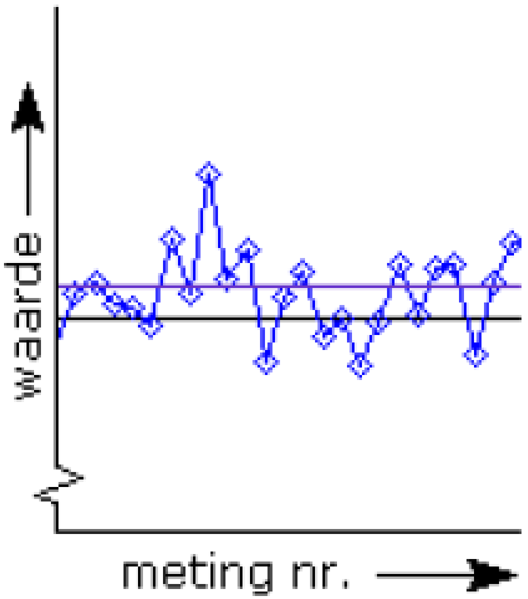
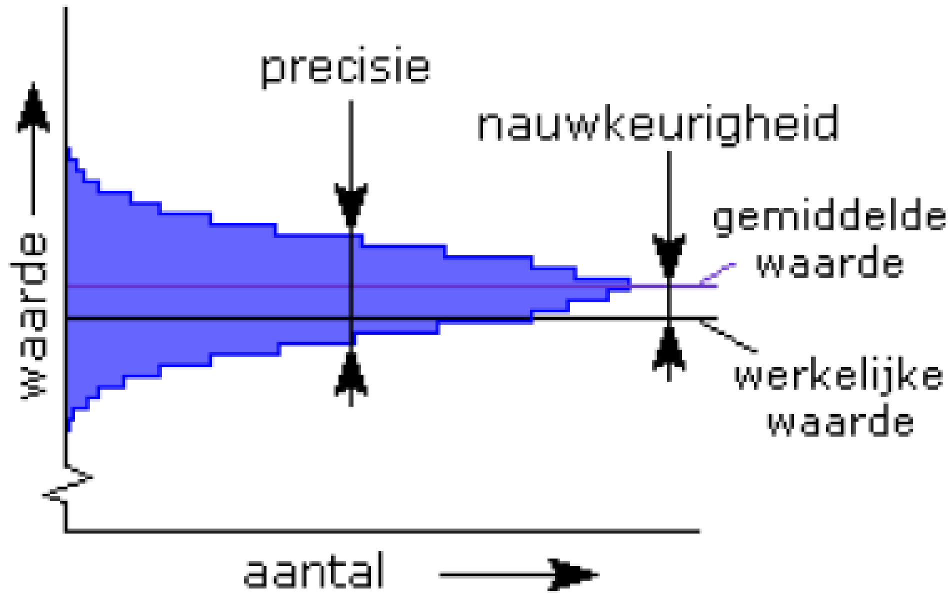
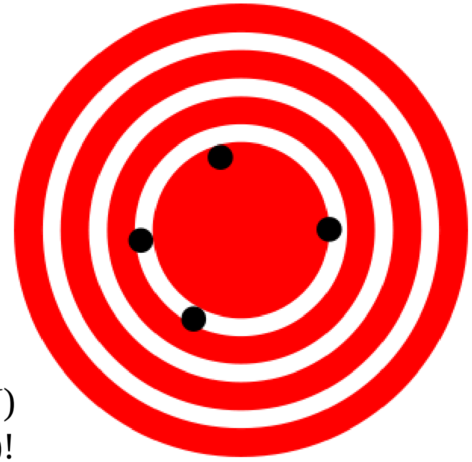
Modeling sensor-uncertainty?

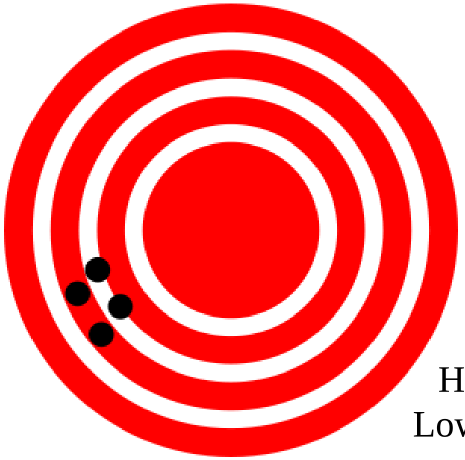
What?
Sensor uncertainty





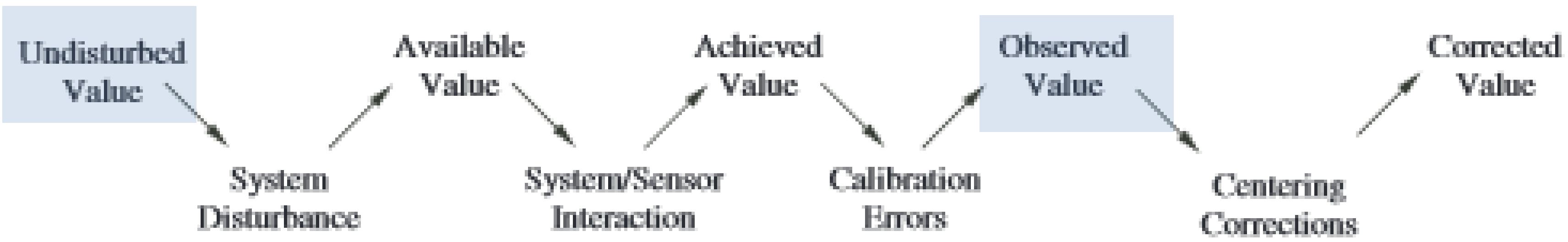


Low Precision (large WN)
High Accuracy (small offset)!

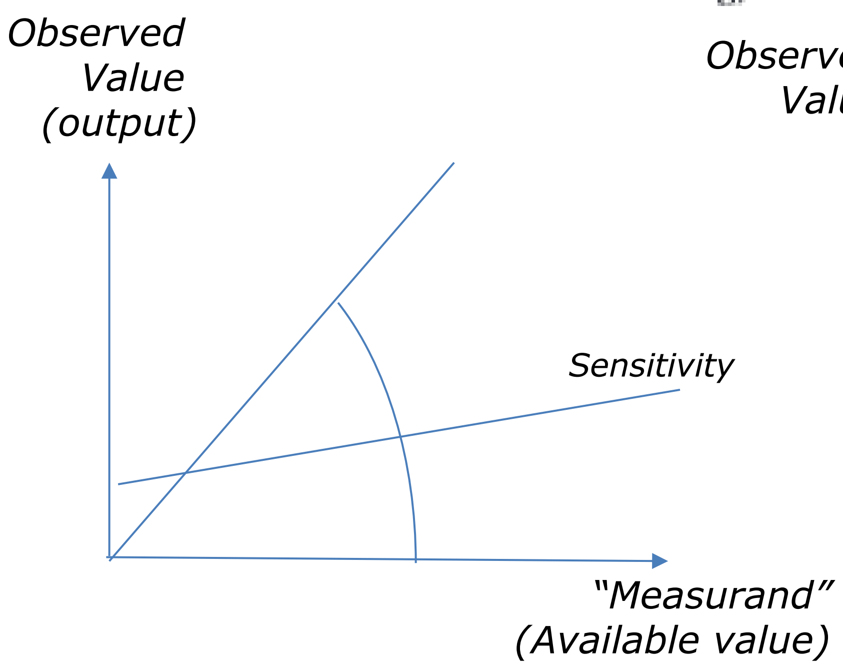


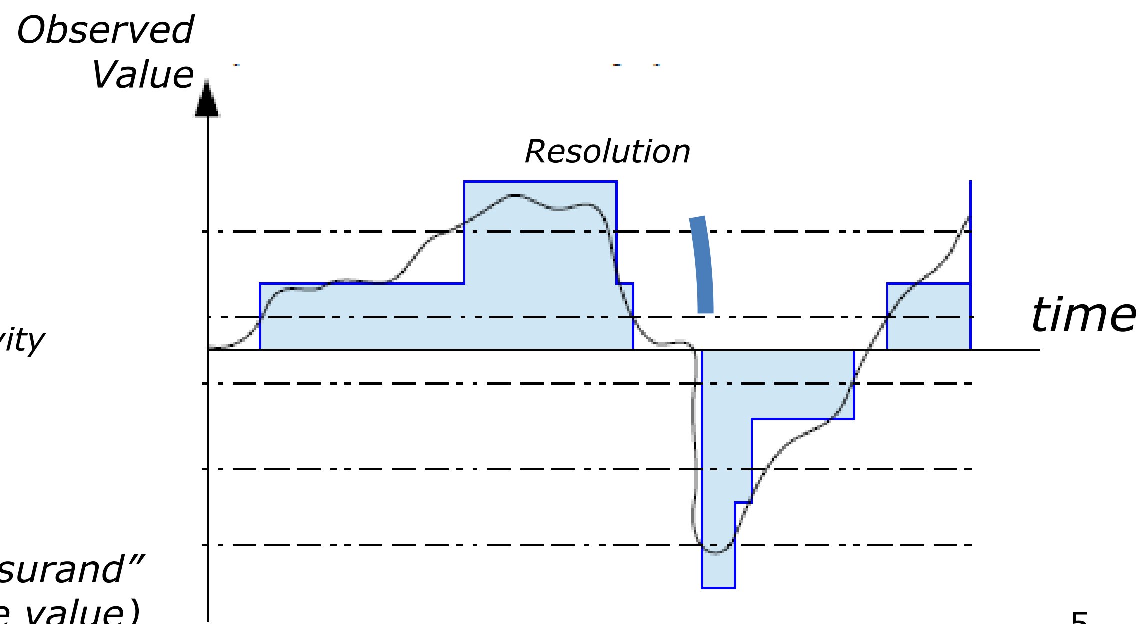
High Precision (small WN)
Low Accuracy (large offset)!

What?
Terminology



Adapted from R.J. Moffat, " Uncertainty Analysis" . Chapter 2, in **Thermal Measurements in Electronic Cooling**, Kaveh Azar, ed., 1997, CRC Press, Boca Raton, FL.





What?
Types & timing

- Types of uncertainties:
  - ***Fixed offset (multiplicative or additive)***
  - ***White Noise (additive)***
  - Time variable offset (multiplicative or additive)
- Timing:
  - ***From production***
  - Gradual, over years f(t)
  - Sudden, over the lifetime $f(t_{fail})$
- Reality:
  - (Non-linear) combination of the above

Highlighted approaches were implemented

How much?
Magnitude of uncertainty

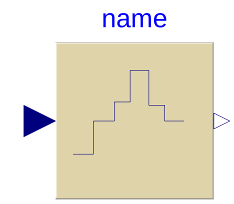
- Typical values for a **temperature sensor** in plastic housing:

  (NTC-thermistor, ref 20k Ohm, Beta = 4200, 14-bit 0-5V DAC)

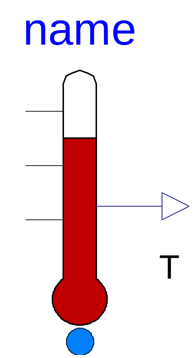
  – Disturbance:-0.4*T_{air}+0.4*T_{rad} (sensor housing dep.)
  – Precision: +-0.25°C (WN, An fixed or var)
  – Accuracy: +-0.5°C (fixed or f(t, T, …))
  – Resolution: +-0.25°C (ADC dep.)
  – Latency: 30 s / 63.2% (fixed or f(t,T, …))
  – Hysteresis: 0.05°C (fixed or degradation)
  – Sensitivity: +-0.1°C (sensor&housing dep.)

Where:in Modelica! Existing T-sensor models?

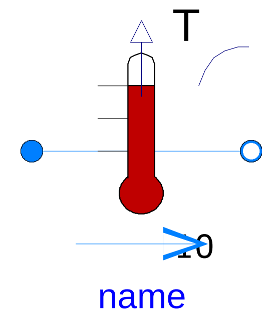
- No heatport (only one T variable):
  - Modelica.Blocks.Discrete.Sampler
  - No predefined type, input -> output
  - Discretise continuous variable with ZOH or sampler



- 1 heatport:
  - Sensors.BaseClasses.**PartialAbsoluteSensor**
  - Buildings.Fluid.Sensors.**Temperature**



- 2 heatports
  - Modelica.Fluid.Sensors.**TemperatureTwoPort**
  - Modelica.Thermal.HeatTransfer.Sensors.**TemperatureSensor**



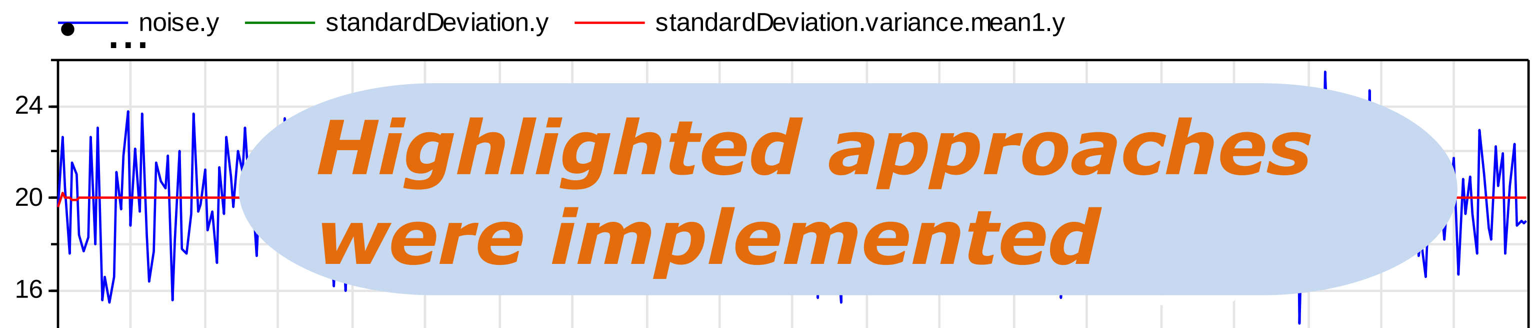
How to add sensor-uncertainty?

Discrete Noise options in modelica:

A. Pre-generate sensor noise and read as input

B. Use existing Modelica code/libraries
  - "On the Noise Modelling and Simulation", by D. Aiordachioaie et al. (2006)
  - **"Noise 0.2", developed by A. Klöckner et al (DLR institute of system dynamics & control) (2014)**

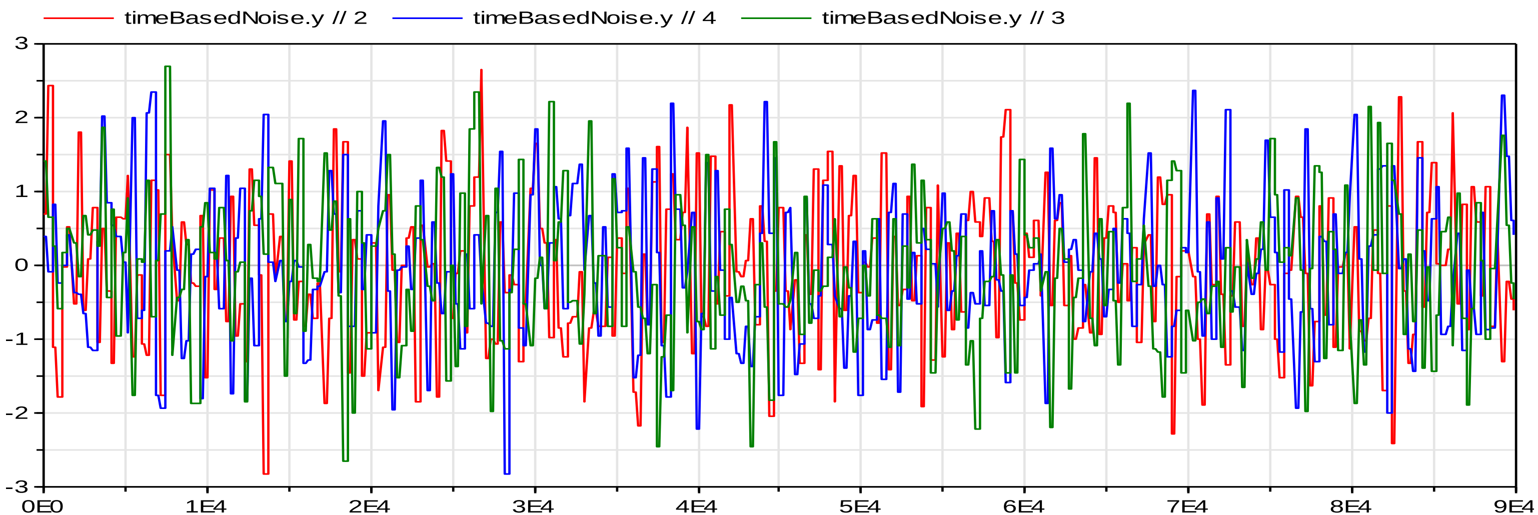
C. Externally generated noise
  - **Python (e.g. numpy)**
  - C-code (e.g/ math.h)
  - ...



Highlighted approaches were implemented

Model using Noise library

- Noise example
  - Default 100 Hz, but low frequency (0.02 Hz)
  - => ZOH required: implemented one shared 'samplePeriod' parameter.
  - Random seed instead of global/sample based
  - Generating one random parameter at startup (for parameter values.
  - 0.03 s CPUtime for 300 timesteps (90ks at sPs = 300 s)

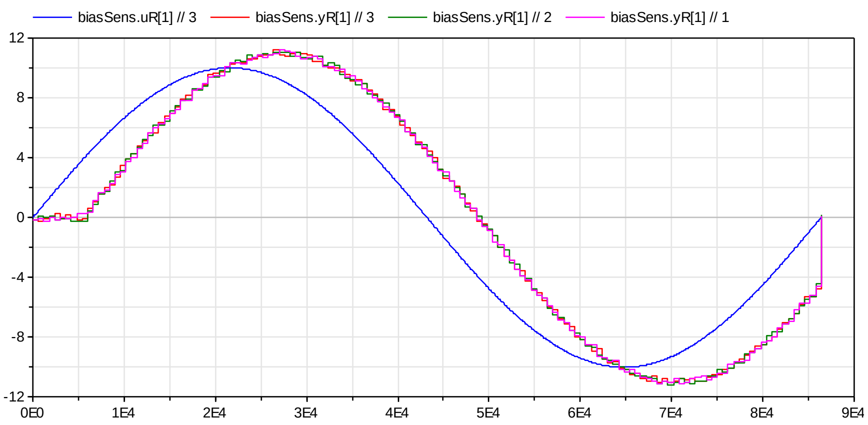


Models: Sensor with lag time

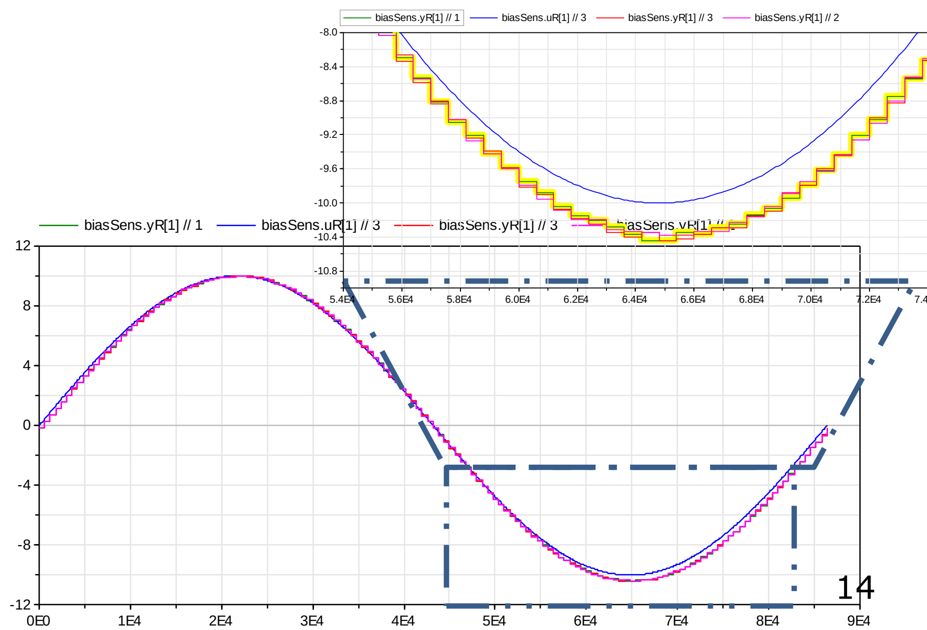
- Available Parameters
  - Amplitude of random error [0:inf]. Default = 0.1°C
  - Additive fixed error [-inf:+inf]. Default value = -0.2°C
  - Multiplier error [-1:+inf]. Default: -.01
  - Lag time [0:+inf]. Default: 30 s
  - Sensor time constant [0: +inf]. Default: 30 s

<u>Extreme example</u>

(t = 1 day, sample freq=10 mins, M=10%, delay = 3 hr, A = 2°C)



<u>with default settings:</u>

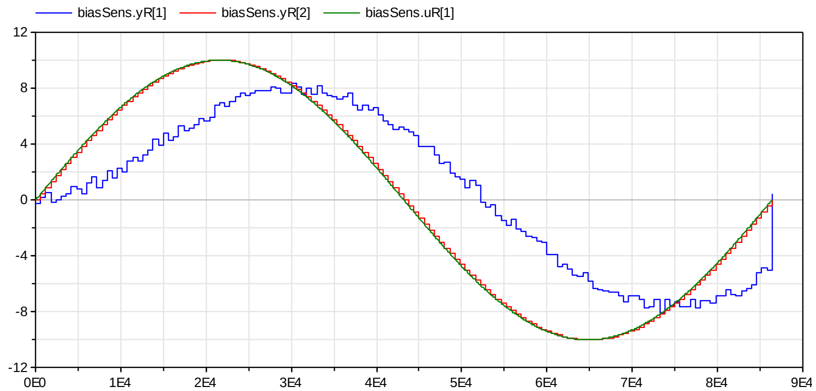


Model:
Sensor with time constant

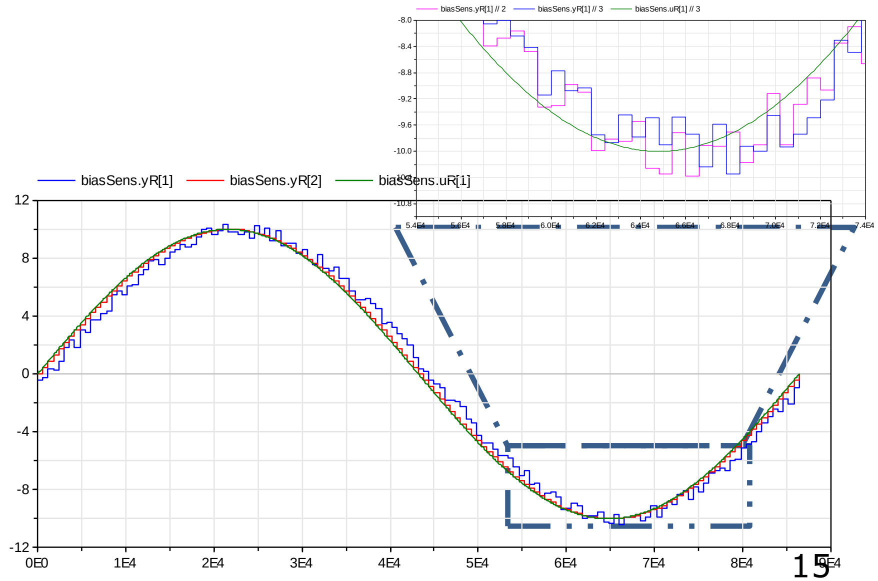
- Available Parameters
  - Amplitude of random error [0:inf]. Default = 0.1
  - Additive fixed error [-inf:+inf]. Default value = -0.2
  - Multiplier error [-1:+inf]. Default: -.01
  - Lag time [0:+inf]. Default: 30 s
  - Sensor time constant [0: +inf]. Default: 30 s

<u>Extreme example</u>

(t = 1 day, sampe freq=10 mins, M=10%, tau= .5 hr, A = 1°C)



<u>with default settings:</u>



Why?
Impact on KPIs!

- Typical results:
  - Increase of energy use & decrease of discomfort
  - decrease of energy use & increase of discomfort
  - Stability issues:
    - Larger temperature variations (+1°C for default param)
    - More erratic control
    - Increase of both if close control required

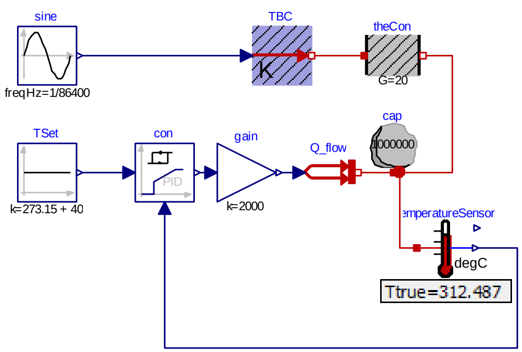
  ➔ Degradation of control stability

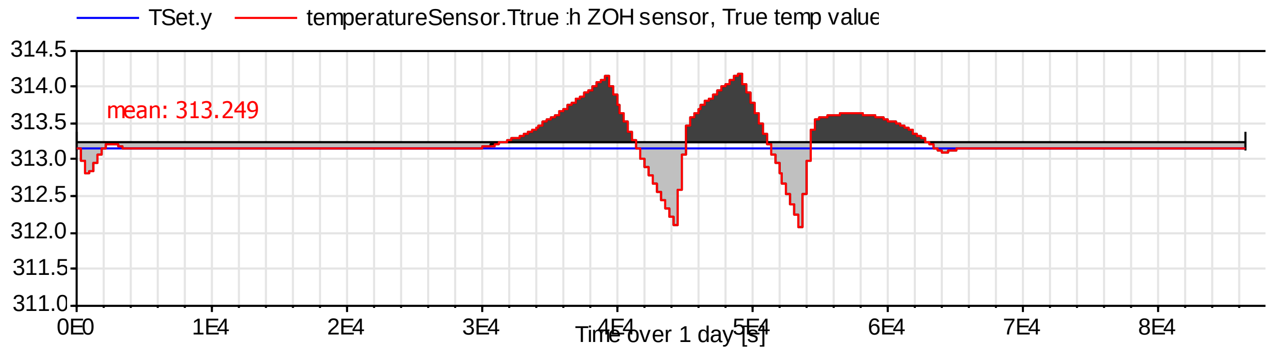
- Exact result highly dependent on controller implementation, settings and controlled system => Monte carlo /LHS advised!

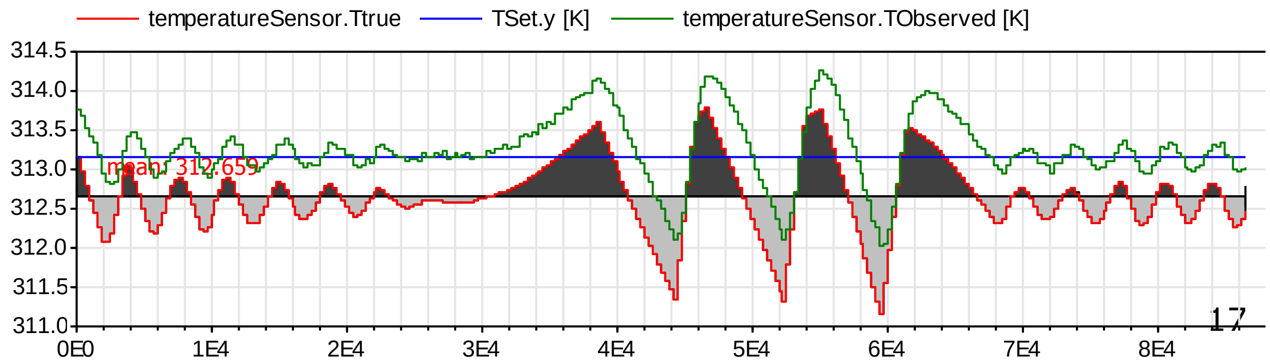
More in-depth analysis in a folluw-up presentation (fault-impact)

Results?
Case 1: PID controller w hyst.

- Correct temp feedback (top pane)
- Slightly biased feedback, fixed params (1 run) (bottom pane)

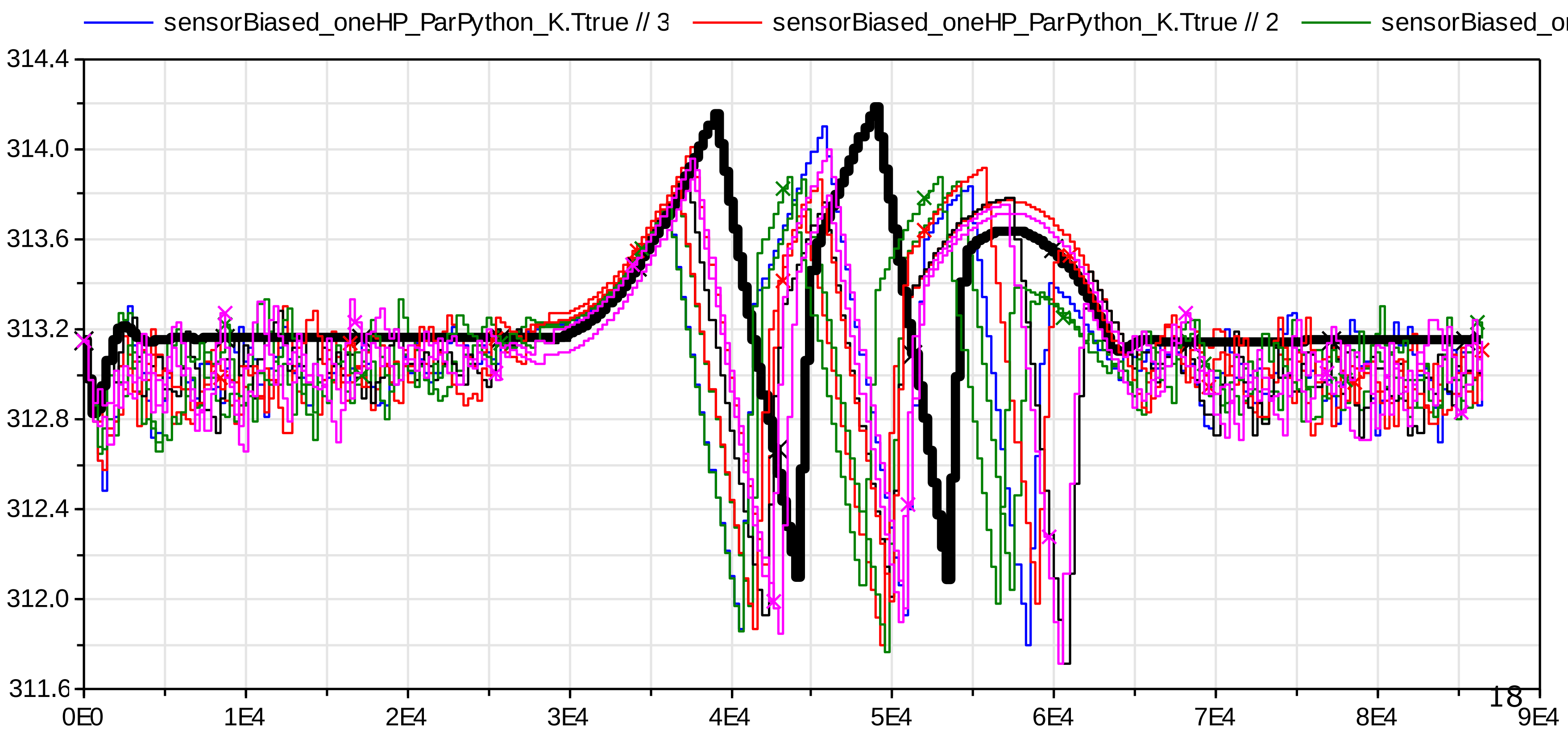






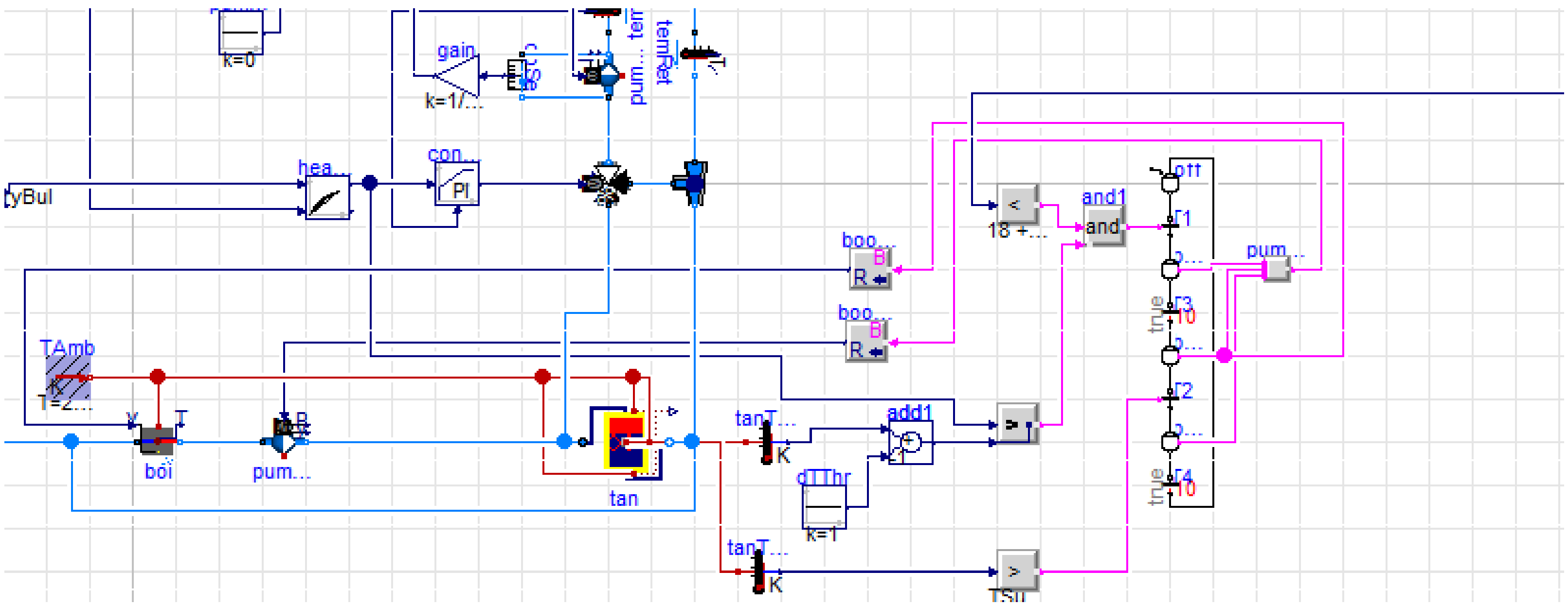
Results?
Case 1: PID controller w hyst.

- **Random sensor uncertainty** (normal distribution with centre & stdev), 8 runs



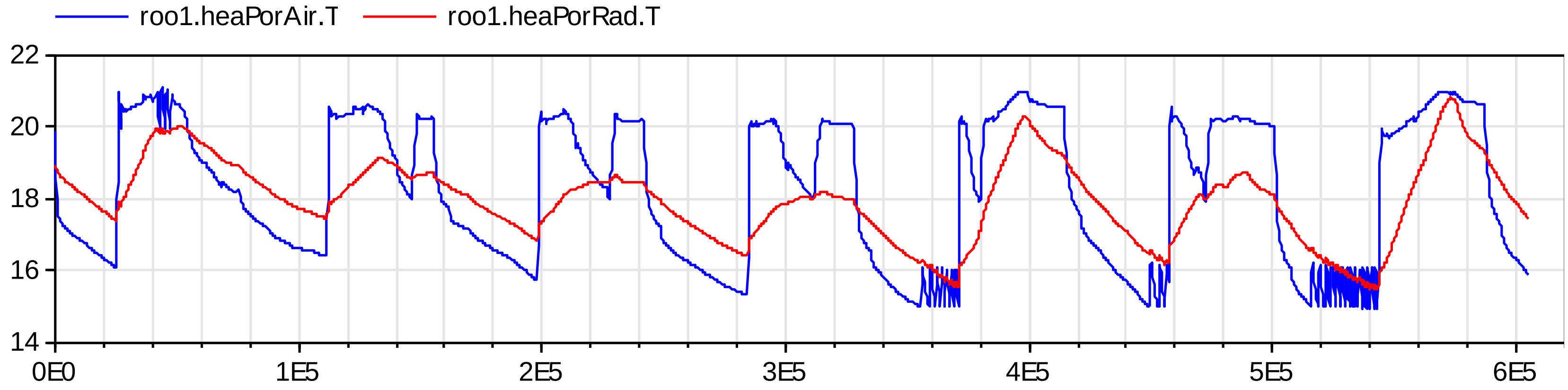
Results?
Case 2:

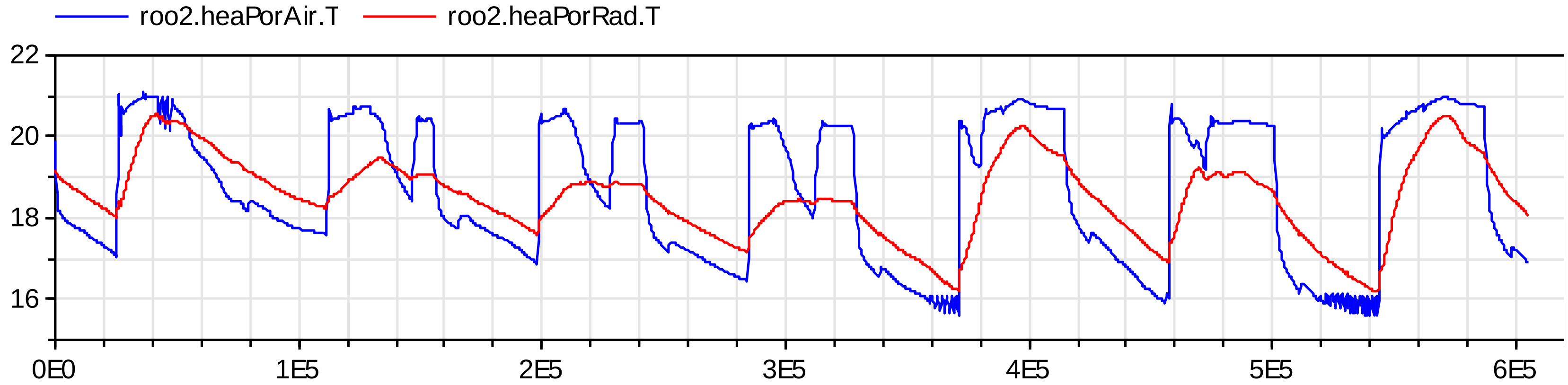
- “TwoRoomsWithStorage” (Buildings 1.7)
  - 2 interacting zones with radiator & boiler control
  - 1 cold week, Tex = -20 to 0°C
  - 6 sensors: 2x Air temp, supply & return temp, buffer tank temp, amb temp



Results?
Case 2: 2RwStor, No bias

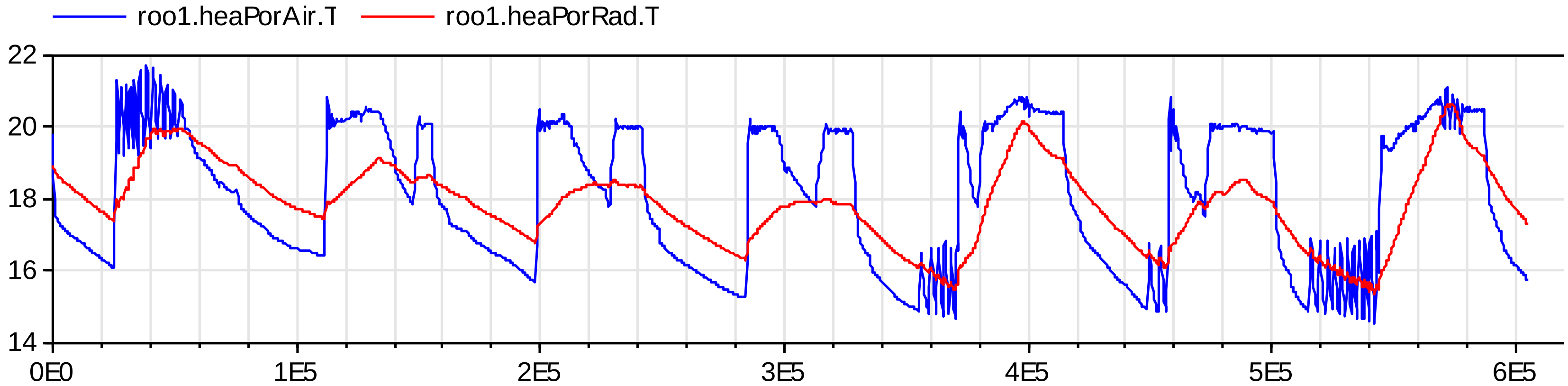
- No sensor bias, (ZOH = 300 s)

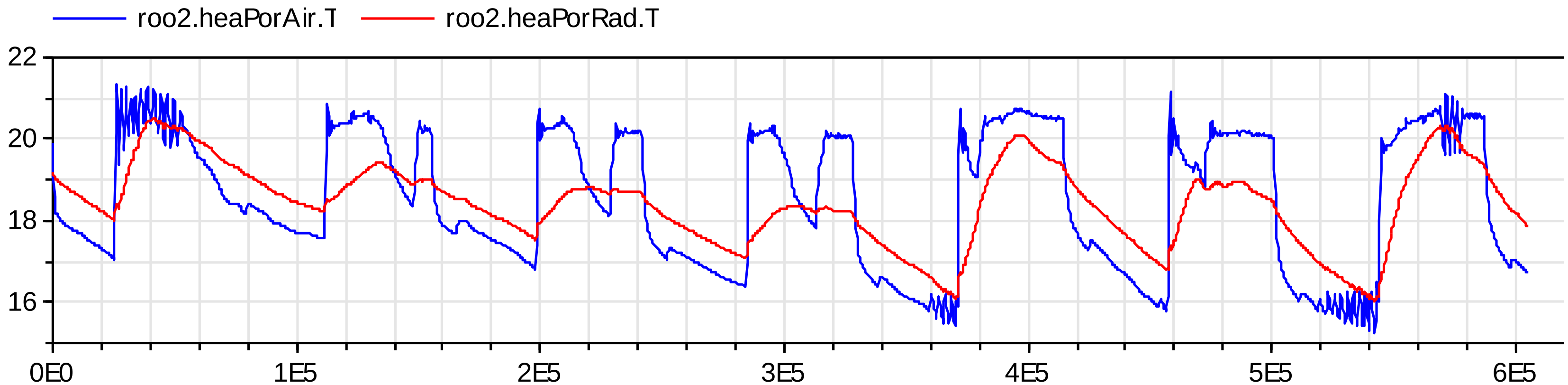




Results?
Case 2: 2RwStor, fixed bias

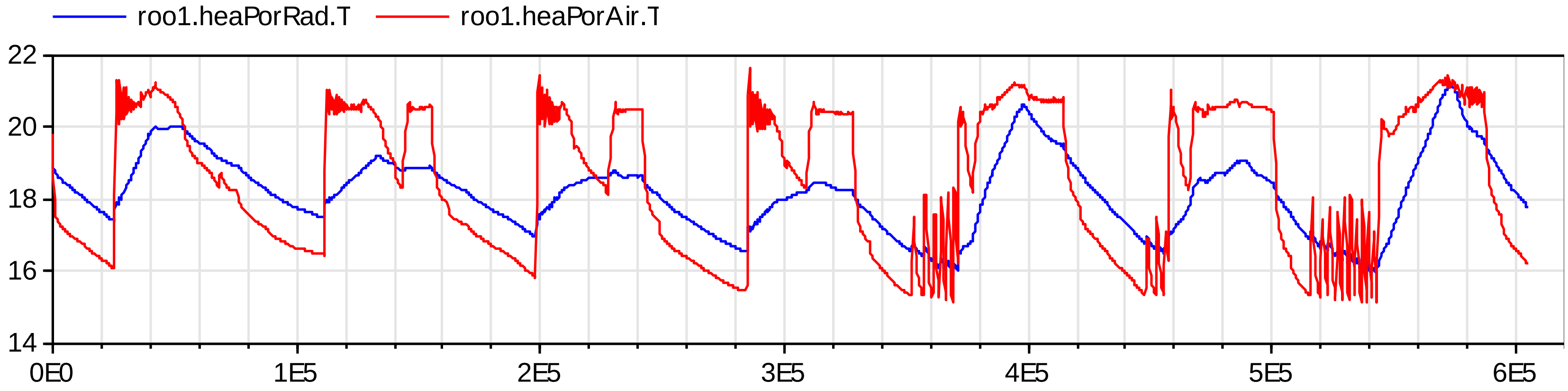
- 4 (fixed) bias sensors: Tex, Tz (x2), Tbuffer

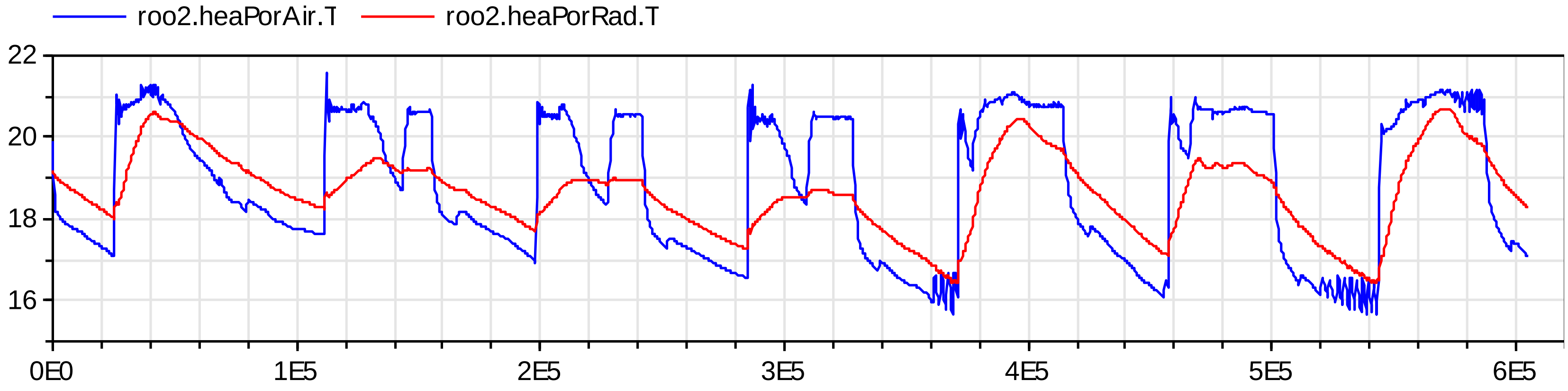




Results?
Case 2: 2RwStor, random bias

- Biased sensors w (normally distrubted)





Conclusion?
Sensor uncertainty matters!

- Sensor uncertainty **CAN** be simulated in Modelica!
  - Random generators available
    - White sensor noise
    - Coloured sensor noise
    - Randomised sensor accuracy/precision
  - Examplar temperature sensor model was developed
    - Plug-compatible with Modelica.library and buildings.sensors
    - Multiple configurations: No, 1 or 2 heatports.
    - External or internal noise calculation
    - # of events not increased

- Sensor uncertainty **SHOULD** be simulated in Modelica!
  - Has significant impact on CL/ OL HVAC control:
    - Increase of energy use & Decrease of discomfort
    - Decrease of energy use & Increase of discomfort
    - Stability issues:
      - Larger temperature variations
      - Increase of both if close control required

    ➔ Degradation of control stability

Modeling Sensor-uncertainty?

Future work

Future work

Future work: When? Timing of sensor bias

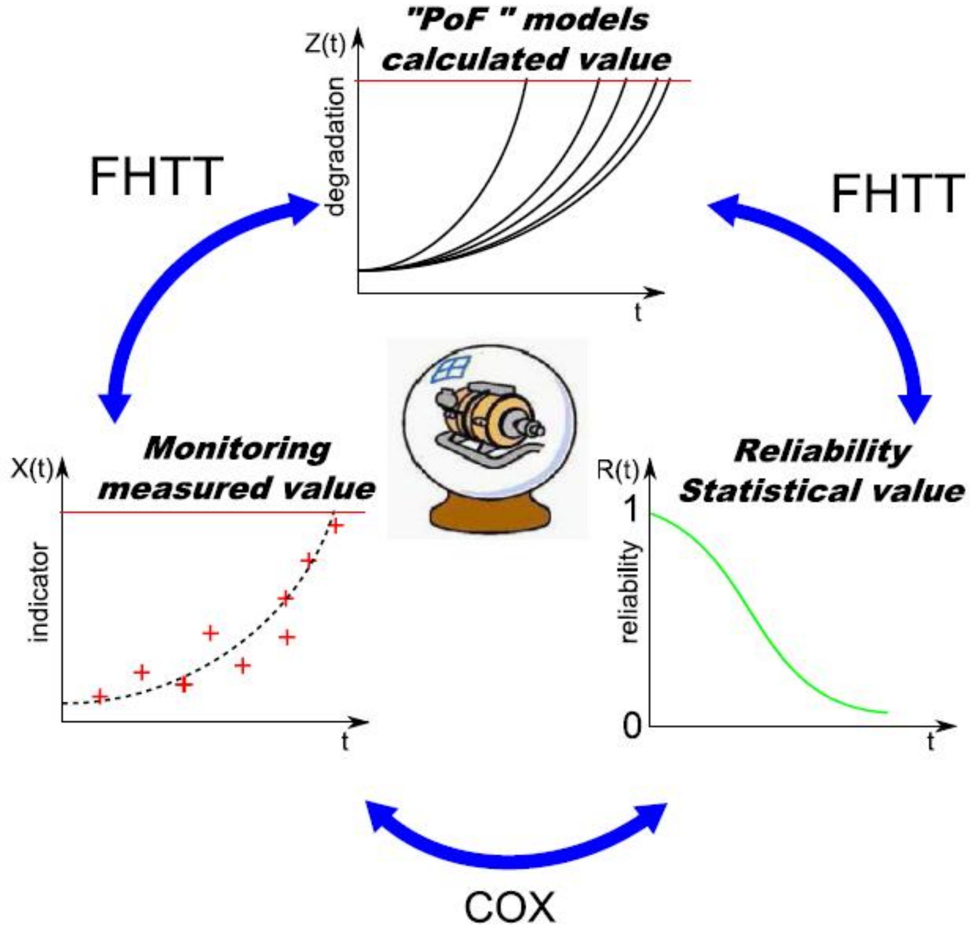


Fig. 1. The three approaches to estimates MRL and their links

YOU CAN, YOU SHOULD, AND IF YOU'RE BRAVE ENOUGH TO START, YOU WILL.

STEPHEN KING

Questions?