Optimised IES-VE model calibration methodology integrating IoT, smart meter and BMS data

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Introduction

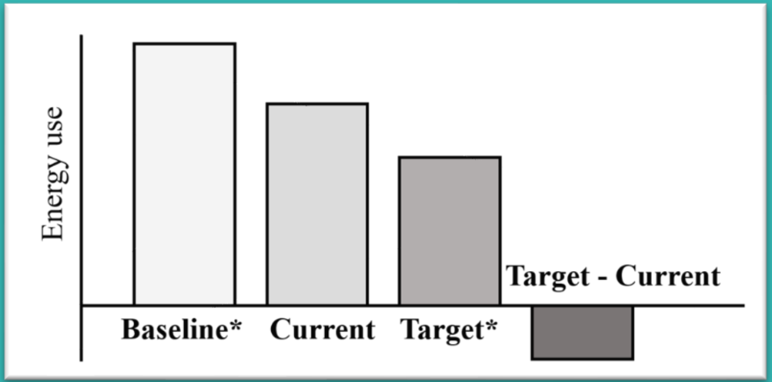
Building Energy Simulations (BES) are used:

Design stage

- Inform design decisions (Manz et al., 2018)
- Evaluate occupants' comfort (ASHRAE Standard 55-2013)
- Ensure compliance with energy efficiency codes (Energy Step Code, PRM ASHRAE 90.1)
- Gain credits in building rating systems (LEED and BREAM)

Operational stage

- Energy savings estimation (M&V)
- Model-based Fault Detection and Diagnostics (FDD)
- Model predictive control (MPC)
- Enabling model-free control techniques Reinforcement Learning (RL)
- Evaluation of demand-response (DR) technologies
- Prediction of future savings as a result of retro-commissioning activities.



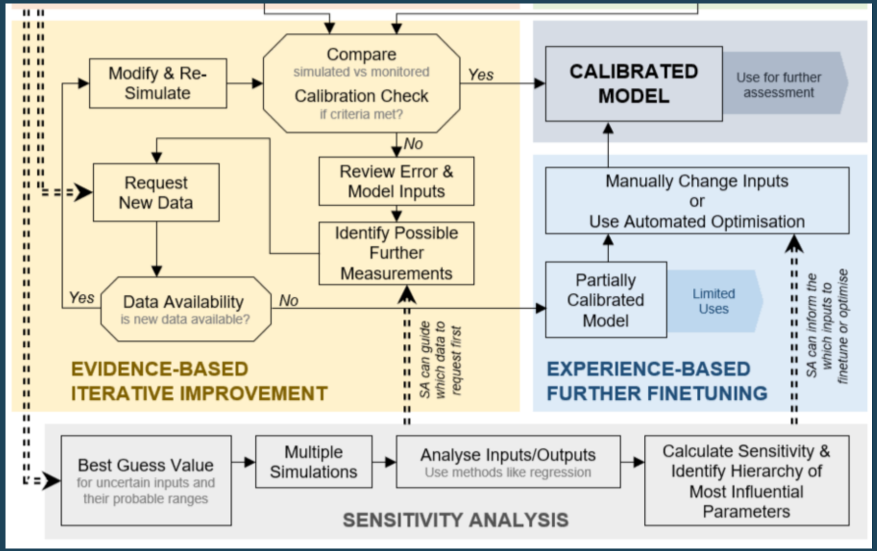
Introduction

“The process of reducing the uncertainty of a model by comparing the predicted output of the model under a specific set of conditions to the actual measured data for the same set of conditions“ (ASHRAE, 2002).

However, model calibration is widely recognised as a time consuming activity. Identified challenges are:

- Lack of standardization
- Costs
- Model input data
- Uncertainty
- Lack of automation

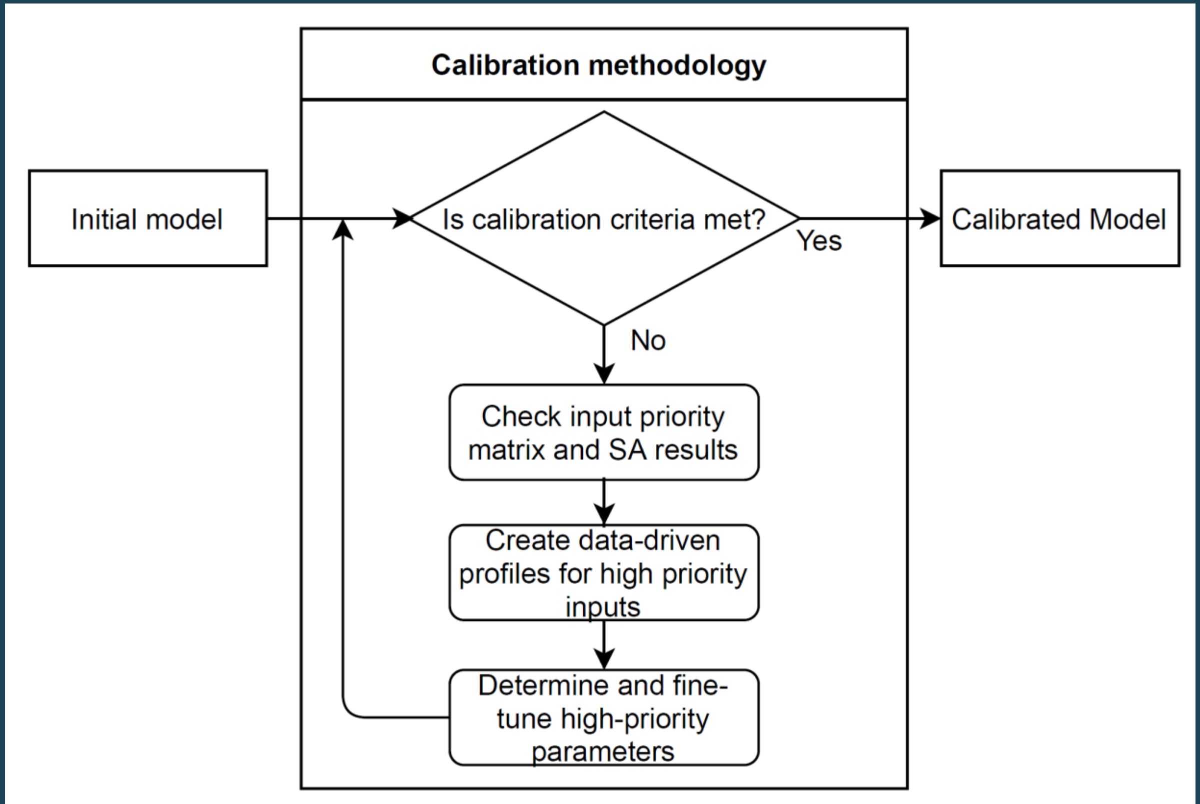
CIBSE TM63 Evidence based calibration workflow (CIBSE, 2020)



Methodology

This methodology is aimed for buildings with available time-series data consisting of three high-level stages:

1. Check input priority matrix and SA results
2. Create data-driven profiles for high priority inputs
3. Determine and fine-tune high-priority parameters.



Methodology – Calibration metrics

Totalled units (energy-related outputs)

$$NMBE(\%) = \frac{\sum_{t=1}^{N}(y_t - \hat{y}_t)}{(N-P)\times\mu} \times 100\%$$

$$CVRMSE(\%) = \frac{\sqrt{\frac{\sum_{t=1}^{N}(y_t-\hat{y}_t)^2}{N-P-1}}}{\mu} \times 100\%$$

Untotalled units (temperature, C02)

$$RMSE(unit) = \sqrt{\frac{\sum_{t=1}^{N}(y_t - \hat{y}_t)^2}{N-1}}$$

$$MAE(unit) = \frac{\sum_{t=1}^{N}|y_t - \hat{y}_t|}{N-1}$$

Thresholds (ASHRAE (2014) and CIBSE (2020)).

	Monthly	**Hourly**
NMBE	5%	10%
CVRMSE	15%	30%
$\mathbf{RMSE}_{temp}$	N/A	1.5 °C
$\mathbf{MAE}_{temp}$	N/A	1.5 °C

Methodology - Check input priority matrix and SA results

Based on the end-use of the model, look up the most critical parameters in a model.
Long term applications rely more on envelope properties, short term require day to day information.

End-uses are:

- Long-term assessment
- Urban energy simulations
- Model-based commissioning
- Pre-occupancy commissioning
- Post-construction commissioning
- Retro-commissioning
- Measurement and verification

Model Application

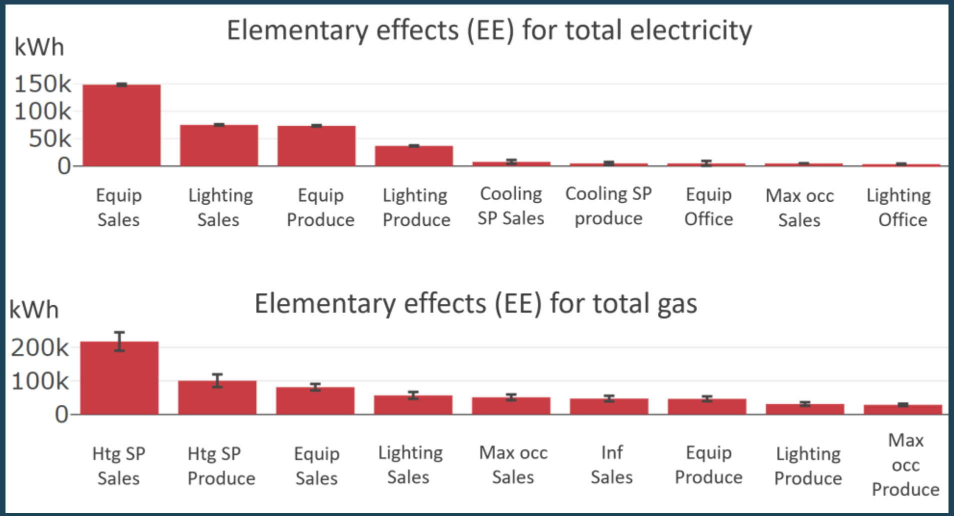
	Model Inputs	Long Term Assessment	Urban Energy Simulations	Commissioning: Pre-Occupancy Commissioning	Commissioning: Post-construction Commissioning	Commissioning: Ongoing Commissioning	Commissioning: Retro-commissioning	M&V	Short Term Prediction
Fixed Parameters	*Site Plan Drawings*	High	High	Medium	Medium	Medium	Medium	Medium	Medium
Fixed Parameters	*Building Geometry (elevations, sections & floor plans)*	High	High	High	High	High	High	High	High
Fixed Parameters	*Construction details*	High	High	Medium	Medium	Medium	Medium	High	High
Fixed Parameters	*Air tightness/Infiltration*	High	High	Medium	Medium	Medium	Medium	High	High
Fixed Parameters	*HVAC Layout & Schematics*	Medium	Medium	High	High	High	High	Medium	Medium
Fixed Parameters	*HVAC Equipment Schedules & Specifications*	Low	Low	High	High	High	High	Medium	Medium
Fixed Parameters	*Lighting Layout*	Low	Low	High	High	High	High	High	High
Fixed Parameters	*Plug loads*	Low	Low	High	High	High	High	High	High
Dynamic Parameters	*Room setpoints*	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Dynamic Parameters	*Internal gains (Equipment, computers, etc)*	Medium	Medium	Medium	Medium	Medium	Medium	High	High
Dynamic Parameters	*HVAC Control strategies*	Low	Low	Medium	Medium	Medium	Medium	High	High
Dynamic Parameters	*Lighting Operation Profiles*	Medium	Medium	High	High	High	High	High	High
Dynamic Parameters	*Equipment Operation Profiles*	Medium	Medium	High	High	High	High	High	High
Dynamic Parameters	*System Operation Profiles*	Medium	Medium	High	High	High	High	High	High
Dynamic Parameters	*Occupancy Profiles*	Medium	Medium	High	High	High	High	High	High
Dynamic Parameters	*Site Weather Data*	High	High	High	High	High	High	High	High
	Measured Data								
Measured	*Monthly Electricity Bills*	High	High	Medium	Medium	Low	Low	Low	Low
Measured	*Monthly Heating Bills*	High	High	Medium	Medium	Low	Low	Low	Low
Measured	*< Hourly Electricity Data*	Medium	Medium	High	High	High	High	High	High
Measured	*< Hourly Heating Data*	Medium	Medium	High	High	High	High	High	High

Methodology - Check input priority matrix and SA results

Optionally, a sensitivity analysis can provide a more accurate priority list:

- Morris method + LHS (Campolongo et al., 2007).
- A growing list of model transforms (lighting gain, equipment gain, infiltration, COP, ventilation rates, …)
- Space level parameters can be grouped (e.g. by activity, location, floor,…)
- A feasible range for each transform and group is required

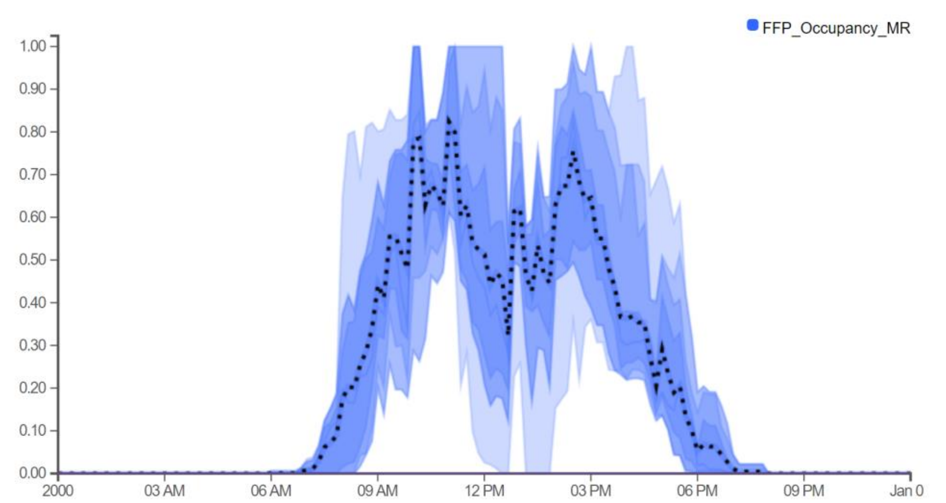
Transform 1 e.g. Lighting max gain	Space group 1	Feasible range
	Space group 2	Feasible range
Transform 2 e.g. Air exchanges per hour	Space group 1	Feasible range
	Space group 2	Feasible range



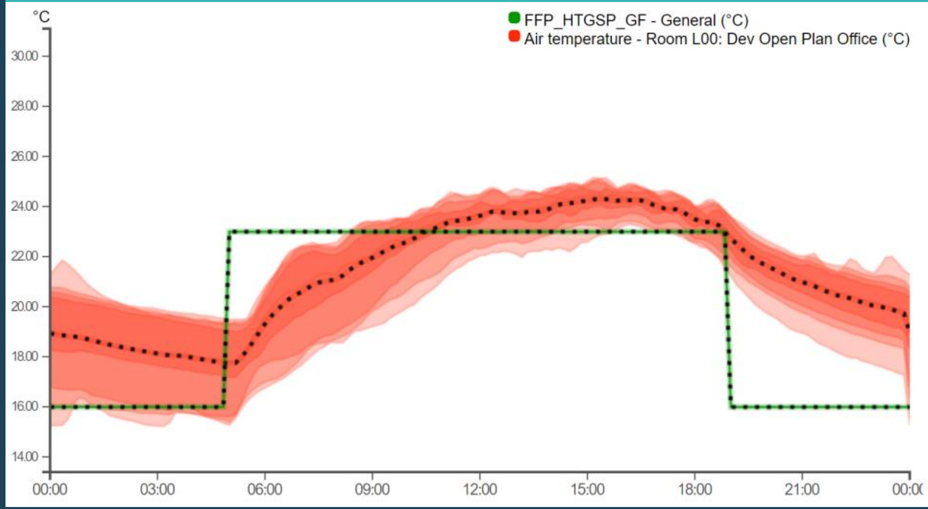
Methodology – Create data driven profiles

The aim is to take advantage of existing time-series data and incorporate it into the model in the form of Free-From-Profiles (FFPs) or Parametric Profiles (PPs).

Free-From-Profiles (FFPs)
FFPs are used to import data coming directly from a third-party source, e.g. a machine learning (ML) model.



Parametric Profiles (PPs)
PPs used to characterise dynamic inputs largely explained by a set operation rules. (use syntax expressions)



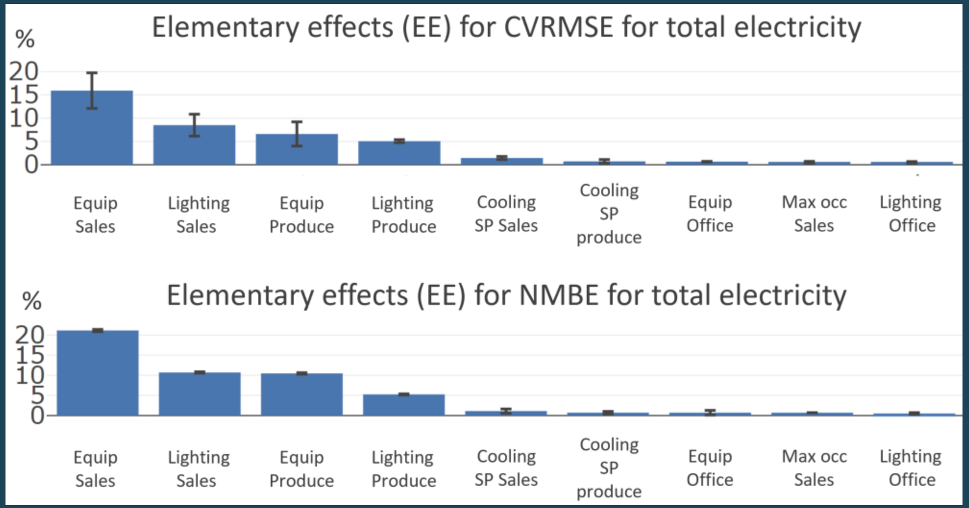
Methodology - Determine and fine-tune high-priority parameters

Initial value from a hierarchy of information sources. Raftery et al. (2011)

1. Data logged measurements
2. Short-term measurements
3. Observation from site survey
4. Interview to operator
5. Operation manuals
6. Commissioning documents
7. Benchmarks
8. Standards, specifications and guidelines
9. Design stage information

Transform 1
- Space group 1 — Uncertainty range
- Space group 2 — Uncertainty range

Transform 2
- Space group 1 — Uncertainty range
- Space group 2 — Uncertainty range



Methodology - Determine and fine-tune high-priority parameters

To fine-tune the parameter values, an optimisation-based method using the Ant Colony Optimisation (ACO) algorithm is used (Dorigo et al., 2006)

Optimise for all outputs simultaneously . Calculates the range normalized root mean squared error for all simulated and metered outputs (Chakraborty et al.,2018).

$$RNRMSE(\%) = \frac{\sqrt{\frac{\sum_{t=1}^{N}(y_t - \hat{y}_t)^2}{N-1}}}{range(y)} \times 100\%$$

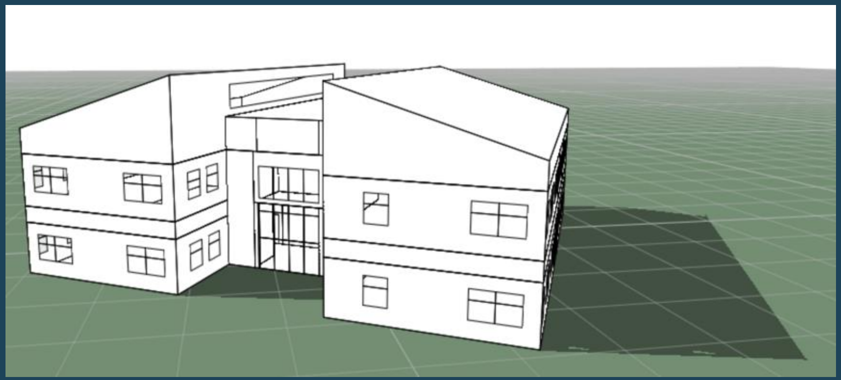
The optimisation problem is then defined as finding the minimum sum of RNRMSE for all outputs

$$\min_x f(x)$$

$$\text{where } x = \sum RNRMSE_{output}$$

Case study: Office building

- The helix building is an office type building with a floor area of 2,900 m2
- The building has natural ventilation and heating is provided by a biomass (main)
- Accommodates around 180 people.
- Controlled by two thermostats.
- The typical temperature setpoint is 23 C, with a night setback of 15 C.
- The thermostat has two typical days: working and weekend day.
- A server room is equipped with a cooling unit (mini-split).
- Currently, the building has 14 indoor environmental sensors at desk level
- Smart metering



Case study: Input priority matrix for ongoing commissioning

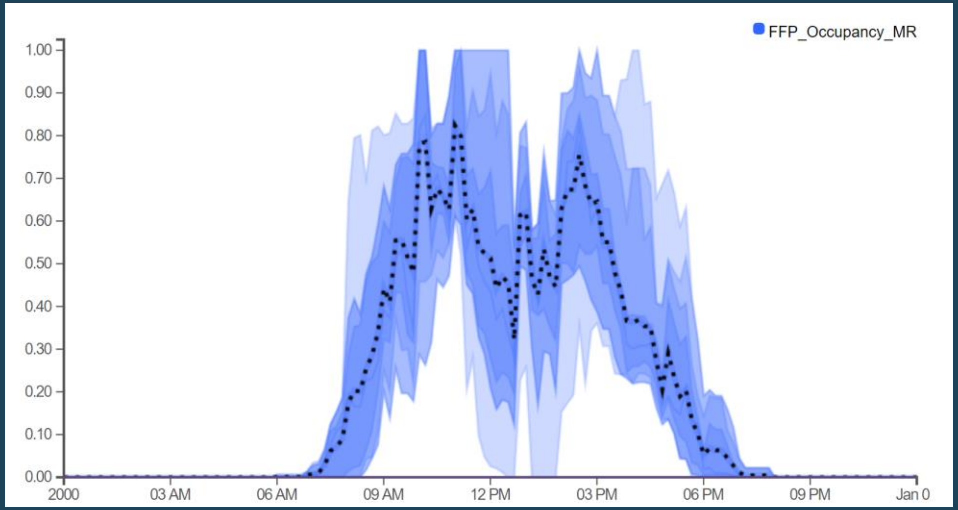
- The calibration period 01-October-2019 to 01-November-2019.
- Electricity use and space air temperatures hourly calibration.
- The application of the model is ongoing commissioning. Fixed parameters with high importance include HVAC layout and schematics and HVAC equipment and specifications.
- Relevant dynamic parameters are: room setpoints, site weather data and schedules (e.g. lighting, equipment, system and occupancy).

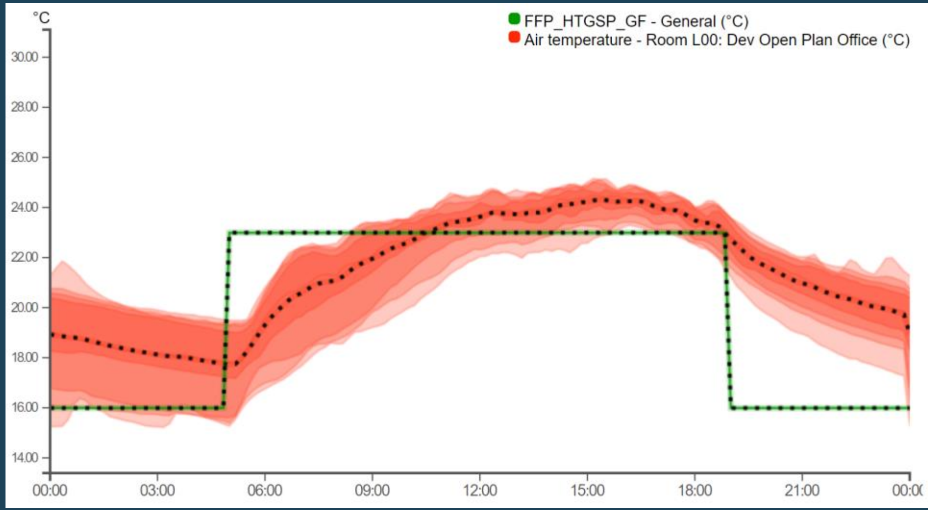
	Model Inputs	Ongoing Commissioning
Fixed Parameters	*Site Plan Drawings*	Medium
	Building Geometry (elevations, sections & floor plans)	High
	Construction details	Medium
	Air tightness/Infiltration	Medium
	HVAC Layout & Schematics	High
	HVAC Equipment Schedules & Specifications	High
	Lighting Layout	High
	Plug loads	High
Dynamic Parameters	*Room setpoints*	Medium
	Internal gains (Equipment, computers, etc)	Medium
	HVAC Control strategies	Medium
	Lighting Operation Profiles	High
	Equipment Operation Profiles	High
	System Operation Profiles	High
	Occupancy Profiles	High
	Site Weather Data	High
	Measured Data	
Measured	*Monthly Electricity Bills*	Low
	Monthly Heating Bills	Low
	< Hourly Electricity Data	High
	< Hourly Heating Data	High

Case study: Data-driven profiles for main occupied rooms

- Motion detection used as a proxy value to determine occupancy, lighting and equipment profiles. The occupancy trends are exported to the models via FFPs.

- Heating setpoints are derived from air temperature readings for weekday and weekends. A PP of the setpoint for each relevant room of the building was created



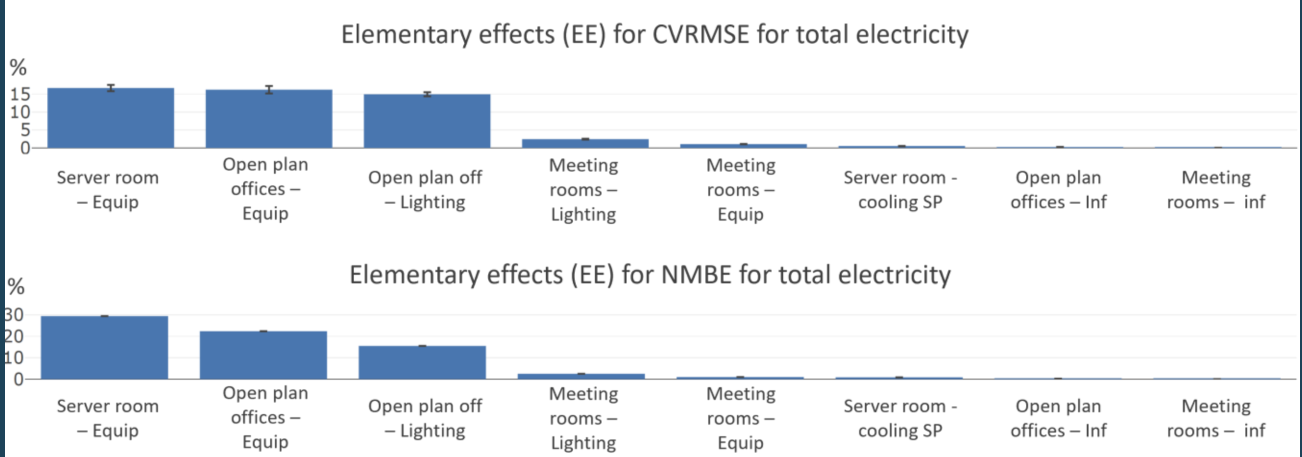


Case study: Determine and fine-tune high-priority parameters

Model parameters (**uncertain parameters**):

- Weather data from station located in the rooftop complemented with METAR data
- Ground temperature based on OAT 30-day moving average
- U-Values for Roof 0.155 W/m2K Walls 0.26 W/m2K
- **Initial estimated infiltration rate of 0.25 ACH**
- **Initial estimated lighting density 8 W/m2**
- **Initial estimated equipment 12 W/m2**
- **Initial server room cooling setpoint 23 C**

Parameter	Abs/Scale	Range
Open plan offices - Equip*	Scale	0.7-1.3
Open plan offices - Lighting*	Scale	0.7-1.3
Open plan offices - Inf*	Scale	0.7-1.3
Meeting rooms - Equip*	Scale	0.7-1.3
Meeting rooms - Lighting*	Scale	0.7-1.3
Meeting rooms - Inf*	Scale	0.7-1.3
Server room - cooling SP*	Abs	21-24
Server room - Equip*	Scale	0.5-2



Sensitivity analysis (350 sims).
The total calculation time was 3352 seconds.

Case study: Determine and fine-tune high-priority parameters

- 500 simulations were required
- The total calculation time was 4394 seconds.

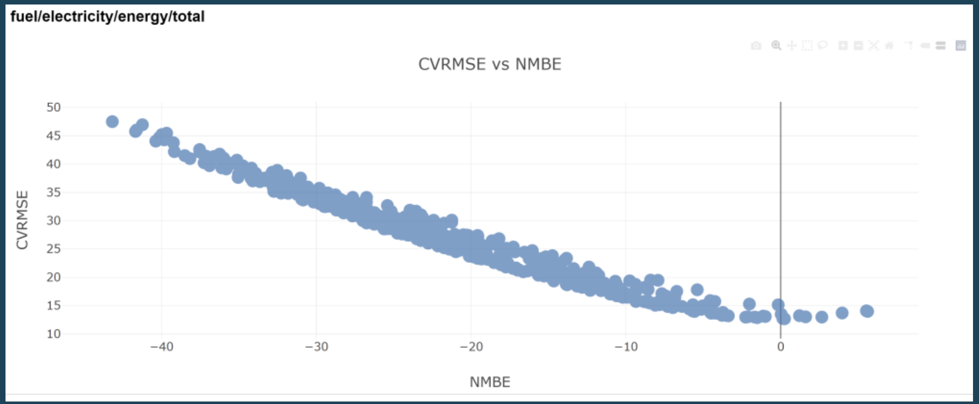
	CVRMSE before	CVRMSE after
Electricity	70.35% °C	**15.89%**
	NMBE before	**NMBE after**
Electricity	-40.48% °C	**-7.09%**

Parameter	Updated
Open plan offices - Lighting	6.81 W/m^2
Open plan offices - Equip	9.56 W/m^2
Open plan offices - Inf	0.24 ACH
Meeting rooms - Equip	9.18 W/m^2
Meeting rooms - Lighting	10.01 W/m^2
Meeting rooms - Inf	0.55 ACH
Server room - Equip	39.78 W/m^2
Server room - cooling SP	23.63 °C

Space (Group)	RMSE before	RMSE after
Nevis (Meeting room)	1.42 °C	**1.24 °C**
Cuillings (Meeting Room)	0.98 °C	**0.79 °C**
Grampian (Meeting Room)	**1.22 °C**	1.36 °C
Consultancy (Open area)	0.97 °C	**0.90 °C**
Support (Open Area)	1.07 °C	**1.06 °C**
Server room	0.72 °C	**0.47 °C**
Torridon (Meeting Room)	1.14 °C	**0.91 °C**
Training (Meeting Room)	1.32 °C	**1.29 °C**
Knoydart (Meeting Room)	1.26 °C	**1.24 °C**
Developers (Open Area)	1.22 °C	**1.08 °C**
Average	1.13 °C	**1.06 °C**

Conclusion

- The calibration methodology is model-agnostic and relies on a 3-step process
- The process relies on the use of specialised tools for Sensitivity Analysis, Optimisation-based fine-tuning and calibration metrics computation.
- A SA determined the most relevant variables for the optimisation-based parameter fine tuning
- The ACO algorithm was used to fine-tune the internal gains, infiltration rates and the server room setpoint.
- Electricity calibration achieves a NMBE -7.09% and CVRMSE of 15.89%.
- Air temperatures were improved in average 6% were kept within the 1.5 C recommended threshold.
- We provide evidence that metered data can benefit the model prediction outputs both at the energy and space level and that SA and optimisation tools can speed up the calibration process.



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Thank you

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