# Calibration of Building Performance Simulation (BPS) Models to Measured Data: Selection of Measurement Points and Measurands


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## Research highlights

- We explore calibration of BPS models with a large number of input & output parameters
- Most influential input & output parameters relevant for calibration are found in a screening process
- Sensors with accompanying measurement uncertainty are associated with each output parameter
- Accuracy of calibrated model is investigated as a function of sensor uncertainty & sensor configuration

**Starting point: Uncalibrated model** → 1. Find influential input & output parameters through screening → 2. Assign sensors & measurement uncertainty to each output parameter → 3. Calibrate model with different sensor choices and uncertainties → 4. Investigate accuracy of calibrated model

## Background

Building performance simulation (BPS) models are increasingly being used throughout a whole building's lifecycle. In order to ensure model reliability and accuracy, calibration is an integral part of the overall modeling process, providing the modeler with increased confidence. Although BPS models have hundreds of output parameters, typical calibration approaches use only one or two of these [1]. The calibration problem is thus generally over-parameterized and under-determined. Choice of measurement points, measurement sensors and corresponding accuracy requirements for model calibration has been given limited attention in the literature.

## Method

### Model & analysis framework

- BPS simulations are made using Simien, the leading tool for energy simulations in buildings in Norway
- Analysis is done in the SensiRob framework [2], Python-based sensitivity analysis framework interfacing with Simien
- Metamodel made using Random Forest Regression approach
- Regressions-based indicators (Standardised regression coefficients; SRC) are used to determine importance relations between input and output parameters in screening process

### Sensitivity & uncertainty analysis approach

- Model calibration is based on combining a prior probability distribution of each measurable with a corresponding sensor uncertainty distribution, giving a posterior probability distribution for each calibration parameter
- Sensor uncertainty is modeled using Gaussian distributions around the measurement value

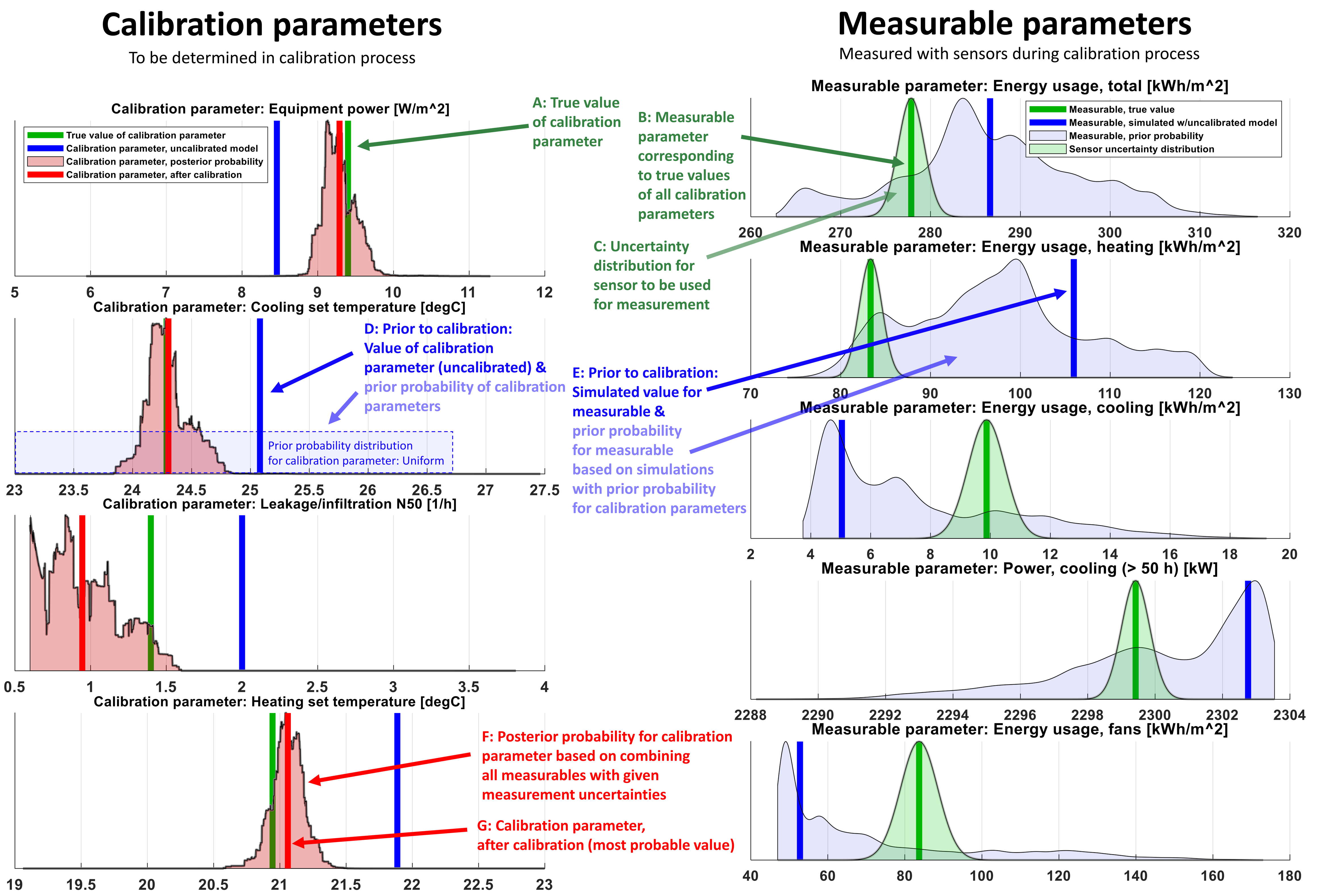
### Case study

- The approach is applied on a case study for a hospital building in Northern Norway
- Fully model-based approach applied; measurement data simulated by introducing model errors
- Probabilistic distributions ($P_{in}$) set up for the input parameters based on relevant data for the hospital
- Calibration cases defined by introducing error in most influential input parameters, randomly chosen from $P_{in}$

## Results

### Model calibration approach

The model calibration approach is illustrated in the below figure. True values and predefined sensor uncertainties are shown in green. Prior parameter values and distributions are shown in blue. Posterior parameter values and distributions are shown in red.



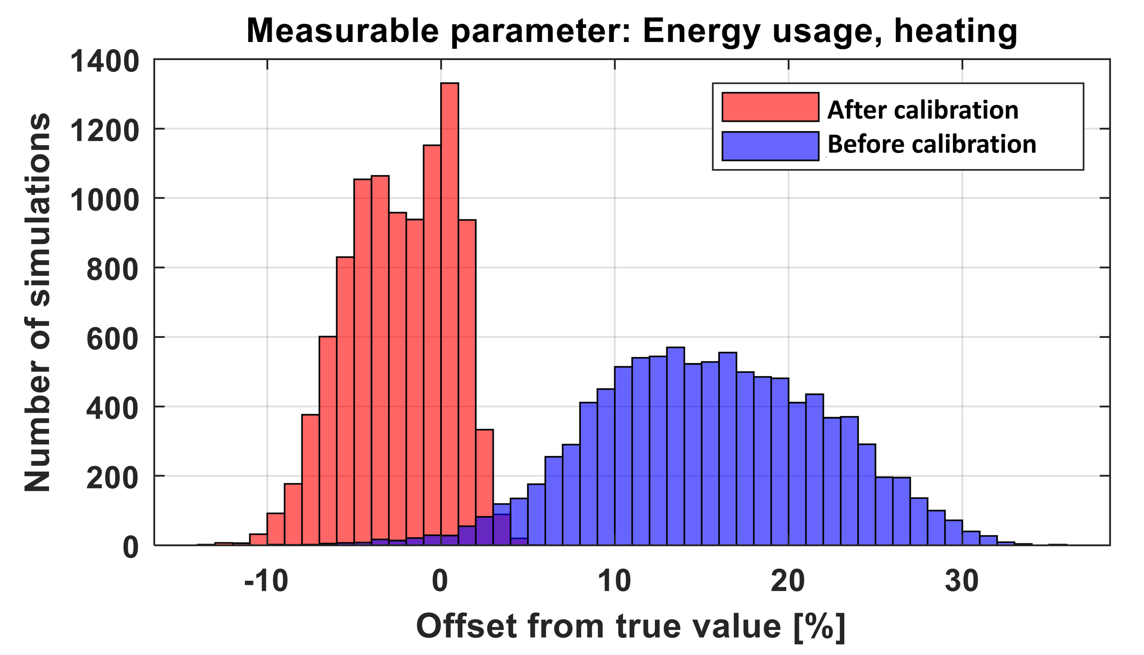

### Screening of input and output parameters

Identification of input and output parameters of importance is done in the original Simien model, based on SRC. SRC for pairs of input and output parameters are shown in the below table. Pairs with high coupling are red, pairs with low coupling are blue.

| | Energy usage, total | Energy heating, total | Energy cooling, total | Power heating, total | Power room cooling, total | Energy room heating, total | Energy ventilation heating, total | Energy room cooling, total | Energy ventilation cooling, total | Energy fans, total | Energy zone1 | Energy zone2 | Energy zone3 | Energy zone4 | Energy zone5 | Energy zone6 | Energy zone7 | Energy zone8 | Energy zone9 | Energy zone10 | Energy zone11 | Energy zone12 | Energy zone13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Climate winter temp** | 0.36 | 0.43 | 0.04 | 0.15 | 0.00 | 0.11 | 0.33 | 0.04 | 0.02 | 0.00 | 0.39 | 0.34 | 0.14 | 0.04 | 0.30 | 0.29 | 0.37 | 0.25 | 0.04 | 0.07 | 0.43 | 0.45 | 0.36 |
| **Equipment power** | 0.28 | 0.15 | 0.39 | 0.11 | 0.22 | 0.12 | 0.05 | 0.38 | 0.00 | 0.00 | 0.11 | 0.12 | 0.46 | 0.67 | 0.14 | 0.03 | 0.11 | 0.44 | 0.65 | 0.74 | 0.09 | 0.12 | 0.09 |
| **Ventilation SFP 100** | 0.41 | 0.18 | 0.02 | 0.01 | 0.01 | 0.00 | 0.18 | 0.01 | 0.18 | 0.98 | 0.46 | 0.34 | 0.22 | 0.18 | 0.46 | 0.43 | 0.29 | 0.35 | 0.15 | 0.21 | 0.36 | 0.42 | 0.44 |
| **Ventilation supply temp summer** | 0.05 | 0.02 | 0.33 | 0.36 | 0.56 | 0.11 | 0.07 | 0.37 | 0.94 | 0.00 | 0.02 | 0.05 | 0.24 | 0.16 | 0.03 | 0.15 | 0.02 | 0.22 | 0.16 | 0.15 | 0.02 | 0.07 | 0.09 |
| **Ventilation exchanger efficiency** | 0.53 | 0.61 | 0.00 | 0.00 | 0.01 | 0.00 | 0.59 | 0.00 | 0.00 | 0.01 | 0.53 | 0.65 | 0.33 | 0.16 | 0.56 | 0.52 | 0.64 | 0.45 | 0.15 | 0.19 | 0.48 | 0.43 | 0.47 |
| **Cooling set temperature** | 0.21 | 0.05 | 0.63 | 0.02 | 0.59 | 0.01 | 0.04 | 0.62 | 0.00 | 0.00 | 0.07 | 0.08 | 0.45 | 0.47 | 0.17 | 0.02 | 0.12 | 0.34 | 0.48 | 0.42 | 0.04 | 0.11 | 0.01 |
| **Heating set temperature** | 0.21 | 0.24 | 0.01 | 0.50 | 0.01 | 0.61 | 0.26 | 0.01 | 0.01 | 0.00 | 0.20 | 0.08 | 0.00 | 0.00 | 0.19 | 0.41 | 0.08 | 0.06 | 0.00 | 0.01 | 0.29 | 0.32 | 0.34 |
| **Ventilation supply temp** | 0.21 | 0.13 | 0.37 | 0.44 | 0.09 | 0.54 | 0.56 | 0.37 | 0.01 | 0.01 | 0.05 | 0.21 | 0.44 | 0.43 | 0.17 | 0.05 | 0.31 | 0.29 | 0.47 | 0.34 | 0.00 | 0.03 | 0.01 |
| **Leakage/infiltration N50** | 0.23 | 0.32 | 0.16 | 0.25 | 0.08 | 0.27 | 0.09 | 0.16 | 0.00 | 0.00 | 0.31 | 0.13 | 0.02 | 0.11 | 0.05 | 0.09 | 0.20 | 0.08 | 0.08 | 0.05 | 0.43 | 0.38 | 0.37 |
| **Ventilation extract air volume** | 0.25 | 0.28 | 0.18 | 0.14 | 0.07 | 0.22 | 0.10 | 0.17 | 0.00 | 0.10 | 0.32 | 0.31 | 0.01 | 0.08 | 0.30 | 0.37 | 0.27 | 0.15 | 0.11 | 0.02 | 0.30 | 0.27 | 0.32 |

### Calibrated vs uncalibrated model – example results

Calibrated vs uncalibrated model for 10.000 simulations. Both calibration parameters and other input parameters are varied. Similar results are seen for all output parameters.

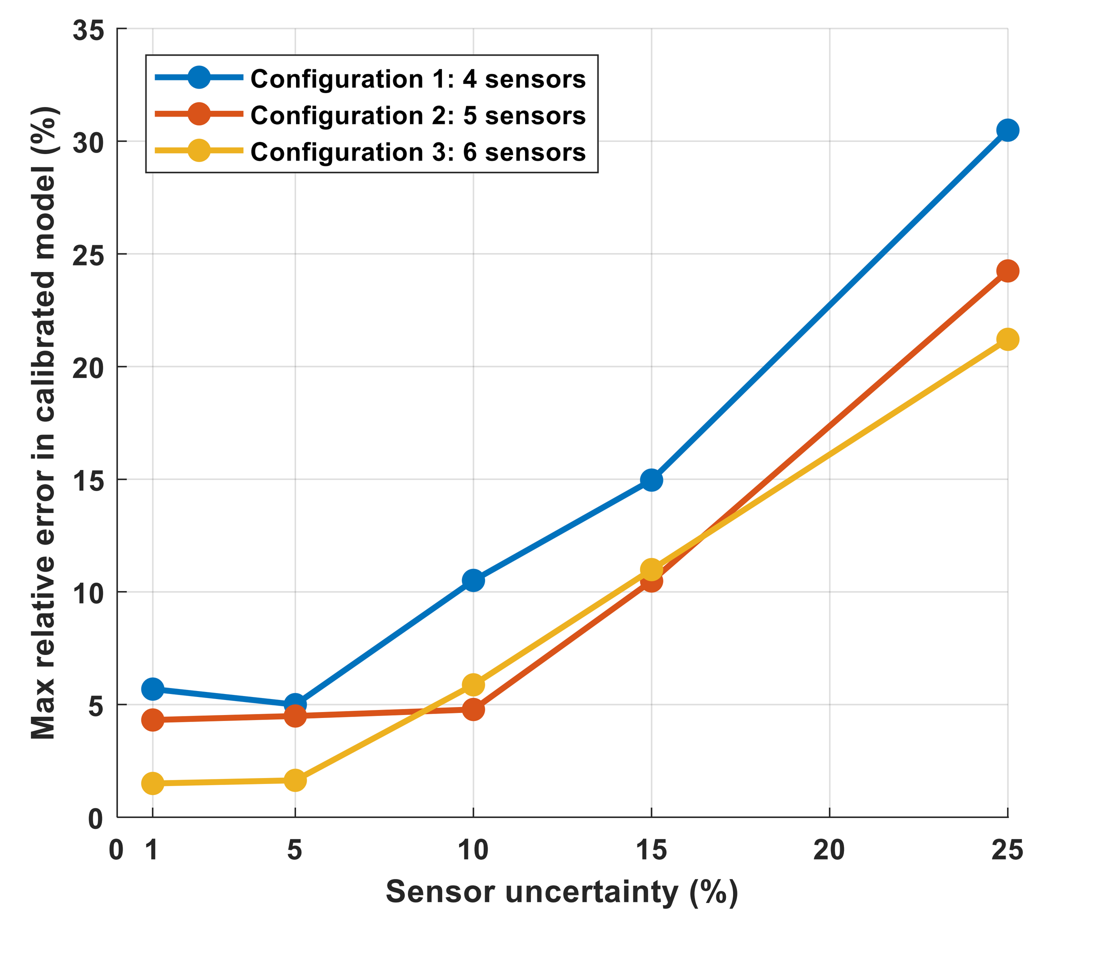



### Calibration accuracy vs sensor uncertainty & configuration

The error for the calibrated model is investigated as a function of sensor uncertainty and sensor configuration. The below figure shows how this approach can be used to see how the calibration error is reduced when

1. The sensor uncertainty is reduced.
2. The number of sensor is increased

Sensor configuration 3 adds an extra energy measurement sensor in Energy zone 10 based on the highest zonal SRC-value (red ring) in table to the left.




## Discussion & Conclusions

This study shows how it is possible to use a simulation model to investigate how sensor configuration and sensor accuracy influence calibration accuracy for BPS models. Due to the high cost of accurate measurement instrumentation, this is an important question when deciding on a strategy for model calibration.


**References**

[1] Chong, A., Gu, Y. and Jia, H., 2021. Calibrating building energy simulation models: A review of the basics to guide future work. Energy and Buildings, 253, p.111533.

[2] Kocbach, J., Folgerø, K., Skålvik AM., Olsen MW., Kjellberg B., Harsem. TT. (2022), Framework for effective robust design of building energy systems: Bridging the gap between predicted and actual energy use, in proc. of BuildSim Nordic 2022, August 2022, Copenhagen, Denmark



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