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Potential Energy Savings by Using the Operational EnRiMa DSS

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Energy Efficiency and Risk Management in Public Buildings

Potential Energy Savings by Using the Operational EnRiMa DSS

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Overview

Energy Savings Audit for Heating System

- verify building inventory from WP1
- verify multi zone-to-single zone calculations and vice versa
- identify base-case days for EnRiMa comparison
- run operational EnRiMa and collect results
- normalize the base-case days to the optimization day weather conditions
- assessment of savings

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Verify Building Inventory

- test site: University of Applied Sciences Burgenland, Campus Pinkafeld
  - office & educational facility
  - available technologies: district heating, HVAC, PV
  - heating/cooling/air handling strategy: user comfort
  - weighted U value: 0.41 $W/(m^2K)$
  - buildings surface: 6143 m^2
  - glass surface: 426 m^2

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Multi-Zones - Single-Zone - Multi-Zone Calculations

Date	Time	$T^t_{room}\,(i)$ (°C)					
		T3.1.12	T3.1.13	T3.1.14	T3.0.04	T3.0.06	T3.0.07
2013-04-03	23:00	22.0	20.6	23.3	21.0	21.7	21.6

Date	Time	$T^t_{building}$
		(°C)
2013-04-03	23:00	21.6

Fig.1a: Calculation of the weighted building temperature

$$T^t_{building} \approx T^t_{six\ rooms} = \frac{\sum_{i=1}^{s}\left[\,T^t_{room}\,(i)\cdot V_{room\,,prop\,.}(i)\right]}{\sum_{i=1}^{s}\left[V_{room\,,prop\,.}(i)\right]}$$

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Date	Time	$T^t_{room}(i)$ (°C)					
		T3.1.12	T3.1.13	T3.1.14	T3.0.04	T3.0.06	T3.0.07
2013-04-03	23:00	22.0	20.6	23.3	21.0	21.7	21.6

Date	Time	$T^t_{building}$ (°C)	$T^t_{sp,building}$ (°C)	$\Delta T^t_{sp,building}$ (°C)	lower limits $\underline{K}^t$ (°C)	upper limits $\overline{K}^t$ (°C)
2013-04-03	23:00	21.6	-	-	-	-
2013-04-04	0:00	-	17.5	-4.1	17.5	18.5
	1:00	-	17.5	0	17.5	18.5

Fig.1b: calculation of the temperature difference per room

$$\Delta T^t_{sp,building} = T^t_{sp,building} - T^{t-1}_{sp,building}$$

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Multi-Zones - Single-Zone - Multi-Zone Calculations

Date	Time	$T^{t}_{room}(i)$ (°C)					
		T3.1.12	T3.1.13	T3.1.14	T3.0.04	T3.0.06	T3.0.07
2013-04-03	23:00	22.0	20.6	23.3	21.0	21.7	21.6

Date	Time	$T^{t}_{building}$	$T^{t}_{sp,building}$	$\Delta T^{t}_{sp,building}$	lower limits $\underline{K}^{t}$	upper limits $\overline{K}^{t}$
		(°C)	(°C)	(°C)	(°C)	(°C)
2013-04-03	23:00	21.6	-	-	-	-
2013-04-04	0:00	-	17.5	-4.1	17.5	18.5
	1:00	-	17.5	0	17.5	18.5

Date	Time	$T^{t}_{sp,room}(i)$ (°C)					
		T3.1.12	T3.1.13	T3.1.14	T3.0.04	T3.0.06	T3.0.07
2013-04-04	0:00	17.9	16.5	19.2	16.9	17.6	17.5
	1:00	17.9	16.5	19.2	16.9	17.6	17.5

Fig.1c: calculation of the new room temperature set points

$$T^{t}_{sp,room}(i) = T^{t-1}_{sp,room}(i) + \Delta T^{t}_{sp,building}$$

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Base-Case Days

- week day: Mo - Sa
- weekend: So
- base-case winter days selected from Pinkafeld BMS database (similar to audit days)

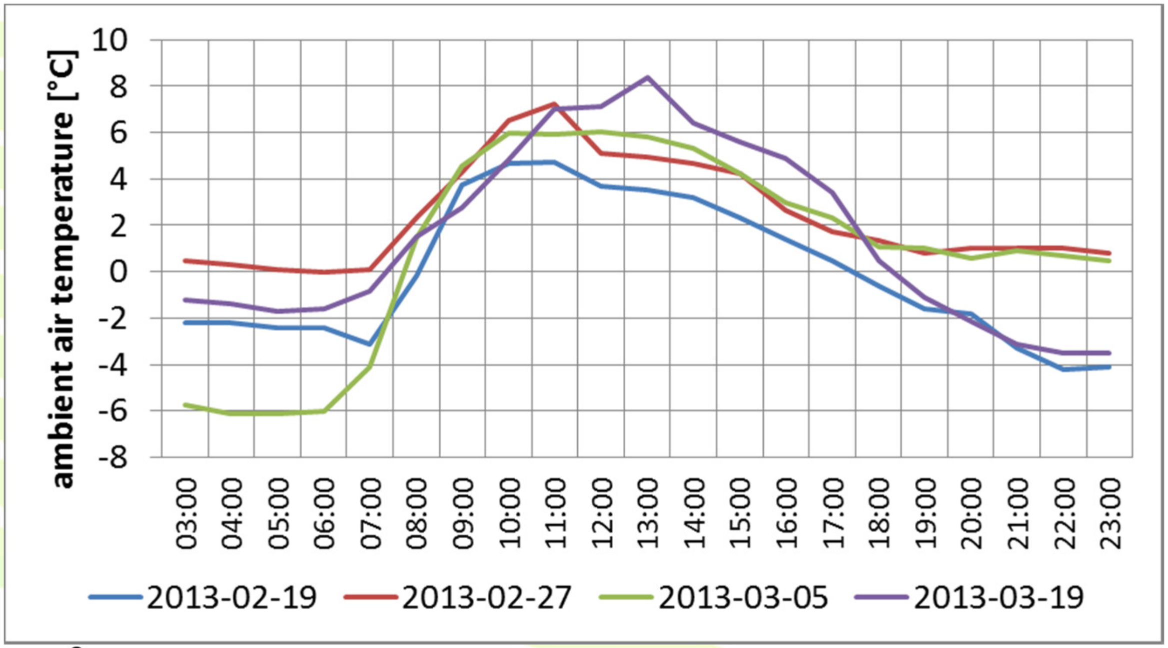

Fig.2: observed weather conditions

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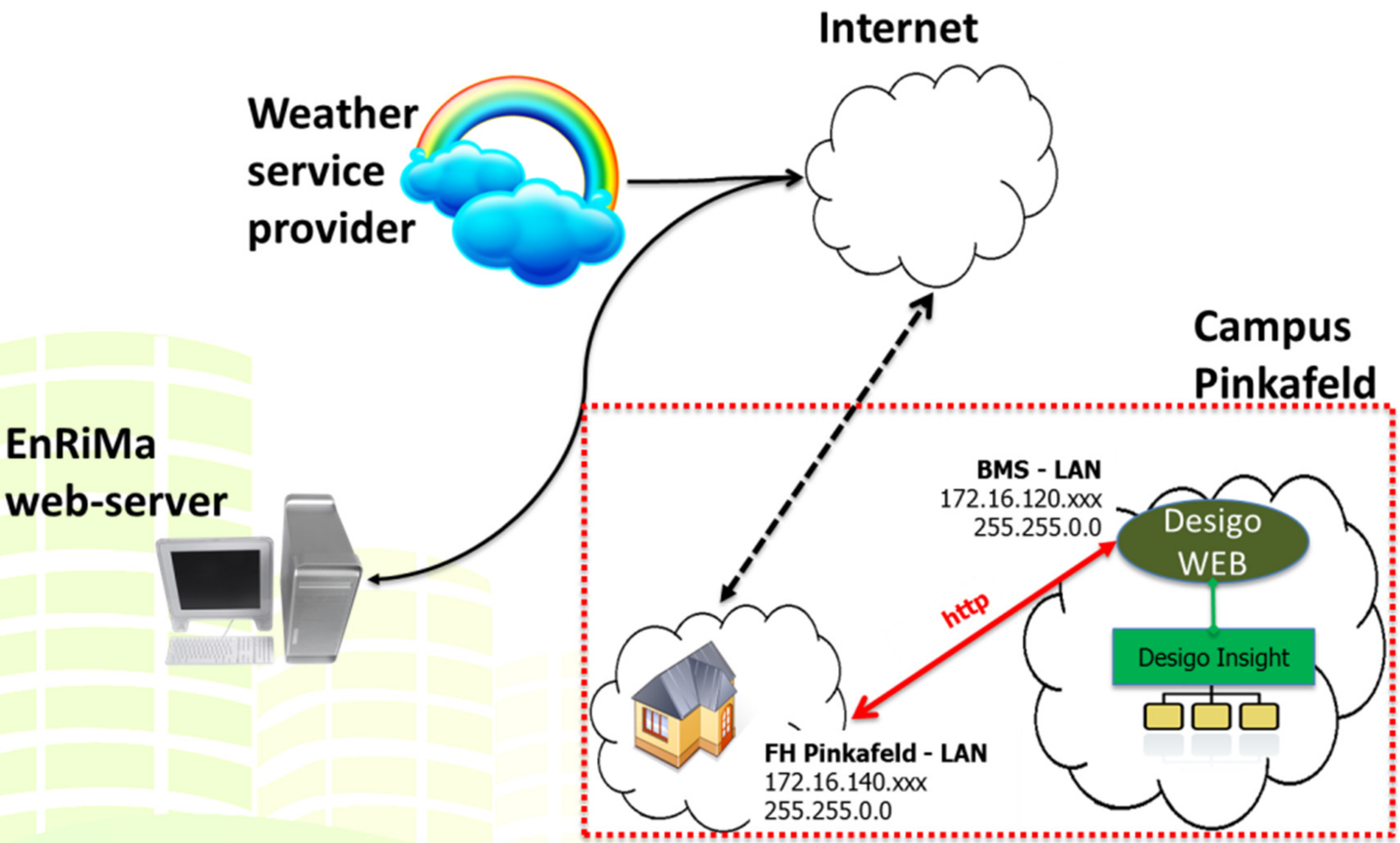
Run Optimization - Concept



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Run Optimization

Day	Actions
#1	☺ collect weather forecasts for Campus Pinkafeld ☺ adjust the operational EnRiMa DSS and run it ☺ calculate set-points for inside room temperatures by the results of the operational EnRiMa DSS
#2	☺ adjust set-points manually for inside room temperatures by the installed BMS every hour
#3	☺ reset the operation mode of the heating system at Campus Pinkafeld to the BAU status

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Normalize the Base-Case Days to the Optimization Day Weather Conditions

Why is a regression analysis required?

- build a linear model to describe the energy consumption of the base case days depending on the following parameters:
  - thermal energy consumption
  - ambient air temperature
  - internal air temperature set-point
  - …
- a good result requires $\bar{R}^2$ close to 1 and a t-statistic value >1.96 or <-1.96

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Final Regression Model

$$Q_{modeled}\,(\mathrm{t}) = \beta_1 \cdot T_{ext}(t) + \beta_2 \cdot T_{sp,int}(t) + \beta_3 \cdot f_{heat}(t) + \beta_4 \cdot f_t(5) + \beta_5 \cdot f_t(6) + \beta_6 \cdot f_t(7) + \beta_7 \cdot f_t(8) + \beta_8 \cdot f_t(9) + \beta_9 \cdot f_t(10) + \beta_{10} \cdot f_t(11) + \beta_{11} \cdot f_t(15) + \beta_{12} \cdot f_t(16) + \beta_{13} \cdot f_t(17)$$

t	observed time period (in this case: one hour)
j	hour of the day j:0…23 (-)
$f_t(j)$	dummy variable (boolean: either ‘0’ or ‘1’) for the actual hour of the day j (-)
$\beta_1 \ldots \beta_{13}$	constants (elasticities) according to regression analysis results
$T_{ext}(t)$	the average external air temperature in the time period t (°C)
$T_{sp,int}(t)$	BAU set-point for the building’s internal air temperature in the time period t (°C)
$f_{heat}(t)$	represents the heating systems’ operation characteristics for the whole building (-)
$Q_{modeled}\,(\mathrm{t})$	thermal energy consumption per hour for the whole Campus modeled by the linear regression model (kWh)

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Regression Model Statistics

regression statistics	
$\bar{R}^2$	0.976
$standard\ error$	4.893

coefficients	constants		standard error	t-statistic	unit
$T_{ext}(t)$	$\beta_1 =$	-1.65	0.27	-6.01	kWh/°C
$T_{sp,int}(t)$	$\beta_2 =$	1.06	0.04	23.13	kWh/°C
$f_{heat}(t)$	$\beta_3 =$	119.86	10.17	11.79	kWh
$f_t(5)$	$\beta_4 =$	23.08	2.62	8.81	kWh
$f_t(6)$	$\beta_5 =$	-104.67	15.34	-6.82	kWh
$f_t(7)$	$\beta_6 =$	-59.14	10.26	-5.77	kWh
$f_t(8)$	$\beta_7 =$	-35.58	7.19	-4.95	kWh
$f_t(9)$	$\beta_8 =$	-17.13	4.49	-3.81	kWh
$f_t(10)$	$\beta_9 =$	7.82	2.82	2.77	kWh
$f_t(11)$	$\beta_{10} =$	6.79	2.84	2.39	kWh
$f_t(15)$	$\beta_{11} =$	-18.96	2.86	-6.66	kWh
$f_t(16)$	$\beta_{12} =$	-24.56	2.90	-8.48	kWh
$\mathrm{f}_t(17)$	$\beta_{13} =$	-48.96	4.78	-10.24	kWh

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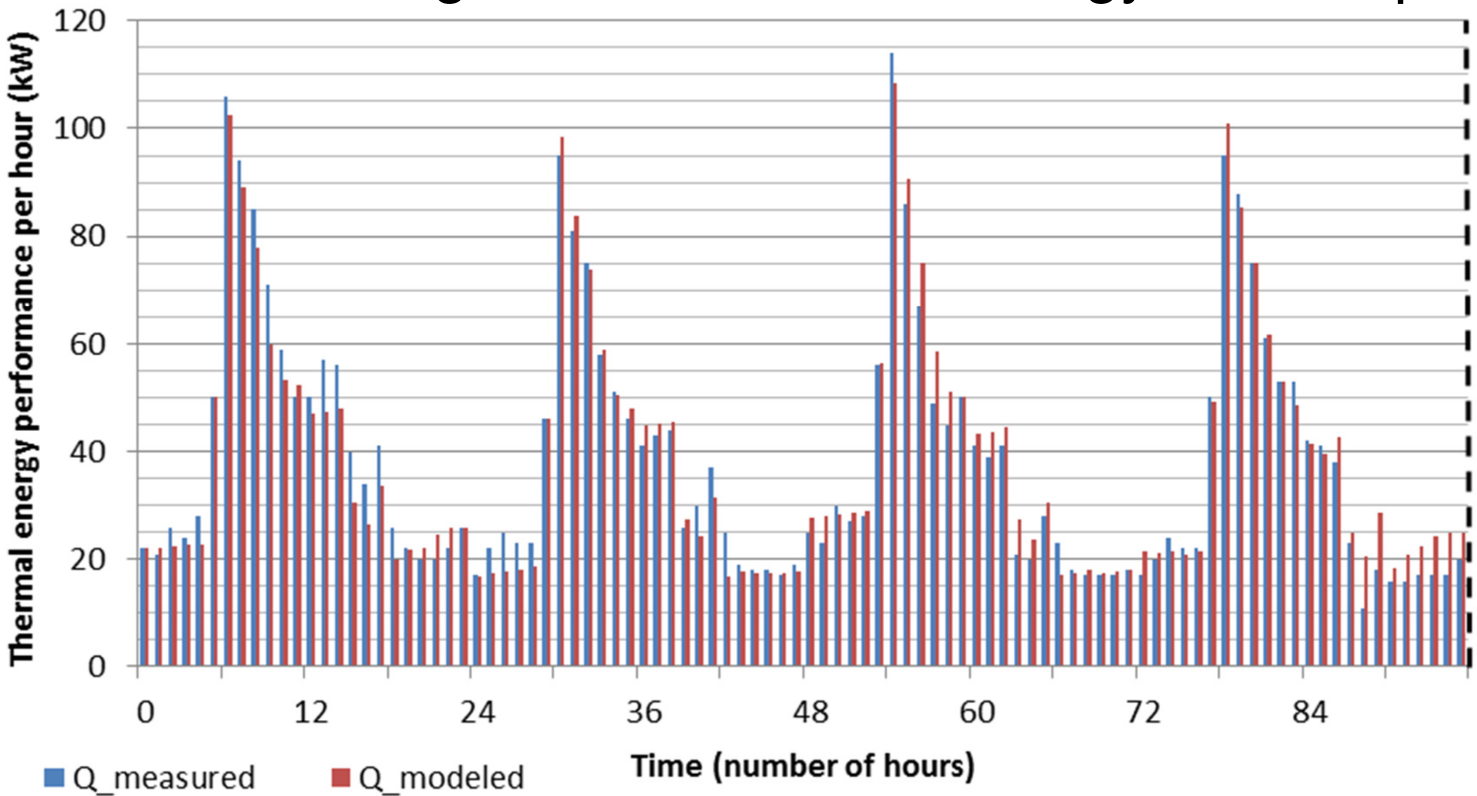
Normalize the Base-Case Days to the Optimization Day Weather Conditions

measured versus regression modeled energy consumptions



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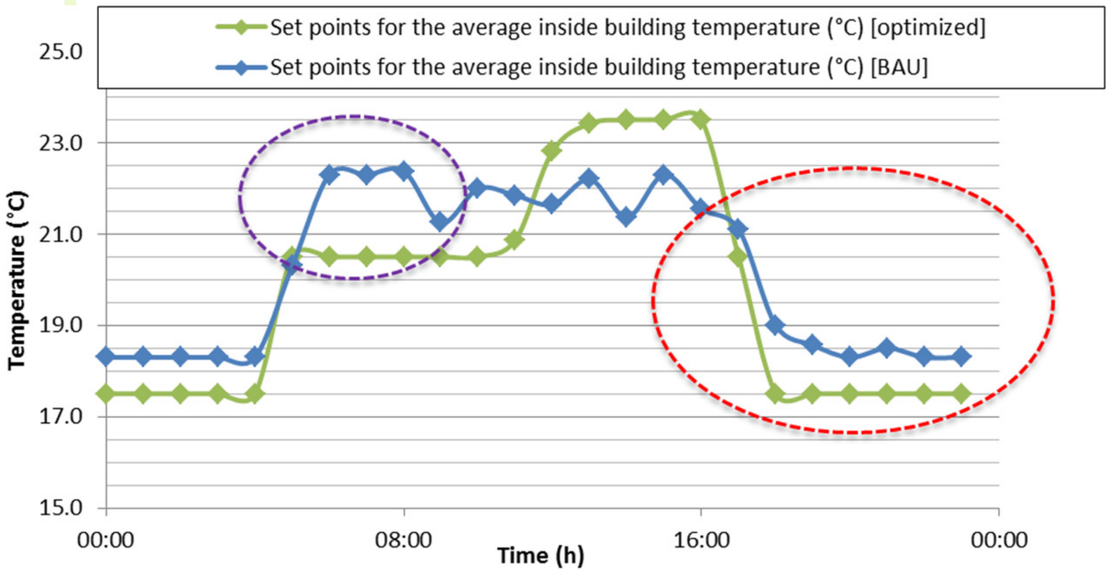
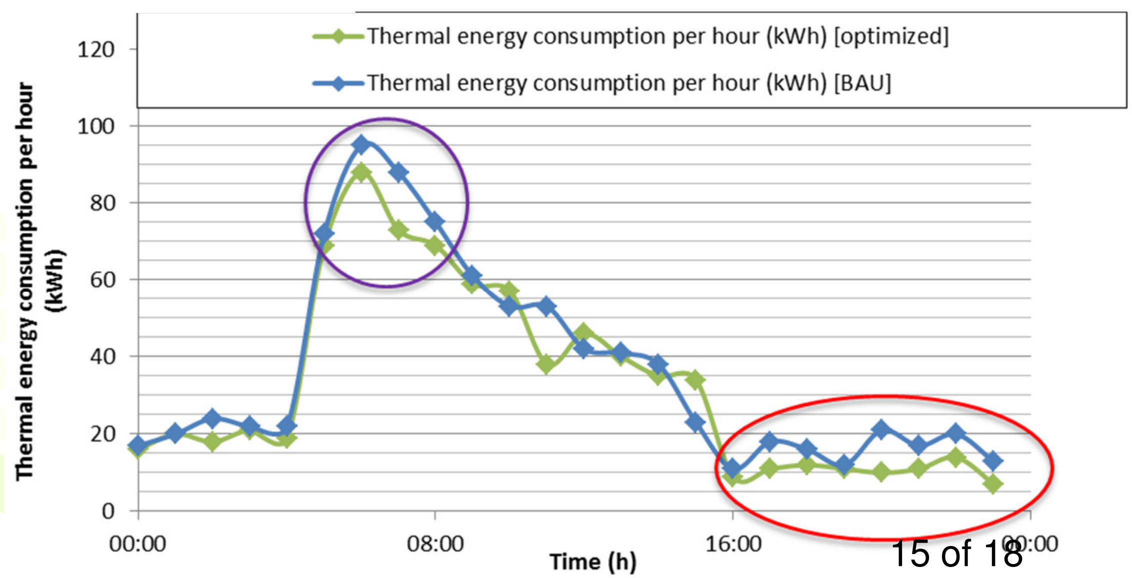
Assessment of Savings



results of operational EnRiMa DSS on 4.4.2013



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Assessment of Savings

dates for the scenarios	daily thermal energy consumption (kWh)		
	BAU (measured) days	BAU (adjusted by regression model) days	optimized days
19.02.2013	1050.0	1038.1	1052.0
27.02.2013	**746.0	**669.5	*527.0
05.03.2013	**742.0	**788.3	*762.0
19.03.2013	856.0	853.0	771.0

dates for the scenarios		savings by the optimized comp. to the BAU (measured) scenarios		savings of the optimized days comp. to the BAU days using the regression adjustment	
BAU	optimized	kWh	%	kWh	%
19.02.2013	27.03.2013	-2.00	-0.2	-13.86	-1.3
27.02.2013	21.03.2013	219.00	41.6	142.51	27.0
05.03.2013	28.03.2013	-20.00	-2.6	26.30	3.5
19.03.2013	04.04.2013	85.00	11.0	82.02	10.6
		average:	12.4	average:	10.0

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Observed Challenges

☹ each room has adjustable control buttons where the user can increase or decrease the room set-points
→ turn off control buttons during optimization

☹ a malfunction of the data logging system is "highly" possible and the system is very unstable
→ regular BMS server restarts results in missing data

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Conclusion

- savings of about 10% are feasible (based on four days) (reliable result? more days?)
- savings depends on the user flexibility
- independent energy audit will review this procedure and results this winter
- further details regarding case study in Session 6c (Smart Buildings - Predictive Control): Rocha Paula et al. (2013): “An Integrated Approach to Optimal Energy Operations in Buildings” (Friday, 11:30)

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Thank you!

Questions and comments are very welcome

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