## **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

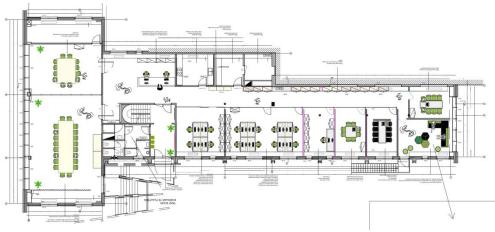




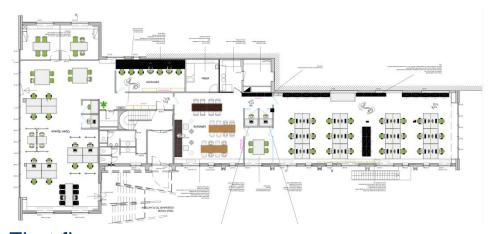


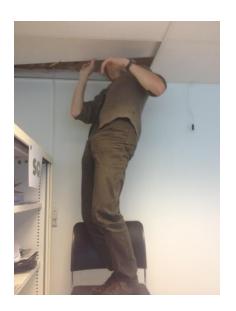


# Building envelope



#### Second floor

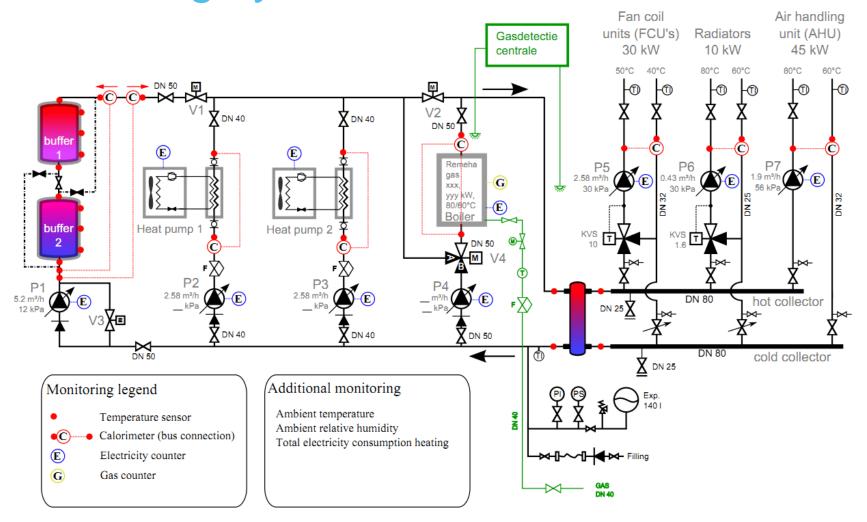








# Heating system





## 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





# 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

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

Mean? Standard deviation?

→ Revised Measure (Campologno et al.)

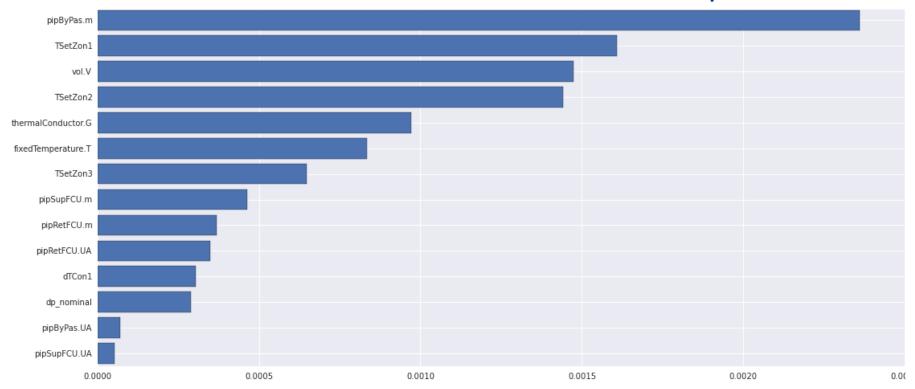
$$\mu^* = \frac{1}{r} \sum_{j=1}^r |d_i(X^{(j)})|$$





# Sensitivity 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

All iterations (end) 116 4 41 1 0.23674711521741768 -53.91842882871954 266.6666890554747 13.522280928900205 333.41229388573817 Line search, lambda = 22.737367544323188, 42 1 0.23674927889311864 -53.87064824508643 266.6668481539532 13.526703098076192 333.44039104664296 Line search. lambda = 18.18989403545855. - - X oda = 11.641532182693474. da = 9.31322574615478. File Chart Window About Assigning 4 threads for simulations. Result overview Initialize. Legend objective TSetZon1 vol.V Compute search direction. TSetZon2 pipByPas.m Simulation 1: objective = 0.0054128946131186935 0.006 293.2 294.5 350 0.009 Simulation 4: objective = 0.005474993242567908 ||dX|| = 4.423886088414839Simulation 3: objective = 0.005458040773964667 ||dX|| = 0.611042988856923Simulation 2: objective = 0.00542909189719736 Simulation 5: objective = 0.00545056195560346Checking decrease. Simulation 6: objective = 0.005407776789605702 Decrease obtained. Start line search. Starting line search with k = 0Simulation 7: objective = 0.005574311108716195 Simulation 8: objective = 0.00554097919956734 Reduce step size. Simulation 9: objective = 0.005599717634355445 Reduce step size. 0.0055 293 294.25 300 0.0085 Simulation 10: objective = 0.00562774373678707Reduce step size. Simulation 11: objective = 0.00562315552857459 Reduce step size. Simulation 12: objective = 0.00537703673925643 Ending line search with k = 4. Reject iterate. Insufficient decrease. Compute search direction. Simulation 16: objective = 0.00544992981748237 Simulation 14: objective = 0.00543329887040046 Simulation 13: objective = 0.00542290683021845 = 0.00547968367214023 Simulation 15: objective Checking decrease. 0.005 292.8 294 250 0.008 = 0.00540921557864552 Simulation 17: objective Decrease obtained. Start line search. 10 Starting line search with k = 0result number **KU LEUVEN** 

# Challenges

Number of sensitive parameters to select?

Initial values to use?

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

Optimization algorithm?







# Questions?