Energy performance of buildings based on short-term weather forecast

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47. Međunarodni kongres i izložba o KGH, Beograd, 30.11–2.12.2016
47th International HVAC&R Congress and Exhibition, Belgrade, Nov.30–Dec.2 2016

Introduction

› Energy conservation in buildings – one of top priorities

› 37% final energy consumption in EU

› 40% of primary energy consumption in USA

› 50% of energy consumption in Serbia

› How to reduce energy consumption?
  - Improving envelope
  - Energy efficient HVAC
  - Renewables
  - What about improving system operation? – large potential

Introduction

- In order to improve HVAC system operation – models of buildings and related systems necessary
- Building energy modeling:
  - Short-term for daily operation, scheduling and load shifting / short-term weather forecasts
  - Mid-term for system maintenance / typical meteorogical year
  - Long-term for system planning / typical meteorogical year
- Short-term modeling + optimization:
  - White-box incorporated in building simulation tools / what parameters to optimize? – sensitivity analysis can give answer
  - Black-box
  - Gray-box

Sensitivity analysis - SA

- Determines parameters which affect model output(s) the most
- In calibration – parameters that should be double checked and measured
- In operation – parameters to be optimized – reducing number of variables
- Determines the contribution of individual “uncertain” parameter to the model output (energy consumption i.e.)
- 3 types of SA:
  - Screening – reducing number of input parameters
  - Local – one parameter at time
  - Global – all parameters simultaneous
- Global SA – usually Monte Carlo
  - Sampling technique

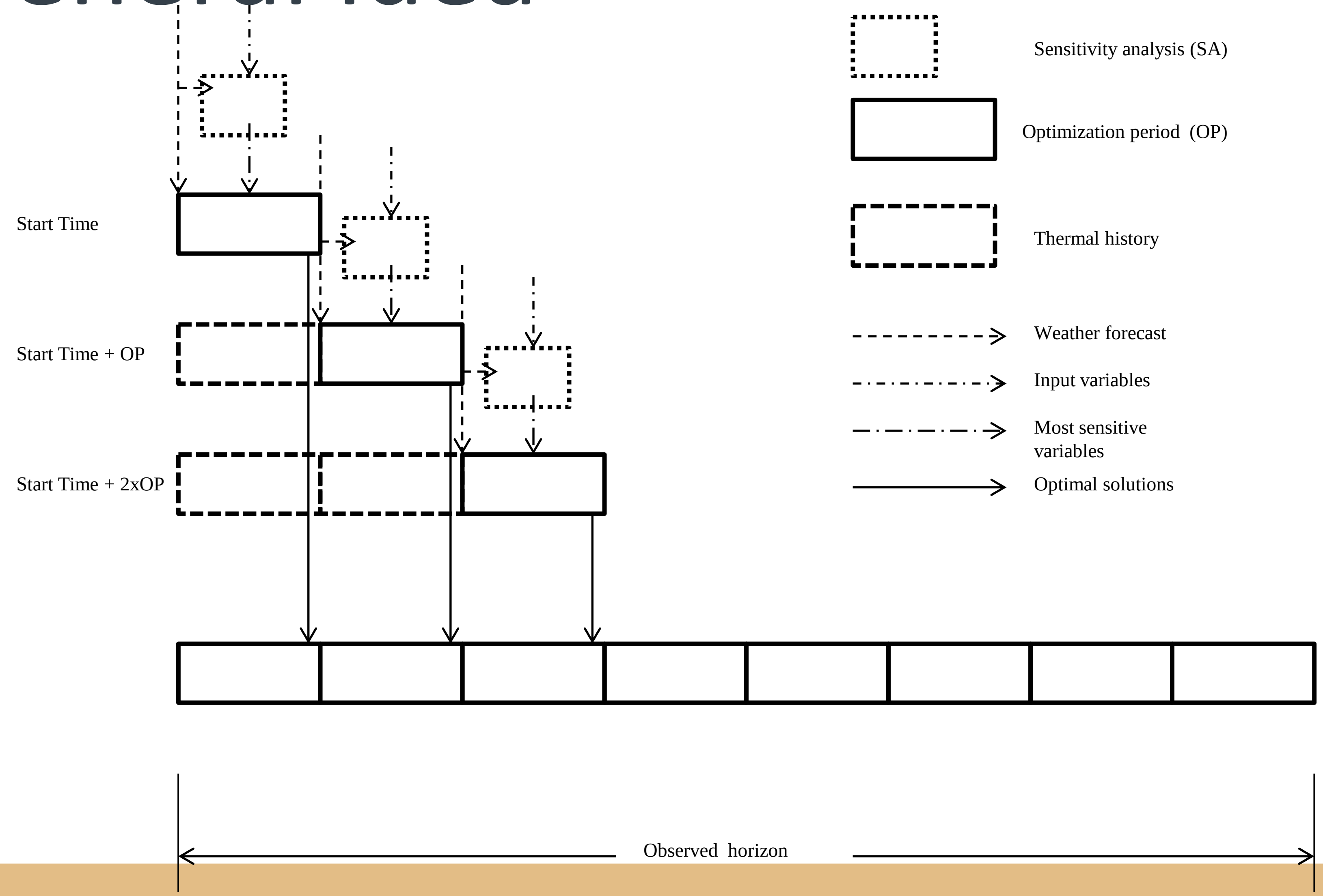
SA methodology

- 6 steps:
  - determine variations (probability distributions) of input parameters
  - sampling
  - create building energy models based on generated samples
  - collect simulation results
  - run sensitivity analysis
  - presentation of sensitivity analysis results

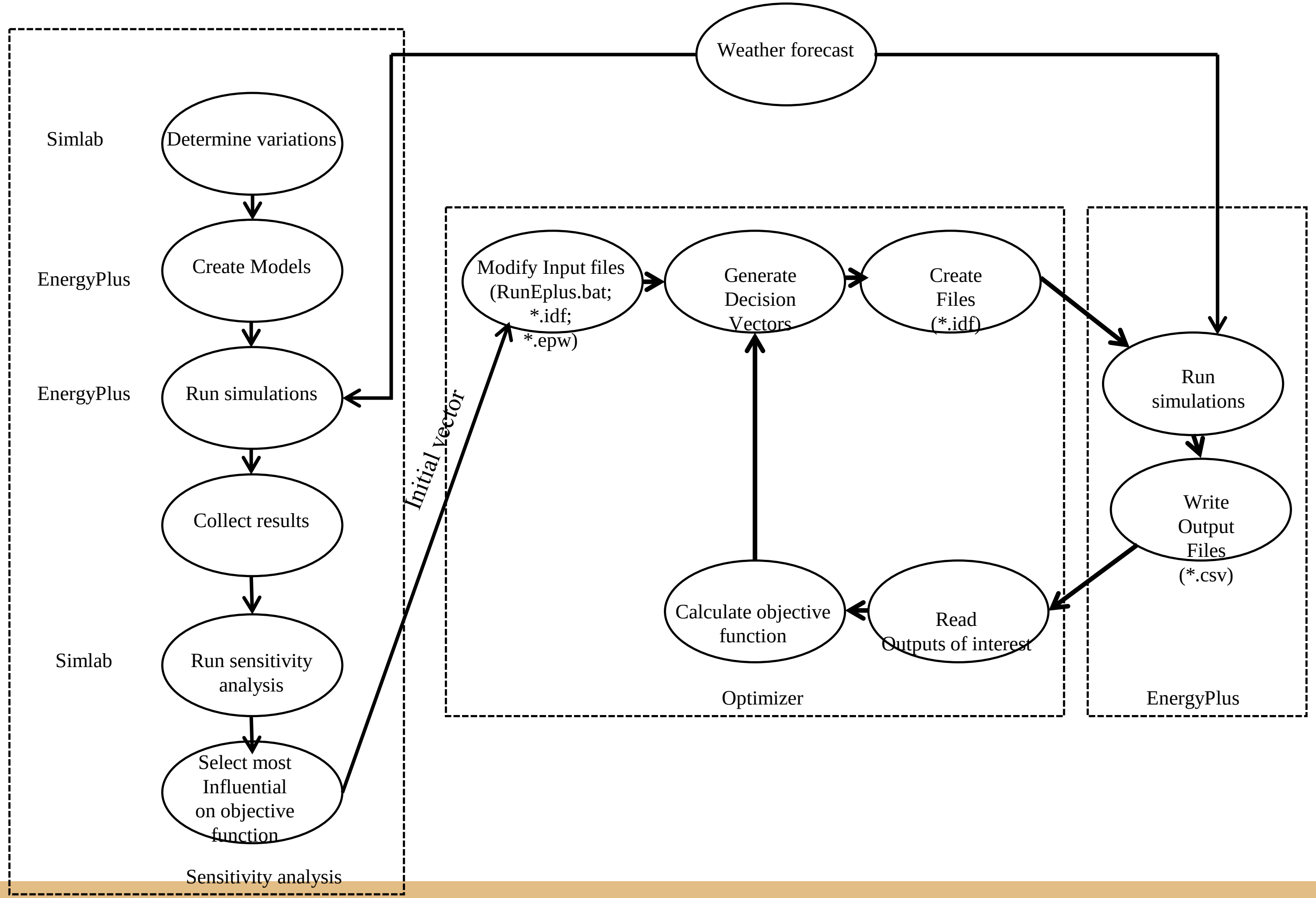
SA methodology - workflow

- Input variations – SimLab/SPSS/R…
- Sampling – SimLab/SPSS/R…
- Building models – EnergyPlus (Parametric)
- Collect simulation results – custom postprocessors
- Sensitivity analysis – SimLab
- Presentation of results – MSExcel…

General idea



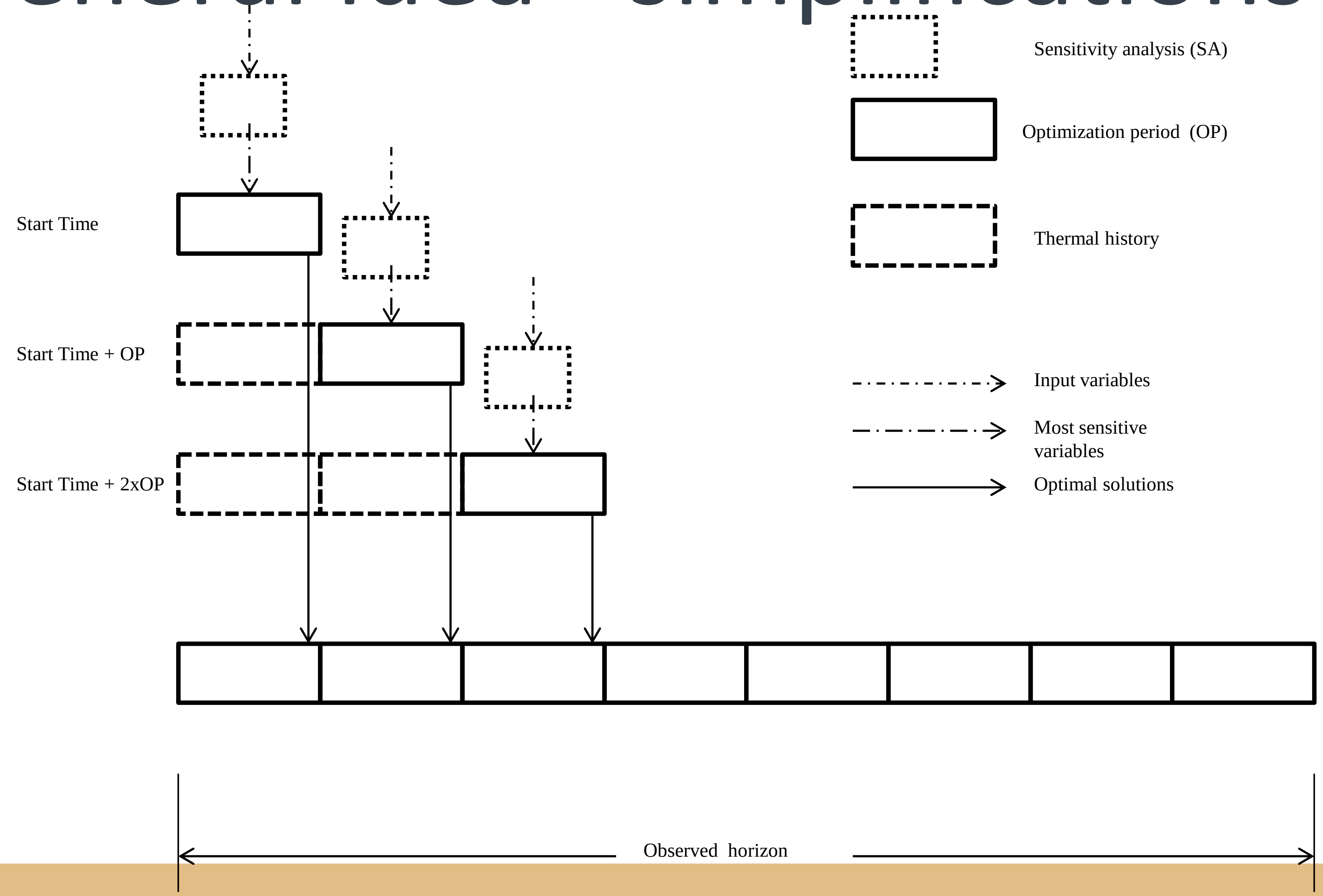
General idea



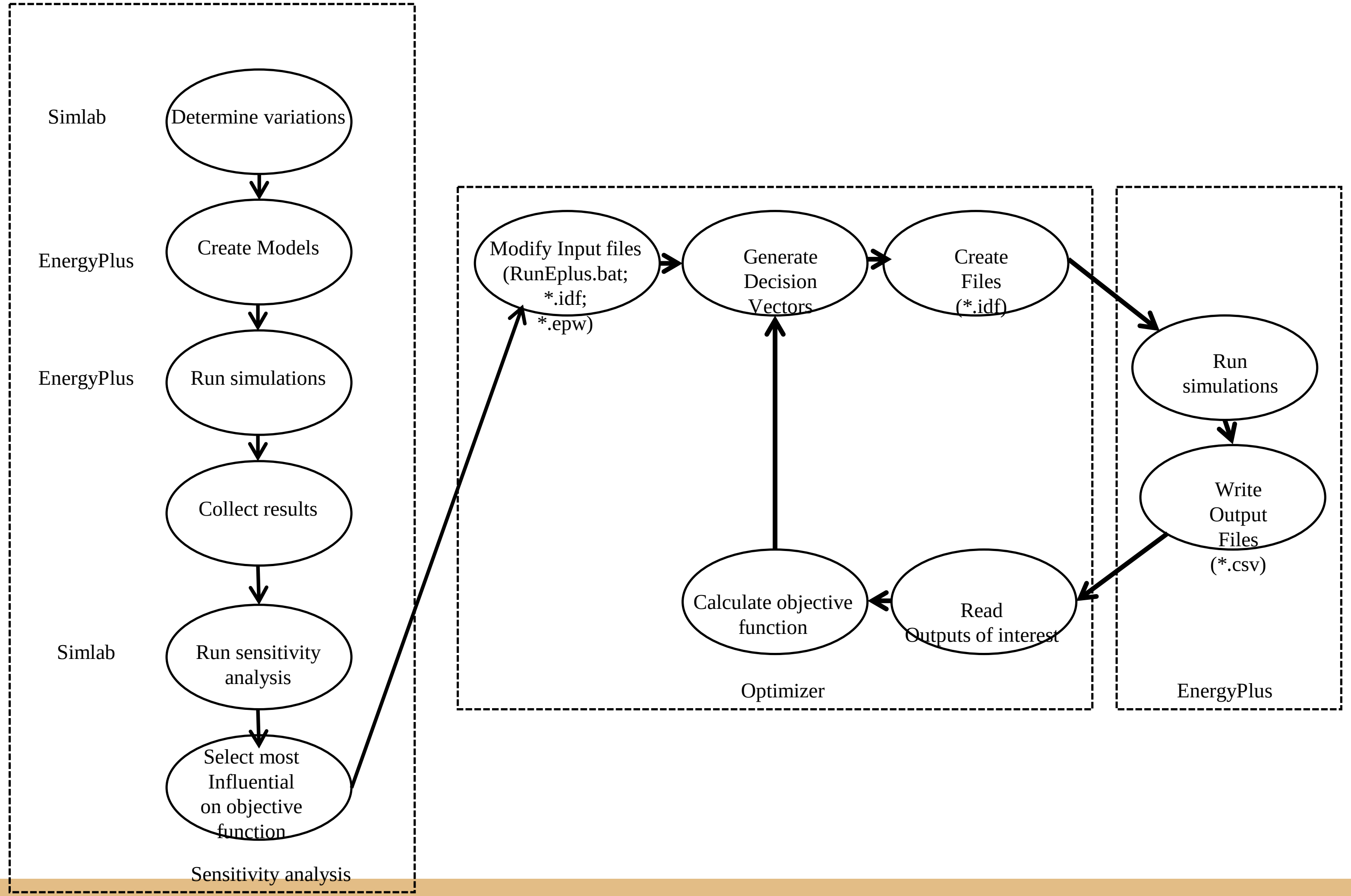
Weather forecasts

- Major source of uncertainties especially considering all weather parameters (temperature, wind speed and direction, and global radiation)
- Not easily available
- Numerical models for predetermined grid – location of the particular building could be problem
- Updated on every 12 hours, very hard to implement optimization with BEPS tools
- Pre-processing necessary

General idea - simplifications

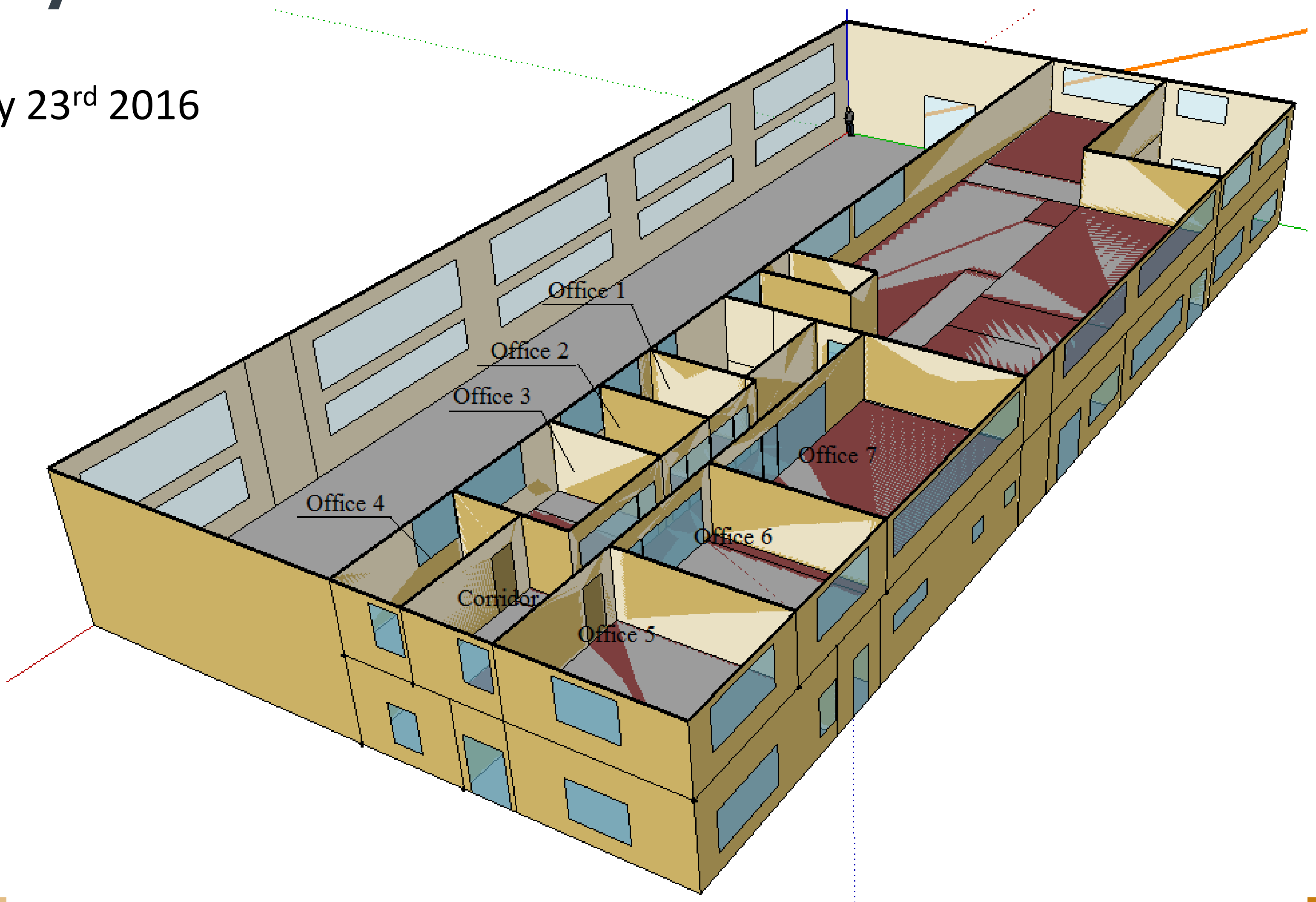


General idea - simplifications



Case study

› Run period: January 18th – January 23rd 2016



Case study – objective function

$$\min E[kWh] = E_B \times 1.1 + (E_{SF} + E_{RF}) \times 2.5$$

$$-0.5 < TCF < 0.5$$

$$TCF = \sum_{i=1}^{i=8} (\min PMV_i) \times \frac{N_i}{N_{tot}}$$

Case study – step 1

- Perform SA on input variables for two days in order to find most influential on the objective function of optimization process
- Equipment availability treated as sensitive
- Supply water temperature treated as sensitive
- Each day divided in 6h periods (occupied and unoccupied periods divided) – all variables within it have the same values and respective distribution (normal or uniform)
  - Airflow – 1 variable / normal distribution
  - AHU supply temperature – 8 variables / normal distribution
  - Manufacturing area temperature set-point – 8 variables / uniform distribution
  - Electronic production temperature set-point – 8 variables / uniform distribution
  - Offices 4 – 7 & corridor temperature set-point – 40 variables / uniform distribution

Case study – step 1

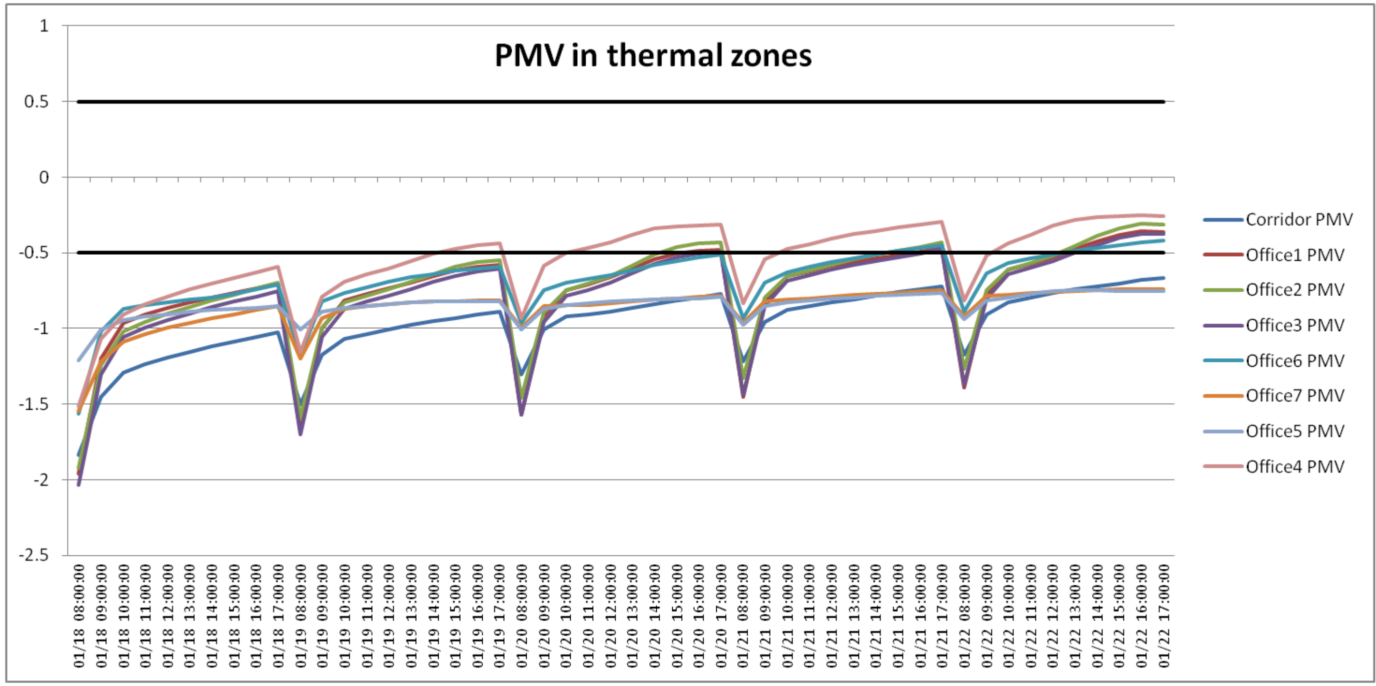
- Latin-hypercube sampling for 1500 values
- SRRC as sensitivity index
- SA performed for the period January 18th – January 23rd 2016 for every pair of two days (Mon-Tue; Tue-Wed; Wed-Thu; Thu-Fri; Fri-Sat)
- SA Results
  - Mon-Tue: 5 variables
  - Tue-Wed: 9 variables
  - Wed-Thu: 13 variables
  - Thu-Fri: 13 variables
  - Fri-Sat: 10 variables

Case study – step 2

- Optimization process
  - Parallel Particle Swarm Optimization – developed in C# and coupled with EnergyPlus
  - Besides sensitive variables, 40 variables were added in every optimization:
    - Supply water temperature – (without any dependencies) – 8 variables
    - AHU Heat recovery availability – 8 variables
    - AHU Heating coil availability – 8 variables
    - Baseboard heating availability – 8 variables
    - AHU minimum outside air – 8 variables
    - Other variables were kept at upper limits (temperature set-points)
  - Swarm size (population) set to 1000, maximum number of iterations (generations) 50
    - Exit criteria: 2% relative difference in 35 consecutive generations

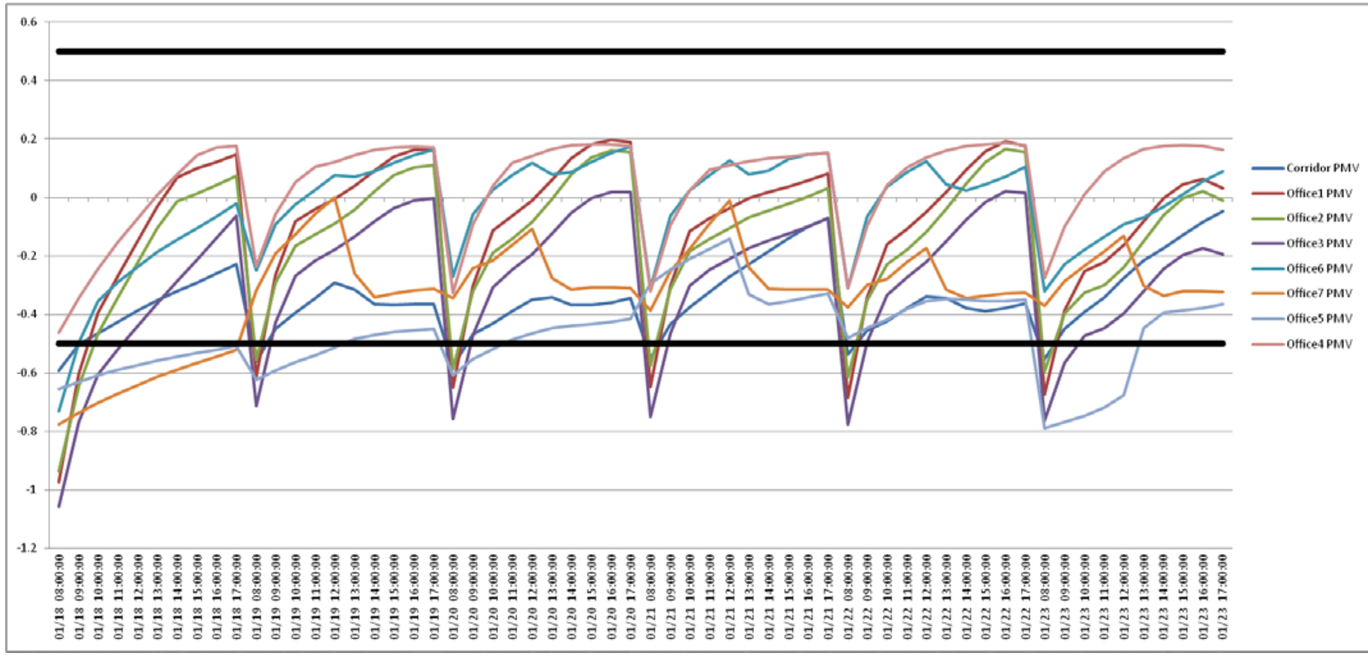
Case study – baseline

- Usual building operation:
  - Outdoor temperature reset for supply water temperature
  - HVAC systems start in pre-defined schedules
  - Temperature set-points constant all the time
- Weekly energy consumption (objective function – primary energy): 3886kWh (3624kWh + 262kWh)
- Weekly energy consumption baseboards and heating coil: 380kWh + 300kWh

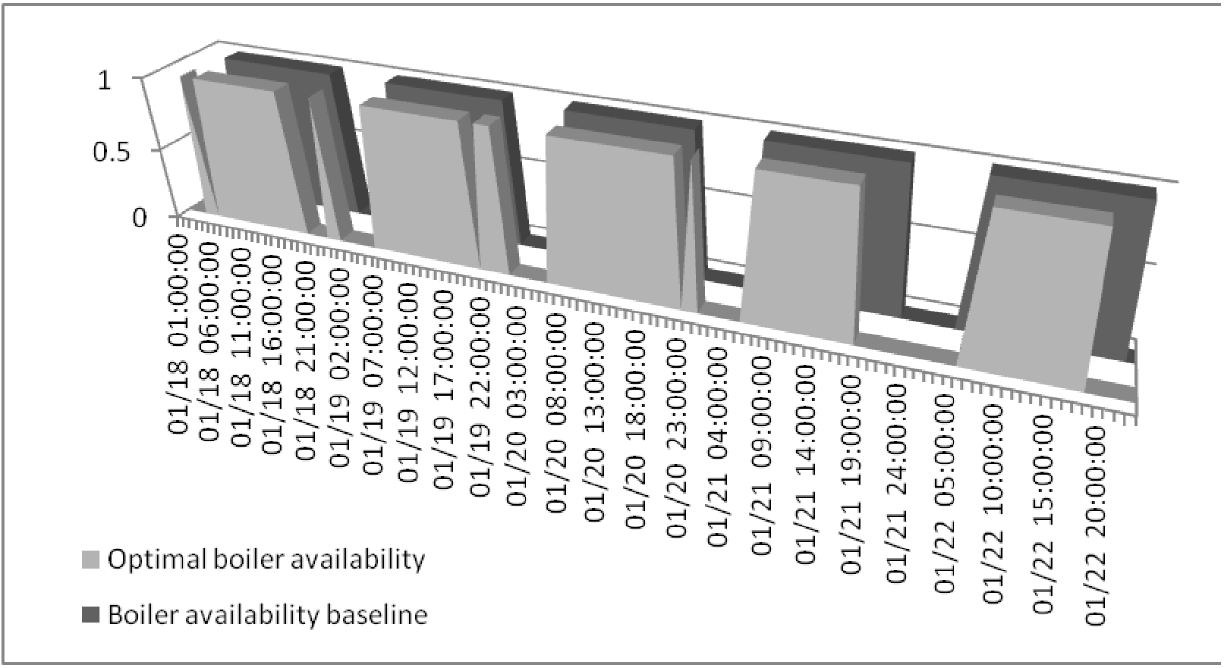


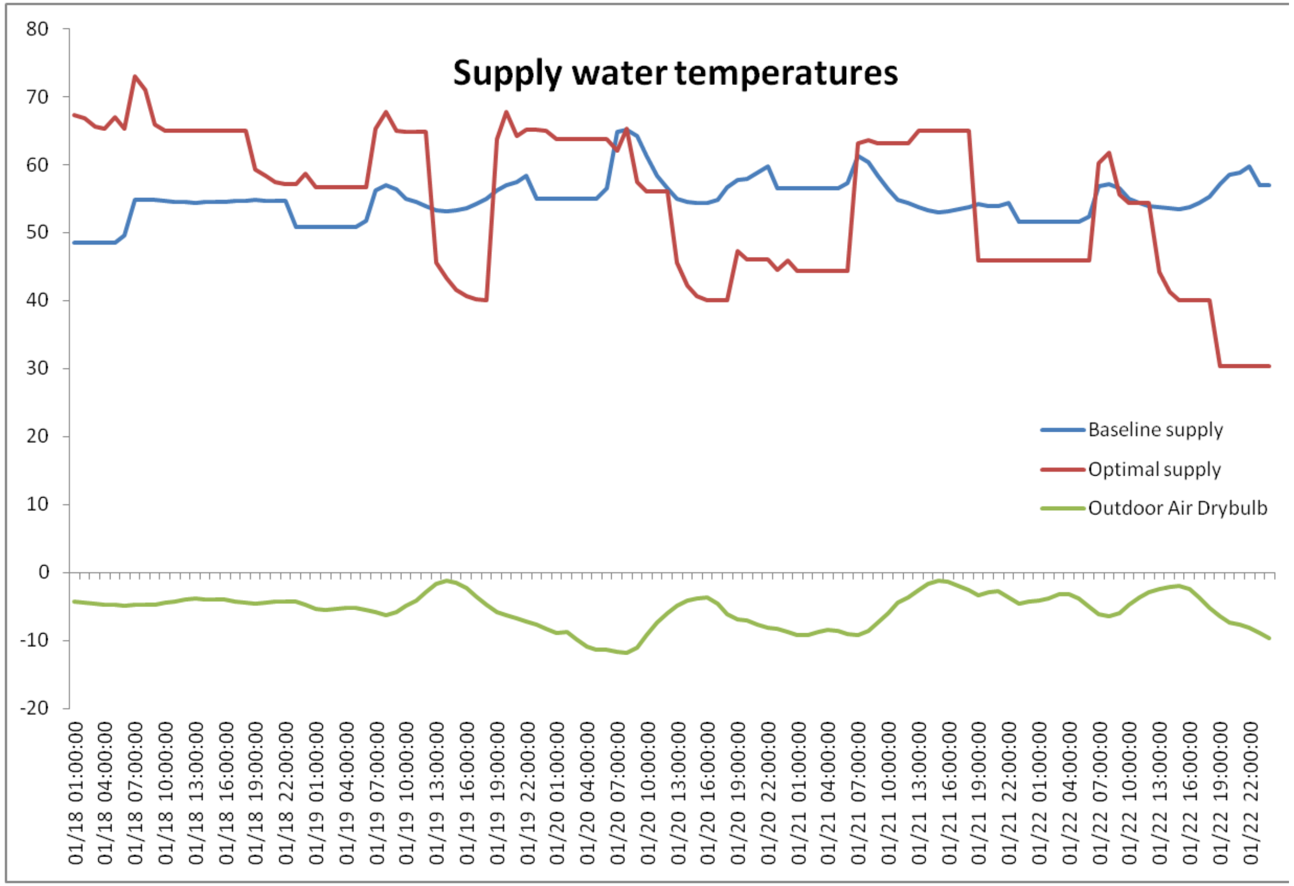
Case study – results

- Optimal building operation:
  - Supply water temperature
  - HVAC systems start and stop optimized
    - AHU not running
  - Temperature set-points vary over time (distinction between occupied and unoccupied period)
- Weekly energy consumption (objective function – primary energy):   2498kWh (no electricity)
- Weekly energy consumption baseboards and heating coil: 317kWh + 0kWh



Case study – results





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Conclusion

- It is possible and justified to include sensitivity analysis in simulation-assisted HVAC system operation in order to reduce number of optimization variables since the duration of optimization process is significantly reduced (from more than 30 hours to just over 22 hours in average on the 24-core 32GB RAM station)
- Optimizing energy performance with weather forecasts and BEPS has several obstacles:
  - Uncertainties in forecast must be included which leads to excessive computer power needed to do the optimization with BEPS
  - Implementation “online” is very hard (if possible at all) due to limited time to complete all the tasks and implement optimal solutions in building
  - Implementation “offline” is plausible but assuming weather forecast to be nearly perfect during at least two optimization periods
    - It should be tested in the real object – future research

THANK YOU FOR THE ATTENTION !

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