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
Heating system

Monitoring legend:
- Temperature sensor
- Calorimeter (bus connection)
- Electricity counter
- Gas counter

Additional monitoring:
- Ambient temperature
- Ambient relative humidity
- Total electricity consumption heating
Model

Libraries
  o IDEAS (KU Leuven)
  o Buildings (LBNL)
  o 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

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

Mean? Standard deviation?

⇒ Revised Measure (Campologno et al.)

\[ \mu^* = \frac{1}{r} \sum_{j=1}^{r} |d_i(X^{(j)})| \]
Sensitivity analysis results

Sensitivities on CVE towards water return temperature:

- pipByPas.m
- TSetZon1
- vol.V
- TSetZon2
- thermalConductor.G
- fixedTemperature.T
- TSetZon3
- pipSupFCU.m
- pipRetFCU.m
- pipRetFCU.UA
- dtCon.1
- dp_nominal
- pipByPas.UA
- pipSupFCU.UA

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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

All iterations [end]

...
Challenges

Number of sensitive parameters to select?

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

Optimization algorithm?
Questions?