Evidence-based calibration of a building energy simulation model: Application to an office building in Belgium

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BES models & Energy Services Process

Benefits

Energy audit Inspection

+ Disaggregation of WBEU
+ Identification of ECMs

M&V of energy efficiency improvement actions

+ Evaluation of ECMs (when measurements are not feasible)

Lifetime commissioning & energy management

+ Lifetime commissioning and performance verification

+ Confirm user's knowledge of the building
+ Document baseline conditions

Limitations

- The model remains an abstraction of the reality

- The use of a BES model to study an existing situation may be tricky

- A compromise has to be found:

  Accuracy-simplicity-flexibility

- Availability and uncertainty on data used to check the validity of the model

Modeling an existing situation is a complex task

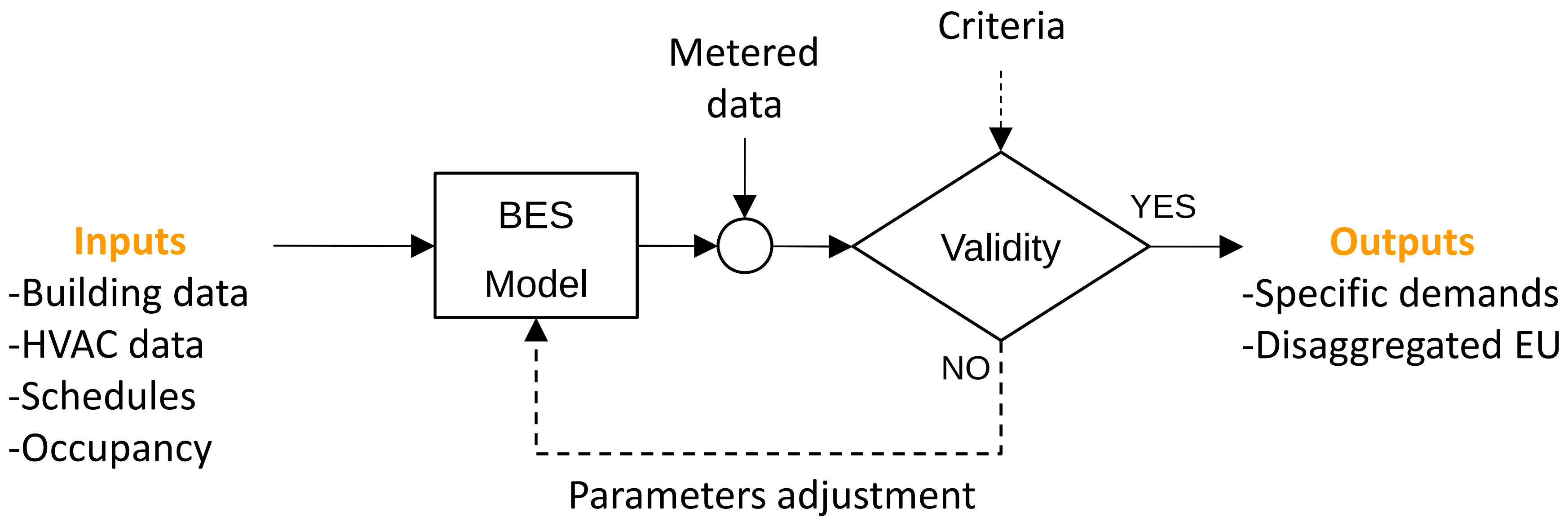
- BES model required to be able to closely represent the actual behavior of the building under study

- Use of non-adjusted models → discrepancies between 30% (total energy use) and 90% (individual components such as hot water use…)

→ Impossible to trust uncalibrated models when trying to analyze an existing situation

What is model calibration ?

Model calibration = fitting of a building energy simulation model to an existing situation



→ Highly undetermined problem

Objectives of this work

- Development of a new simplified building energy simulation model dedicated to existing buildings and adapted to calibration

- Development of an evidence-based calibration procedure including sensitivity, measurement and uncertainty issues

→To support energy use analysis

Evidence-based calibration for energy use analysis

Simple BES model

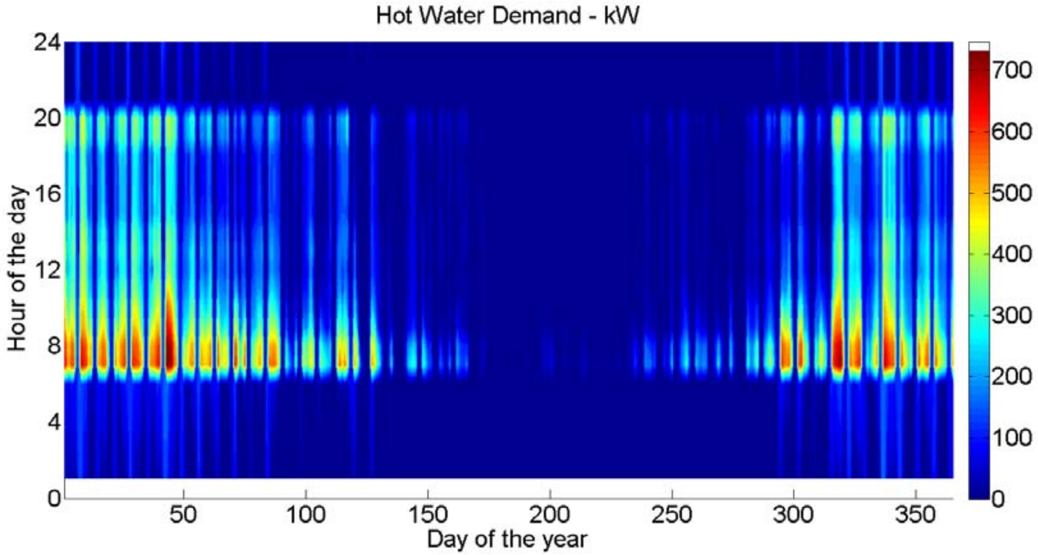
Evidence-based calibration

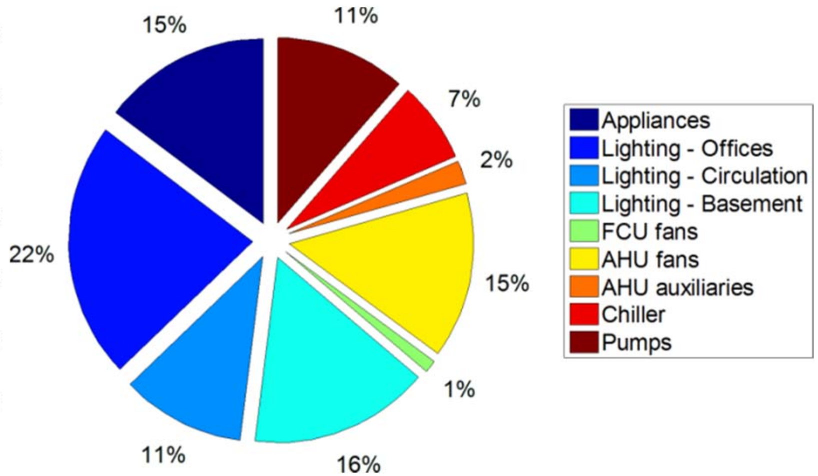
Case Study

Conclusion and perspectives

Required outputs for energy use analysis

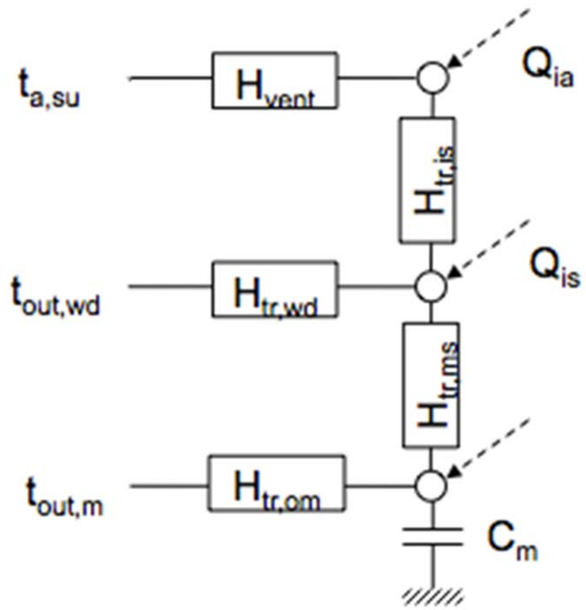
- Specific energy demands (per zone, per use…)
- Specific final energy consumptions (per zone, per use…)
- Disaggregation of final energy use





Simplified BES model

- Simple multizone building model (simple hourly method ISO/EN 13790)
- Moisture balance:Water capacitance method
- Secondary HVAC system
  - All Air (CAV+RH/VAV+RH)
  - Air / Water (CAV+TU)
  - All Water (TU)
- Primary HVAC system
  - Hot water boiler
  - Air or water cooled chillers
  - Heat rejection devices

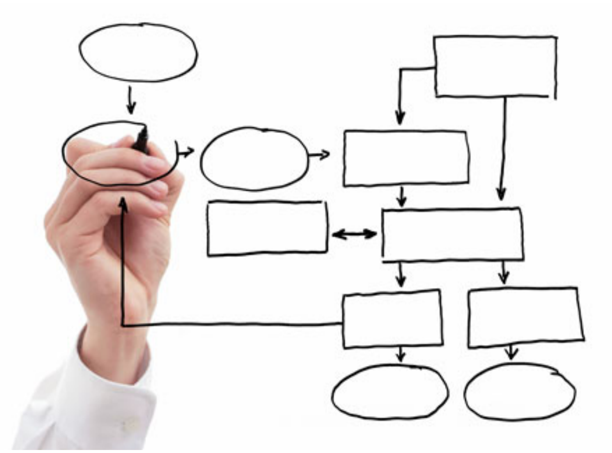


Sensible thermal zone model

Evidence-based calibration for energy use analysis

Simple BES model

Evidence-based calibration



Case Study

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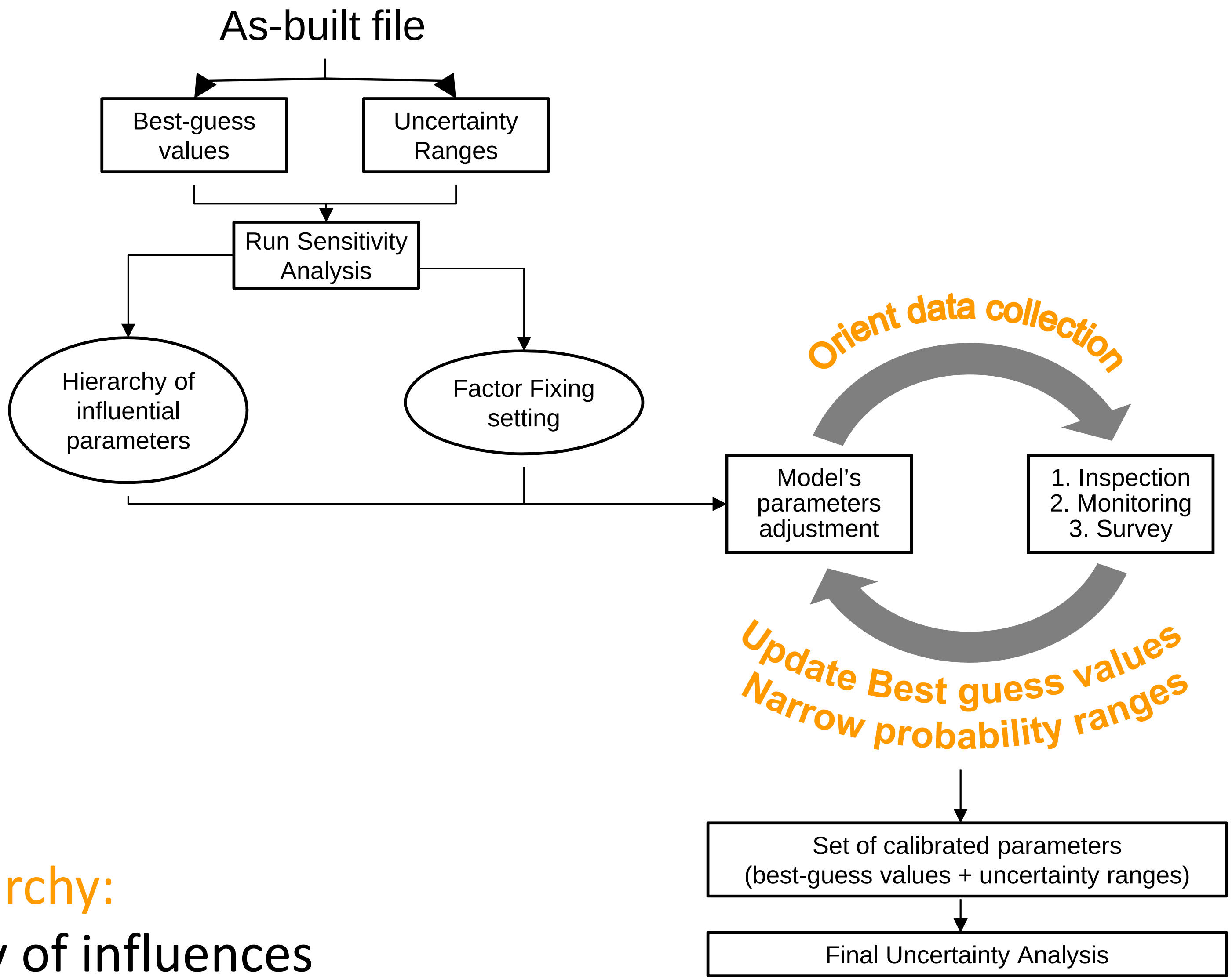
Problems encountered in practice

- The adjustment of the parameters is generally not systematic but is related to data availability and skills of the user
- Final quality of the "calibrated" model is generally not (or badly) controlled
- Sensitivity and uncertainty are crucial issues but generally not studied
- Automated methods are not commonly used and the available too global billing data do not generally allow proper application of optimization methods

→ non-realistic and bad representation of the behavior of the system

Evidence-based calibration process



2 types of hierarchy:

- Hierarchy of influences
- Quality of information (monitoring > observation > estimation)

Validity of the calibrated model

Validity checked by means of:
- Visual verification (plots)
- Statistical criteria

$$MBE = \frac{\sum_{i=1}^{n} (Q_{pred,i} - Q_{data,i})}{n Q_{data}}$$

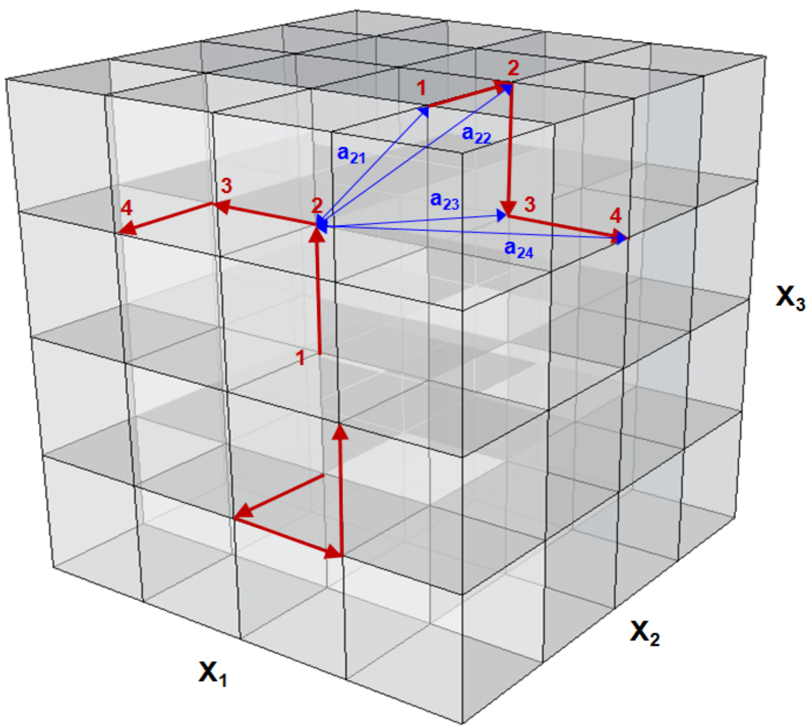
$$CV(RMSE) = \frac{RMSE}{Q_{data}} = \frac{\sqrt{\frac{\sum (Q_{pred,i} - Q_{data,i})^2}{n}}}{Q_{data}}$$

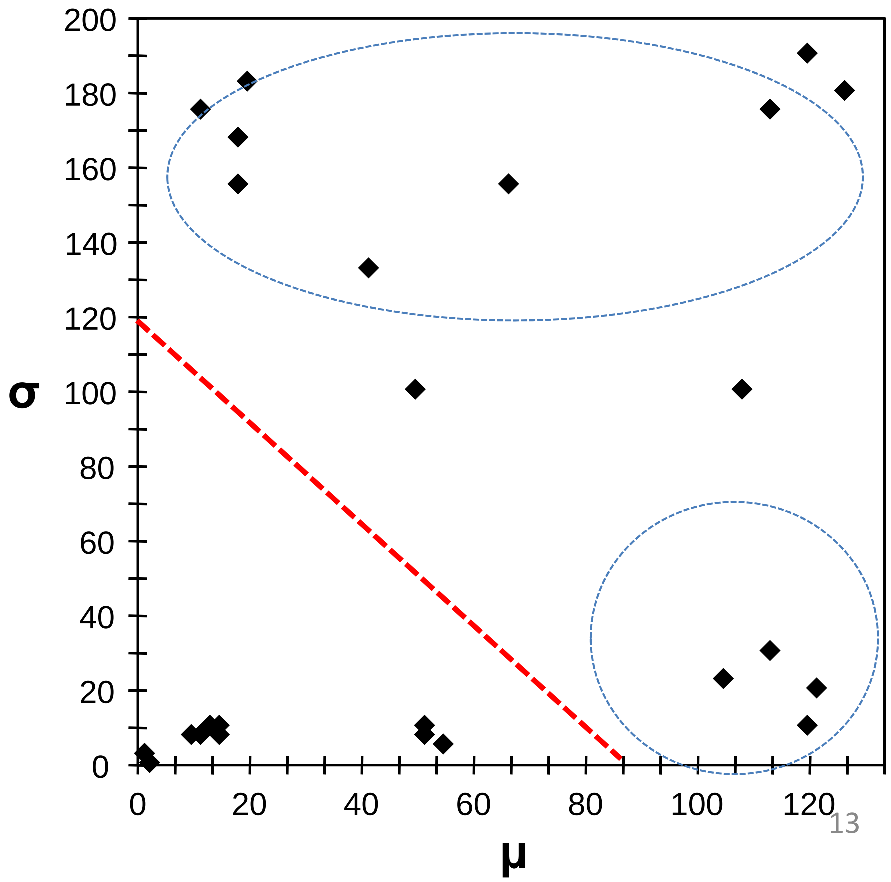
Criteria for estimation of energy and demand savings

Index	Waltz (2000) (%)	ASHRAE 14 (%)	IPMVP (%)	FEMP (%)
MBEyear	+/- 5			
MBEmonth		+/- 5	+/- 20	+/- 5
CV(RMSE)month		+/- 15	+/- 5	+/- 15
MBEhour		+/- 10		
CV(RMSE)hour		+/- 30		

SA: Morris method for factor fixing

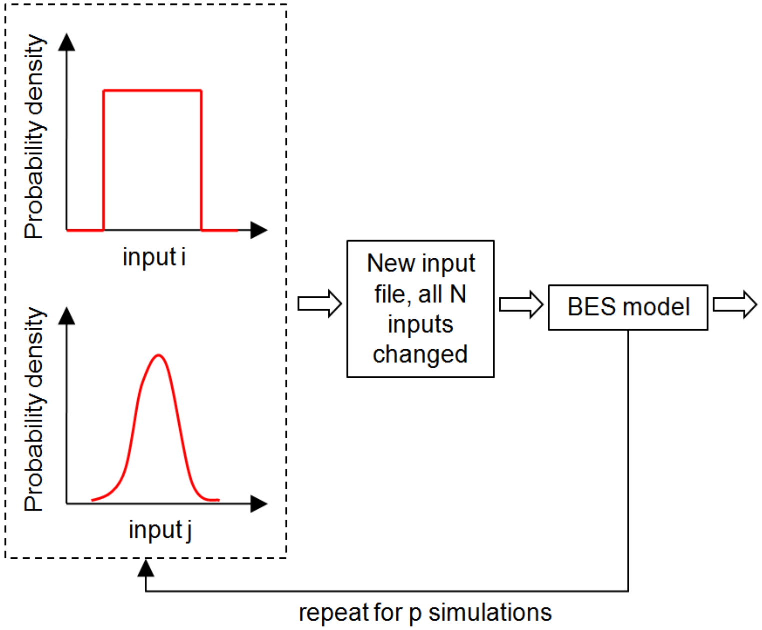
- Morris method = Screening Method (adapted to Factor Fixing)
- Global (≠ Local) method
- Definition of trajectories covering the parametric space
- Computation of the « Elementary Effect »

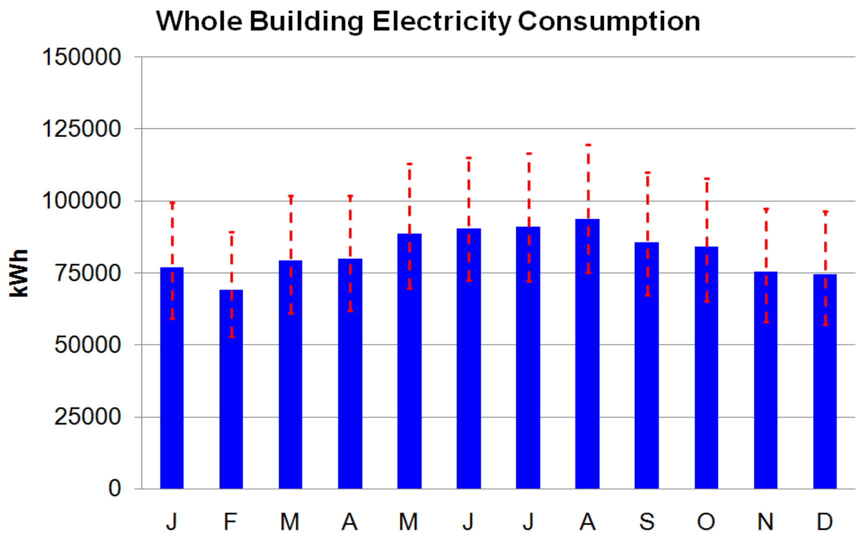




UA: Uncertainty on the ouputs

- Use of the LHMC method
- Final uncertainty (probability) ranges are used to generate a sample (p = 100 runs)
- Uniform or Normal PDF can be used





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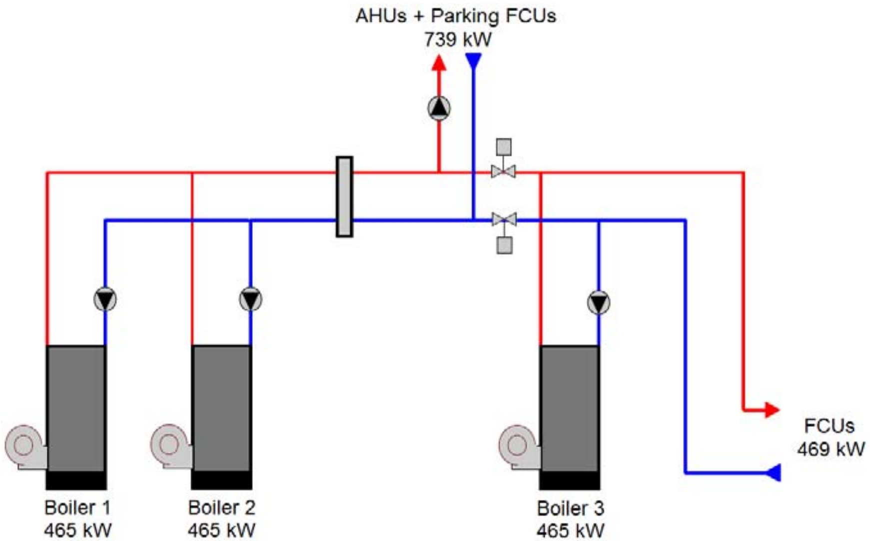
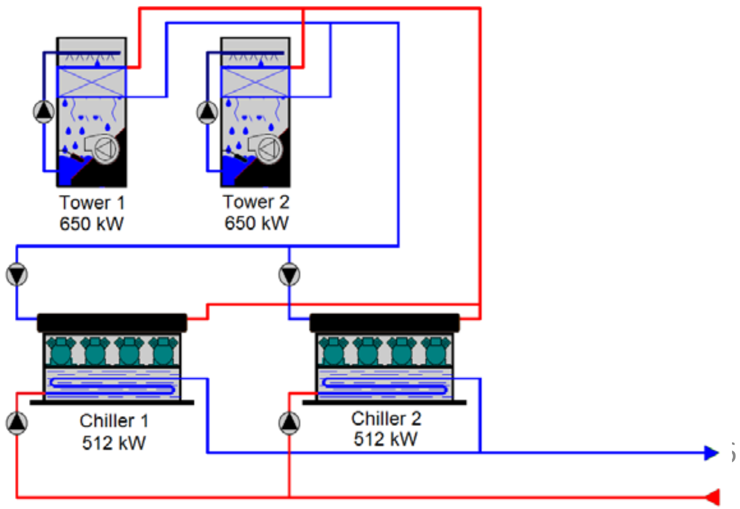
Case study

- Typical office building located in Brussels (D+ energy rating; Avg : D)
- 10100 m² of usable floor area
- CAV (Adiab. Humidification)+ FCU
- Basement parking heaters (141 kW)
- 3 x Natural Gas Boilers
- 2 x Water cooled chillers
- 2 x IC Cooling Towers
- 3 years of consumption data: 2008 to 2010



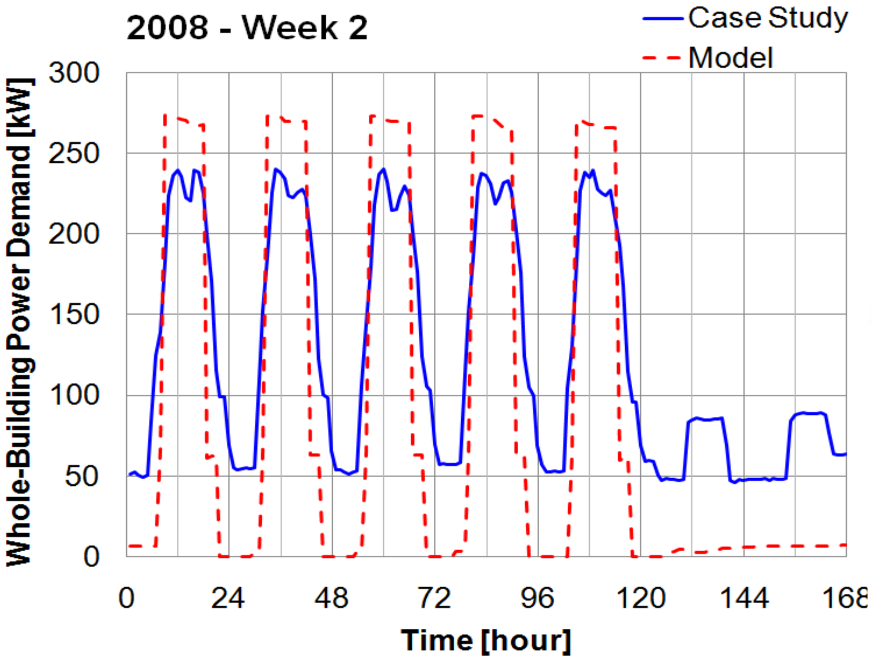


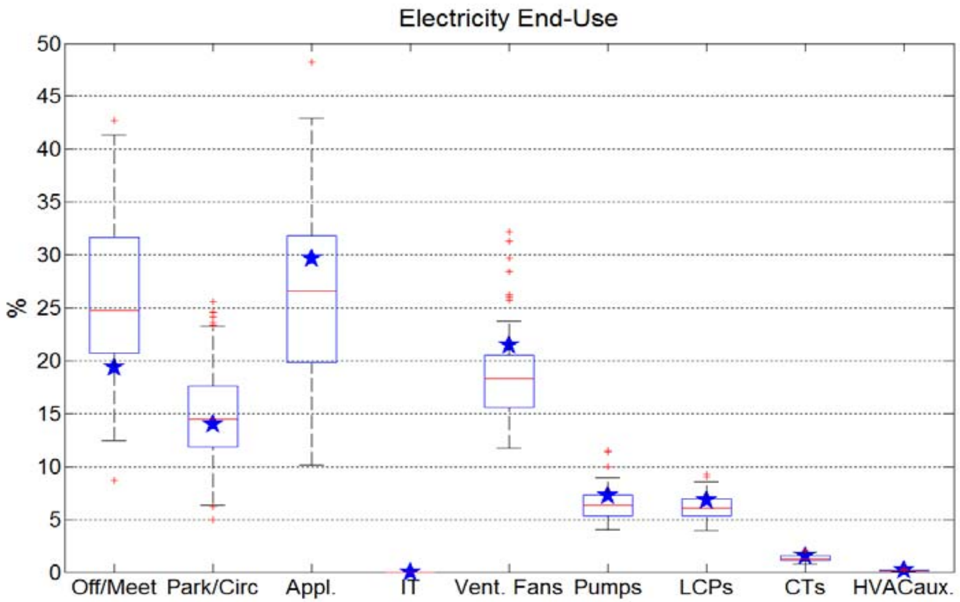
Step 0 – As-built input file

Complete description of building and HVAC system (nominal perf.)

No information about occupancy and operating conditions/schedules

- Acceptable representation of gas & WBE cons.
- Bad representation of peak/off-peak split
- Large uncertainties on energy end-use

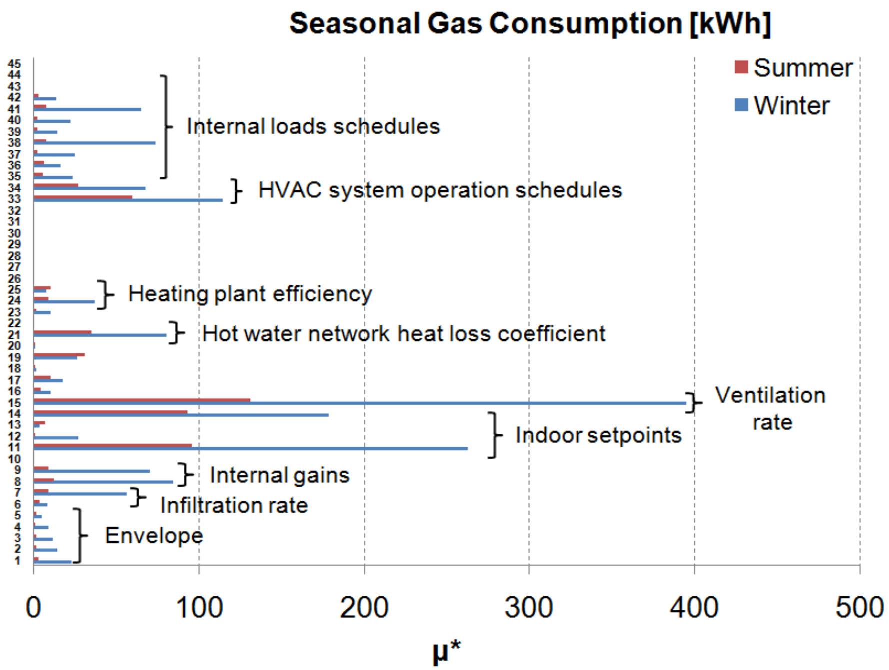


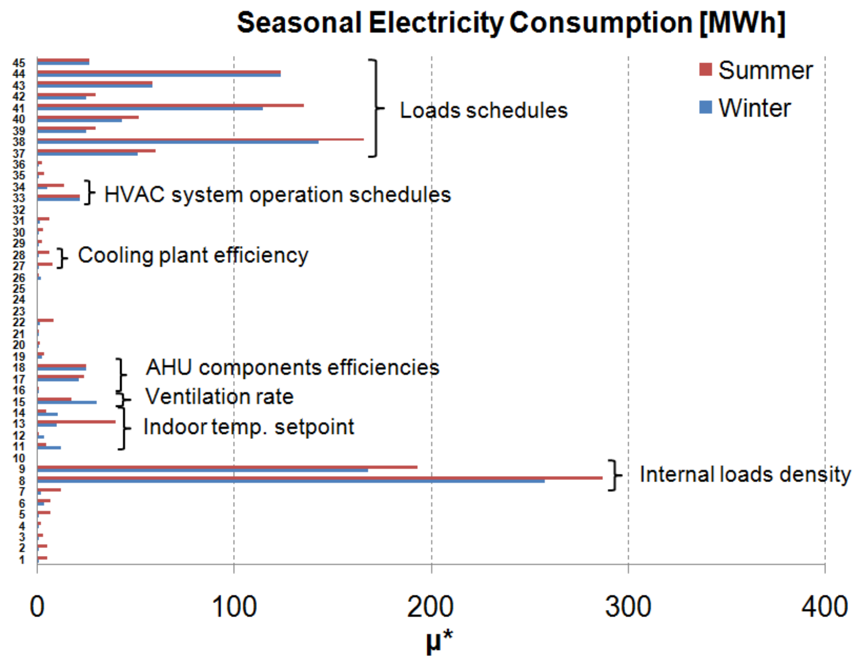


Preliminary sensitivity analysis

Focus on:

1. Internal loads (power and schedules)
2. HVAC system operation (setpoints and schedules)
3. HVAC components efficiencies





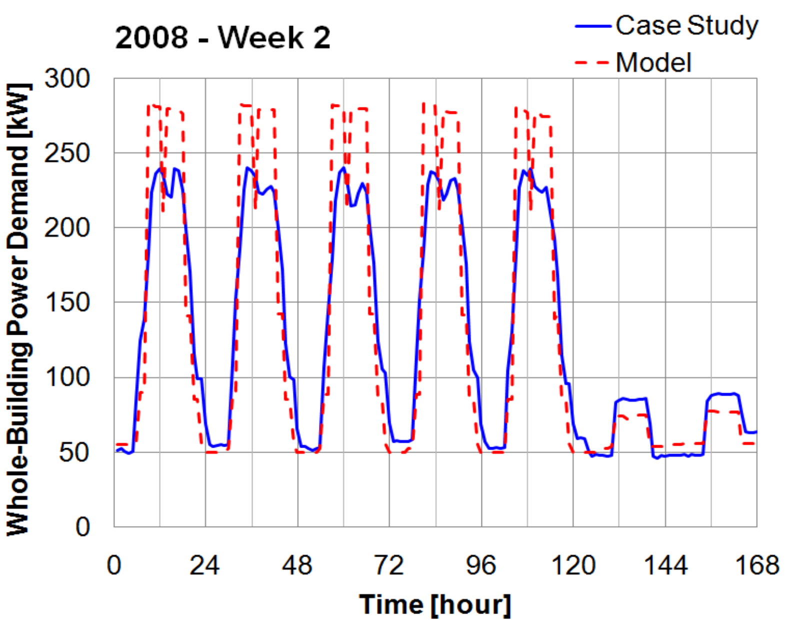
Step 1– Inspection

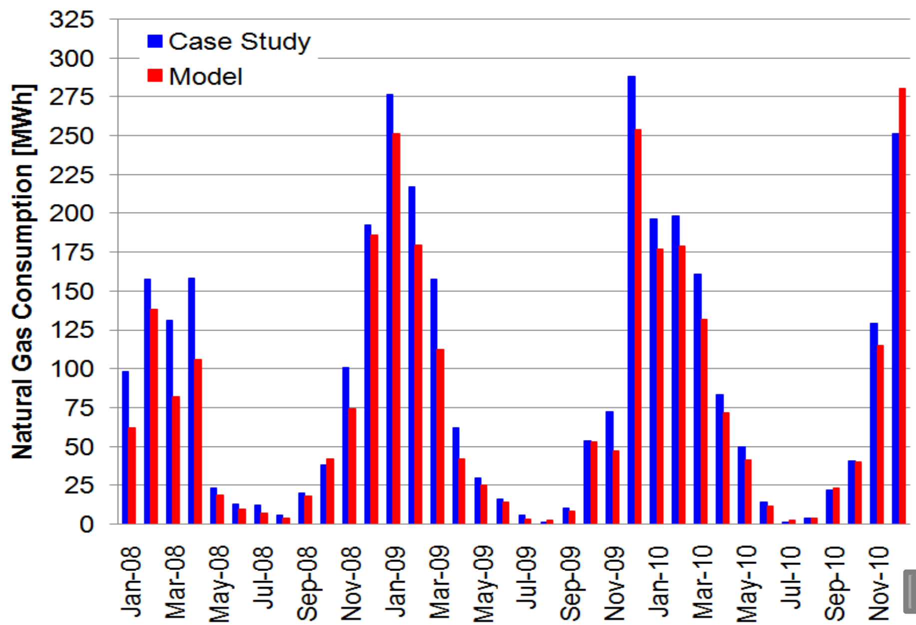
Analysis of the BEMS (system schedules and theoretical setpoints)

Survey of installed internal loads densities & IT power

→ Update of concerned parameters & narrowing of the uncertainty ranges

- Acceptable representation of gas cons.
- Good representation of offpeak cons.
- Overestimation of peak cons. (hyp: 100% occupancy/use)





Step 2– Monitoring phase

Winter period only

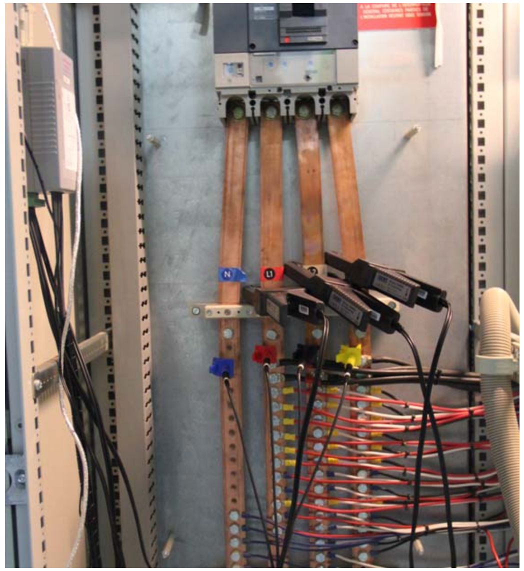
Power metering

- Floor level (lighting & appliances)
- HVAC system parts

Lighting & Appliances use

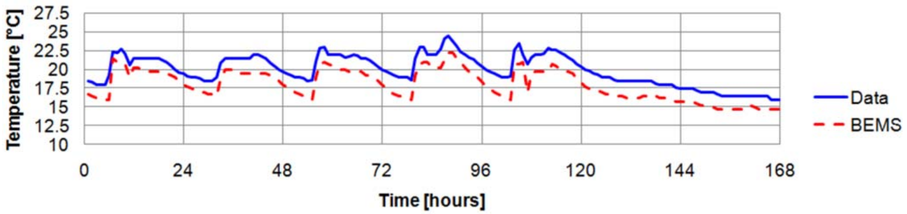
Pumps and fan operation

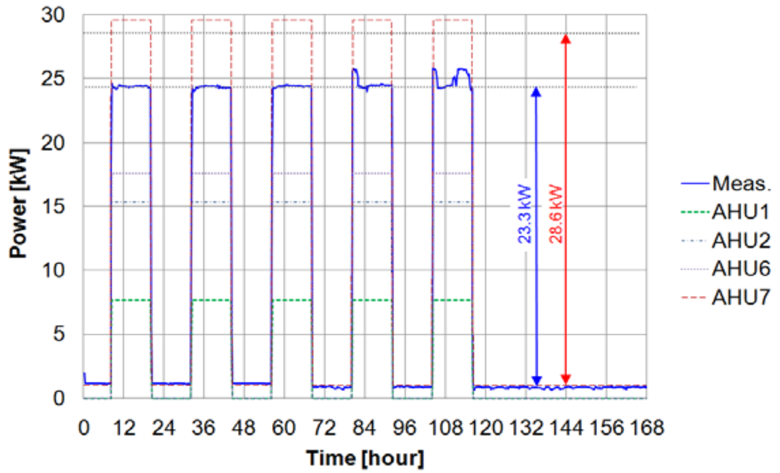
Indoor Temp. & RH

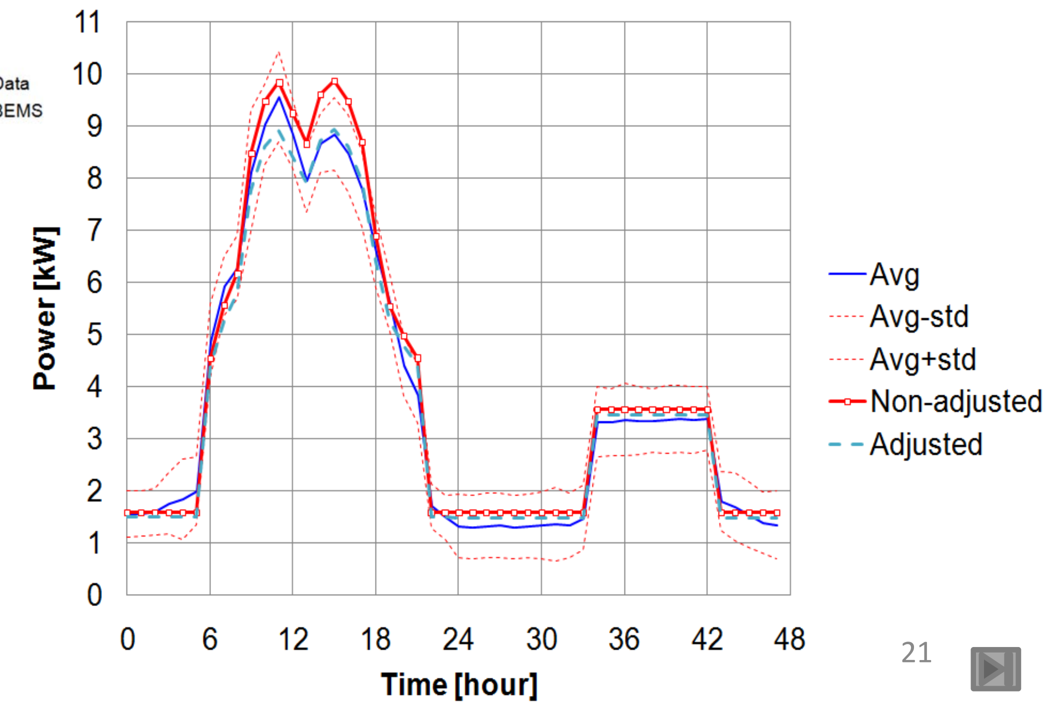


Step 2– Monitoring phase

- Analysis of floor-level power demand → **hourly operation** profiles (max. 85% use rate)
- Achieved temperature: **1.6°C over BEMS recording**
- Achieved humidity level: **42% (avg) instead of 50%**
- Fan cons.: **82% of nominal absorbed power (as-built)**
- Pump power and operation: ok



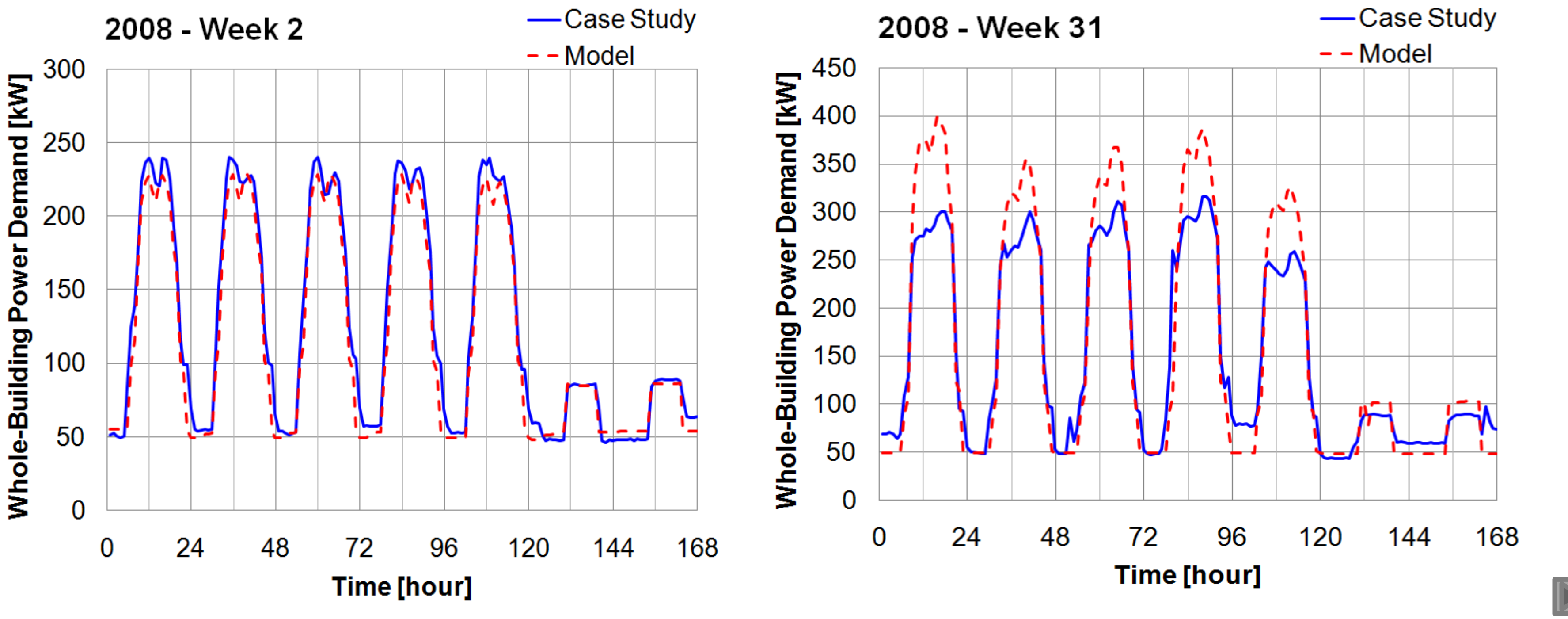




Step 2– Monitoring phase

→ Update of concerned parameters & narrowing of the uncertainty ranges

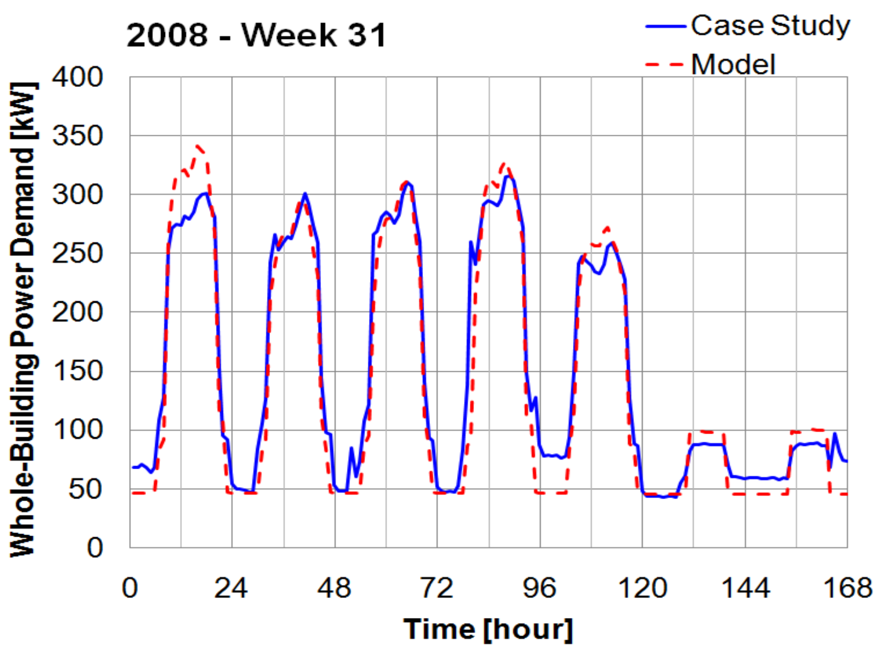
- Good representations of both gas and peak/offpeak electricity cons. (MBE & CV(RMSE) < 6%)
- Good representation of winter power demand
- Overestimation of summer power demand (combined effect of less intensive lighting use and holidays ?)

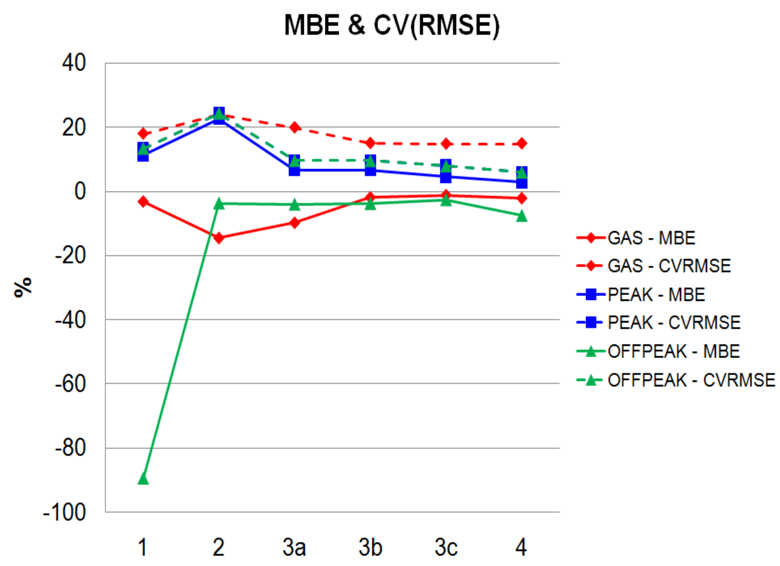


Step 3 – Occupants survey

Identification and estimation of summer holidays period

→ Update of concerned parameters & narrowing of the uncertainty ranges



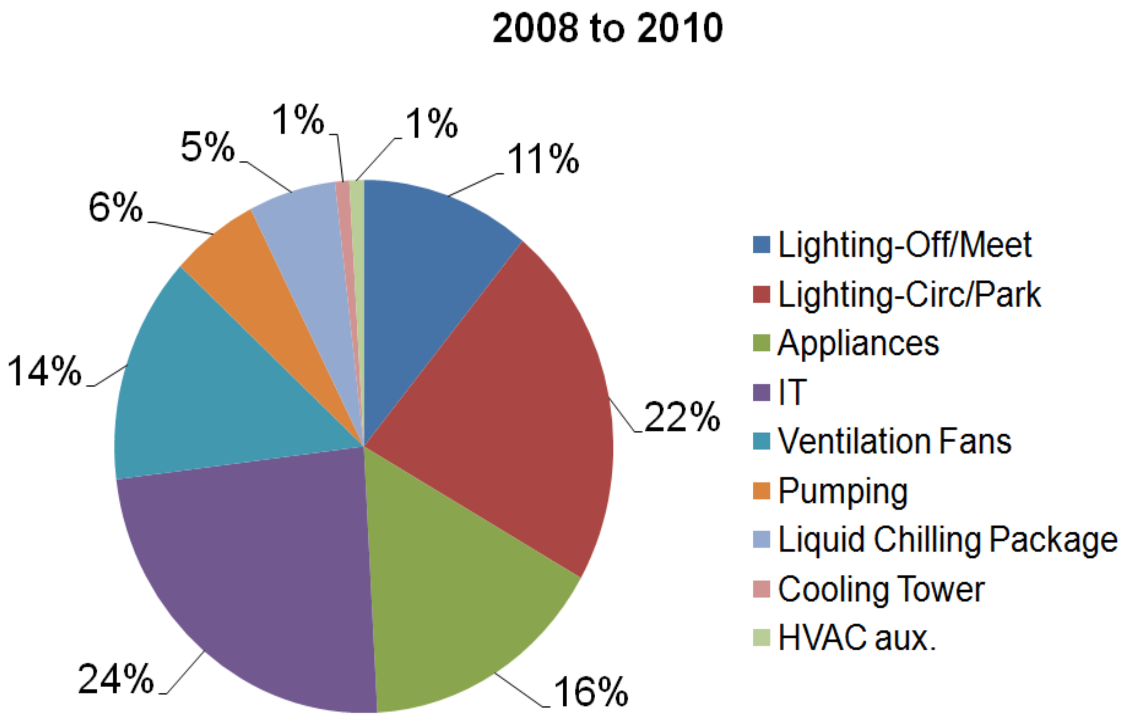


ASHRAE G14 – 2002 criteria

- Monthly consumptions: ✔
- Hourly WBE demand : ✔

Step 3 – Energy end-use analysis

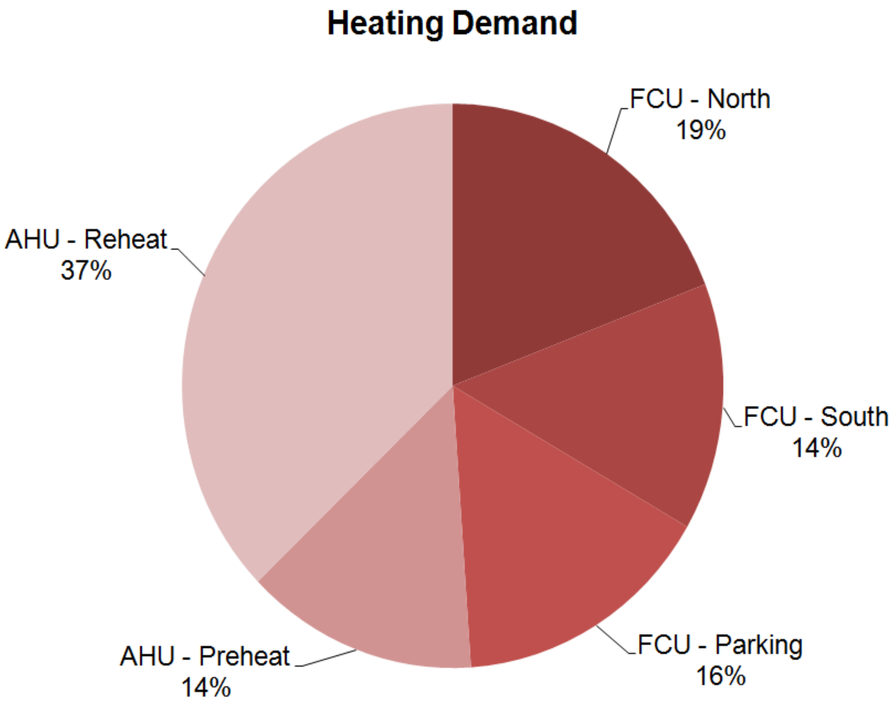
- Uncertainly is drastically reduced
- Main electricity consumers:
  - IT
  - Lighting in non-occupancy zones
  - Offices appliances & lighting

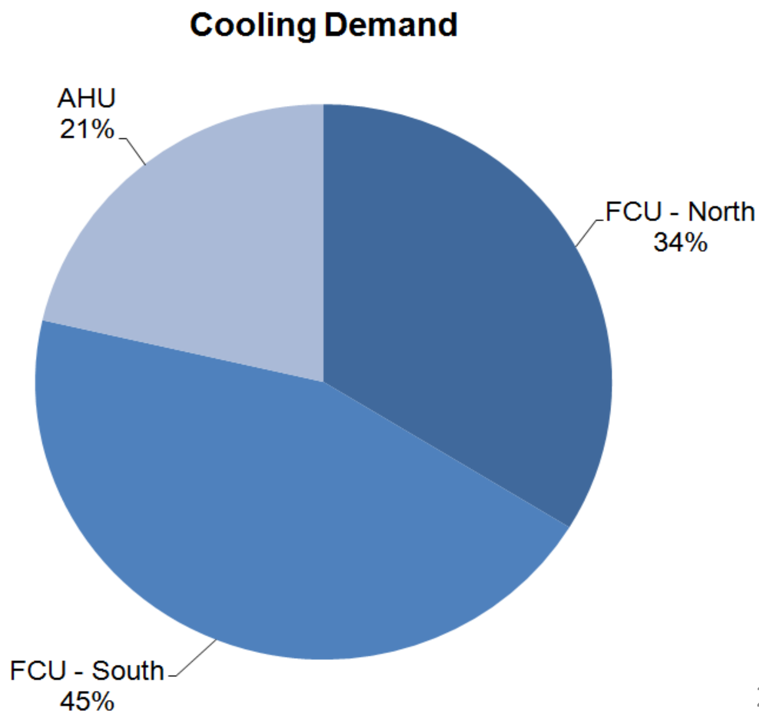


Step 3 – Energy end-use analysis

- Parking heaters: 16% of heat demand
- AHU reheat: 37% of heat demand (high setpoints: 20 to 25°C)
- Offices FCUs: 23% of heat demand (high avg setpoint: 22.6°C)

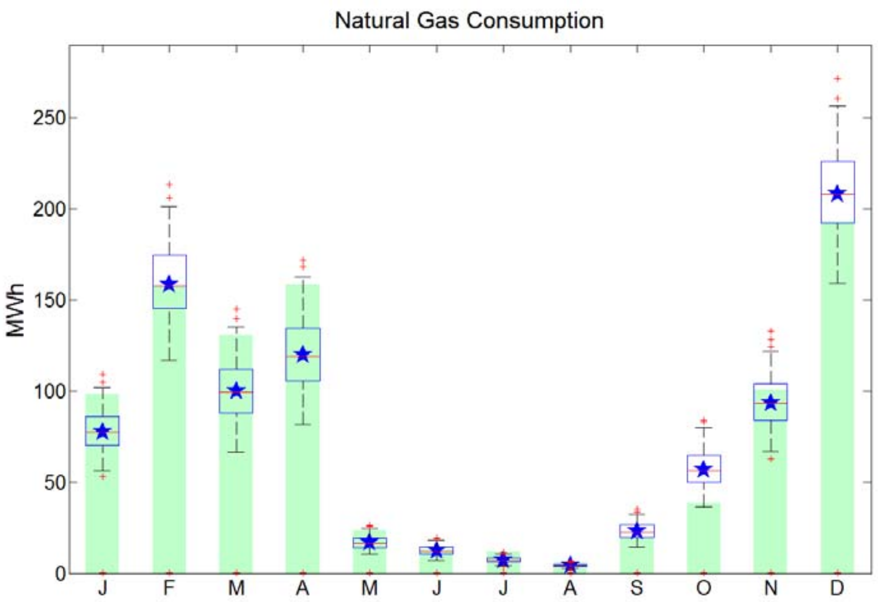
- Inverse conclusions for cooling demand (FCUs > AHU)

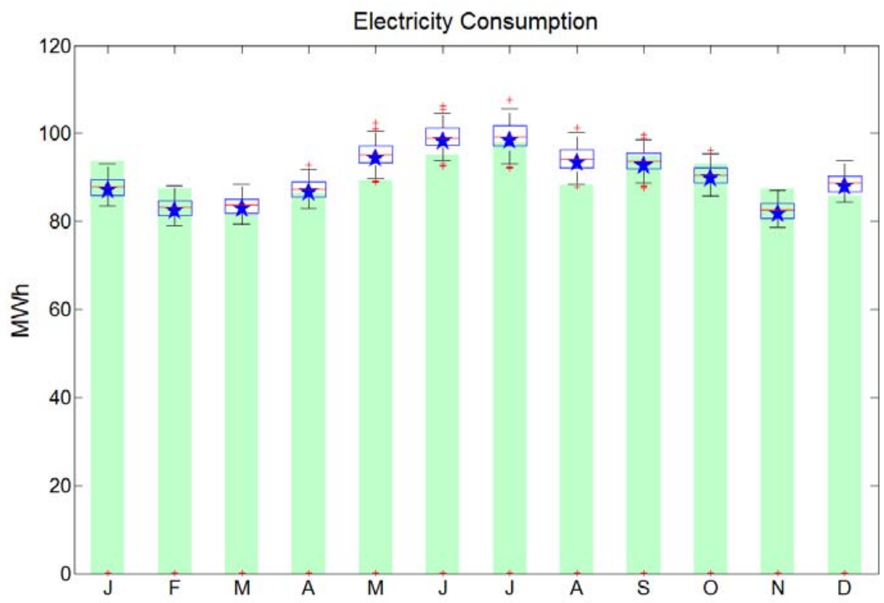




Final uncertainty

- Monthly gas consumption: 11% (December) to 22% (July) stddev
- Monthly electricity consumption: 2 to 3% stddev
- Uncertainty on predicted gas consumption is significant
- Possible improvement: measurement of ventilation flow rate





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Simple BES model

Evidence-based calibration

Case Study

Conclusion and perspectives

The developed tool and methodology provide encouraging results

- Calibration = Highly undetermined problem + complex interactions + very limited information
  - → Perfect automated calibration method is not likely to appear
- Development of a systematic & flexible evidence based method
  1. Hierarchy among influential parameters (screening and factor fixing)
  2. Hierarchy among quality of information (narrowing of uncertainty ranges)
- The methodology integrates sensitivity (Morris) and uncertainty (LHMC) issues
- Validity of the calibration model has to be evaluated by means of:
  - Visual verification
  - Statistical indexes

The developed tool and methodology provide encouraging results

- Calibration levels have been defined and characterized
  - Step 0: bad representation of energy use
  - Step 1: improvement of the model but uncertainties >>
  - Step 2 & 3: acceptable representation of energy end use (but uncertainties on heating and cooling needs may remain significant)

→ Future of BES model calibration is directly related to more common use of energy metering

Perspectives and future research

- Use of the calibrated model to orient future data collection, support commissioning, continuous perf. verification…

- Use of more advanced uncertainty analysis methods to study interactions between parameters (variance based methods…)
- Envisage automated adjustment to refine calibration

- Second monitoring campaign: cooling operation, cooling system performance, ventilation rate
- Evaluation of ECMs on case study building