KU LEUVEN

Calibration and validation of dynamic building emulator model for testing controllers

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Goal

Calibrated building model for testing controllers

- Detailed white-box model: building envelope, heating and ventilation system
- Incorporate all physical phenomena
- Calibrate with measurement data

Framework for calibration of Modelica models

- Automation and re-use
- Reduce modeling time

Why

Emulate the real heating system

- Multiple experiments on identical setup

Compare controllers

- Objectives
- Controller models
- State estimation algorithm
- (solvers)

How

Model the system

Select parameters to calibrate

Sensitivity analysis

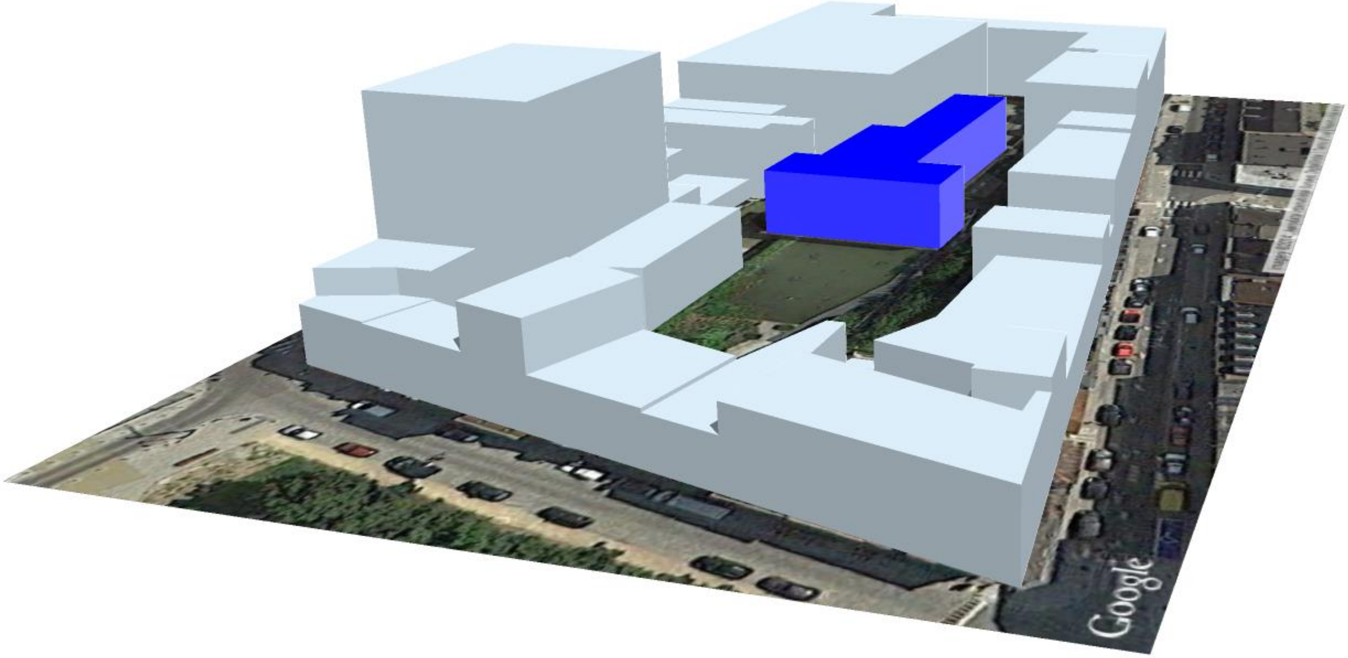
Optimize parameter values

System

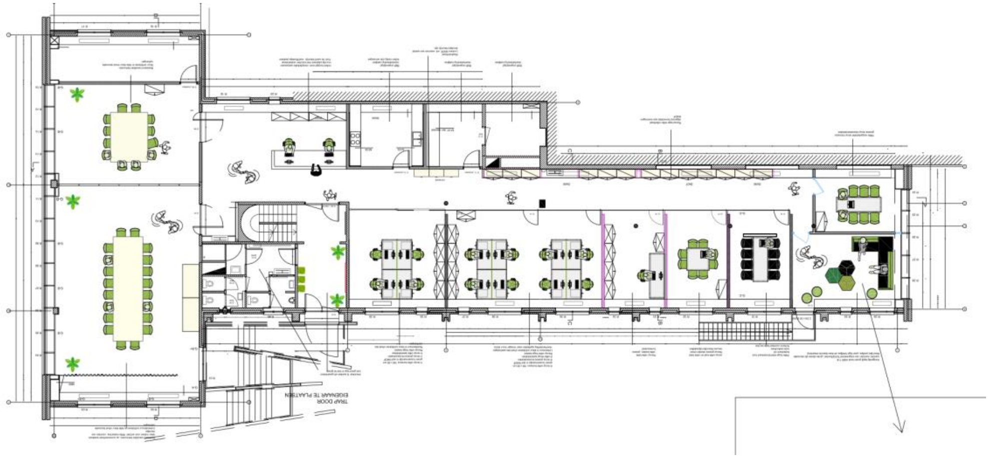
3E headquarters in Brussels

Two floors, 40 – 80 people

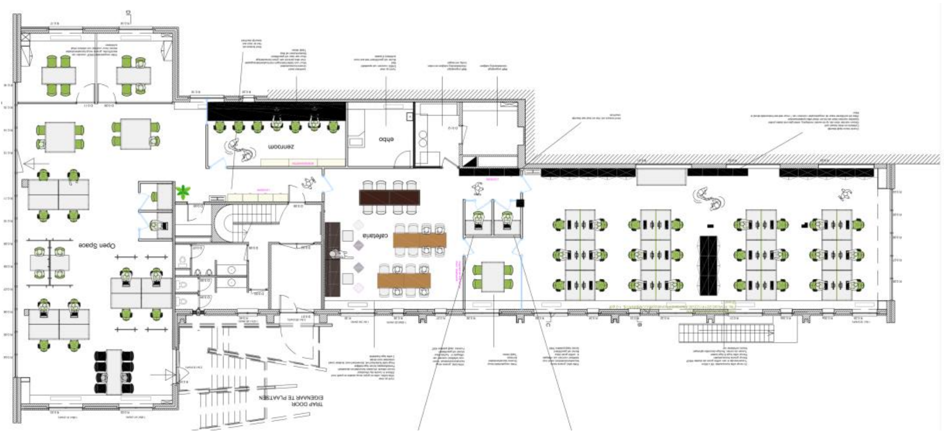
Renewed heating system



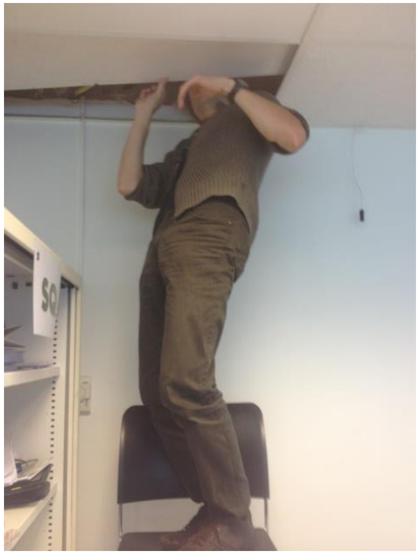
Building envelope



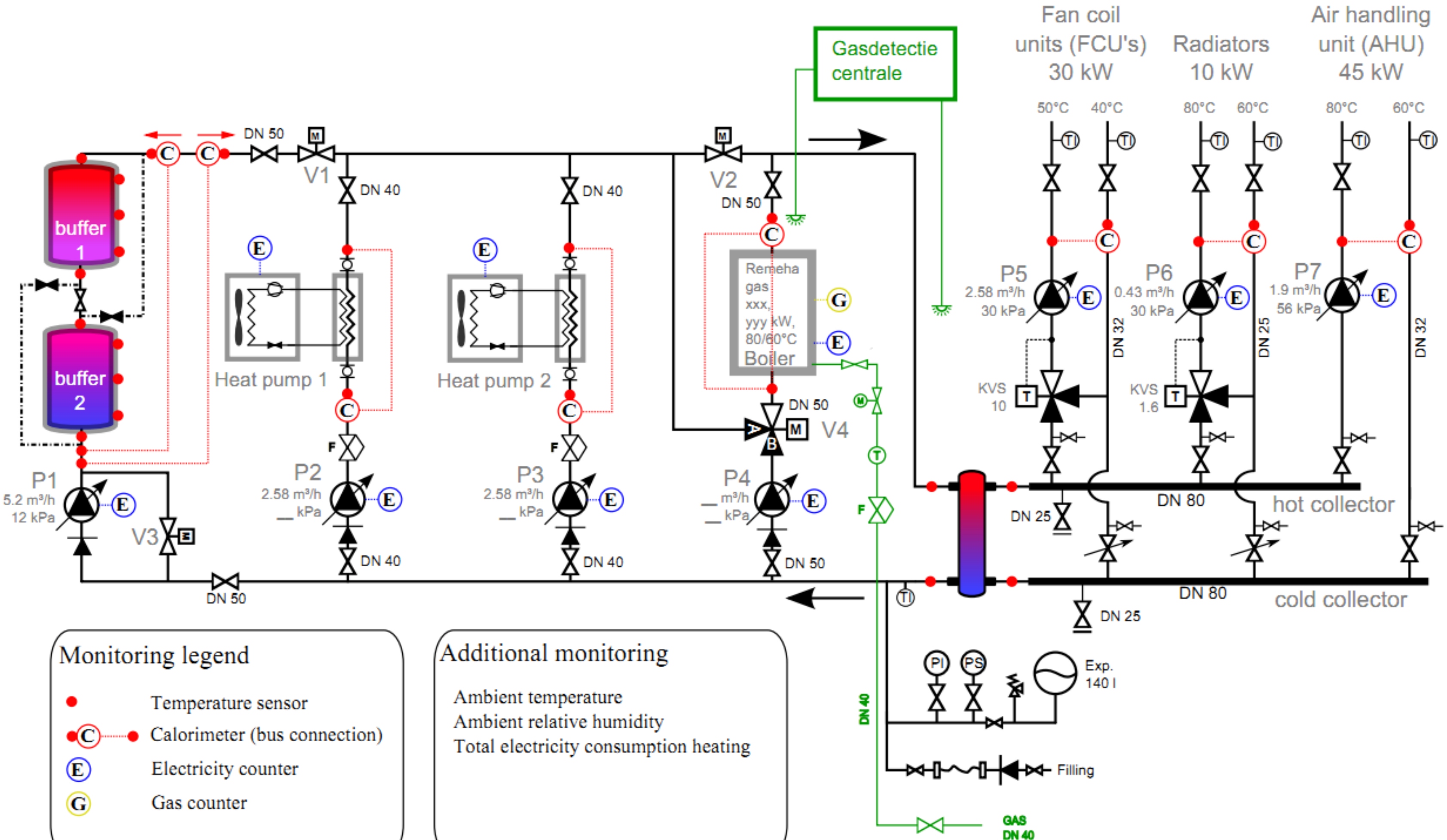
Second floor



First floor



Heating system



Monitoring legend

- Temperature sensor
- C Calorimeter (bus connection)
- E Electricity counter
- G Gas counter

Additional monitoring

Ambient temperature
Ambient relative humidity
Total electricity consumption heating

Model

Libraries

- IDEAS (KU Leuven)
- Buildings (LBNL)
- Own models

→ lots of parameters

Selecting parameters

Well known parameters: knowledge of the system, building drawings, material properties or manufacturer data

→**assume correct**

Uncertain parameters: engineering knowledge, educated guess, specific non-physical parameters

→**calibrate**

1. **sensitivity analysis: Elementary Effects (EE)**

   Sensitive (uncertain) parameters

2. **guided search optimization: Genopt**

   Calibrated parameters!

Challenges

With the system

- Large system = long simulation times
- Calibrate submodels?
  - Not all inputs are measured
  - submodels have interaction with system

With Modelica:

- Parameter not available to change?
  - annotation: Evaluate = false
  - attribute: fixed = true
  - → Check: parameter changed in simulation?

Sensitivity analysis

Elementary Effects (EE) method of Morris

- Investigate influence on Goodness Of Fit indicators (GOFs)
  - Coefficient of Variance of RMSE: $CV(RMSE) = \frac{\sigma_e}{\mu_e}$
  - Normalized Mean Bias Error: $NMBE = \frac{\sum_1^n (y - y_{meas})}{\mu_{y_{meas}}}$
- Walk through parameter space with One-At-a-Time (OAT) parameter change
- Simulate for OAT change in the parameters
- Quantify influence using EE statistics

Sensitivity analysis

Quantify influence using Elementary Effect statistics

$$EE = d_i(X) = \frac{Y(X_1, \dots, X_{i-1}, X_i + \Delta, X_{i+1}, \dots, X_k) - Y(X)}{\Delta}$$

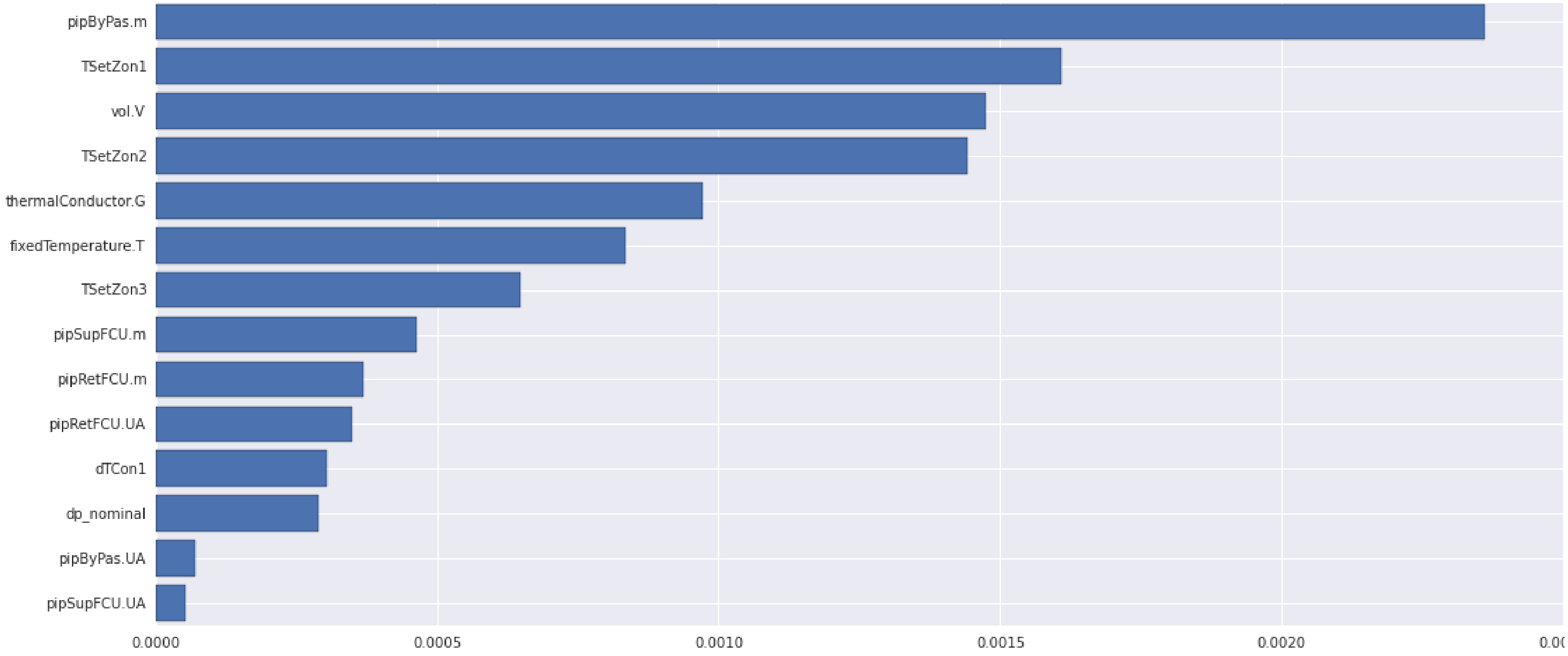
Mean? Standard deviation?

➔Revised Measure (Campologno et al.)

$$\mu^* = \frac{1}{r}\sum_{j=1}^{r} \left| d_i(X^{(j)}) \right|$$

Sensitivity analysys results

Sensitivities on CVE towards water return temperature

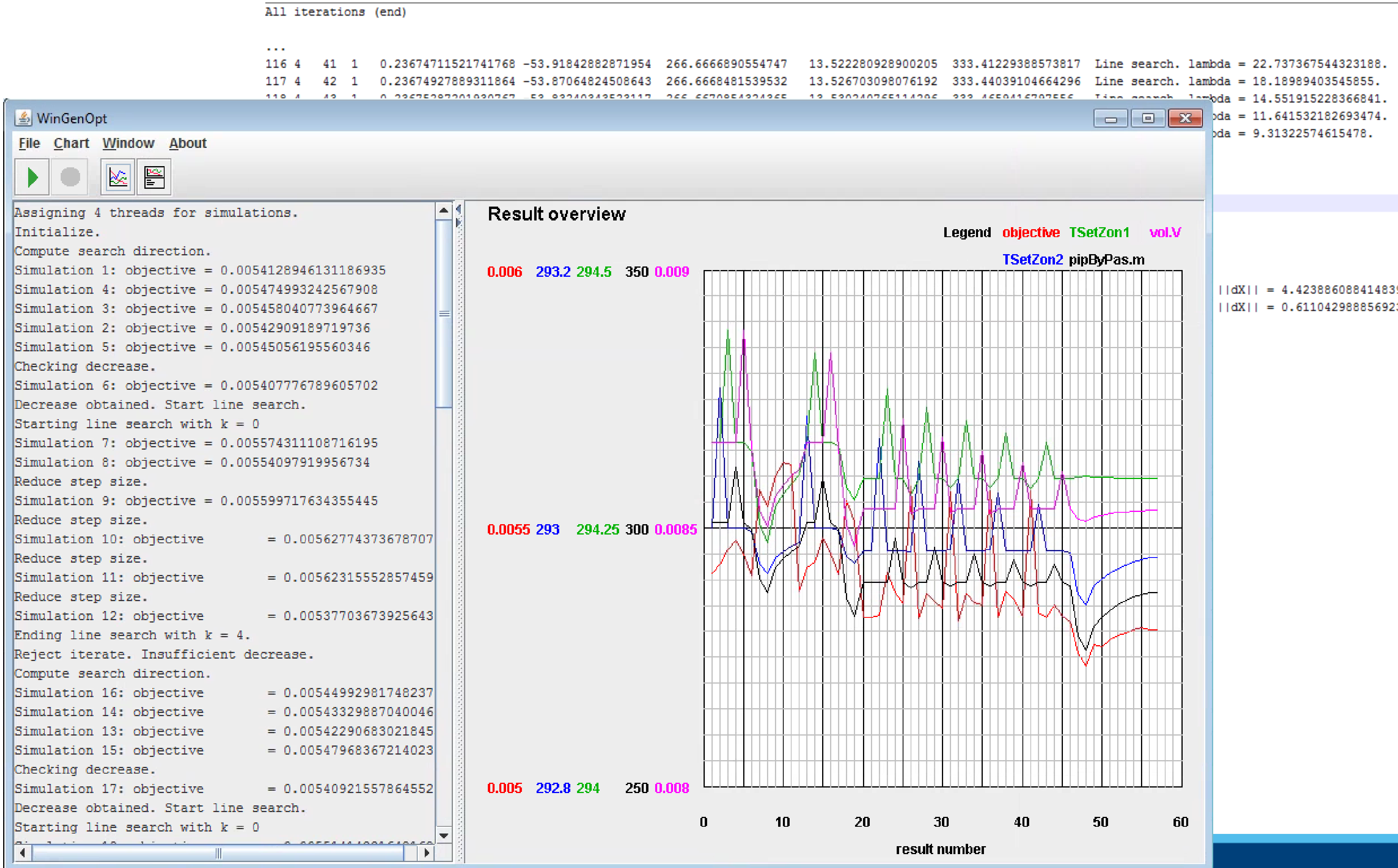


Calibration

Guided search optimization

- Minimize cost function
  - Weighted sum of GOF’s
- GenOpt (general optimization)
  - Discrete Armijo Gradient
  - Generalized Pattern Search (Hookes-Jeeves)
  - Particle Swarm Optimization
  - Nelder and Mead's Simplex
  - ...

Calibration



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Challenges

Number of sensitive parameters to select?

Initial values to use?

- For the values to optimize?
- For the fixed values?

Optimization algorithm?

Questions?