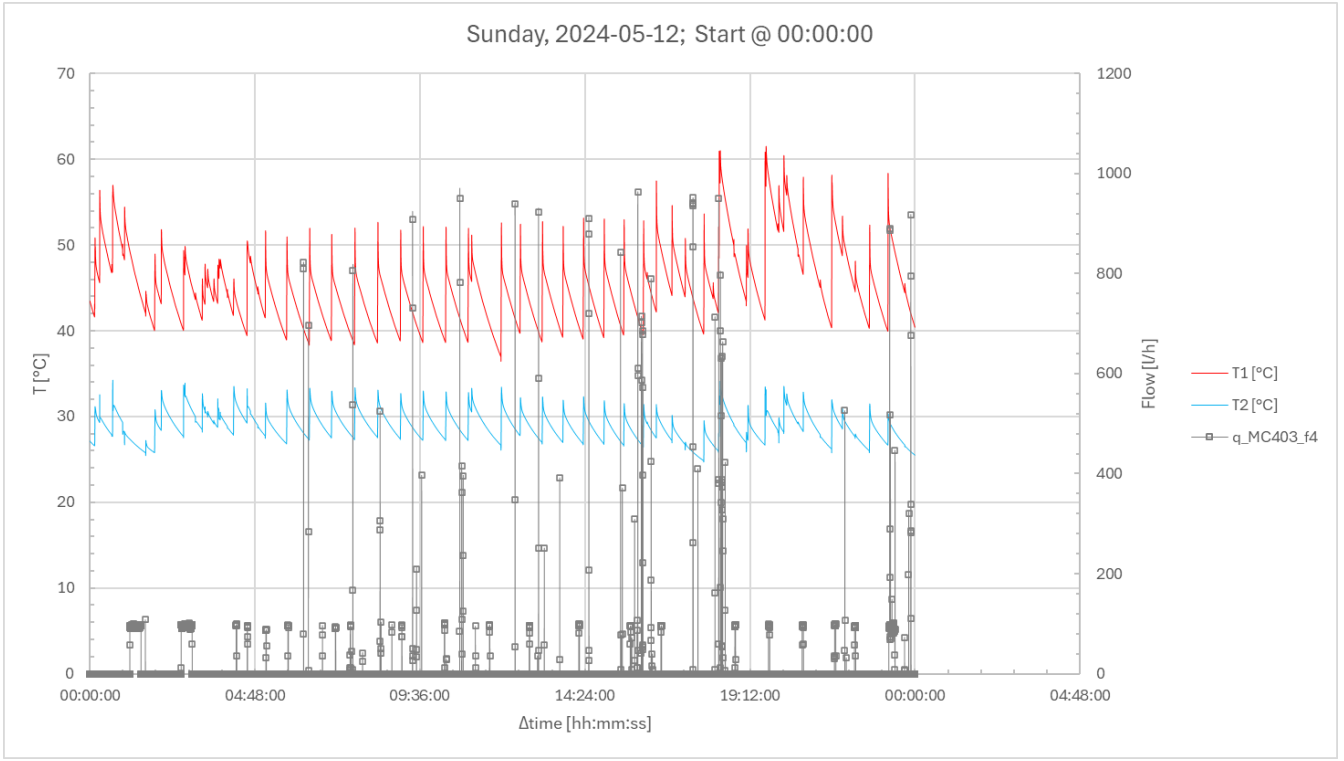
Characterization of district heating unit



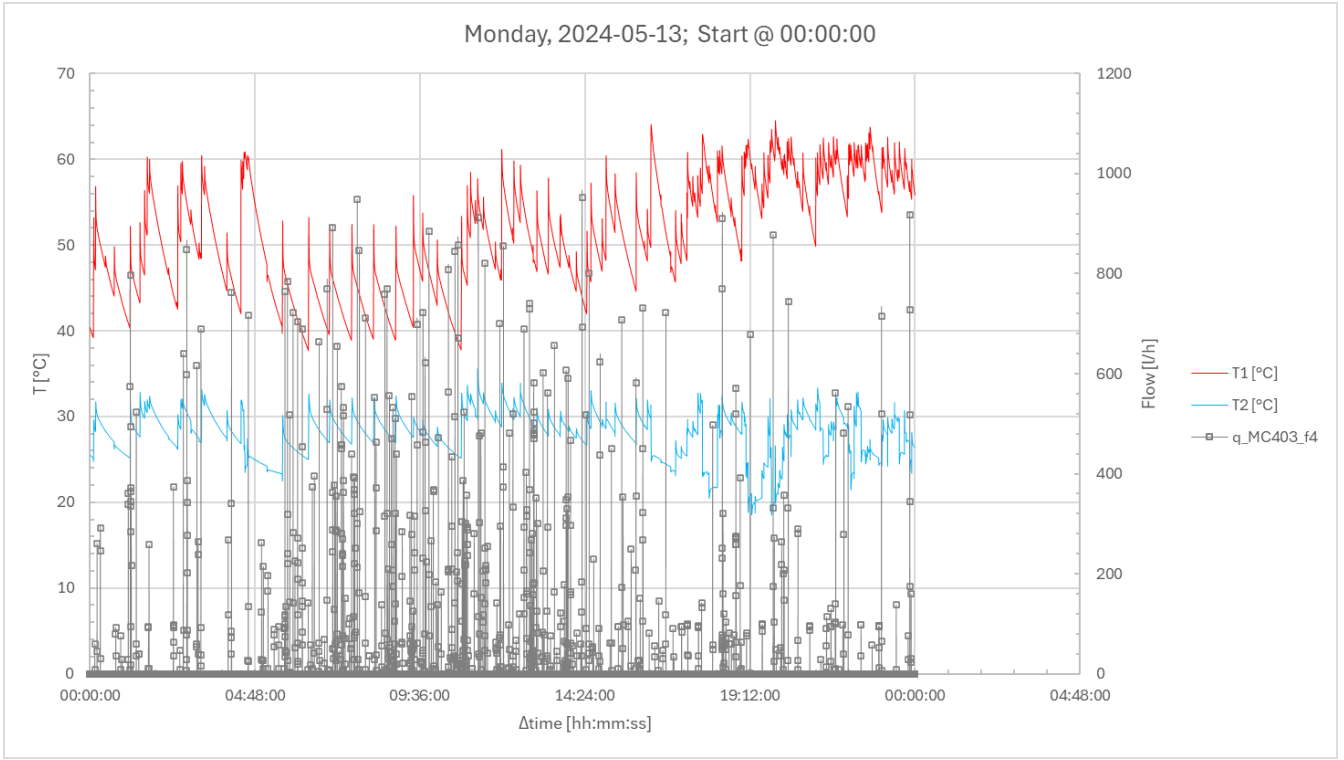
Characterization of district heating unit



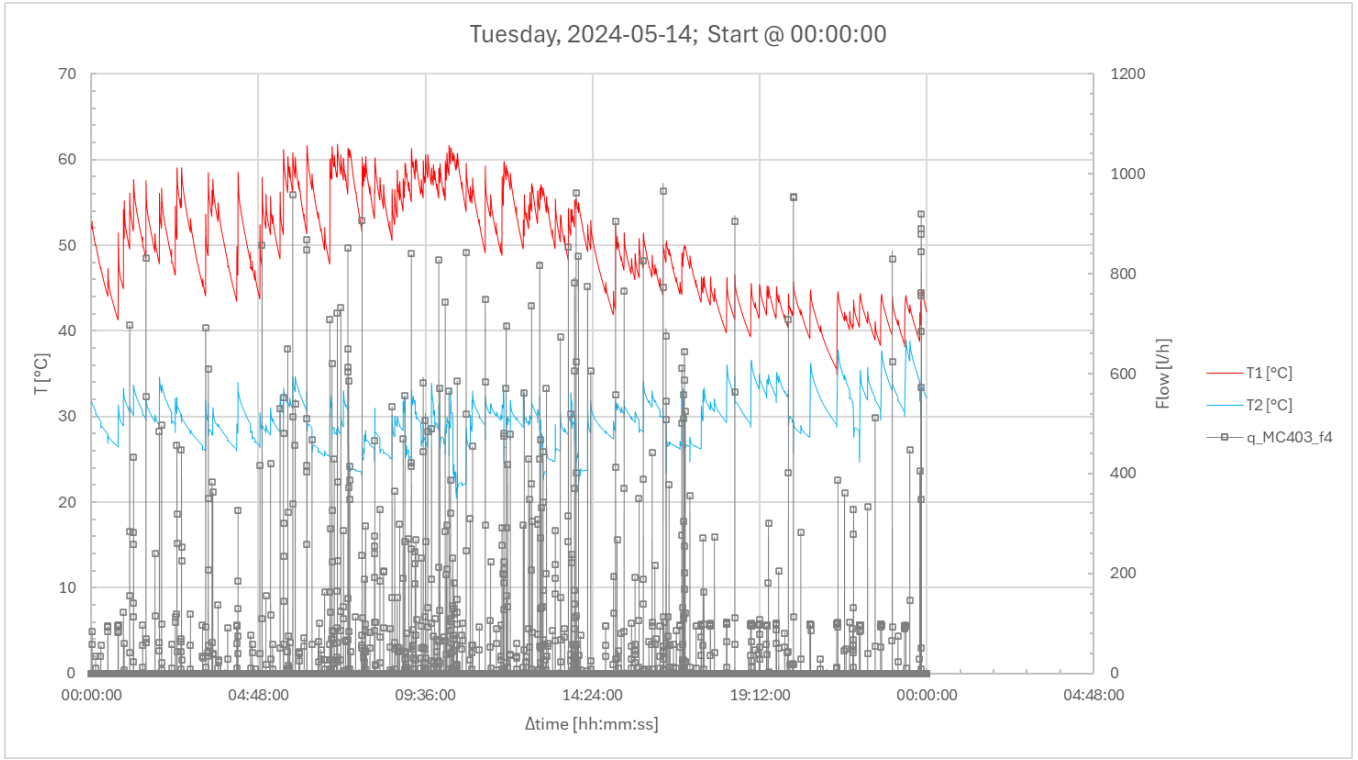
Characterization of district heating unit



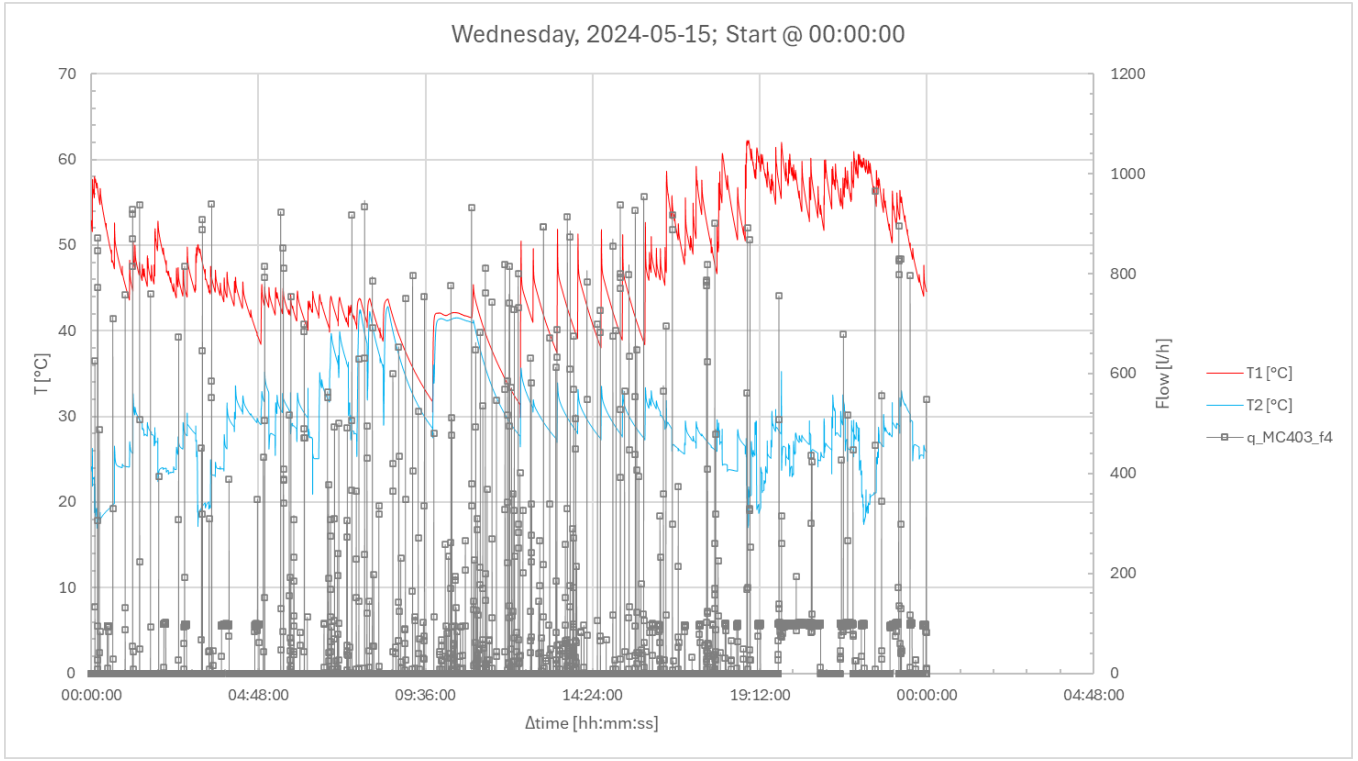
Characterization of district heating unit



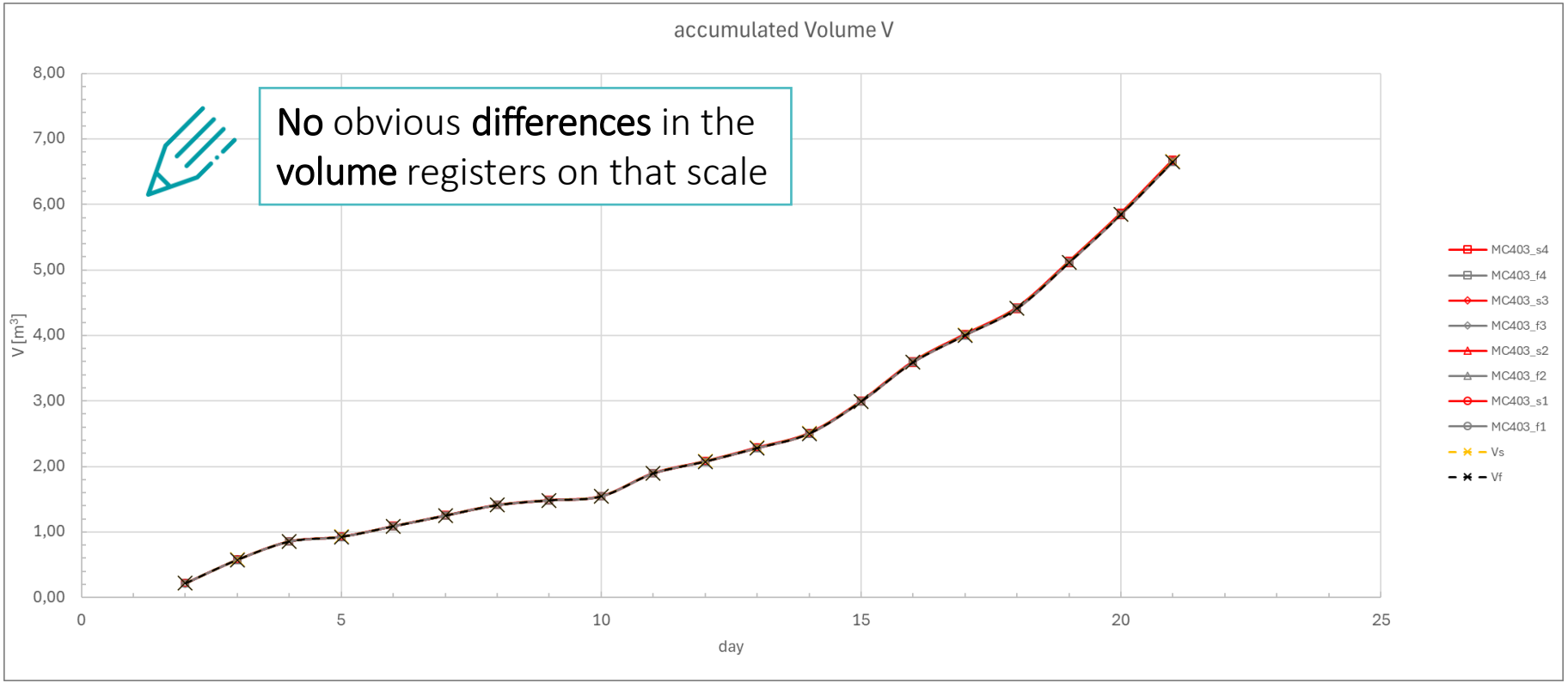
Characterization of district heating unit



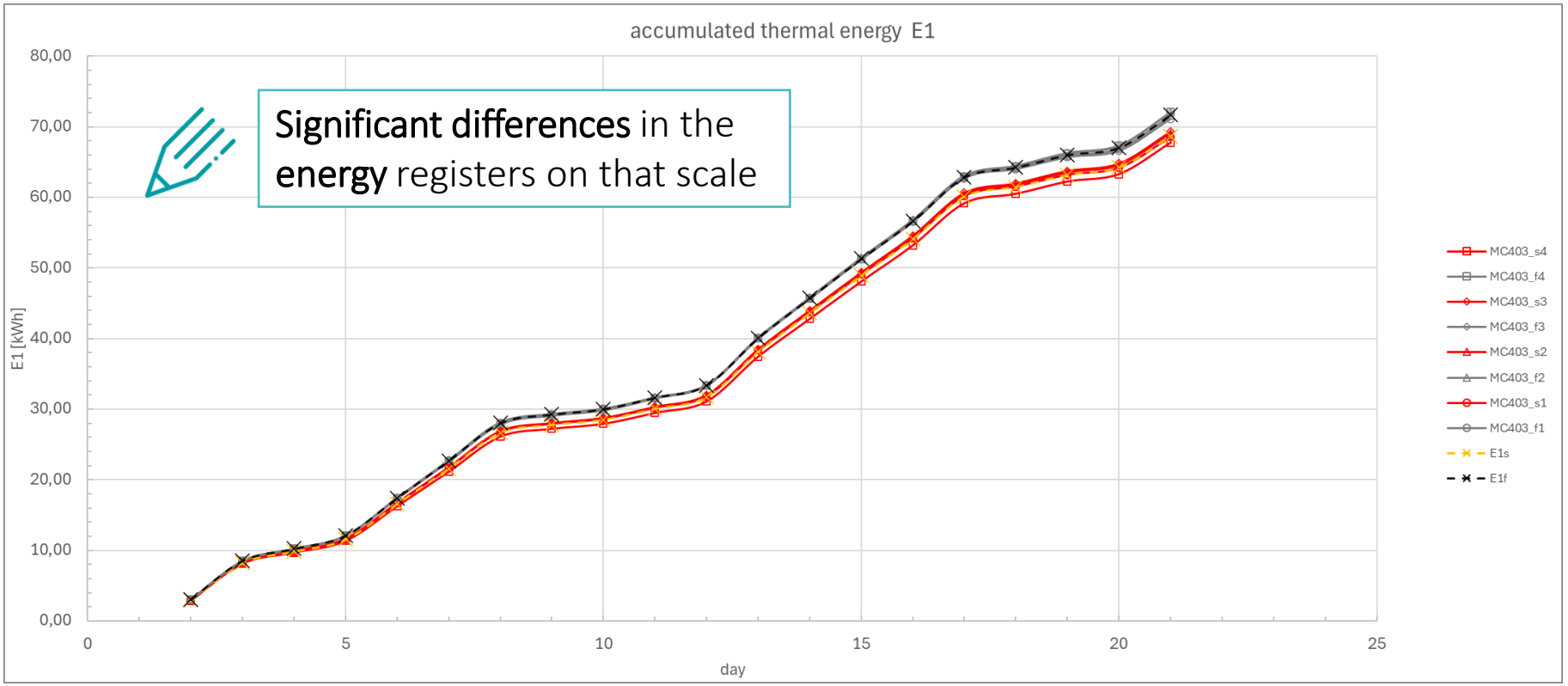
Characterization of district heating unit



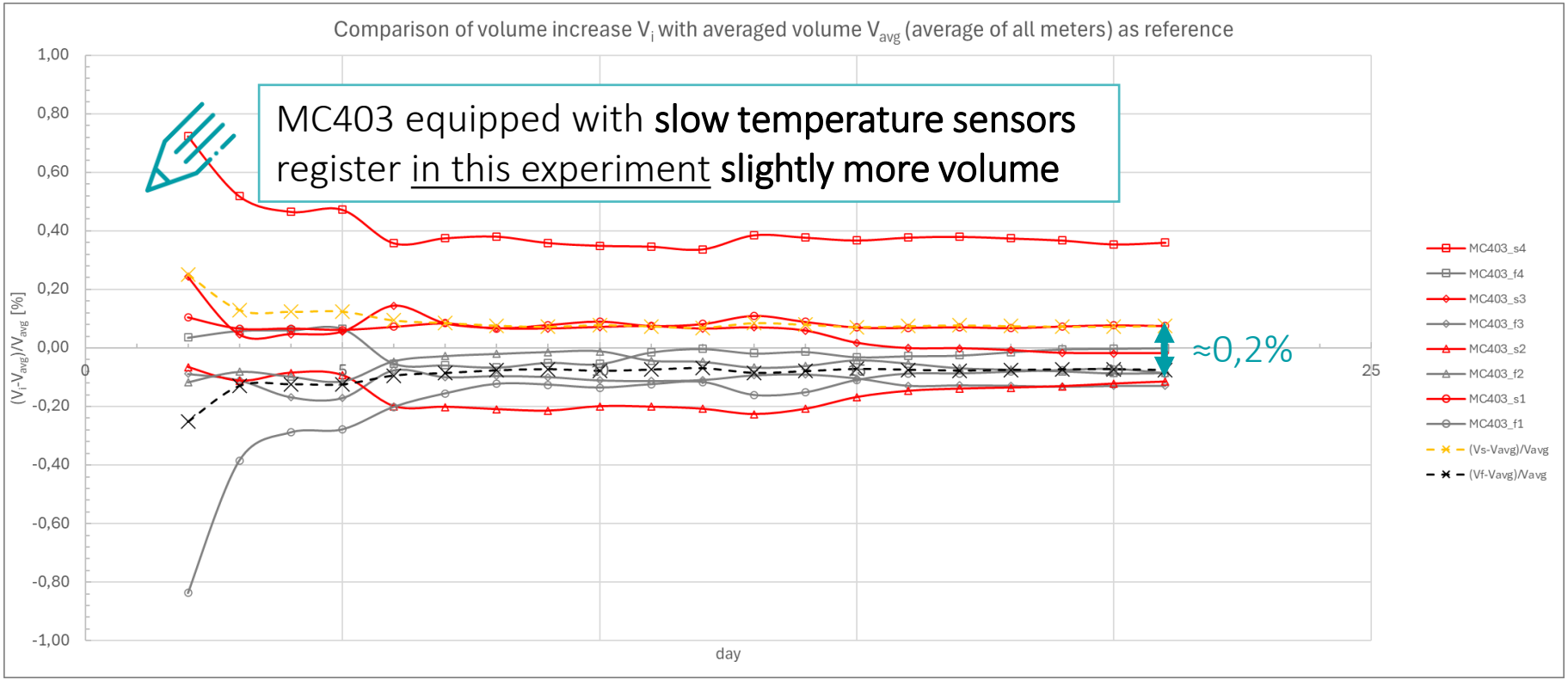
Influence of $t_{0.5}$ on thermal energy measurement



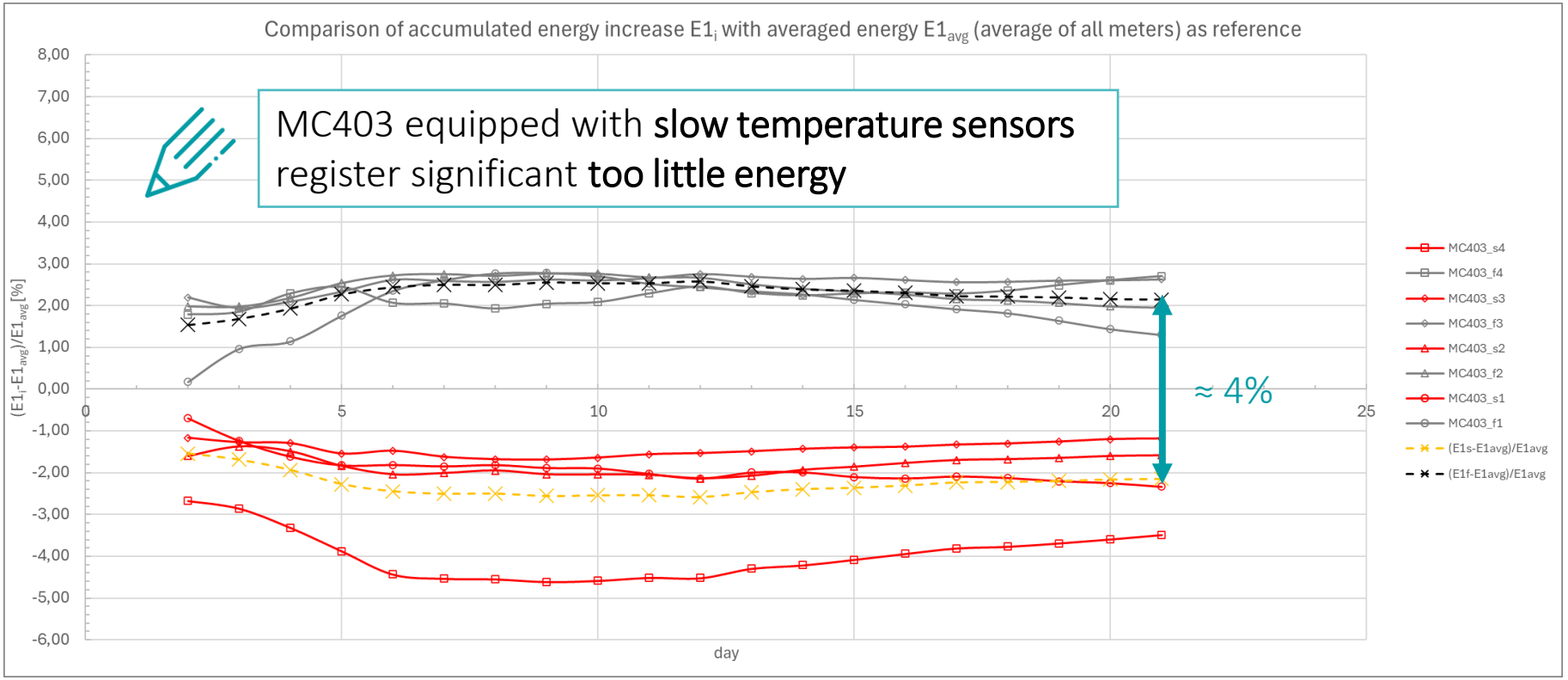
Influence of $t_{0.5}$ on thermal energy measurement



Influence of $t_{0.5}$ on thermal energy measurement



Influence of $t_{0.5}$ on thermal energy measurement



Summary

- Temperature sensors without thermal paste can still be paired. Implementation of automatic response time measurements in ASP2 ensures therefore proper filling with thermal paste.
- Small differences in the test set-ups, used test method, and analysis of data still result in an identical response time $t_{0.5}$ for DS 27.5 mm temperature sensors, taking measurement uncertainties into account.
- For DS 27.5 mm temperature sensors, a response time test in ASP2 can be performed similar to a type test for each single piece during production.
- Comparative experiments with fast and slow responding temperature sensors demonstrate that slow responding temperature sensors lead to the registration of too little thermal energy (≈4%)

Thanks for your attention!

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