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

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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)*

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

Total energy demand error

(simulated value – monitored value)

METHODOLOGY

Cost function - *J(p)*

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Indoor temperature error

(simulated value – monitored value)

METHODOLOGY

Cost function - *J(p)*

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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)*

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

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 $\boldsymbol{AAE_d}$;
- Temperature $\boldsymbol{AAE_t}$.

How to choose the parameter vector?

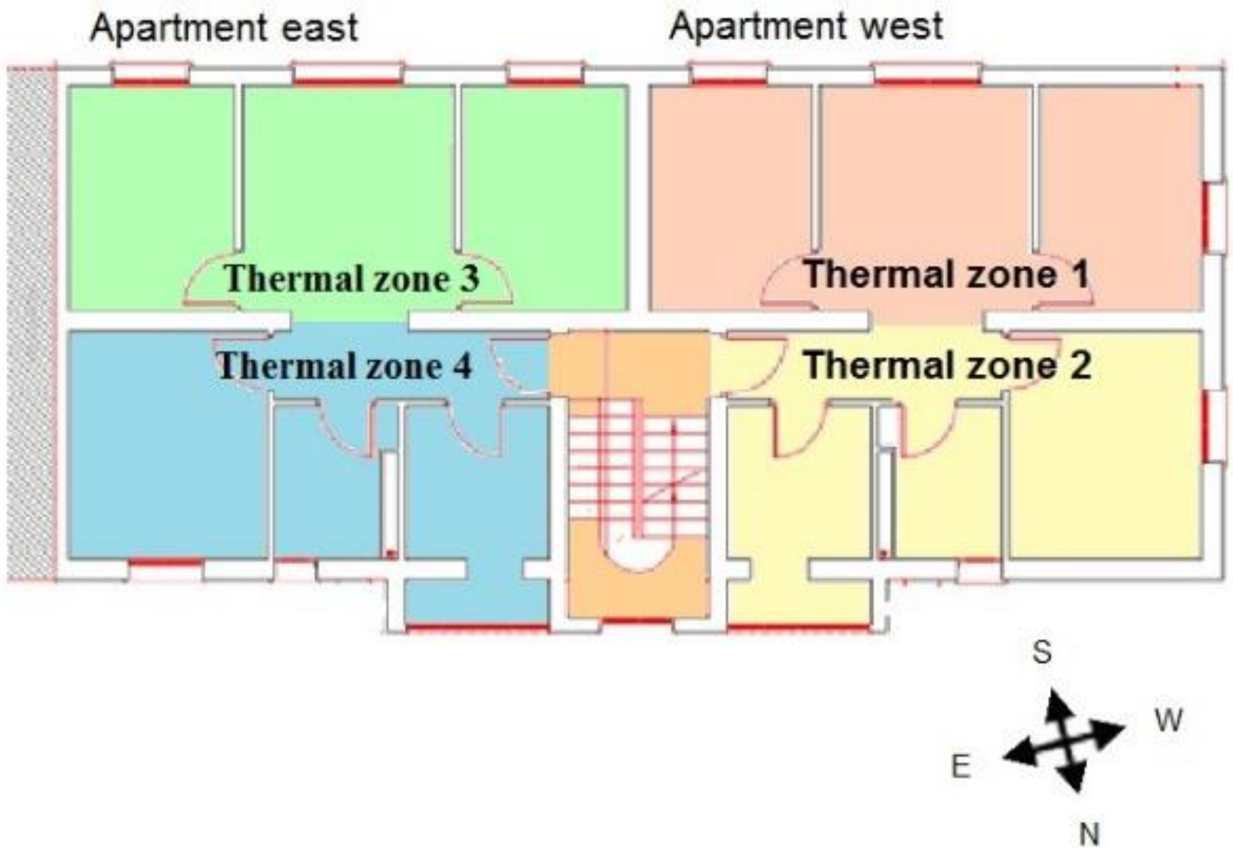
CASE STUDY

Building description

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

CASE STUDY

Building description



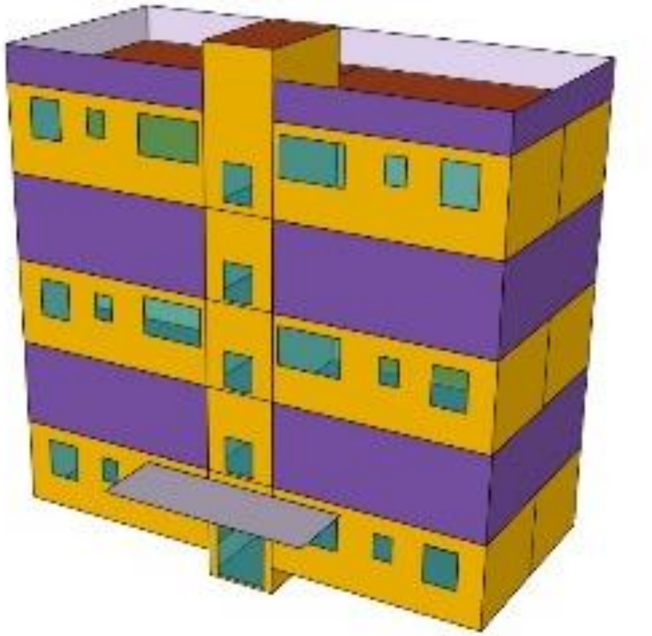
Monitoring data

- 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

Lack of validation phase

CASE STUDY

Simulation model and uncertain parameters

PARAMETER	SOURCE	RELIABILITY
$k_{ext}, k_{int}, k_{roof}$	Constructive elements catalogue by Spanish Institute of construction sciences	Medium
R_{closed}	Blower door test results	High
$\dot{Q}_{Person}$	Handbooks and standards	Medium
$T_{set,nei}$	From IAT measurements	Low

How to choose the parameter vector?

CASE STUDY

Optimization results w/ and w/o regularization

How to define the parameter space?

Preliminary values and realistic ranges

NOTATION	UNIT	INITIAL	MIN	MAX
R_{closed}	[vol/h]	0.4	0.15	0.75
R_{open}	[vol/h]	2.0	0.4	5.5
$\dot{Q}_{Person}$	[W]	75	37.5	150
$T_{set,nei}$	[°C]	22	17	25

CASE STUDY

Optimization results w/ and w/o regularization

How to define the parameter space?

How to choose the parameter vector?

Preliminary values and realistic ranges

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Solutions

NOTATION	UNIT	REGULARIZED	NON-REGULARIZED
R_{closed}	[vol/h]	0.26	0.15
R_{open}	[vol/h]	1.09	2.0
$\dot{Q}_{Person}$	[W]	88.5	35.7
$T_{set,nei}$	[°C]	20.2	17

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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