Uncertainty Reduction for Retrofit Saving Estimates in Residential Buildings Using Validated Building Energy Simulation Models

Maja Miletic, Chiara Dipasquale, Peter Grant, Roberto Fedrizzi
INTRODUCTION

• In the field of **existing buildings retrofit**, the estimation of energy savings is fundamental for the selection of envelope and HVAC system solutions to be adopted;

• A reliable model of the existing building helps for a more precise **energy consumption estimation**;

• Calibration models with monitored data can return a reliable picture of the **real building behaviour**.
INTRODUCTION

Challenges of simulations for energy measures savings estimation:

• Simulation predictions differ from actual consumption;
• Calibration can reduce this error, but solution is not unique;
• Impact of non-technical factors as behavioural is quite high – infiltration, ventilation, shading devices are usually not scheduled or monitored.

→ Need of a methodology for modelling and calibrating the building behaviour and creating realistic annual behavioural patterns
INTRODUCTION

Calibration of residential buildings models:

Simulation model preparation and parameter space definition → How to define the parameter space?

Sensitivity study

Solution space exploration and parameters vector identification → How to choose the parameter vector?

Match measured data and satisfy calibration criteria → Lack of the validation phase
METHODOLOGY

Calibration based on optimization performed by varying parameters within suitable ranges.
METHODOLOGY

**Cost function** - $J(p)$

\[
J(p) = \sum_{k=1}^{n_S} \sum_{z \in Z} \left( w_Q \int_{t_k}^{t_{k+1}} \left( \dot{Q}^Z_s(t) - \dot{Q}^Z_m(t) \right) dt \right) + w_T |T^Z_s(t_k) - T^Z_m(t_k)|
\]

Total energy demand error

(simulated value – monitored value)
METHODOLOGY

Cost function - $J(p)$

$$J(p) = \sum_{k=1}^{n_S} \sum_{z \in Z} \left( w_Q \left| \int_{t_k}^{t_o} (\dot{Q}_s^z(t) - \dot{Q}_m^z(t)) \, dt \right| + w_T \left| T_s^z(t_k) - T_m^z(t_k) \right| \right)$$

Indoor temperature error
(simulated value – monitored value)
METHODOLOGY

Cost function - $J(p)$

$$J(p) = \sum_{k=1}^{n_S} \sum_{z \in Z} \left( w_Q \left| \int_{o}^{t_k} \left( Q_{s}^z(t) - Q_{m}^z(t) \right) dt \right| + w_T \left| T_{s}^z(t_k) - T_{m}^z(t_k) \right| \right)$$

Weight factors to well balance the error terms
METHODOLOGY

PROBLEM

How to identify the parameters vector between all the possible solutions?
Uncertainty reduction strategy

Regularization

Add a penalty term to exclude improbable solutions:

1. **Available information** taken from energy audit, data sheets, lab tests, measurements...;
2. An **initial guess** is done within a set of parameters;
3. Parameters are sorted based on **information source reliability**.

How to define the parameter space?

How to choose the parameter vector?
Uncertainty reduction strategy

Regularization - $R(p)$

$$R(p) = \lambda \sum_{i \in \text{Source}} w_i \frac{|p_i - p_i^{\text{init}}|}{p_i^{\text{max}} - p_i^{\text{min}}}$$

Normalized parameter distances to their initial guess
Uncertainty reduction strategy

Regularization - $R(p)$

$$R(p) = \lambda \sum_{i \in S_{Source}} w_i \frac{|p_i - p_i^{init}|}{p_i^{max} - p_i^{min}}$$

Regularization weight and weight factor based on source hierarchy
Uncertainty reduction strategy

Regularized cost function – $J_{reg}(p)$

$J_{reg}(p) = J(p) + R(p)$

$\min_{p \in P} J_{reg}(p)$

Cost Function  Regularization
Uncertainty reduction strategy

Calibration and Validation criteria

Normalized Mean Bias Error – NMBE

Coefficient of Variation of Root Mean Square Error - CVRMSE

+ 

Cumulative demand and temperature error averaged over all simulation steps for

- Energy demand $\text{AAE}_d$;
- Temperature $\text{AAE}_t$.

How to choose the parameter vector?
CASE STUDY

Building description

- Located in Madrid - Spain
- Built in 1970s
- 10 dwellings - 50 m²
- 5 floors
CASE STUDY

Building description

Monitoring data

- Outdoor air temperature (OAT)
- External relative humidity
- Solar radiation
- Heating consumption on the gas boiler pipelines
- Indoor air temperature (IAT)
- Relative humidity
- CO2 level
CASE STUDY

Building description

- 3D model is created in SketchUp
- Energy model is created in the TRNSYS environment
- Optimization is conducted with GenOpt
CASE STUDY

Simulation model and uncertain parameters

Aug, 5th - Jan, 31st - Apr, 12th

Calibration period - Validation period

Lack of validation phase
CASE STUDY

Simulation model and uncertain parameters

Aug, 5th  |  Jan, 31st  |  Apr, 12th
--- | --- | ---
Calibration period | Validation period |  

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SOURCE</th>
<th>RELIABILITY</th>
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<tr>
<td>$k_{ext}$, $k_{int}$, $k_{roof}$</td>
<td>Constructive elements catalogue by Spanish Institute of construction sciences</td>
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<tr>
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How to choose the parameter vector?
CASE STUDY

Optimization results w/ and w/o regularization

Preliminary values and realistic ranges

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<th>MAX</th>
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How to define the parameter space?
CASE STUDY

Optimization results w/ and w/o regularization

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Solutions

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<tr>
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<th>UNIT</th>
<th>REGULARIZED</th>
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CONCLUSIONS

• Importance of including initial guess or a-priori parameter distribution information;

• Number of "falsely calibrated models" can be reduced if new calibration criteria are added;

• Including criteria on the internal temperature helps to reduce uncertainty;

• Validation phase is required for proving the parameters suitability and individuating behavioural patterns for the estimation of building consumption.
THANK YOU

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