Virtual testbed of the KTH Live-In Lab: development and validation

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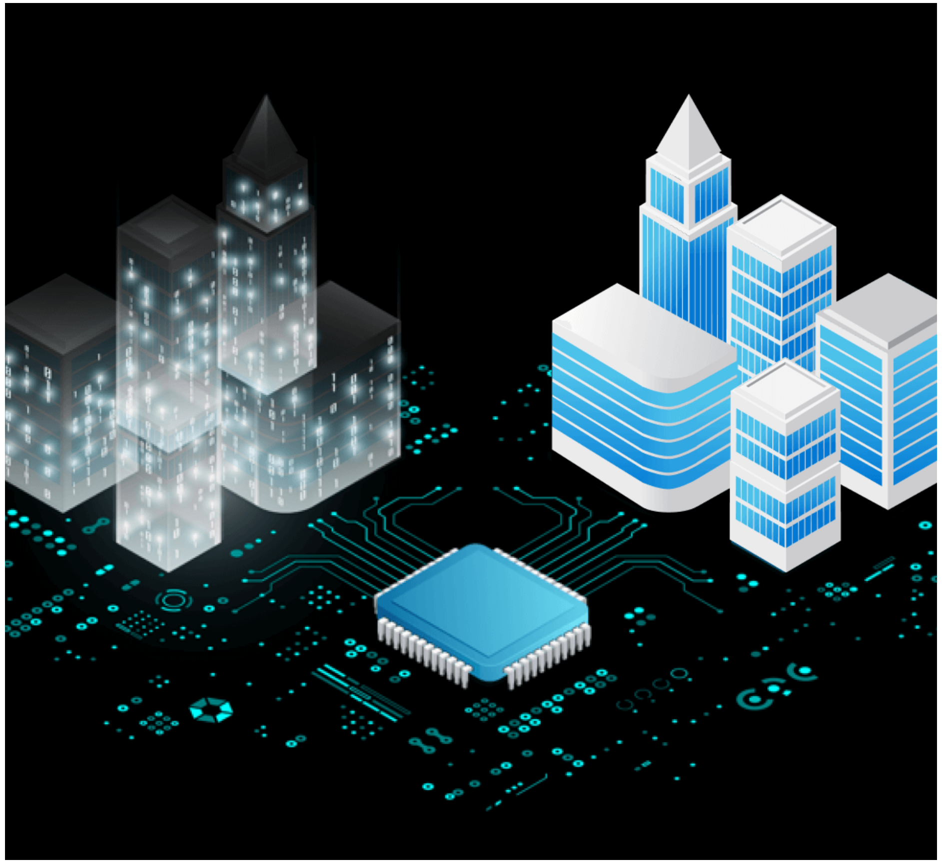
Digital twins in buildings

*"A digital twin is a **digital representation** of an **active unique product** (real device, object, machine, service, or intangible asset) or unique product-service system (a system consisting of a product and a related service) that comprises **its selected characteristics, properties, conditions, and behaviors by means of models, information, and data** within a single or even across multiple life cycle phases."*



Digital twins in buildings

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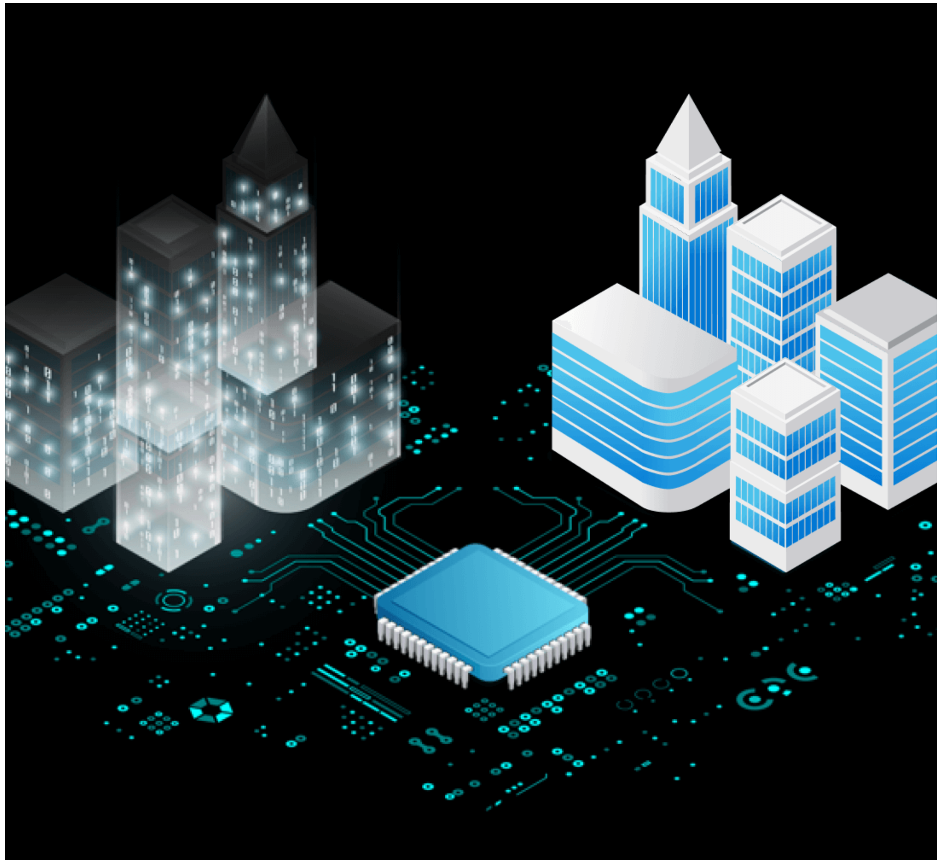
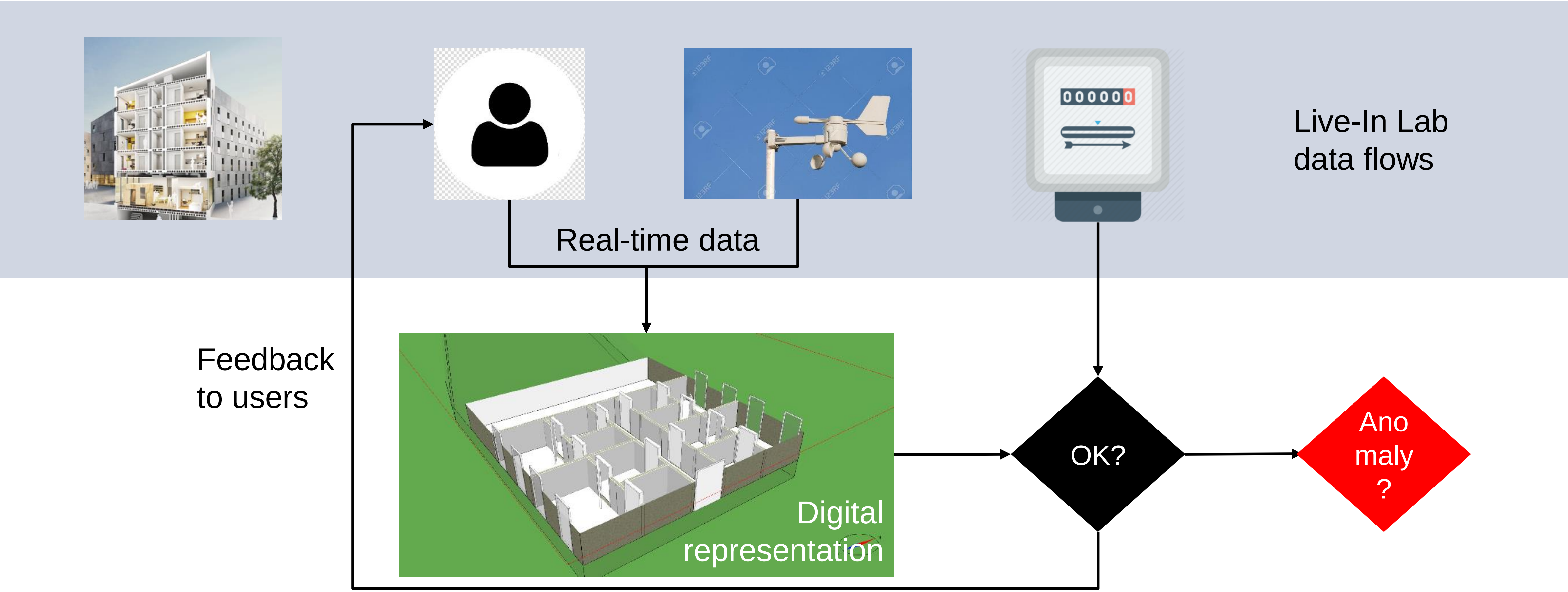


An example of applications of digital twins in buildings



KTH Live-In Lab

Innovation platform for the building sector

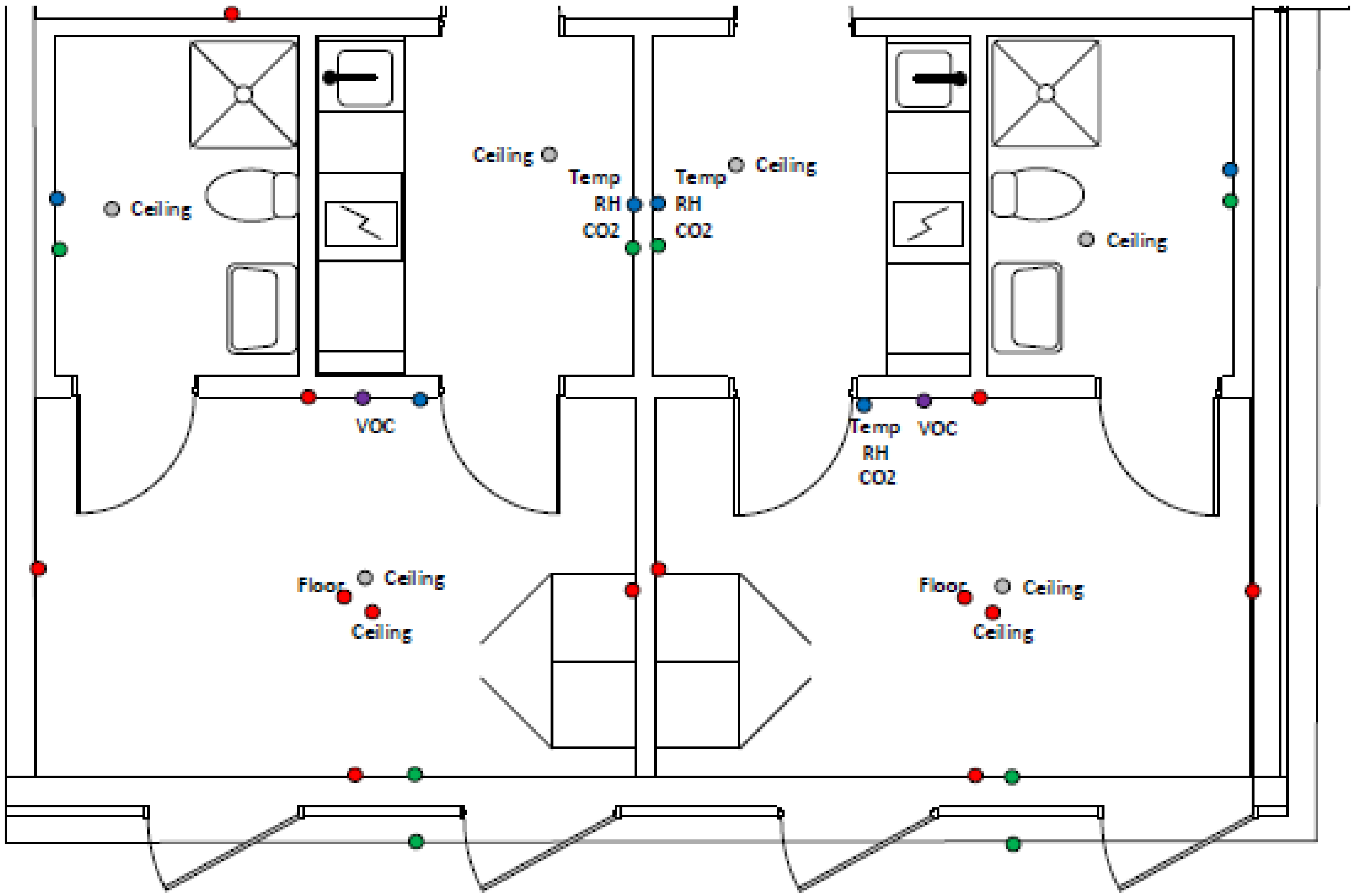
Designed to be a positive energy building

- Low energy building envelope
- Ground source heat pumps: 12 boreholes
- TABS, thermally activated building systems
- Wastewater heat recovery
- PV panels mounted on roof
- Monitoring of the temperature distribution in the boreholes (optical fibers)
- Indoor sensors and weather station
- Energy storage systems

Three buildings

- Testbed Einar Mattsson: ~300 apartments
- **Testbed KTH: 4 apartments, 300 m^2**

Testbed KTH: sensor placement and user interface



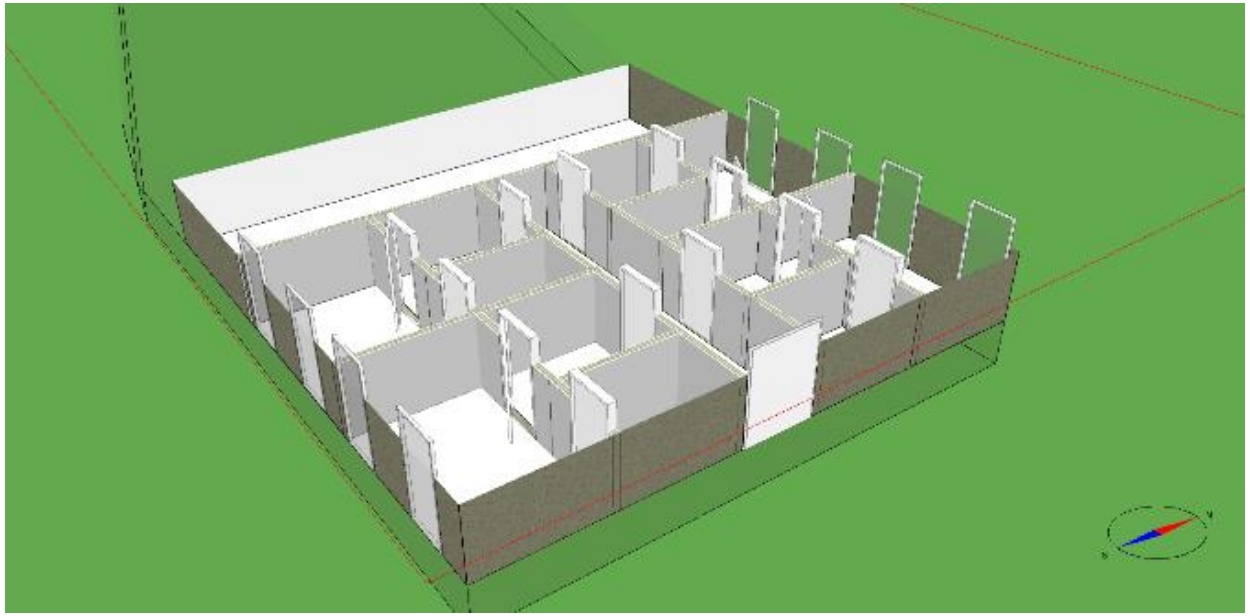
Temperature : 4 apartments with 8 points + 2 sensors in the corridor= 34 in total
Podcomp will install RH in bathroom wall, extra RH in bathroom 4 sensors
Occupancy: 9 motion detectors (2 per apartment + 1 in the corridor)
Pressure: outdoor pressure + pressure in each room
Light sensors

- Temperature
- Pressure
- VOC
- Temp, RH, CO2
- Motion detectors

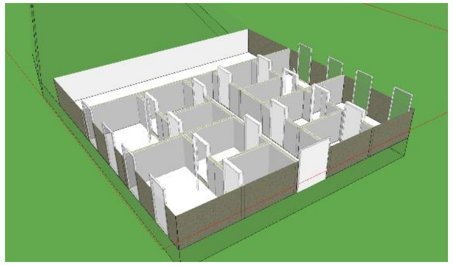
IDA-ICE model of the testbed KTH

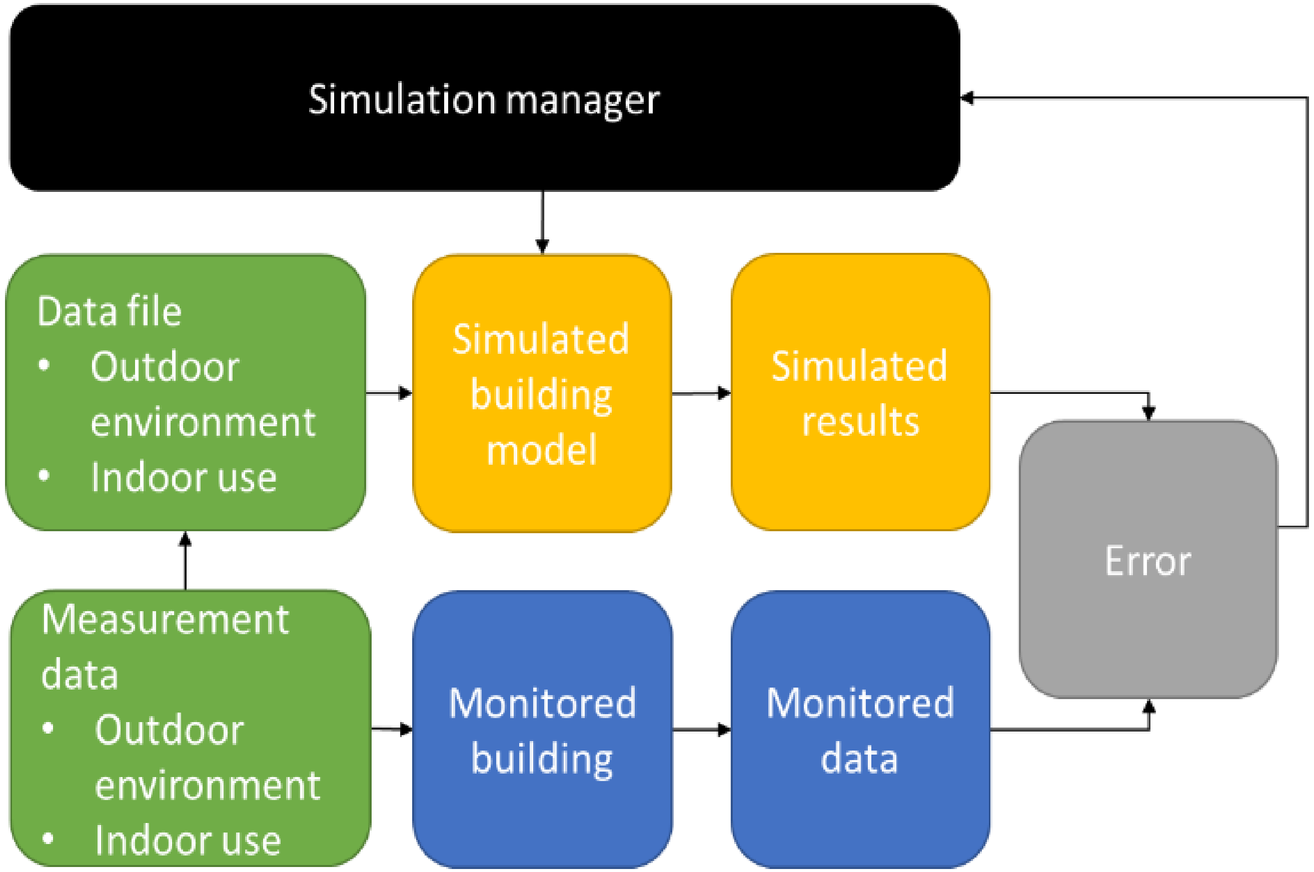
Building

Building model in IDA-ICE



Simulation platform





Box, M. J. 1965. “A New Method of Constrained Optimization and a Comparison With Other Methods”

Methodology

Calibration procedure

Screening analysis

Optimization

KPIs

$$S.I.(\%)=\frac{E_{max}-E_{min}}{E_{min}}$$

$$MBE(\%)=\frac{\sum_{i=1}^{N_p}(m_i-s_i)}{\sum_{i=1}^{N_p}(m_i)}$$

$$CV(RMSE)(\%)=\frac{\sqrt{\sum_{i=1}^{N_p}(m_i-s_i)^2 / N_p}}{\overline{m}}\cdot 100$$

Screening analysis

Type	Parameter	S.I.	Selected
HVAC	Heat recovery efficiency	117.2%	Y
Env	Windows U-value	14.9%	Y
HVAC	Living room maximum airflow	9.3%	Y
Env	Windows G-value	8.7%	N
Env	Insulation thickness	8.3%	Y
HVAC	Kitchen airflows (constant)	8.3%	N
HVAC	Living room minimum airflow	11.9%	N
Be	Living room heating setpoint	5.7%	Y
HVAC	Bathroom airflows (constant)	5.7%	N
Env	Infiltrations	4.7%	N
Be	Living room occupant gains	4.4%	Y
Be	Living room equipment gains	0.8%	N
Be	Living room light gains	0.8%	N
Be	Bathroom light gains	0.8%	N
Be	Kitchen light gains	0.7%	N
Be	Bathroom equipment gains	0.7%	N
Be	Kitchen equipment gains	0.7%	N
Be	Living room cooling setpoint	0.6%	N
Be	Kitchen occupant gains	0.0%	N
Be	Bathroom occupant gains	0.0%	N
HVAC	Bathroom cooling setpoint	0.0%	N
HVAC	Bathroom heating setpoint	0.0%	N
HVAC	Kitchen cooling setpoint	0.0%	N
HVAC	Kitchen heating setpoint	0.0%	N

Types
- HVAC
- Envelope
- Behaviour

Parameter

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S.I.

…

Selection

…

Screening analysis

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Types

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S.I.

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Results

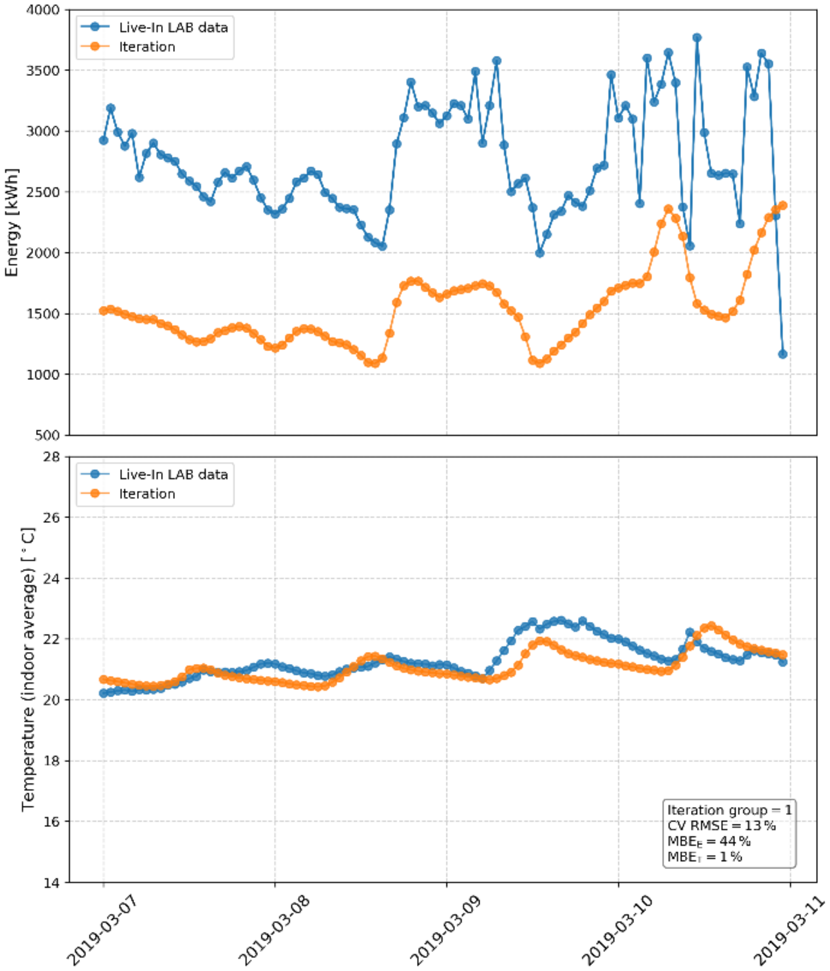
$$Aggregated\ CV(RMSE) = CV(RMSE)(T)\cdot(\beta) + CV(RMSE)(En)\cdot(1-\beta)$$

β	0.25	0.5	0.75
MBE Energy [%]	-8%	-3%	-2
MBE Temperature [%]	2%	-2%	-2
CV(RMSE) Energy [%]	16%	14%	13%
CV(RMSE) Temperature [%]	3%	3%	3%
Aggregated CV(RMSE) [%]	13%	9%	6%

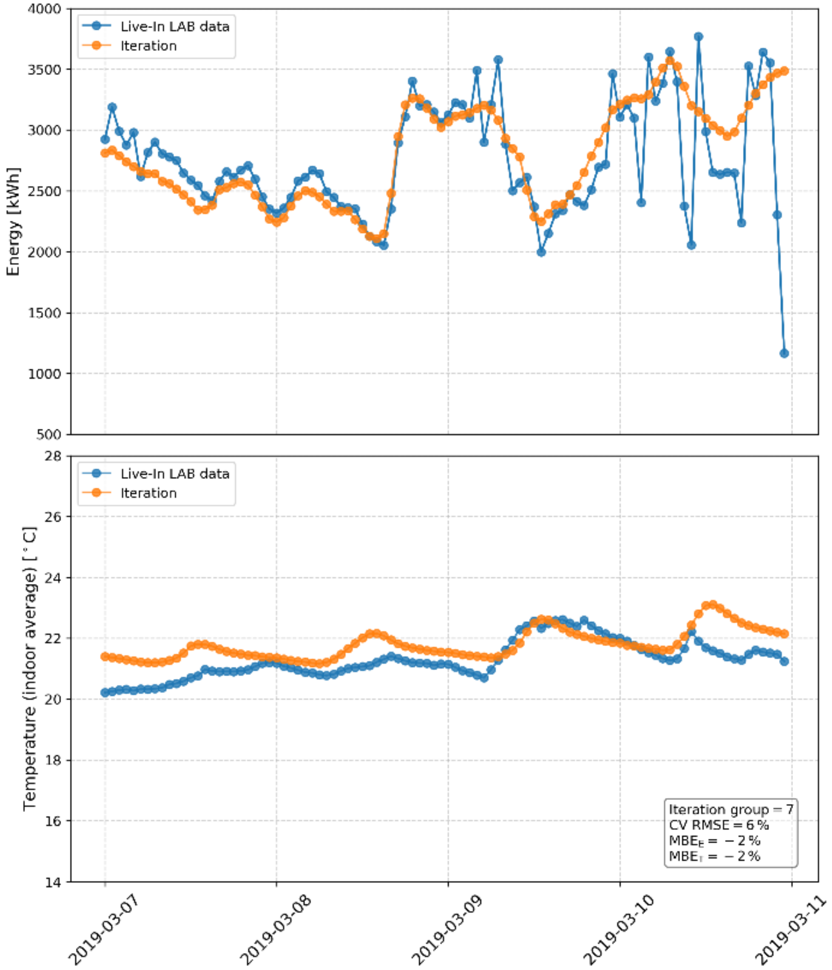
Guideline	Hourly (%)		Monthly (%)	
	MBE	CV(RMSE)	MBE	CV(RMSE)
ASHRAE	±10	30	±5	15
IPMMVP	±5	20	±20	
FEMP	±10	30	±5	15

Optimization results

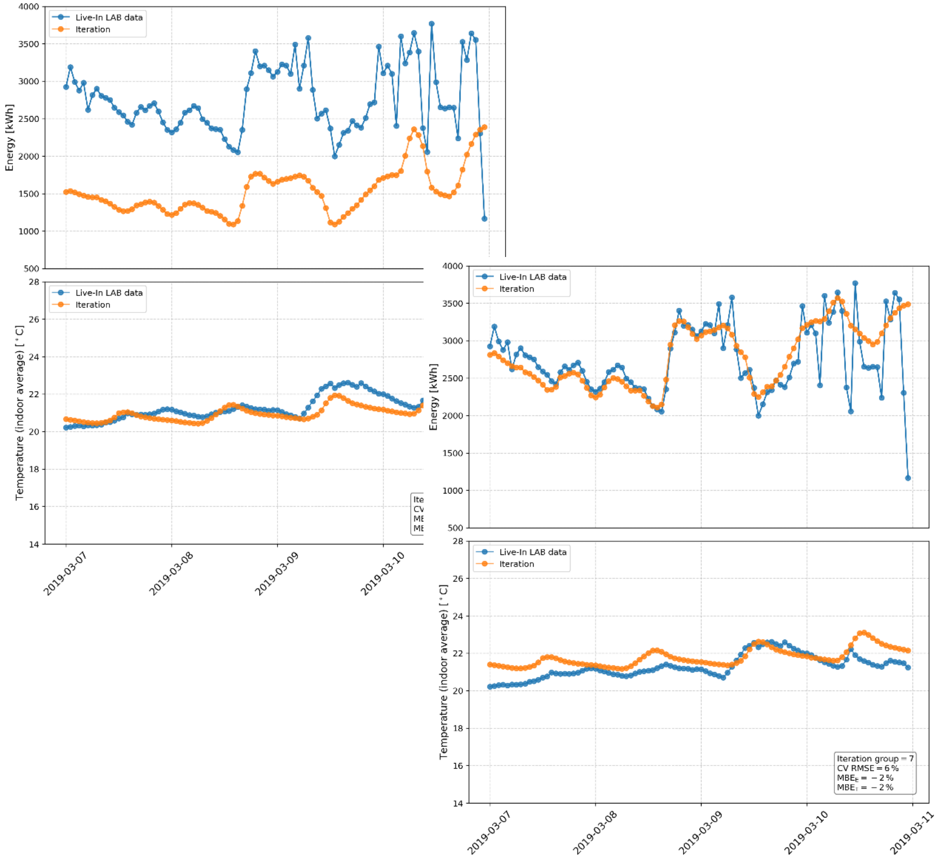
Initial parameter values



Optimized parameter values



Optimized values



Parameter	Initial value	Calibrated value
External walls insulation [m]	0.05	0.10
Windows U-value [-]	1.4	1.87
Living room maximum airflow [l/sm^2]	2.0	2.0
Air heat recovery efficiency [%]	0.85	0.60
Heating set-point [ºC]	22	18
Occupants gain [n_{people}]	1.0	1.5

Discussion and conclusions

Screening analysis

+ minimized number of variables to optimize for

+ parameters with low impact in the calibration is likely to result in higher uncertainty

- degree of **subjectivity**, based on expert knowledge, in the choice of minimum and maximum values of the parameters, which in turn influences the sensitivity index.

- local sensitivity analysis approach: the initial configuration has an impact on the results of the screening analysis.

Weighting factor β central in the context of digital twins. Qualitative assumptions on indoor temperatures may be sufficient for calibrations for models used for energy auditing or the evaluation of renovation measures but not for digital twins

Preliminary results to show viability of the calibration approach **with limited data**– calibration with **yearly data** is ongoing

Thank you for your attention