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HVAC control systems - Simulation-assisted operation improvement

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Improving building energy performance

- Besides classical measures for improving energy efficiency and using renewables such as:
 - Improving thermal properties of building envelope
 - Design and installation of efficient HVAC systems and components
 - Intensive usage of renewables
- Optimized HVAC operation is applicable
 - BACs and BEMS should be already installed in buildings
 - Adding simulation tools in control loops
 - Knowledge of future disturbances acting on the building (weather parameters, number of occupants, occupant expectation on thermal comfort)
 - Future weather parameters – short-term weather forecasts

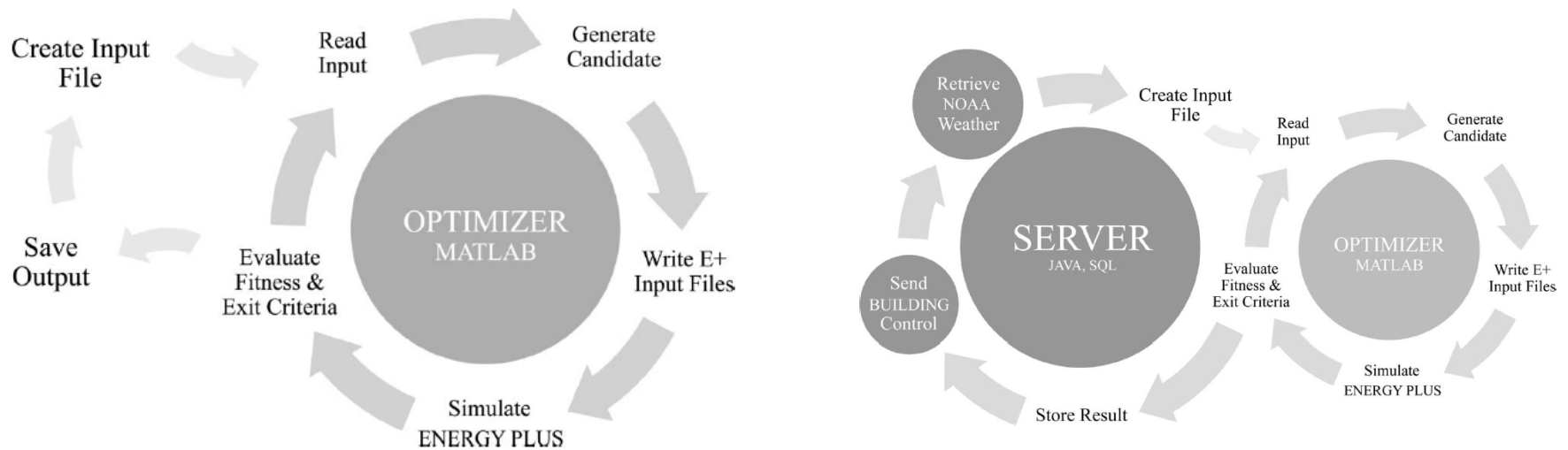
Improving building energy performance with simulation-assisted HVAC operation

- One of the widely researched areas of BEPS application in last several years
- While creating building energy model, existing HVAC control systems in building should be included
 - Contemporary BEPS tools allow usual control systems to be modeled
- Modeling optimal and supervisory control in most BEPS is not included (very difficult to model) so authors use co-simulation approach or external optimization
- Modern control – model based
 - White-box, black-box and grey-box models

Improving building energy performance with simulation-assisted HVAC operation

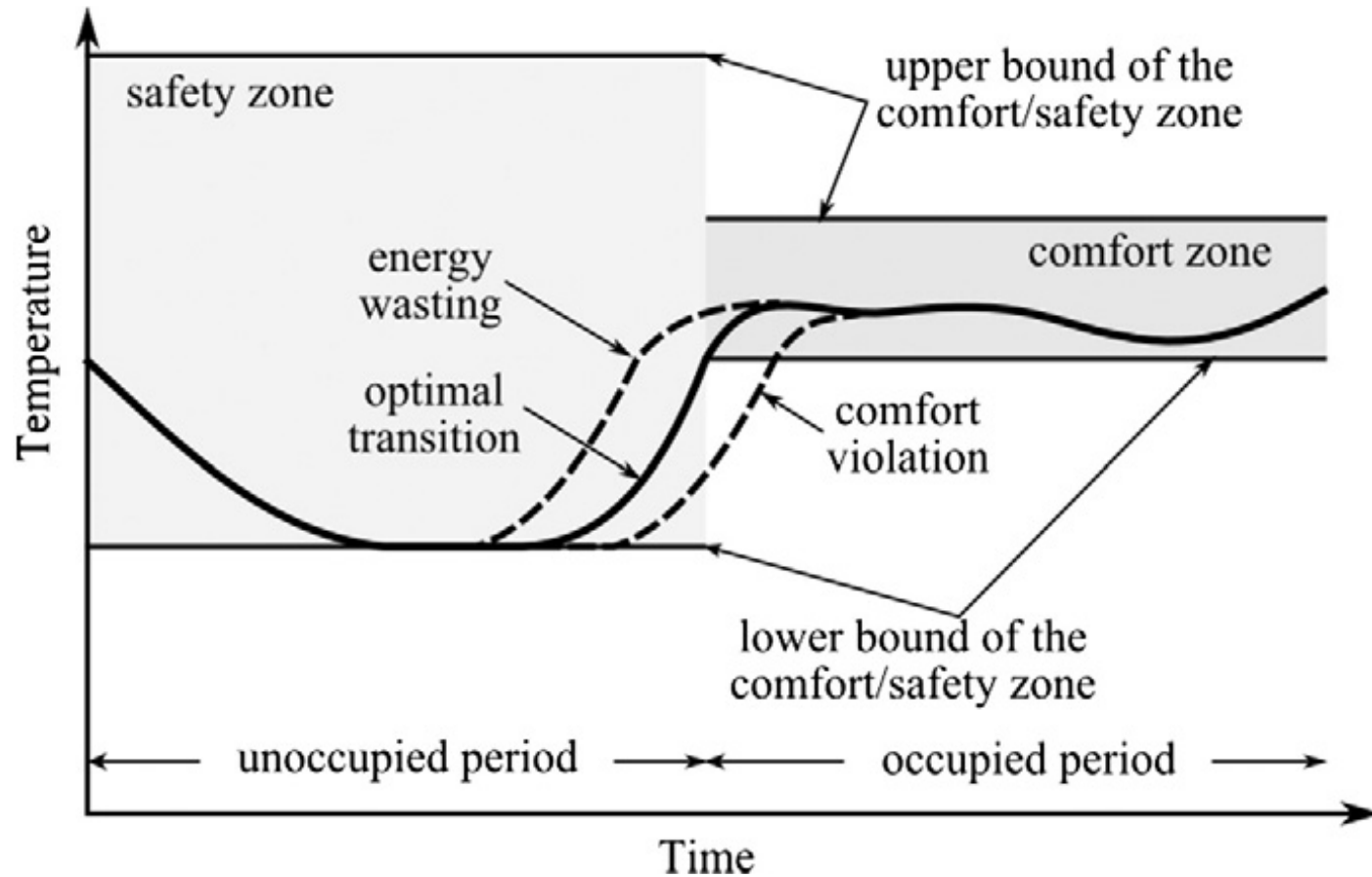
- *Offline* optimization
- *Online* optimization
 - Real-time implementation of optimization process
 - Direct coupling of BEPS with BACs and BEMS
- Reducing model complexity is general trend in research
- Numerous BEPS available
 - TRNSYS and EnergyPlus mainly used
 - GenOpt, MATLAB, MLE+, custom made optimization software etc.
 - Particle swarm optimization, genetic algorithms, branch and bound, internal point etc.

Improving building energy performance with simulation-assisted HVAC operation

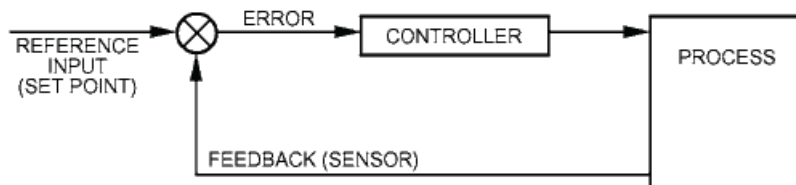


Corbin, C.D., G.P. Henze, and P. May-Ostendorp: offline optimization (left); online optimization (right)

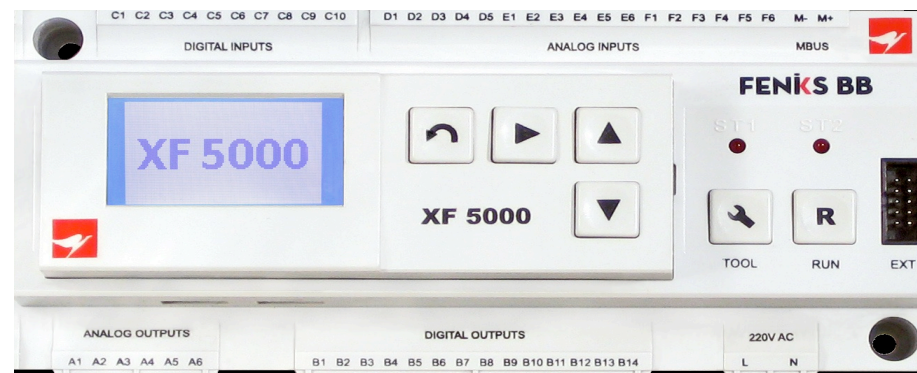
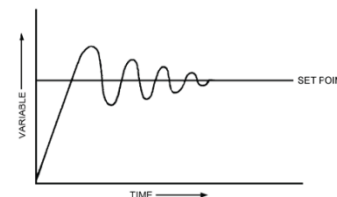
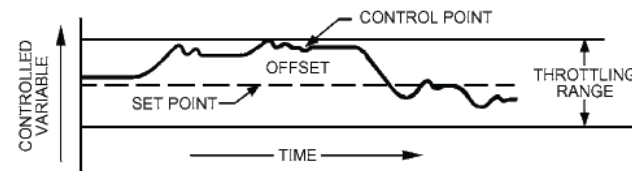
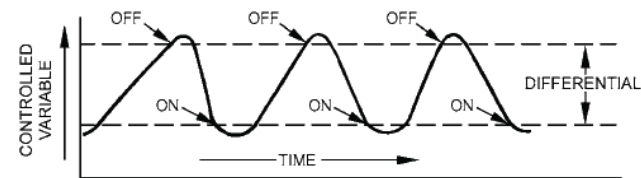
Thermal comfort vs. Energy consumption



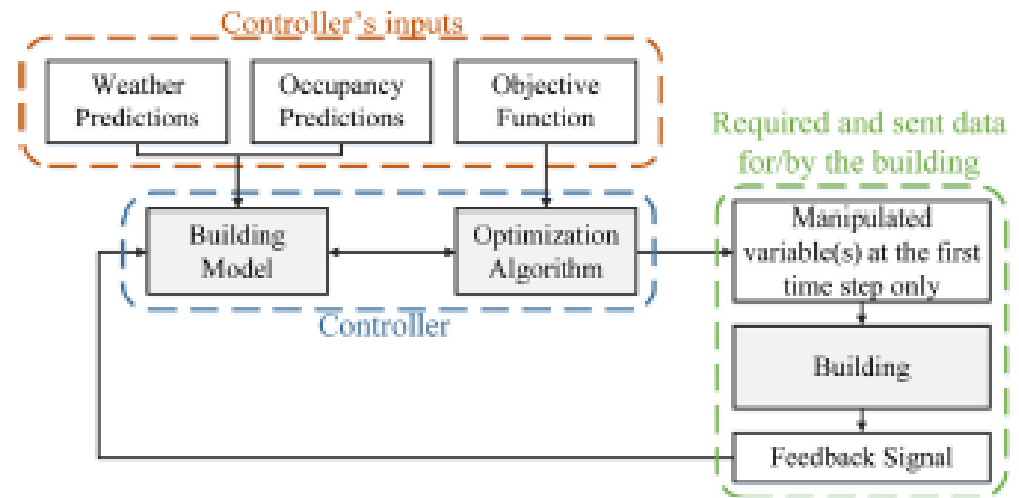
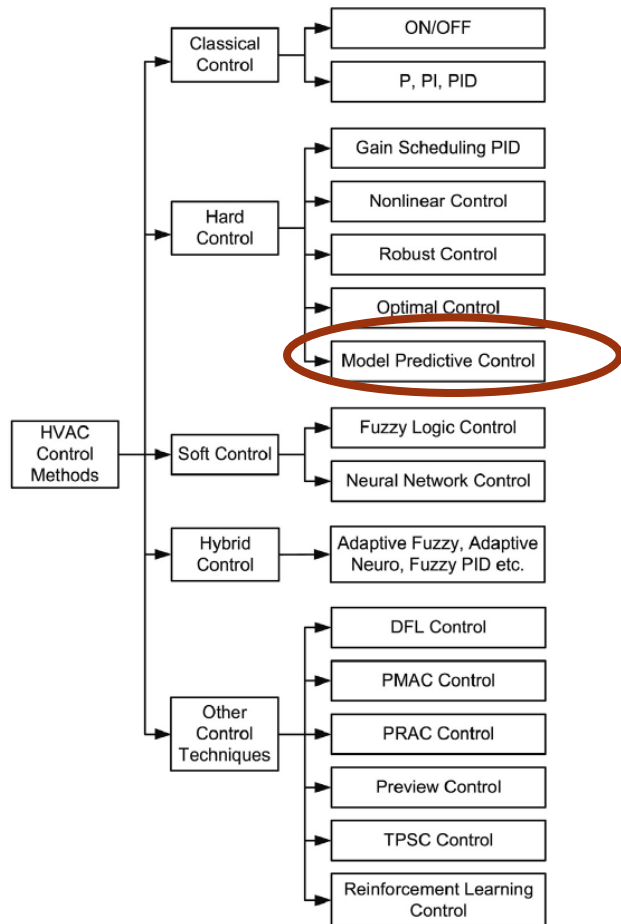
Classical control



- ON/ OFF
- Proportional
- Proportional-Integral
- Proportional-Integral-Derivative
 - Anticipatory action
 - Harder to tune
 - Powerful XF 5000



HVAC control and possibilities to model with BEPS

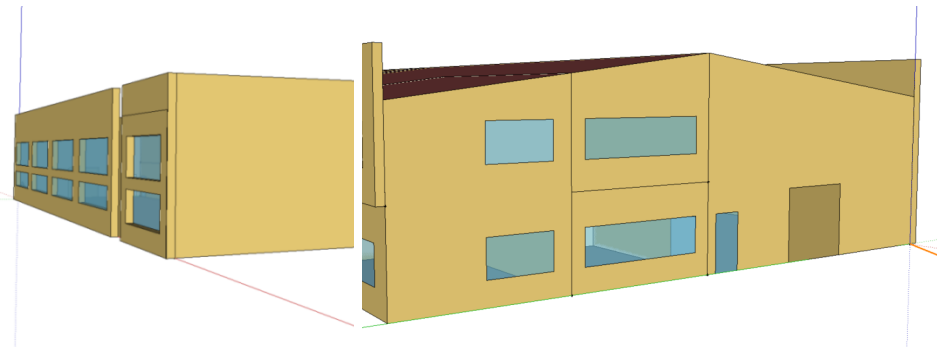
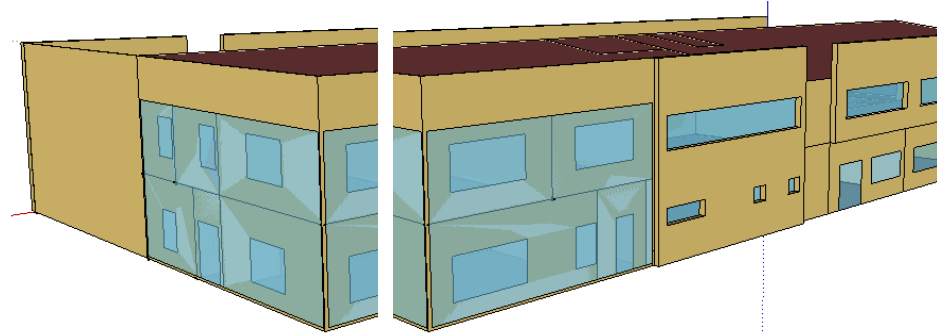


Model-predictive control

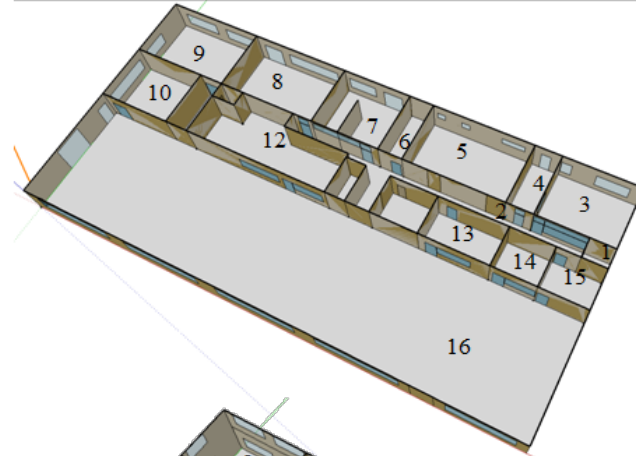
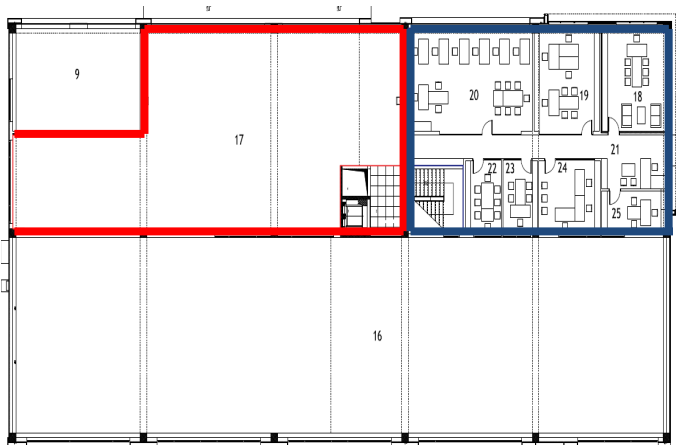
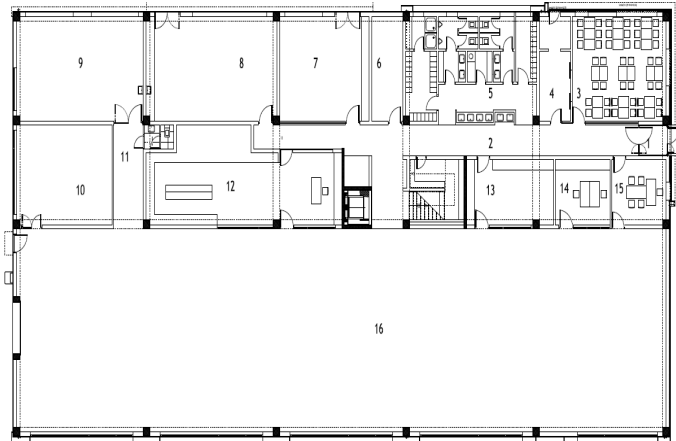
- Integrating disturbance predictions, thermal mass usage, constraints, operation strategies
 - Optimization of variables as a function of future disturbances within predefined horizon
 - Dynamic optimization logic – the same problem is solved while shifting forward in time
- MPC fundamentals:
 - Cost function – main goal of control
 - Constraints
 - Input variables
 - Output variables
 - Actuators
 - Planning horizon – time interval over which cost function is calculated
 - Control horizon – time interval over which control signal is determined
 - Timestep – time interval during which control signal is constant

Case study building

Real building and model (EnergyPlus)

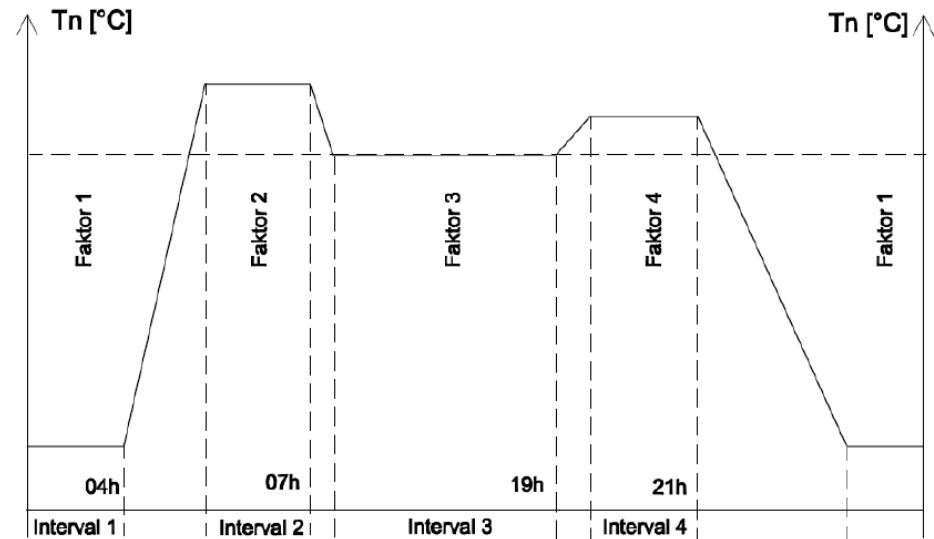
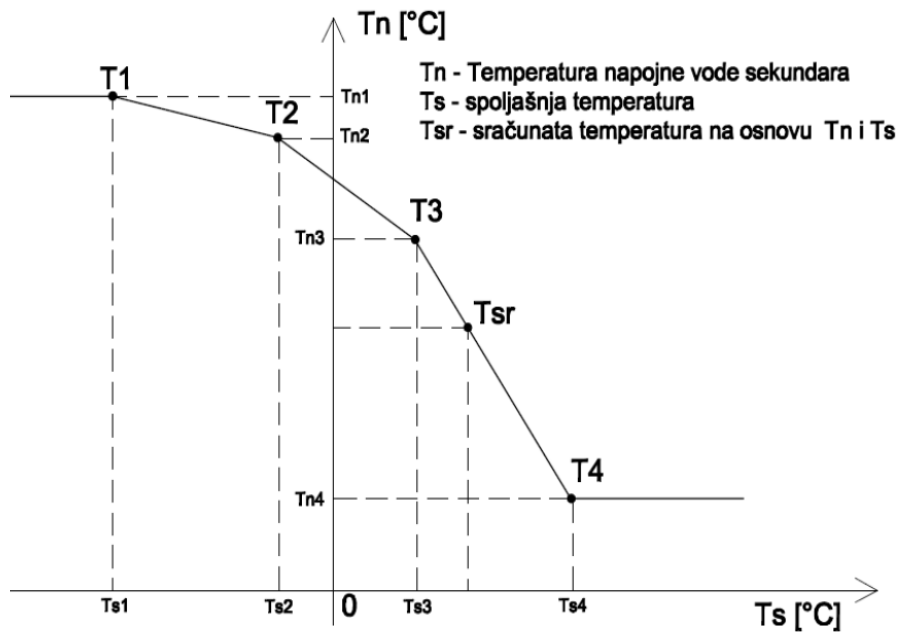


Real building and model (EnergyPlus)

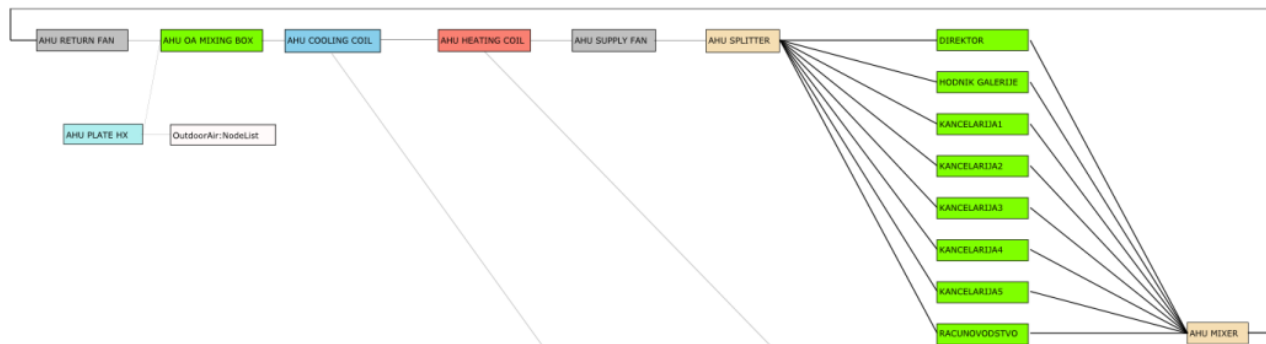
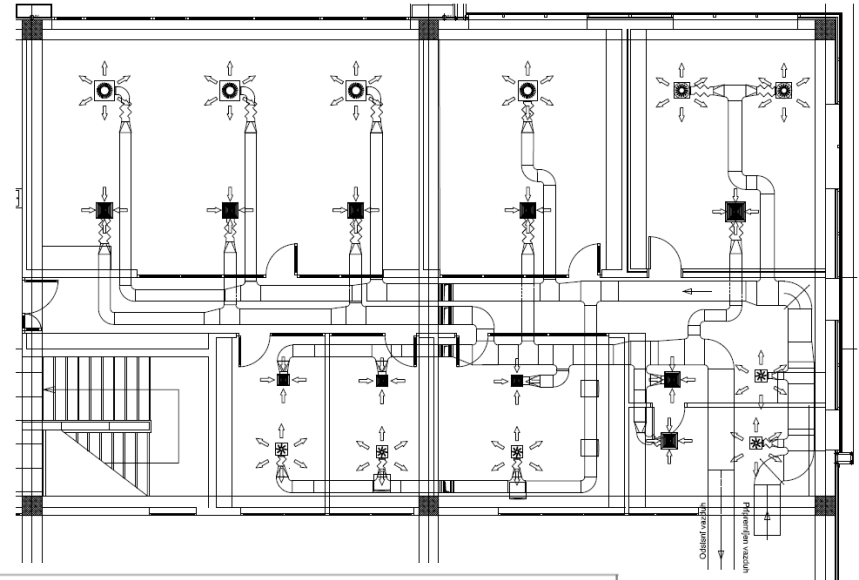
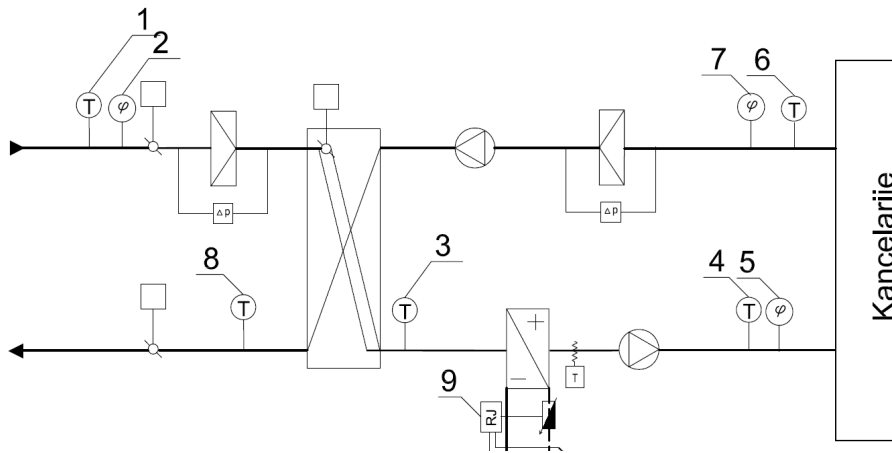


Installed PLCs

- 4-point heating curve control
- Correction factor
 - Day divided in several periods



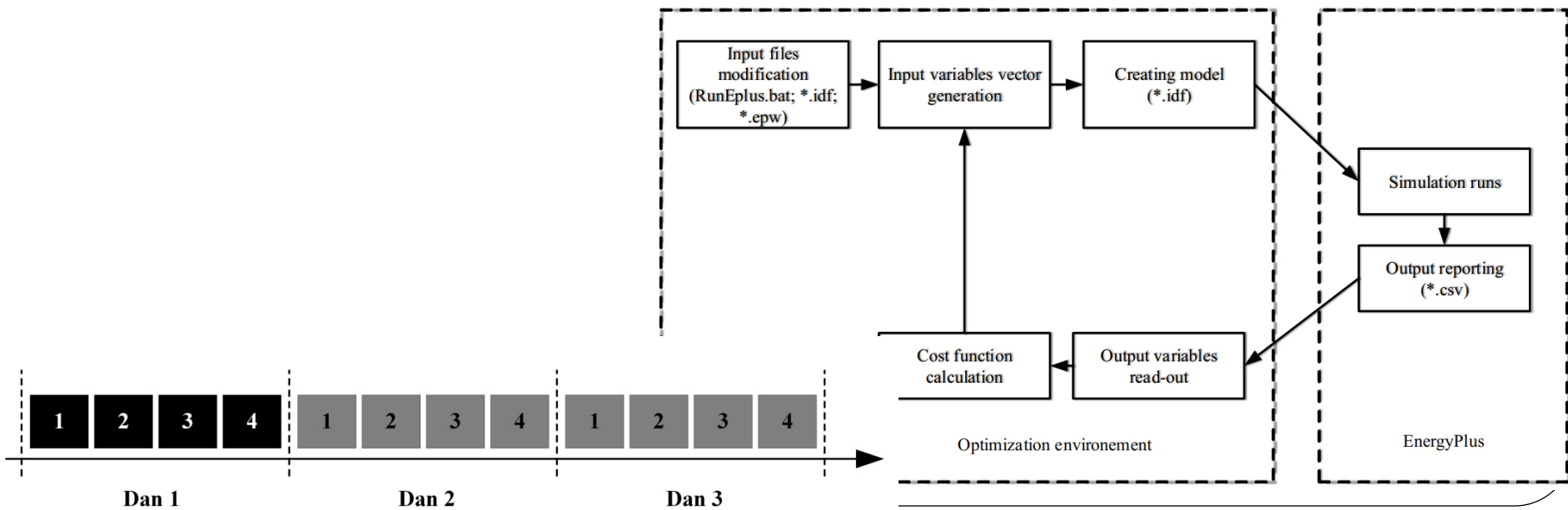
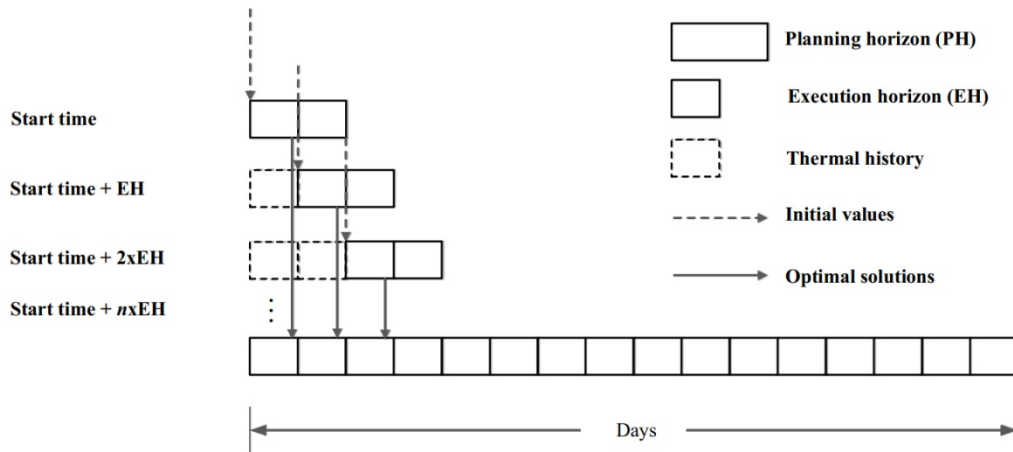
Real building and model (EnergyPlus)



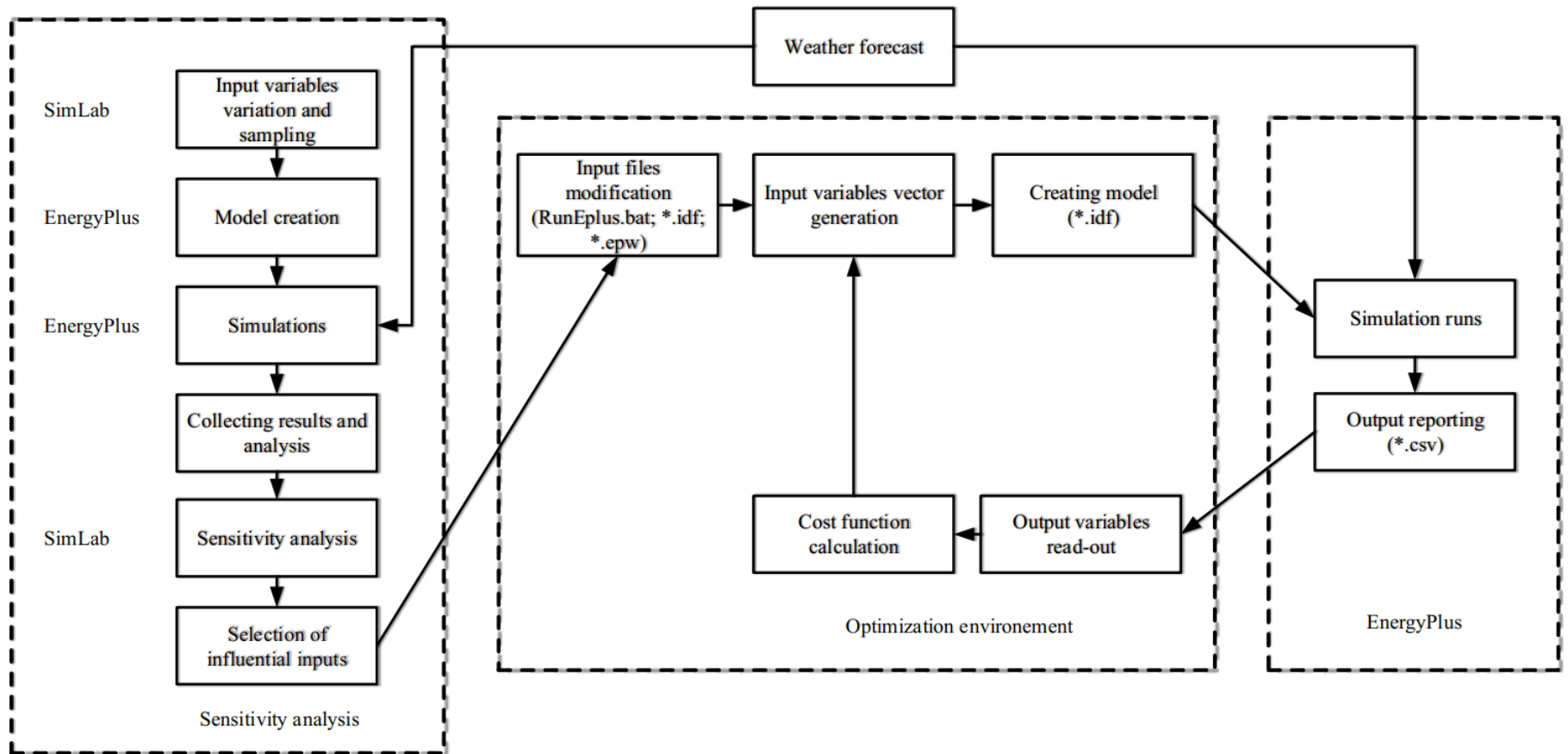
The main idea

- To upgrade existing operation by implementing simulation results on regular basis based on short-term weather forecast, without interventions within HVAC systems or its control system
 - HVAC systems designed in traditional manner – no thermal comfort indices (available as EnergyPlus simulation outputs) used in the design process
- All operation parameters available within the systems become independent variables (local and central)
 - Every planning horizon (days) is divided in blocks belonging to occupied periods and blocks belonging to unoccupied periods
 - One physical parameter – several independent variables in the optimization process
 - Reduce number of independent variables – sensitivity analysis

HVAC operation based on short-term weather forecasts



HVAC operation based on sensitivity analysis



Daily operation strategies

- Independent variables

- Heating coil availability
- Conditioned air temperature setpoint

$$\min E = \sum_{\tau=t_{HP}} E_{DEL}(\tau)$$

$$-\varepsilon < TCF < \varepsilon$$

- Baseboards availability
- Indoor temperature setpoints
- Supply water temperature correction
- Air volume

$$TCF = \sum_{j=1}^{j=6} (\min PMV_j) \times \frac{N_j}{N_{tot}}$$

- Cost function

- Minimize energy consumption
- ε -constraints on thermal comfort
 - No. of people averaged PMV

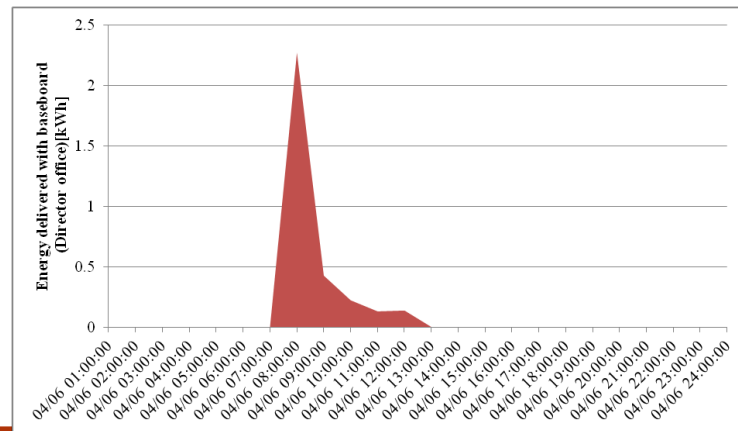
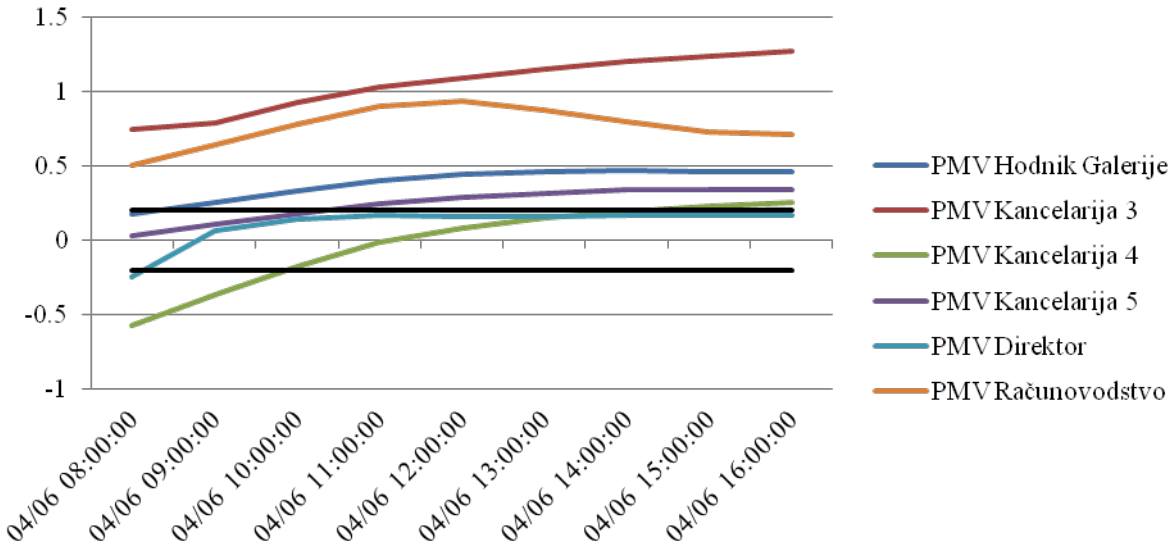
Thermal environment categories [ISO 7730]:

- “A”, $-0.2 < PMV < 0.2$
- “B”, $-0.5 < PMV < 0.5$
- “C”, $-0.7 < PMV < 0.7$

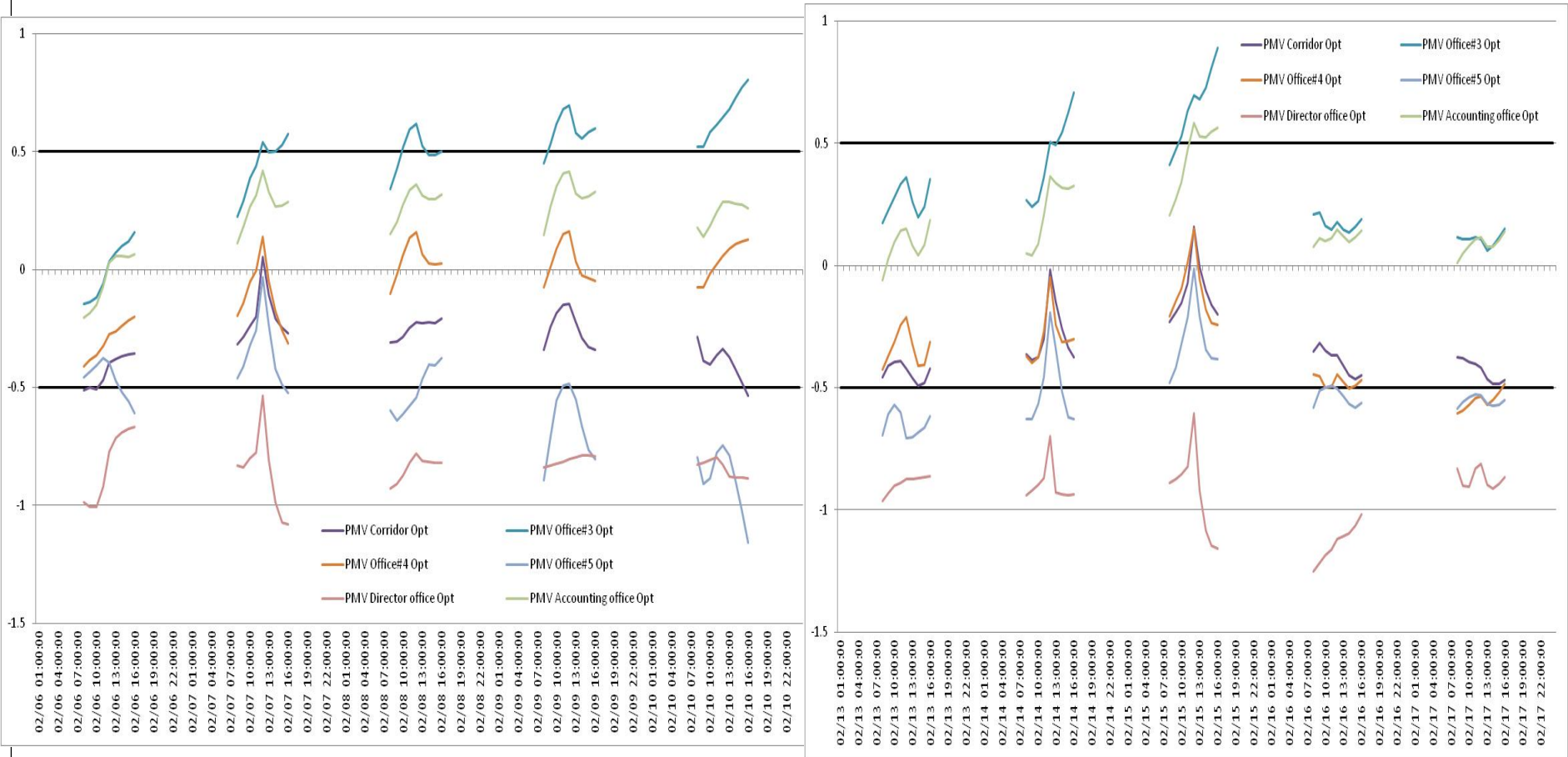
Short-term weather forecast used for operation optimization

Variable Control horizon 06. 04. 2017.

	00:00 – 08:00	8:00 – 12:00	12:00 – 16:00
	16:00 – 24:00		
AHU availability, [0/1]	0	1	1
AHU supply air temperature setpoint, [°C]	–	35	33.3
Radiator availability in <i>Accounting office</i> , [0/1]	1	1	0
Radiator availability in <i>Corridor</i> , [0/1]	1	1	1
Radiator availability in <i>Director office</i> , [0/1]	1	1	1
Radiator availability in <i>Office 4</i> , [0/1]	1	1	0
Radiator availability in <i>Office 5</i> , [0/1]	1	1	0
Temperature setpoint in <i>Accounting office</i> , [°C]	15.4	18	–
Temperature setpoint in <i>Corridor</i> , [°C]	15	23.4	18.3
Temperature setpoint in <i>Director office</i> , [°C]	15	23.5	18
Temperature setpoint in <i>Office 4</i> , [°C]	15.3	19.3	–
Temperature setpoint in <i>Office 5</i> , [°C]	18	22.4	–
Supply water temperature correction, [–]			1.1
Design airflow percentage, [%]	–		0.5

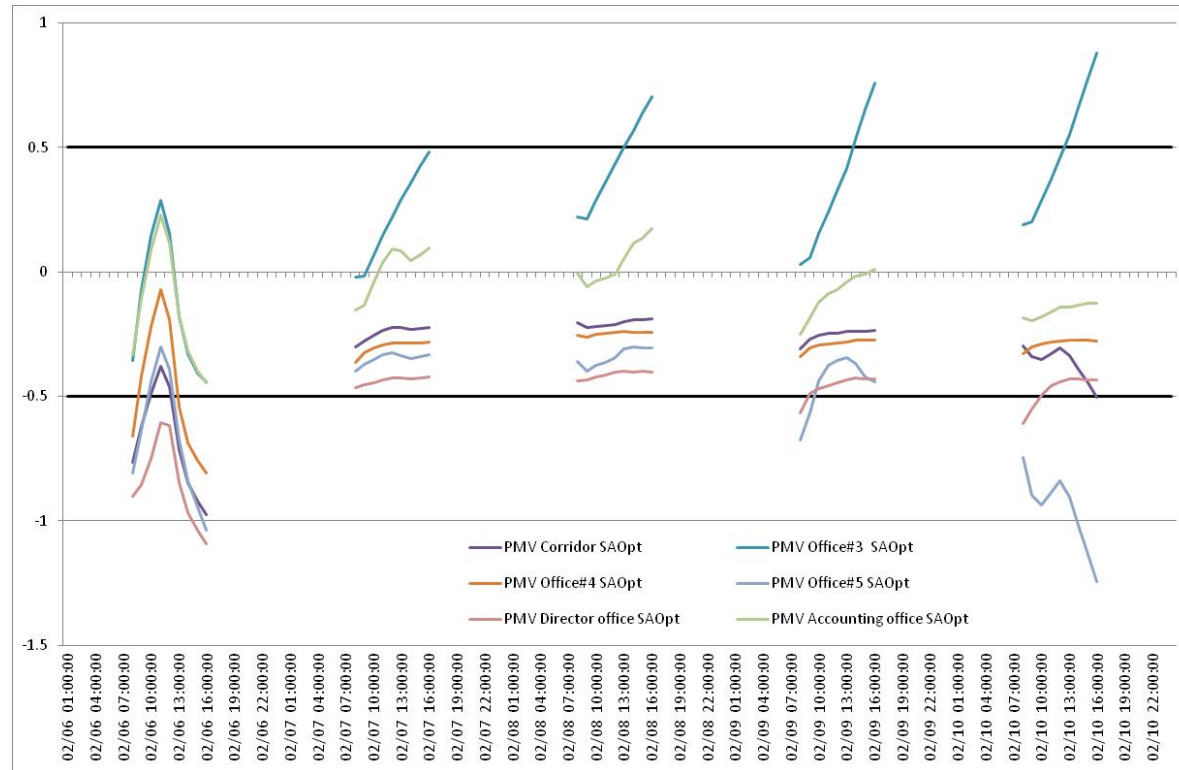


Operation strategies with full number of variables, $\epsilon=0.5$

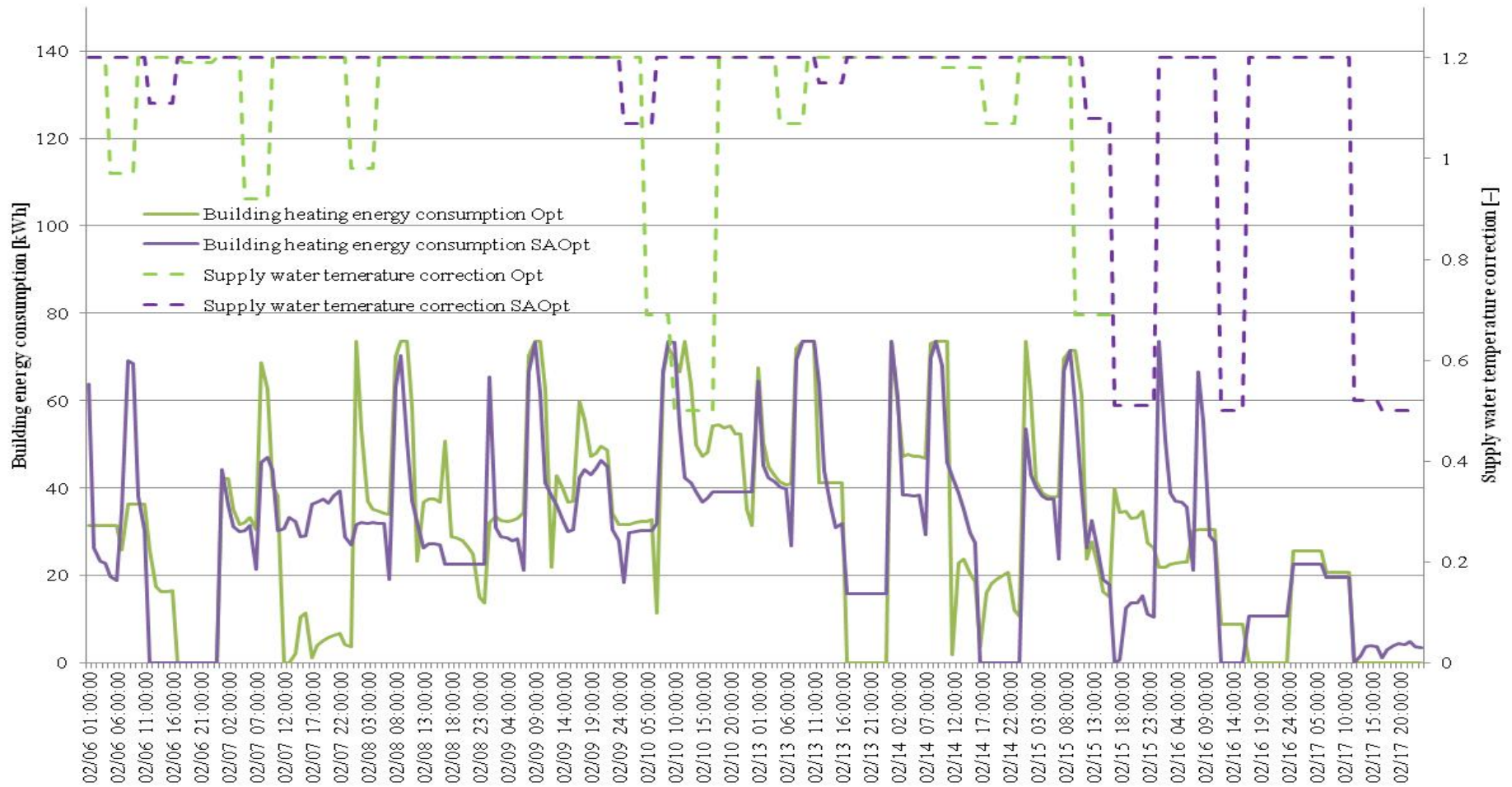


Operation strategies with reduced number of variables, $\epsilon=0.5$

Input variable	06-07. 02.	07-08. 02.	08-09. 02.	09-10. 02.	10-11. 02.
Airflow	YES	YES	YES	YES	YES
Supply water temperature correction 1st day in 1st block	YES	YES	YES	YES	YES
Supply water temperature correction 2nd day in 1st block	YES	YES	YES	YES	YES
Supply water temperature correction 1st day in 2nd block	YES	YES	YES	YES	YES
Supply water temperature correction 2nd day in 2ndblock	YES	YES	YES	YES	YES
Supply water temperature correction 1st day in 3rd block	YES	YES	YES	YES	YES
Supply water temperature correction 2nd day in 3rd block	YES	YES	YES	YES	YES
Supply water temperature correction 1st day in 4th block	YES	YES	YES	YES	YES
Supply water temperature correction 2nd day in 4th block	YES	YES	YES	YES	YES
AHU availability 1st day in 1st block	YES	YES	YES	YES	YES
AHU availability 1st day in 2nd block	YES	YES	YES	YES	YES
AHU availability 1st day in 3rd block	YES	YES	YES	YES	YES
AHU availability 1st day in 4th block	YES	YES	YES	YES	YES
AHU availability 2nd day in 1st block	YES	YES	YES	YES	YES
AHU availability 2nd day in 2nd block	YES	YES	YES	YES	YES
AHU availability 2nd day in 3rd block	YES	YES	YES	YES	YES
AHU availability 2nd day in 4th block	YES	YES	YES	YES	YES
Supply air temperature 1st day in 1st block	NO	YES	YES	YES	YES
Supply air temperature 1st day in 2nd block	YES	NO	NO	NO	NO
Supply air temperature 1st day in 3rd block	NO	NO	NO	NO	NO
Supply air temperature 1st day in 4th block	NO	NO	NO	NO	NO
Supply air temperature 2nd day in 1st block	NO	YES	YES	NO	NO
Supply air temperature 2nd day in 2nd block	NO	YES	YES	YES	YES
Supply air temperature 2nd day in 3rd block	YES	YES	YES	NO	YES
Supply air temperature 2nd day in 4th block	NO	NO	NO	NO	NO
Corridor BBH availability 1st day in 1st block	NO	NO	NO	NO	NO
Corridor BBH availability 1st day in 2nd block	NO	NO	NO	NO	NO
Corridor BBH availability 1st day in 3rd block	NO	NO	NO	NO	NO
Corridor BBH availability 1st day in 4th block	NO	NO	NO	NO	NO
Corridor BBH availability 2nd day in 1st block	NO	NO	NO	NO	NO
Corridor BBH availability 2nd day in 2nd block	NO	NO	NO	NO	NO
Corridor BBH availability 2nd day in 3rd block	NO	NO	NO	NO	NO
Corridor BBH availability 2nd day in 4th block	NO	NO	NO	NO	NO
Accounting office BBH availability 1st day in 1st block	NO	NO	NO	NO	NO
Accounting office BBH availability 1st day in 2nd block	NO	NO	NO	NO	NO
Accounting office BBH availability 1st day in 3rd block	NO	NO	NO	NO	NO
Accounting office BBH availability 1st day in 4th block	NO	NO	NO	NO	NO
Accounting office BBH availability 2nd day in 2nd block	NO	NO	NO	NO	NO
Accounting office BBH availability 2nd day in 3rd block	NO	NO	NO	NO	NO
Accounting office BBH availability 2nd day in 4th block	NO	NO	NO	NO	NO
Director office BBH availability 1st day in 1st block	NO	NO	NO	NO	NO
Director office BBH availability 1st day in 2nd block	NO	NO	NO	NO	NO
Director office BBH availability 1st day in 3rd block	NO	NO	NO	NO	NO
Director office BBH availability 1st day in 4th block	YES	YES	YES	YES	YES
Director office BBH availability 2nd day in 1st block	NO	NO	NO	NO	NO
Director office BBH availability 2nd day in 2nd block	NO	NO	NO	NO	NO
Director office BBH availability 2nd day in 3rd block	NO	NO	YES	YES	NO
Director office BBH availability 2nd day in 4th block	YES	YES	YES	YES	YES
Office#4 and Office#5 BBH availability 1st day in 1st block	YES	NO	NO	NO	NO



Operation strategies, $\varepsilon=0.5$



Operation strategies, $\epsilon=0.5$



Conclusion

- Simulation-assisted upgrade led to significant improvement in PMV index
 - Systems designed in traditional manner
- Slight increase of energy consumption as a result of longer system operation (in order to have satisfactory thermal comfort during occupied period) – possibility to balance between energy consumption and thermal comfort on regular basis
- Sensitivity analysis, as the first step, led to similar results in terms of thermal comfort but very different energy consumption profile (decrease of AHU energy consumption) and operating parameters, but for much shorter runtime
- The simulation-assisted upgrade was implemented without system refurbishment or reconstruction, only the existing parameters and control variables were used

**THANK YOU FOR THE
ATTENTION!**

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