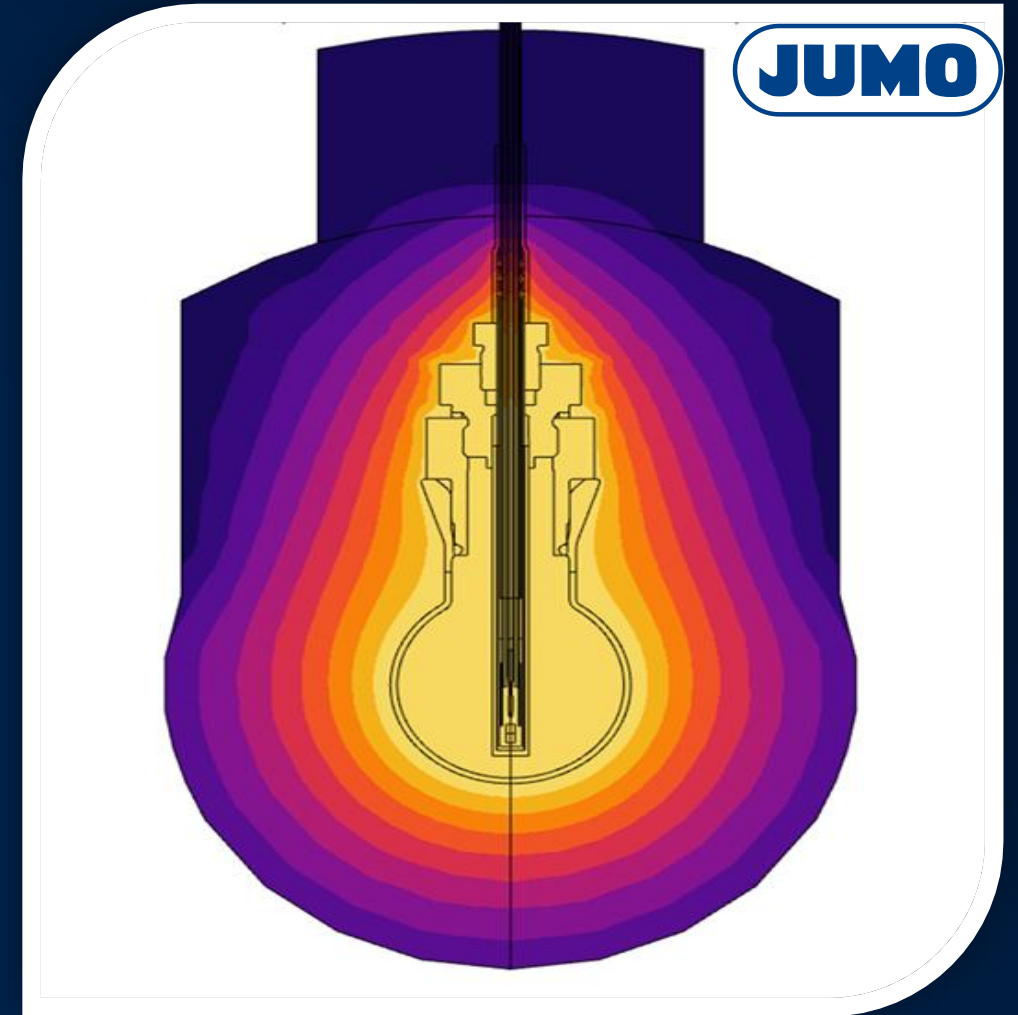


Innovative Approaches to Improving the Accuracy of Thermal Energy Measurement through Simulation and Analysis of Installation Sites (Updated Since 2025)

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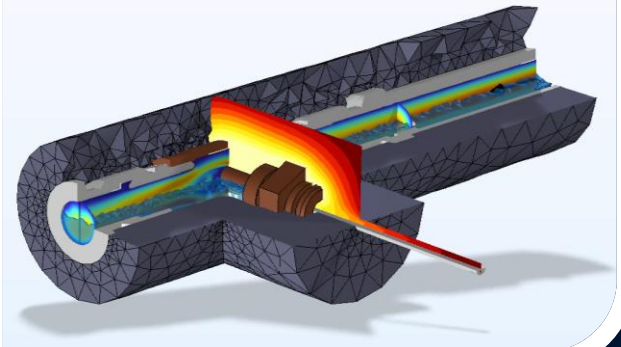


1. Introduction

Background:

- Temperature measurement using insertion temperature sensors with thermowells in water-carrying piping systems
- The use of short insertion temperature sensors in thermowells can be problematic
- Quantification of the factors influencing heat conduction
→ Simulation of two long thermowells
- In Scope of a Research project with the PTB

EMATEM 2025 - short thermowell



Task:

Finite Element Analysis (FEA) and simulation of the factors influencing heat dissipation

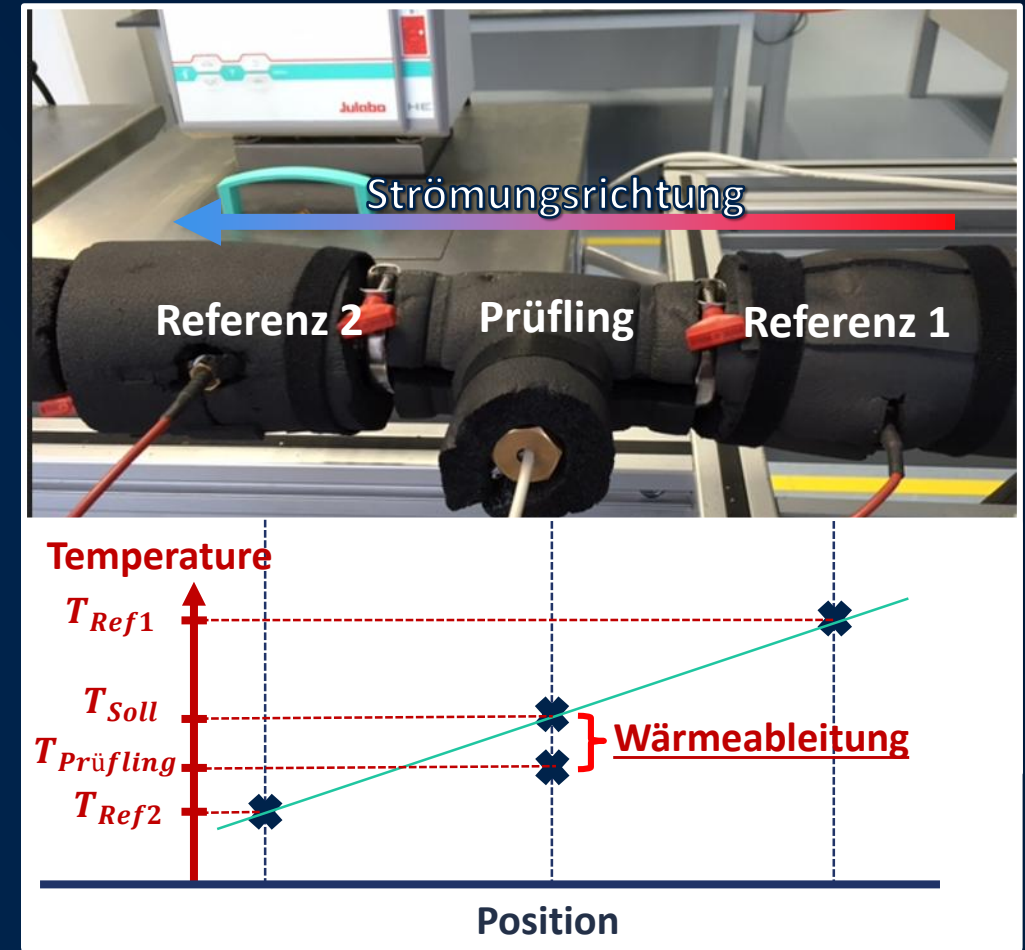
- **Flow rate** and **fluid temperature**
- **Installation configuration** in simulation: existing thermowell with temperature probe

2. Model Configuration - Measurement Method

- Laboratory service at JUMO to verify compliance with DIN EN 1434 requirements for temperature measurement
- **General:** Pipe system with defined volumetric flow rate (medium: water) and specified temperature
 - Temperature measurement before and after the test specimen

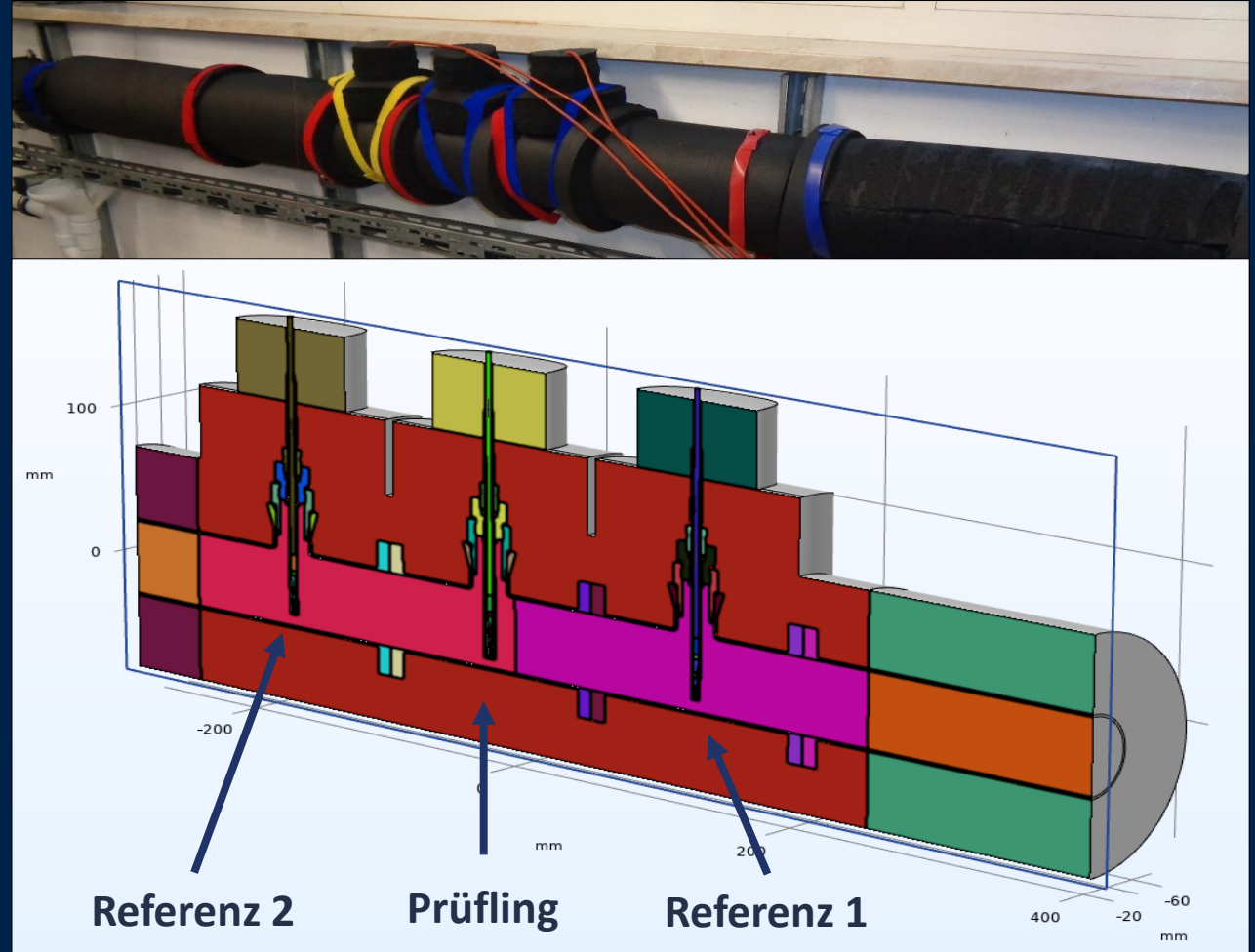
Determination of heat dissipation:

- Difference between the device under test (DUT) and the mean value (from T_{Ref1} and T_{Ref2})
-> „Method A“



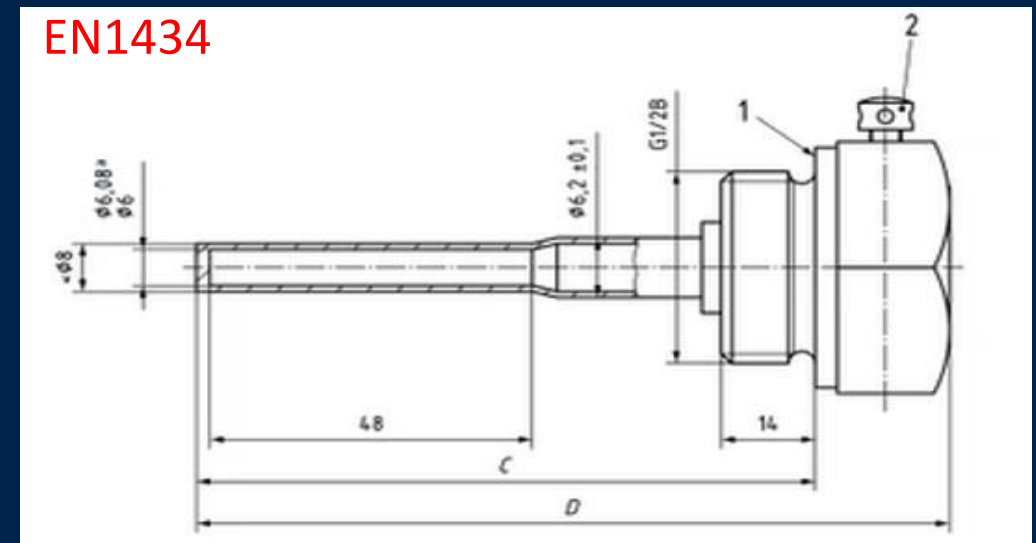
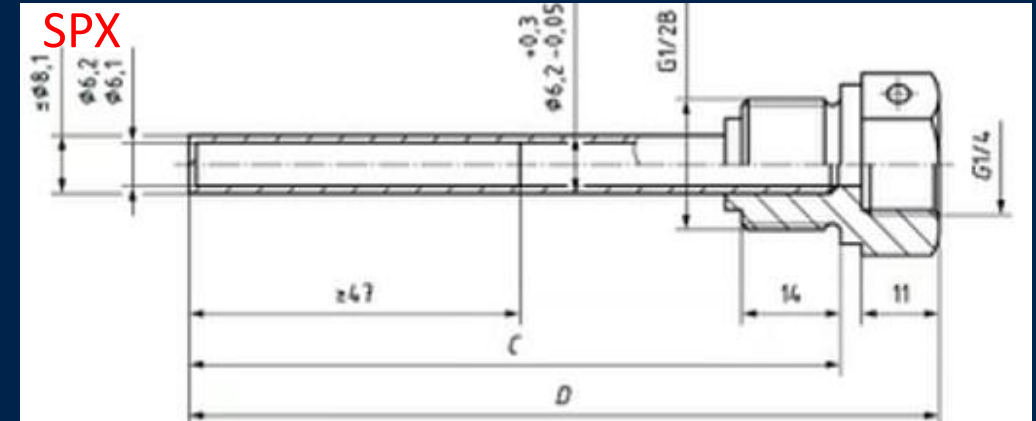
2. Model Configuration – Flow Channel DN50

- Thermally insulated pipe system (insulation thickness: 50 mm)
- Measurement setup comprising three flanged connections
- Measurement principle based on one device under test (DUT) and two reference sensors
- Vertical sensor installation
- Half-geometry model exploiting symmetry conditions
- Steady-state thermal simulation



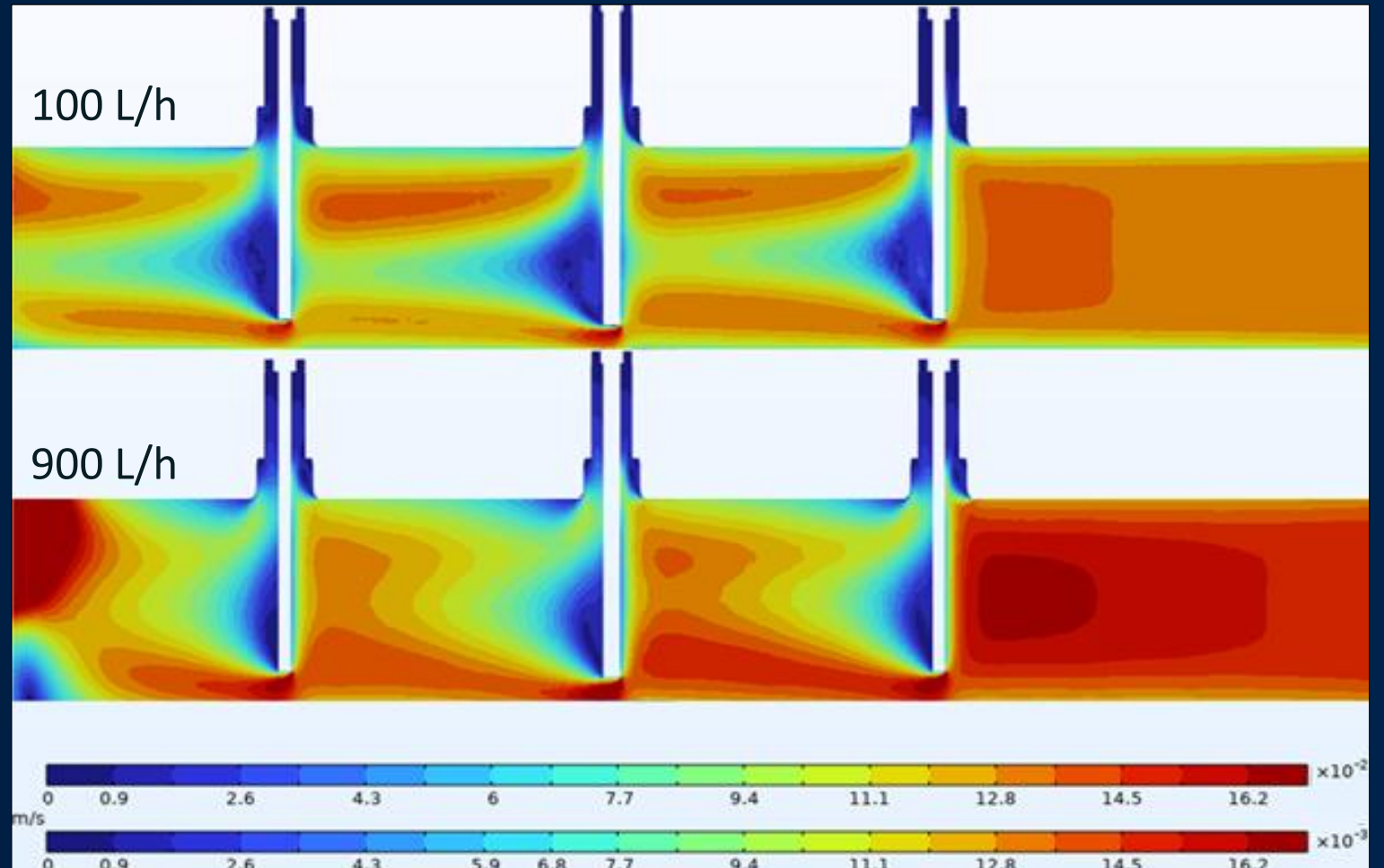
2. Model Configuration – Boundary Conditions

- Evaluation of heat dissipation effects for two extended thermowells (according to DIN EN 1434)
- Task:
 - Temperature measurement within the thermowell
 - Flow rates: 900, 375, 200, and 100 L/h
 - Fluid temperature: 55°C (water)
- Case 1: SPX thermowell (insertion length = 93 mm)
- Case 2: EN 1434 thermowell (insertion length = 85 mm)



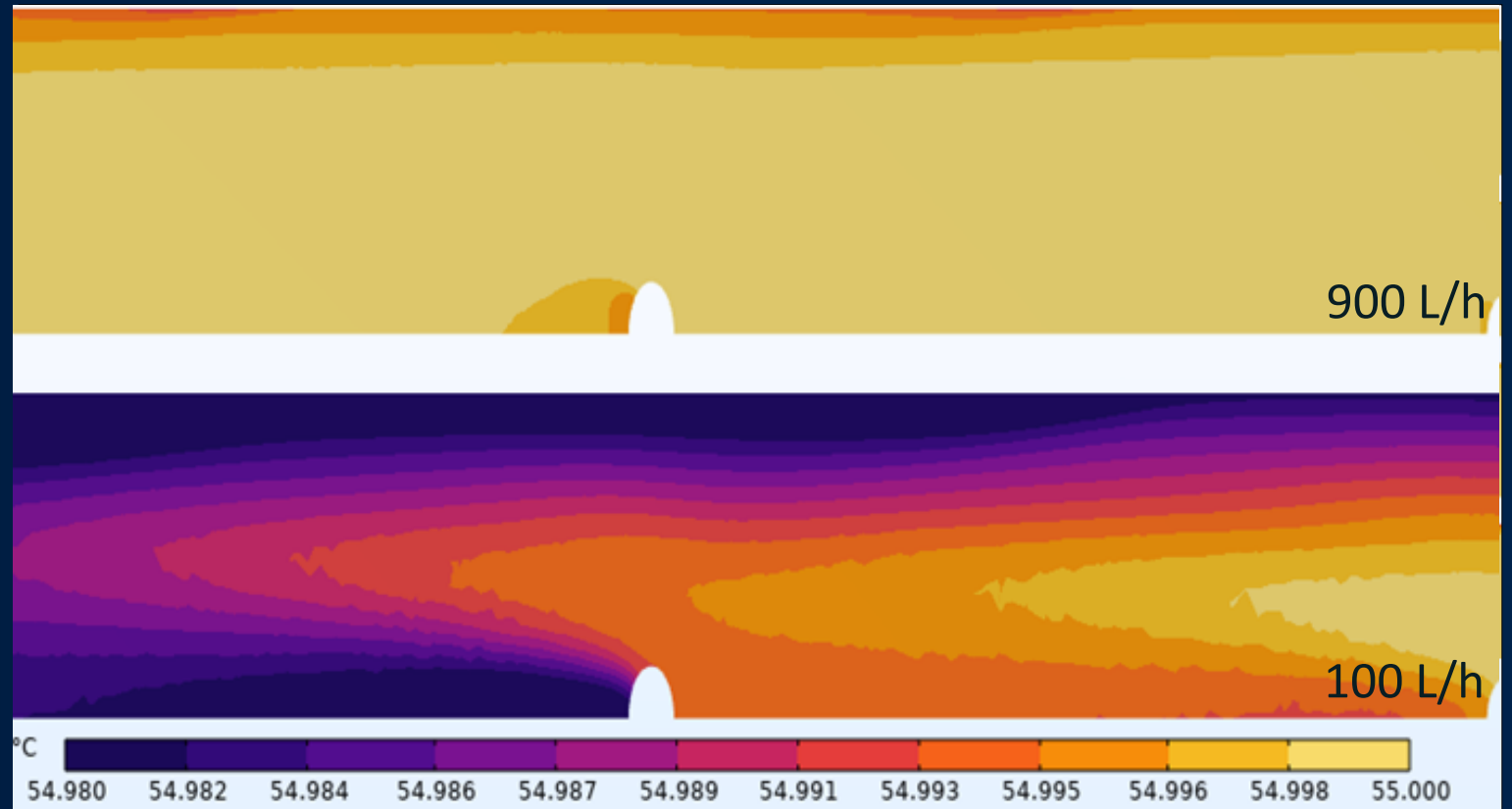
3. Thermowell „SPX“ – Simulation Results - Flow Profile

- Simulation of a non-isothermal flow field (geometry displayed at half-scale in the figure)
- Visualization of flow and temperature inhomogeneities that are difficult to measure experimentally
- Assessment of the interaction between the device under test (DUT) and the reference sensors



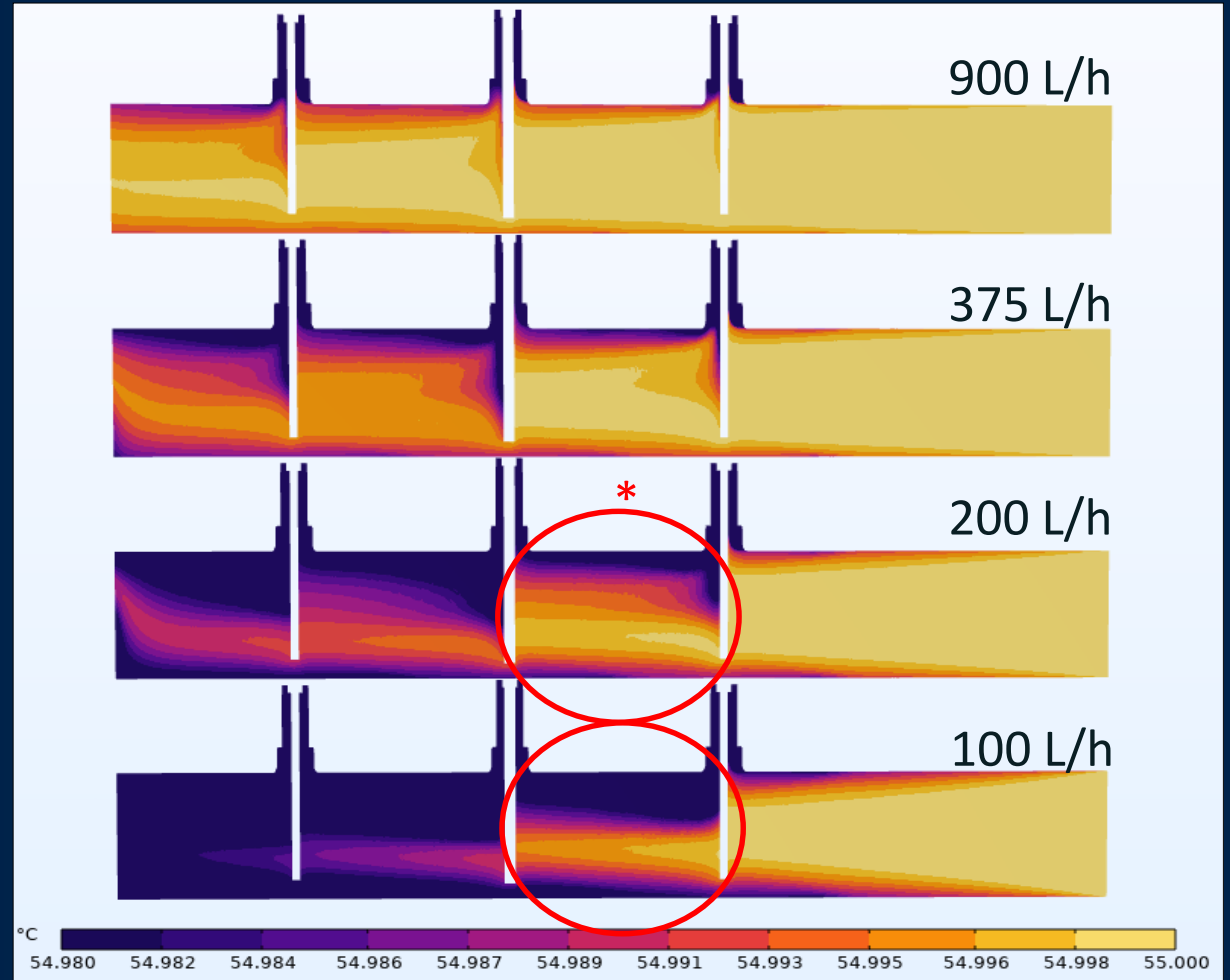
3. Thermowell „SPX“ – Simulation Results - Temperature Profile

- Assessment of the fluid temperature distribution
 - What is the expected reading of an ideal measurement probe?
- Small displayed temperature range of 20 mK
- Increasing turbulence leads to greater thermal homogeneity



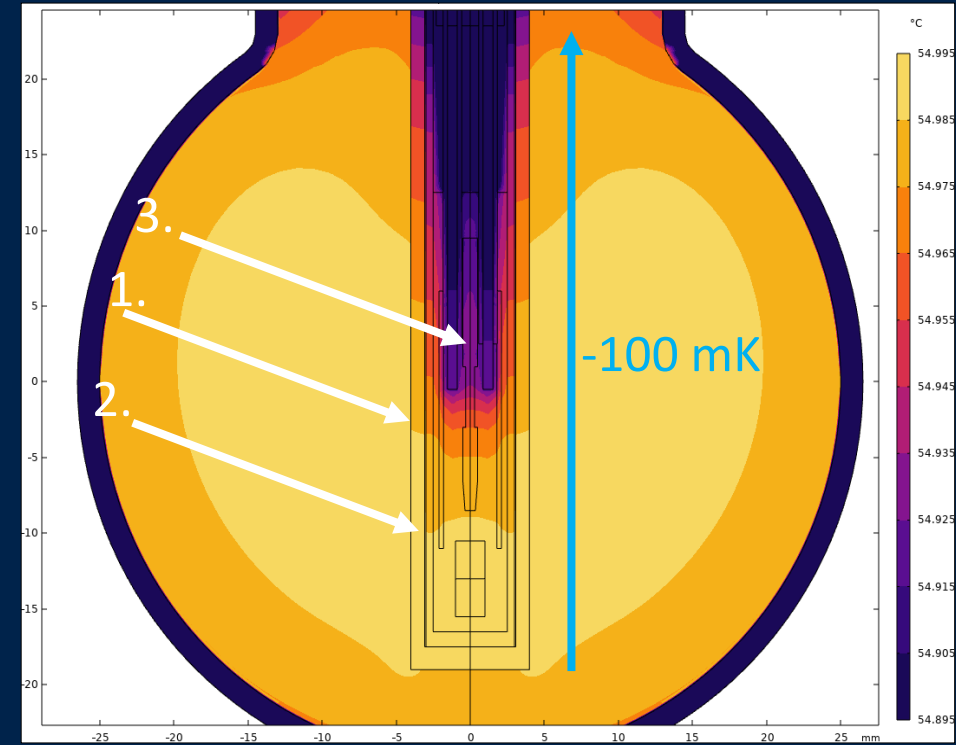
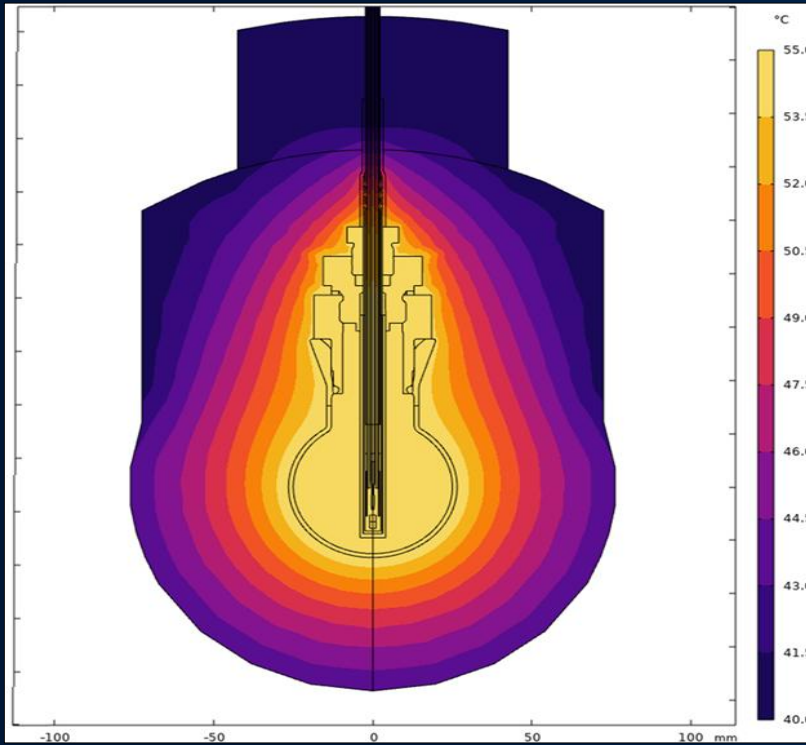
3. Thermowell „SPX“ – Simulation Results - Temperature Profile

- Mutual sensor interaction is noticeable from 200 L/h onward (only fluid domain)
- At flow rates below 375 L/h the DUT no longer fully surrounded by a homogeneous temperature
- The temperature gradient changes substantially when the flow rate decreases from 200 L/h to 100 L/h



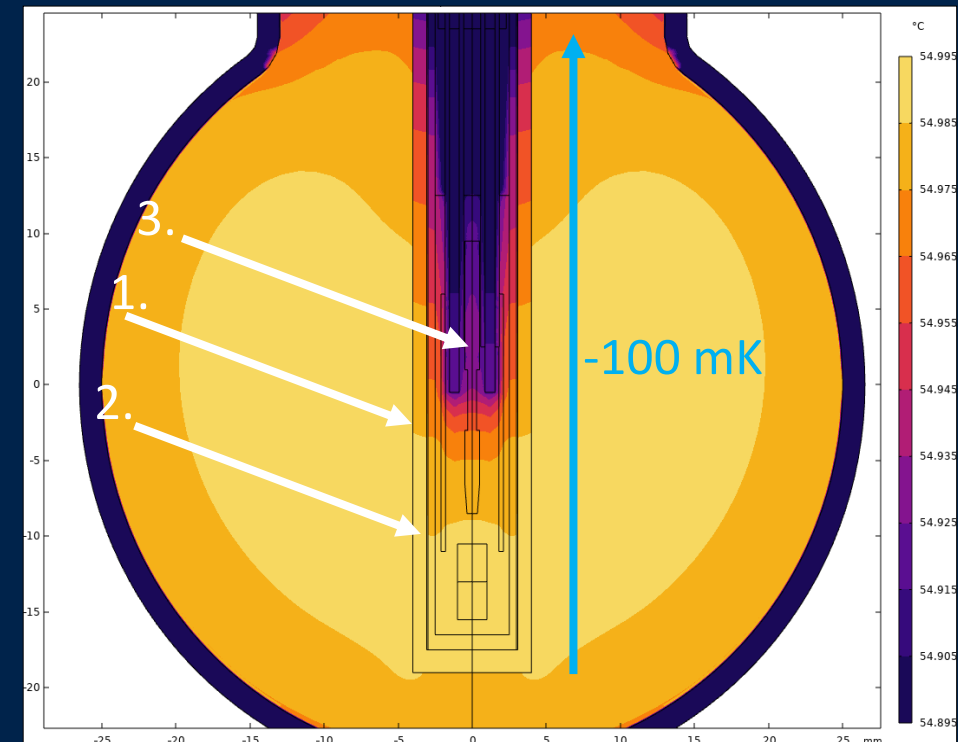
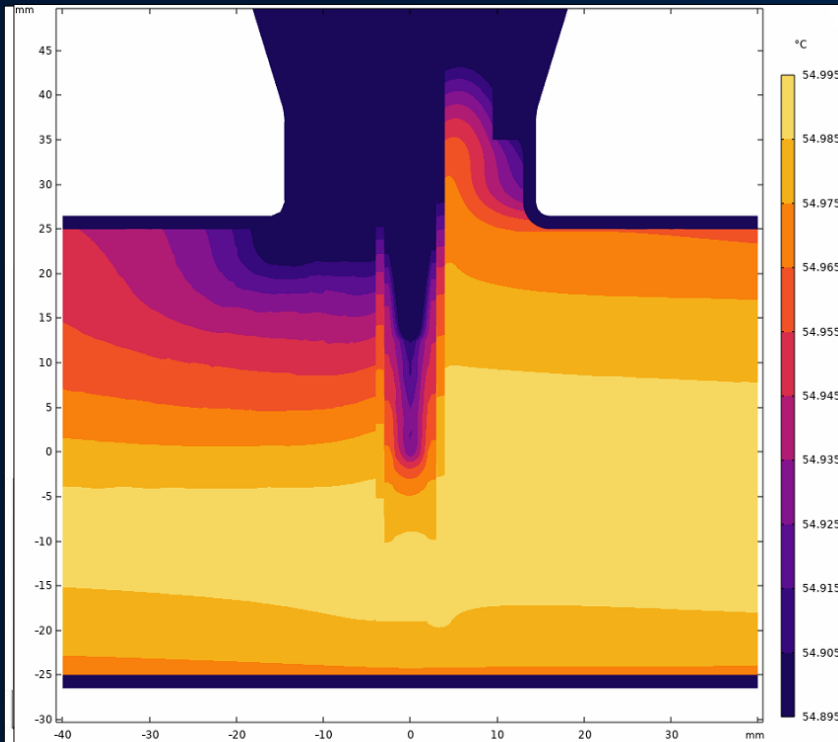
3. Thermowell „SPX“ – Simulation Results - Installation Site for 100 L/h

- Necessity of thermal insulation ($\Delta T \approx 15$ K)
- Different temperature gradients occur across: 1) the thermowell, 2) the protection tube, 3) the connection cable



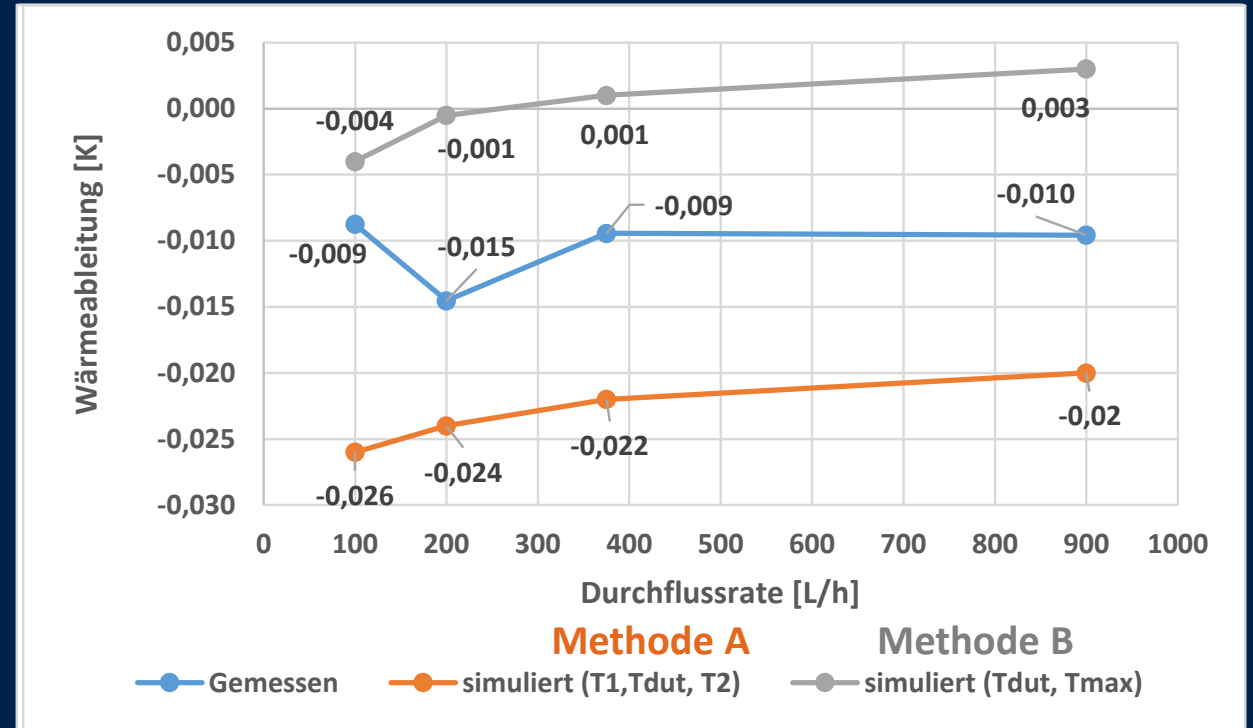
3. Thermowell „SPX“ – Simulation Results - Installation Site for 100 L/h

- Thermal layering at the probe masks the heat dissipation effects
- The flow approach direction has only a negligible influence in the presence of a thermowell



3. Thermowell „SPX“ – Simulation Results - Validation

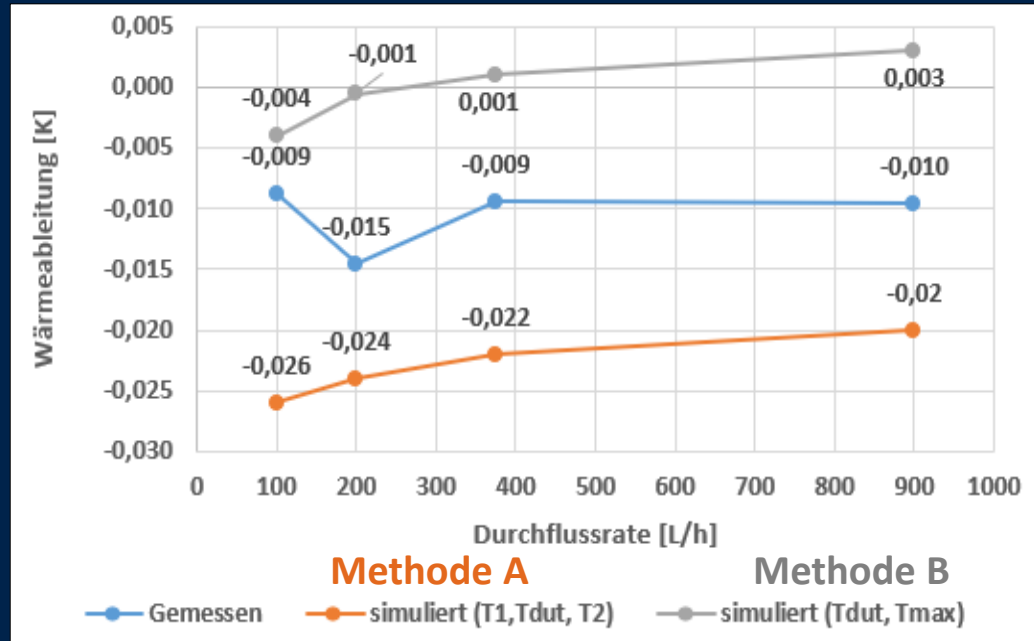
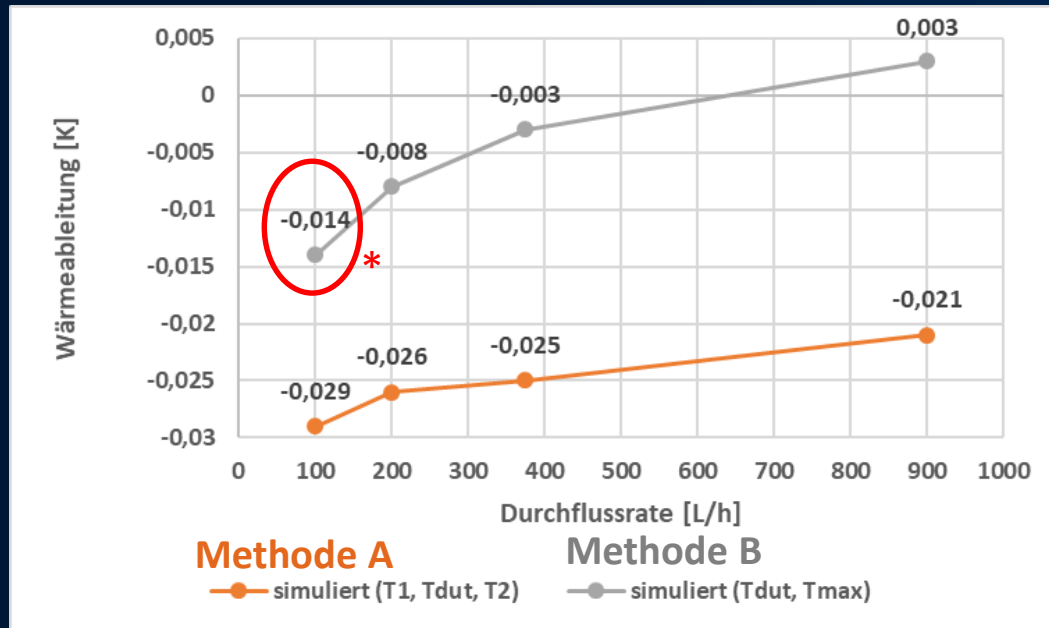
- Measured heat dissipation is small (close to 0 mK, with no clear trend observable)
- The evaluation method can be selected within the simulation:
 - **Method A:** based on experimental setup
 - **Method B:** comparison with the fluid temperature
- The simulated trend agrees with expectations (**-7 mK** and **-6 mK**) across the investigated flow rates
- The observable measurement error is, as expected, very small
→ The simulation results are plausible



3. Thermowell „SPX“ – Simulation Results – Influence of Fluid Temperature 55°C to 85°C

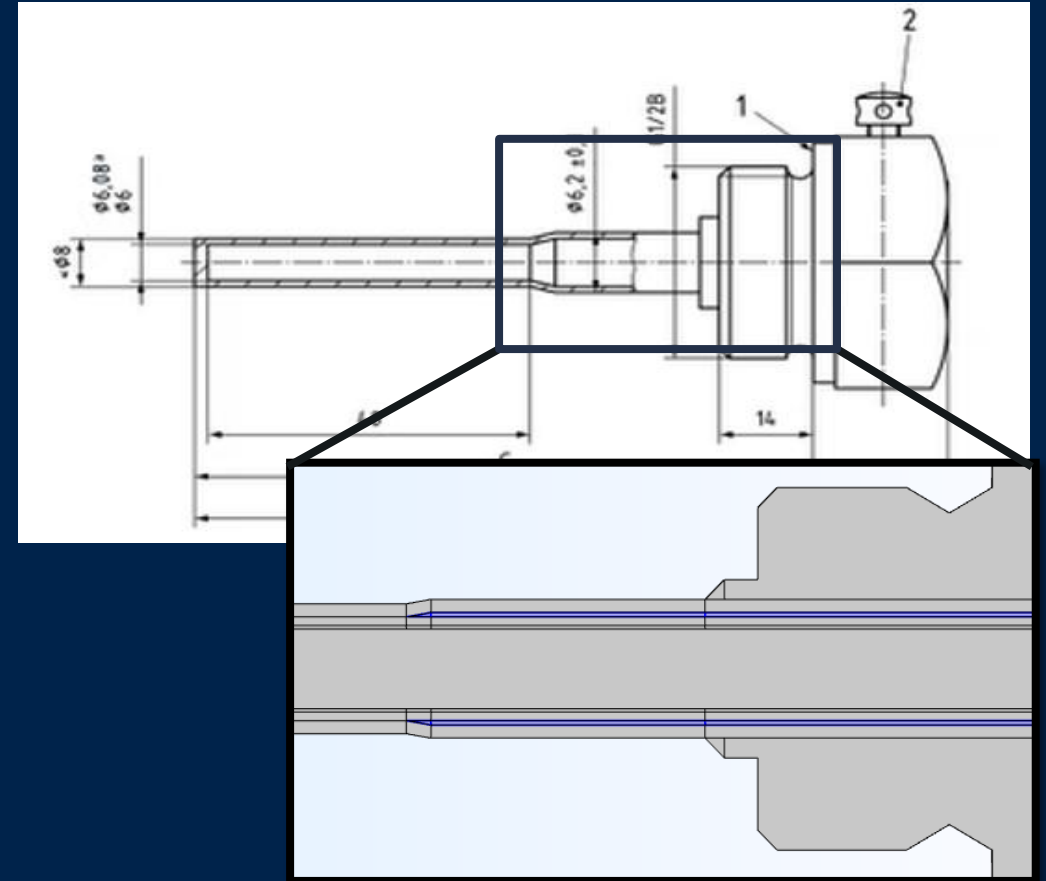
- Maximization of the observable error
- Simulated influence of fluid temperature at 100 L/h (grey data series)

* $-10\text{mK}/30\text{K} \approx 0,3\text{mK}/\text{K}$



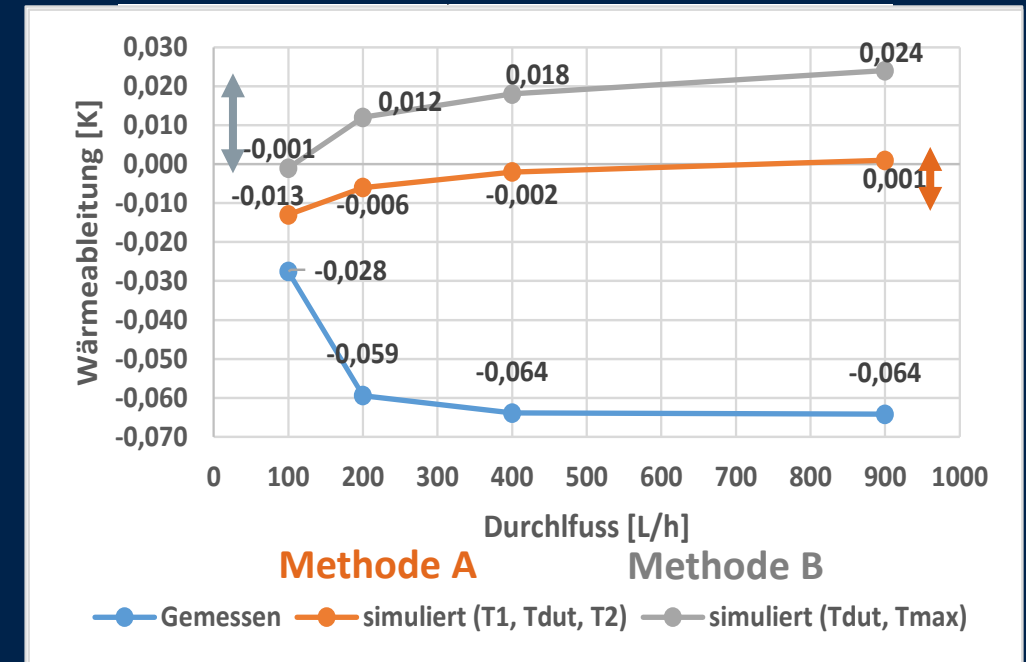
4. Thermowell „EN 1434“

- “EN 1434” thermowell (as specified in DIN EN 1434, Annex V) with a length of 85 mm
- Same measurement setup as before (identical distance from the pipe wall)
- Differences compared to the “SPX” thermowell:
 - Smaller inner diameter tolerance
 - 7 mm longer
 - Variable inner diameter (6.0 mm → 6.2 mm)
 - No fixation by locking screw (no threaded connection for the temperature sensor)



4. Thermowell „EN 1434 – Simulation Results

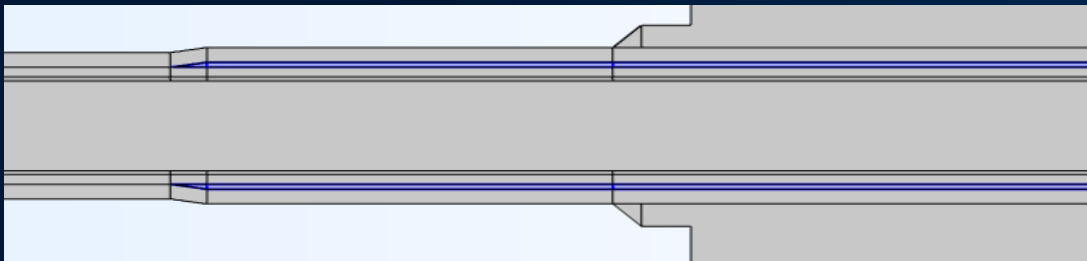
- The flow profile remains unchanged compared to the previous simulation
- Cross-section at the DUT continues to exhibit thermal layering and a local temperature maximum caused by self-heating
- Differences between the evaluation methods:
 $dT(\text{Method A}) = -12\text{mK}$; $dT(\text{Method B}) = -25\text{ mK}$
- The measurements deviate from the simulation results (the trend is not clearly identifiable)
 - Limitations of the measurement principle
 - Thermowell has a different coupling to the thermal layers than the reference probes



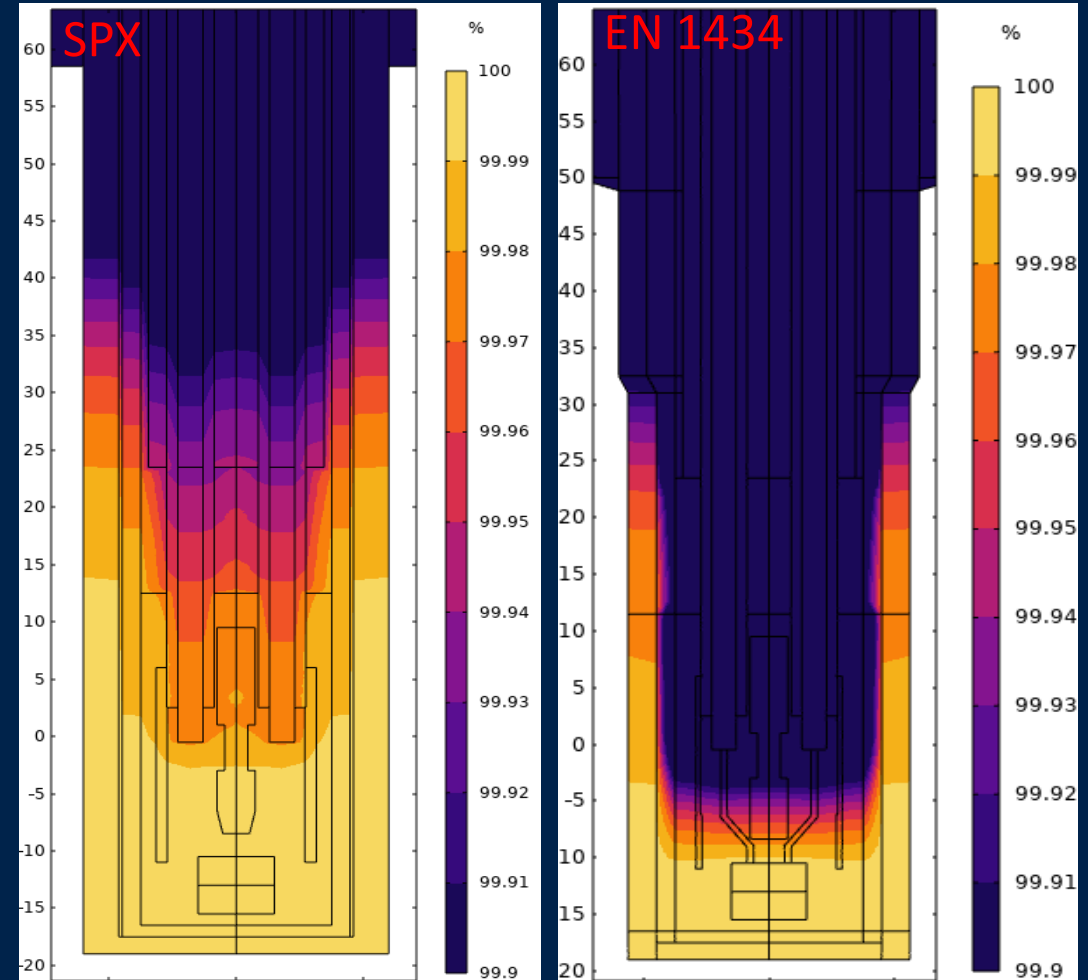
5. Comparison – Thermowells „EN 1434“ to „SPX“

- “SPX” thermowell exhibits a higher temperature level than the “EN 1434” thermowell
- Temperature distribution normalized with respect to Tmax (cross-section)
- A smaller gap width is expected to improve heat transfer to the sensor
- Larger inner diameter of the “EN 1434” thermowell increases heat dissipation

->This tends to reduce thermal coupling to the fluid rather than improve thermal isolation from the surroundings

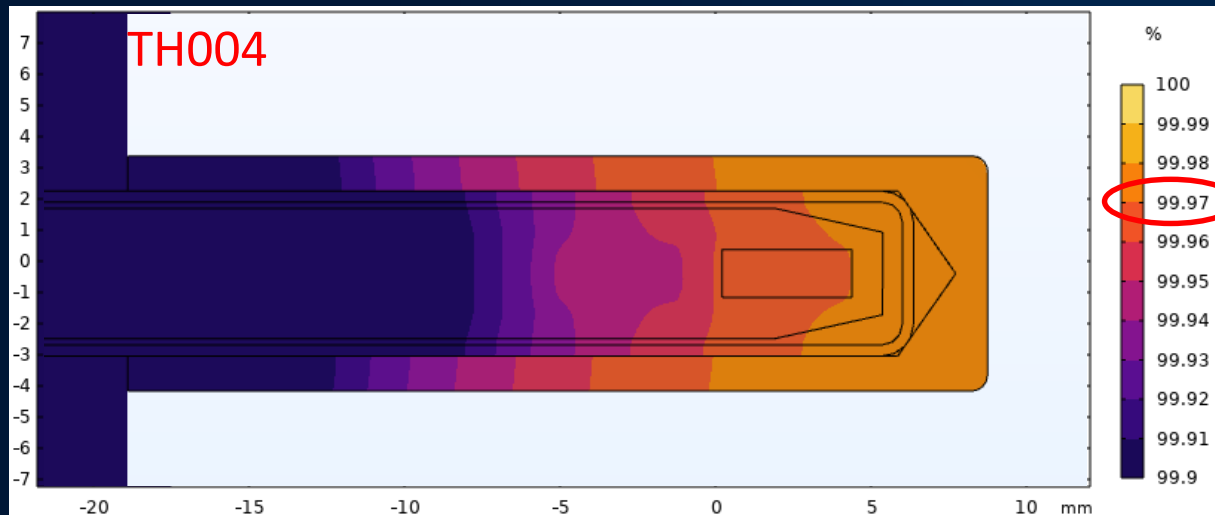


Scaled Geometry Representation

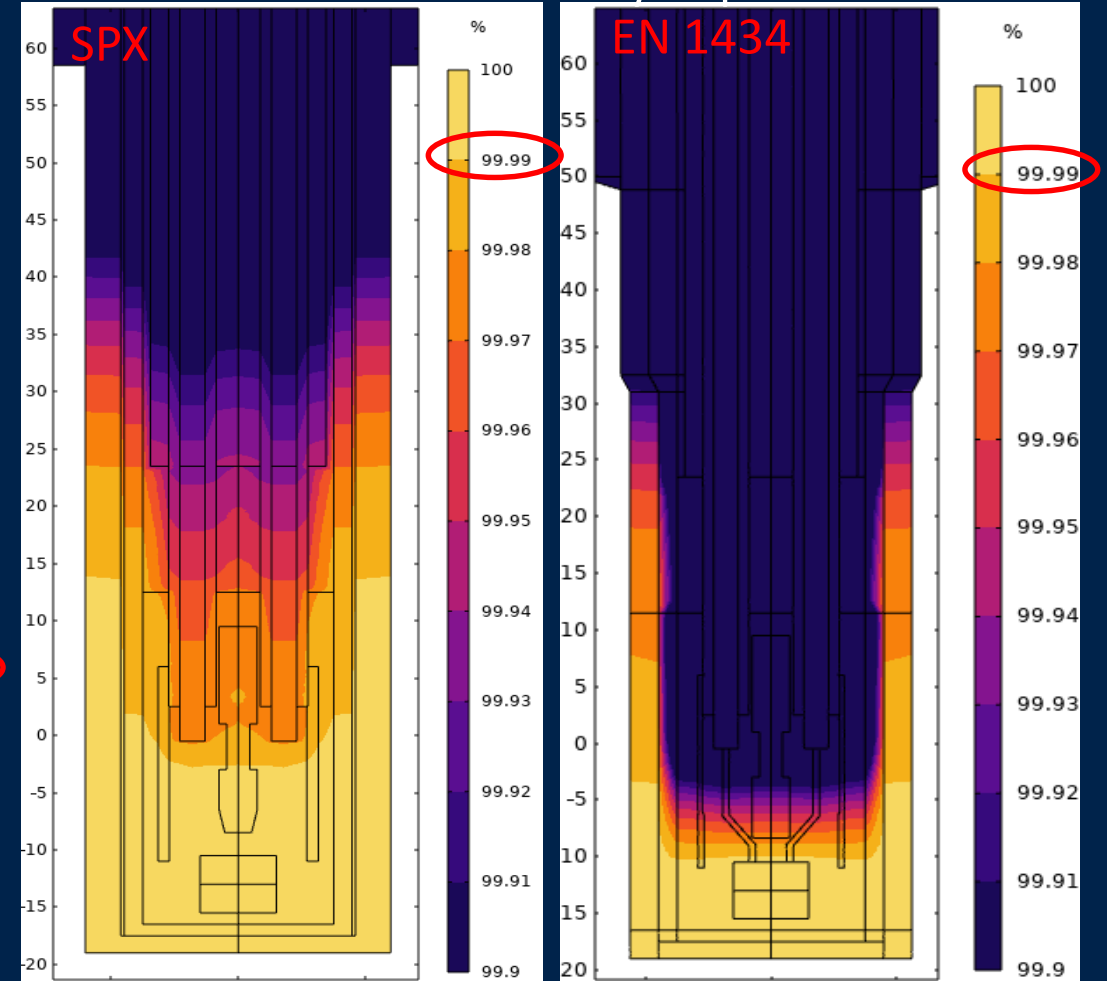


5. Comparison – Thermowell „TH004“

- Long thermowells measure the fluid temperature significantly more accurately than a short thermowell
- Comparison of the absolute temperature differences among the three thermowells provides only limited informative value



Scaled Geometry Representation



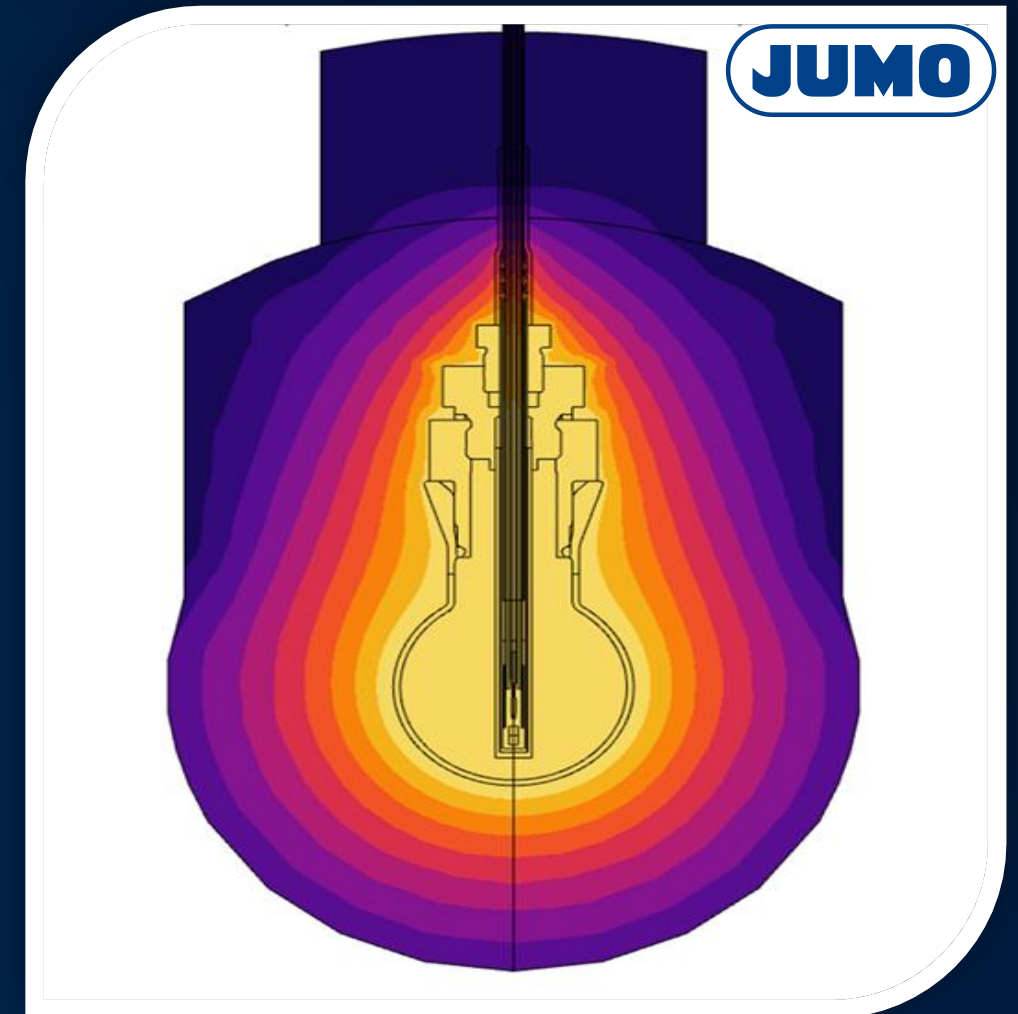
6. Conclusion

- Key question: Is the evaluation of thermowells in piping systems by means of FEM simulation feasible?
- Simulation of both short and long thermowells is feasible (level of detail, computational cost)
- Validation of heat dissipation effects for long thermowells is challenging
 - Magnitude of the observable measurement error is very small
 - Limitations of the measurement principle using three temperature sensors
 - Limitations of the applied flow models
- Particularly useful for assessing poor or otherwise non-testable installation configurations

6. Conclusion Outlook

- Well suited for preliminary investigations of design modifications without the need for physical prototypes
- Fundamental question: How should the flow and temperature profiles be defined for experimental pipe setups?
 - Thermal layering dependent of fluid temperature and horizontal tilting of experimental setup

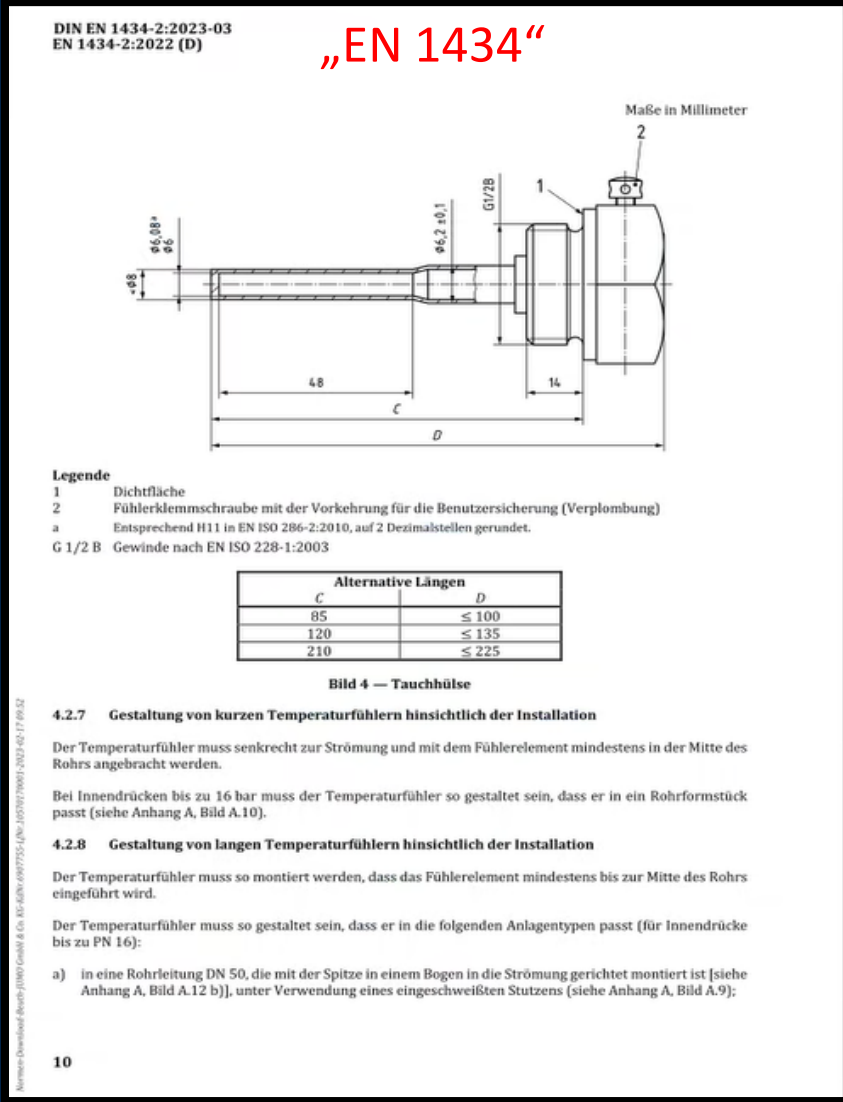
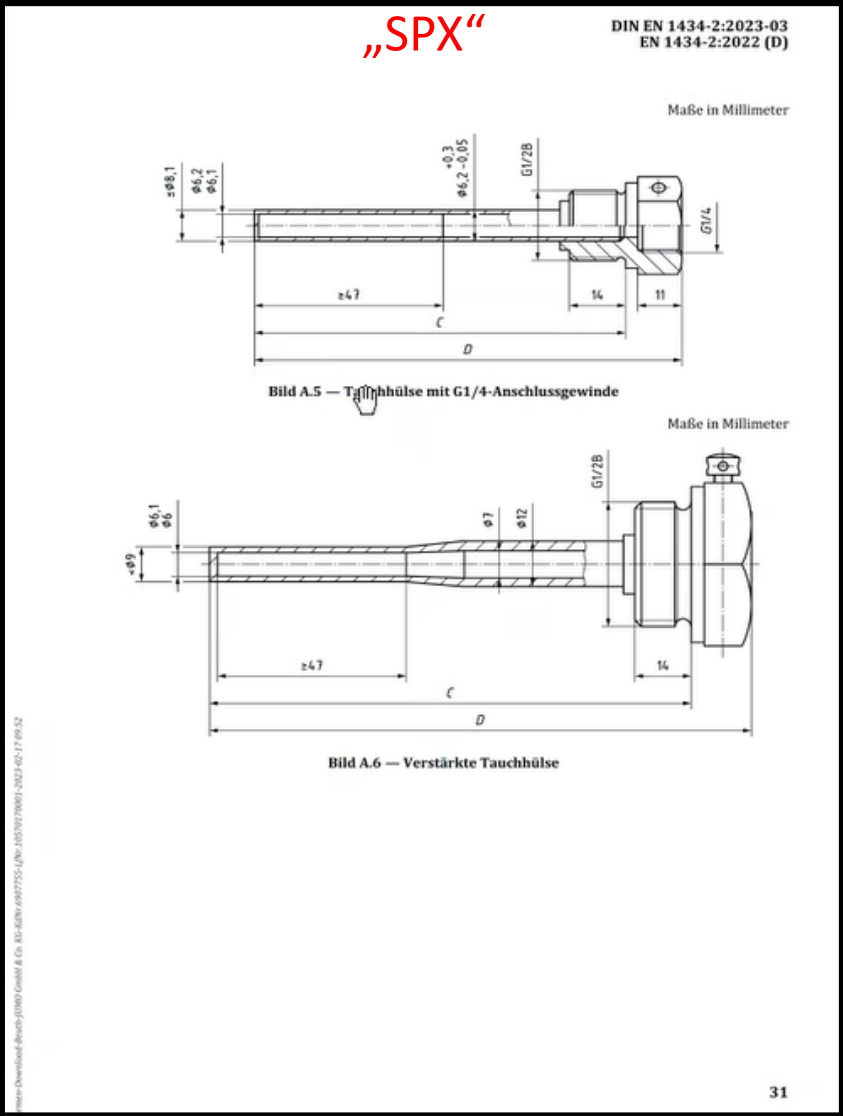
**Better comparability of measurement methods
and thermal measuring devices**



Thank you
for your interest



Annex 1 – Long Thermowells



Annex 2 - Mesh

- 7.6 Million Cells

