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Cascading wood boilers for low emissions

Part 1: Monitoring of series-products from 70 kW – 500 kW with periodic de-ashing systems (Verenum)

Part 2: System modeling for general evaluation (HSLU)

International Energy Agency Bioenergy Task 32 Workshop at
27. Fachgespräch Arbeitskreis Holzfeuerung am 5. Juni 2024, TFZ, Straubing (D)

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HSLU Hochschule Luzern

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Holzfeuerungen Schweiz
Energie Ausserschwyz AG

IEA Bioenergy Task 32

https://task32.ieabioenergy.com/

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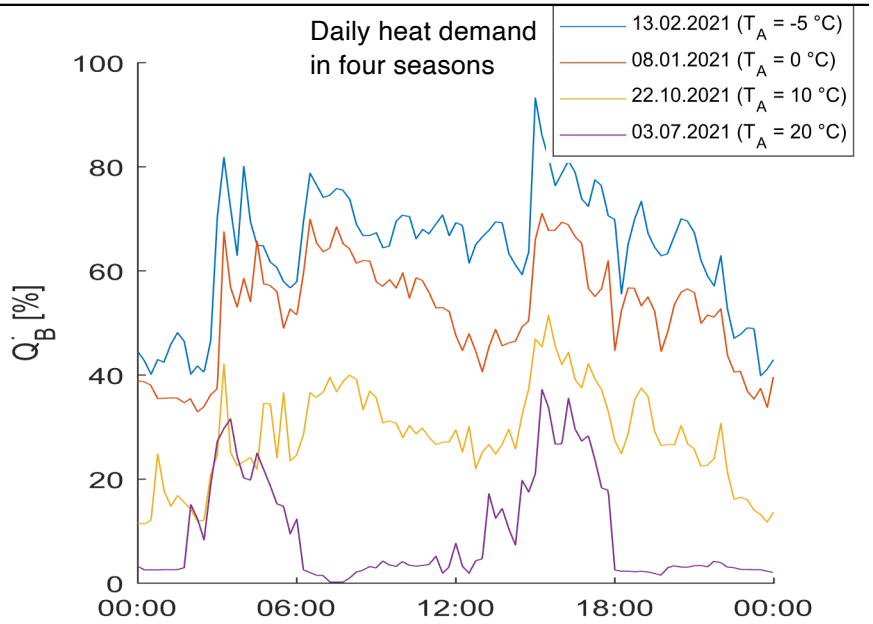
1. Introduction and aim
2. Fundamentals
3. Part 1: Practical investigation
4. Part 2: Process modeling
5. Conclusions

Initial situation: Facts

1. The heat demand of buildings is fluctuating
   - rapidly during a day and
   - slowly during a year

2. Biomass boilers exhibit
   - a limited load range e.g. 50% – 100%
   - a slow behaviour for load changes



This can potentially cause frequent start-ups and increased emissions

Initial situation: Consequence: Requirements from Air Pollution Control Authorities*

R 1: Limitation of boiler starts: - maximum 500 starts per year** (per plant but in discussion)
- maximum 5 starts per day

R 2: Minimum load condition: the operation of biomass heating plant is only allowed if one boiler is in continuous operation for at least 12 hours per day

To fulfill these, **bivalent systems** with fossil boilers for peak and minimum load were often used

This is not accepted any more due to 10% to 25% fossil share

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* The Swiss Association on Air Pollution Control (Cercl'Air factsheet 31p, 2022)
** for boilers > 100 kW (for boilers < 100 kW maximum 1000 starts per year)

Approach

Cascades of wood boilers are applied

- to enable a broad load range
- or in some cases due to practical or economic reasons

Aim

Aim of the project is to investigate under which conditions cascades can fulfill the air pollution requirements, i.e.

- number of starts < 500 per year and operation > 12 hours per day

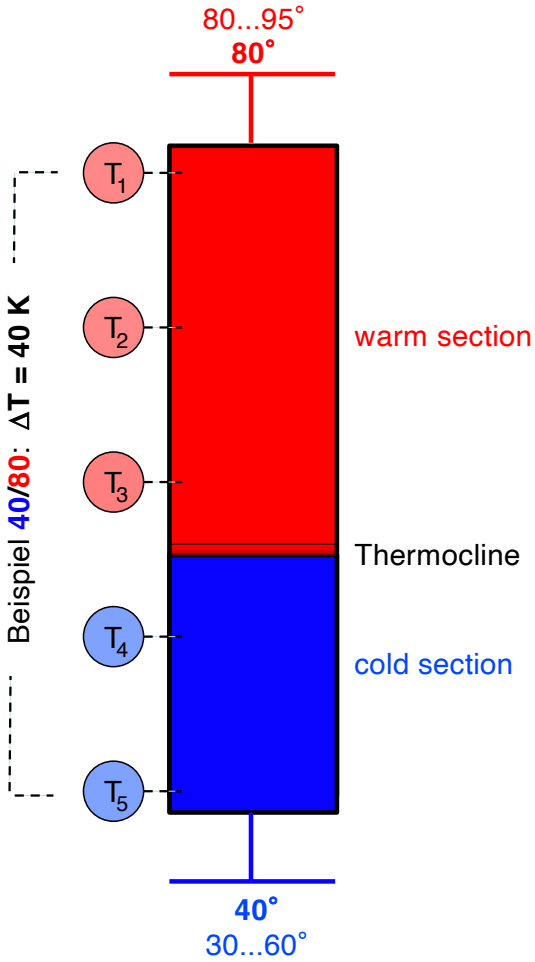
1. Introduction and aim

2. Fundamentals: Effect of

   - definition of storage status S and

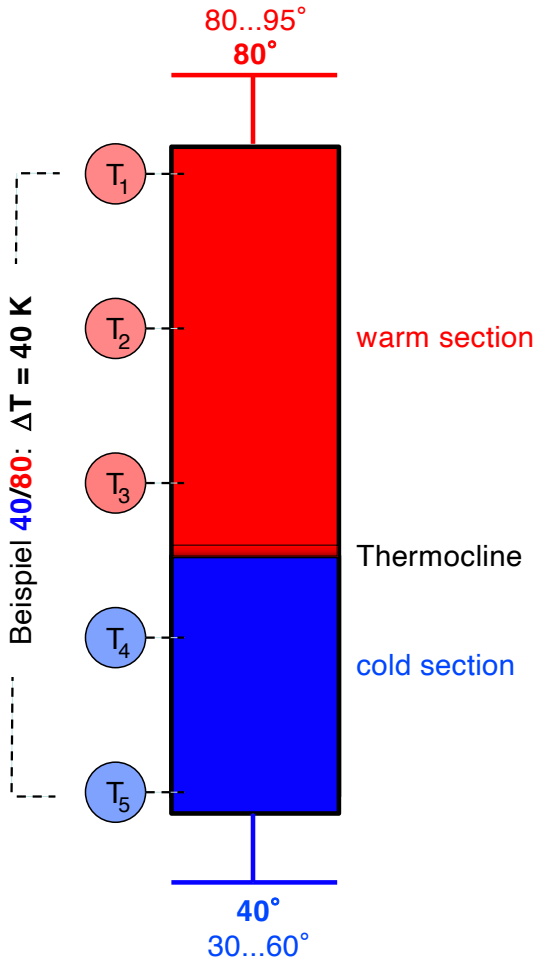
   - control concept for 'load management' for boiler on/off

Heat storage tank with temperature signals and definition of "warm" and "cold" with an ideal stratification and thermocline, thus two temperature levels



Definition of "Storage status"

Standard with 5 temperature sensors and 6 levels for S = 0, 20, 40, 60, 80, 100%



Limitations

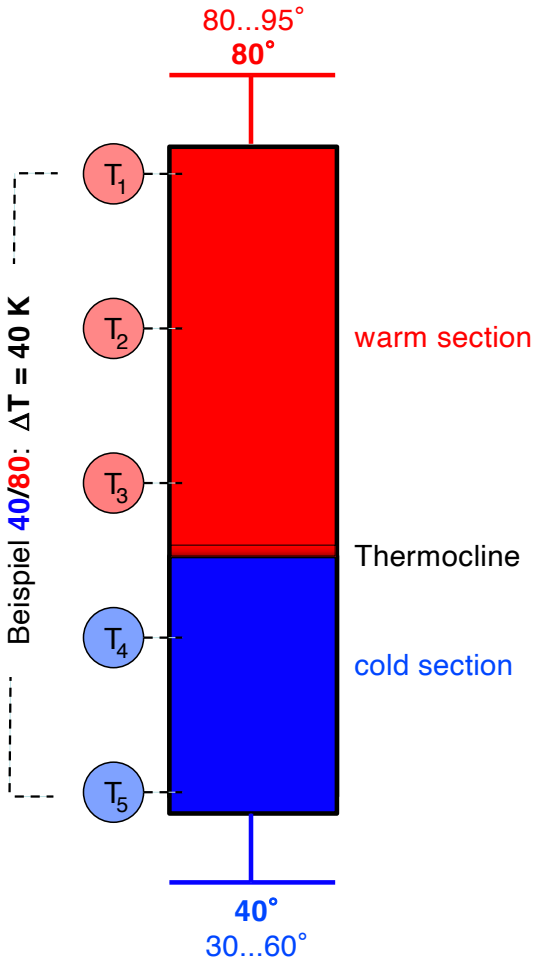
- "warm" and "cold" temperatures vary

- the signal is not continuous but step-wise

Not ideal for control purposes
due to steps, uncertainties and random

Definition of "Storage status"

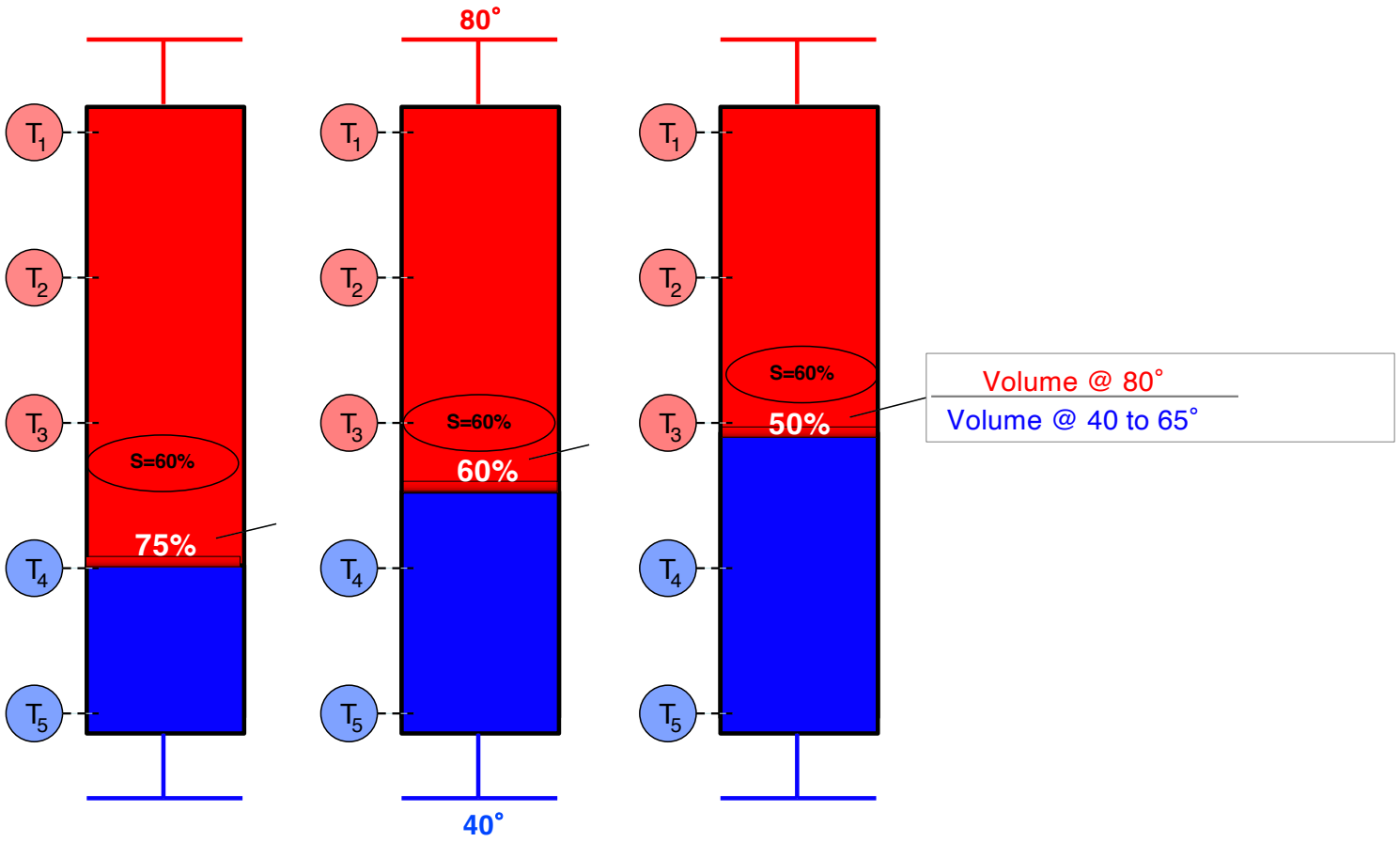
Definition Variant 1: Sensor "warm" or "cold" results in 6 discrete levels for S = 0, 20, 40, 60, 80, 100%



Definition of "Storage status"

Definition Variant 1: Sensor "warm" or "cold" results in 6 discrete levels for S = 0, 20, 40, 60, 80, 100%

Example: S = 60% corresponds to 50% to 75% of warm storage volume, thus definition is not ideal

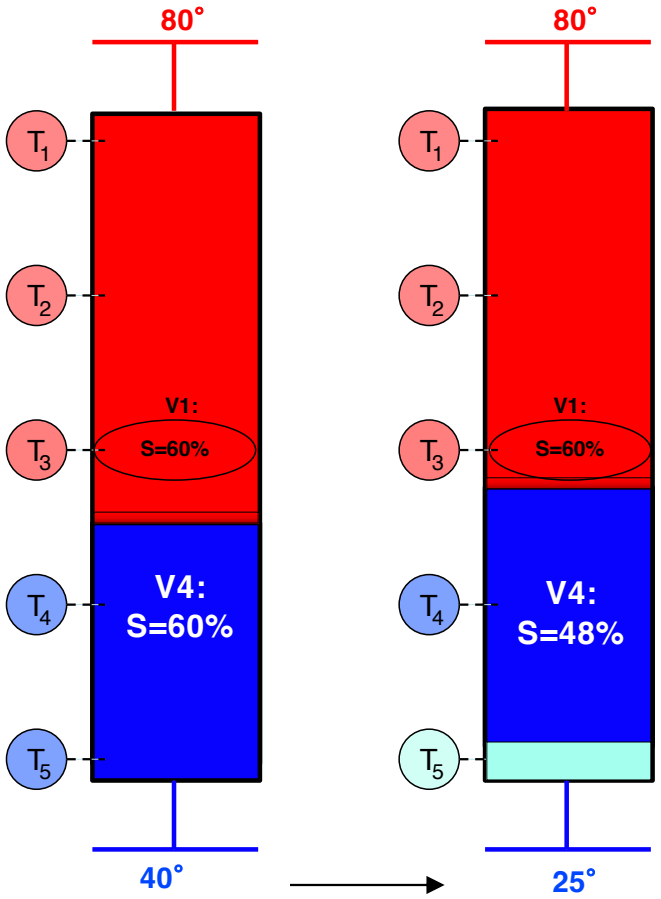


New method (Variant 5)
more comprehensive and stable

$S = (T_s - T_c) / (T_s - T_w)$

T_s = mean storage temp.
T_c = cold temp.
T_w = warm temp.

Variant 1: **S = 60%**



S = 60%

new method for T_w 80° and T_k 40°

$T_s = (\ 2 \times 40° + 3 \times 80°\ ) / 5 = 64°$

S = (64-40) / (80-40) **= 60%**

Return temp. drops to T_k 25°

$T_s = (1x25+1x40+3x80) / 5 = 61°$

for $\Delta T = f(T_k)$ **S = (61-40) / (80-40) = 48%**

1. Introduction and aim

2. Fundamentals: Effect of

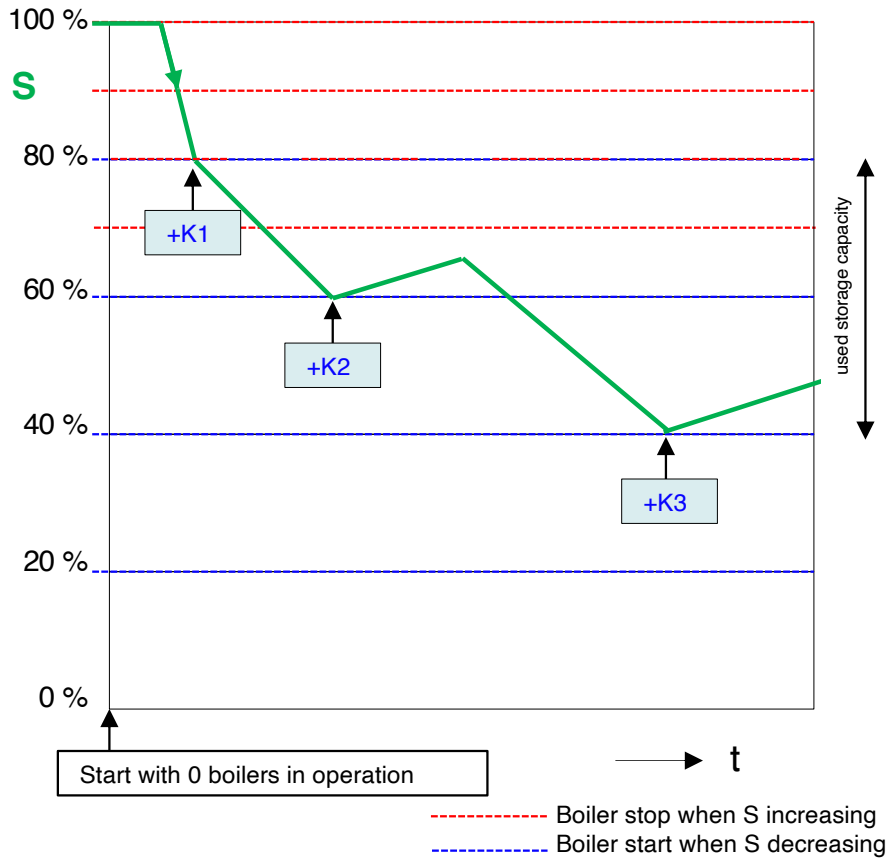
   - definition of storage status S and

   - control concept for 'load management' for boiler on/off

Control concept: Thresholds for start or stop of a boiler

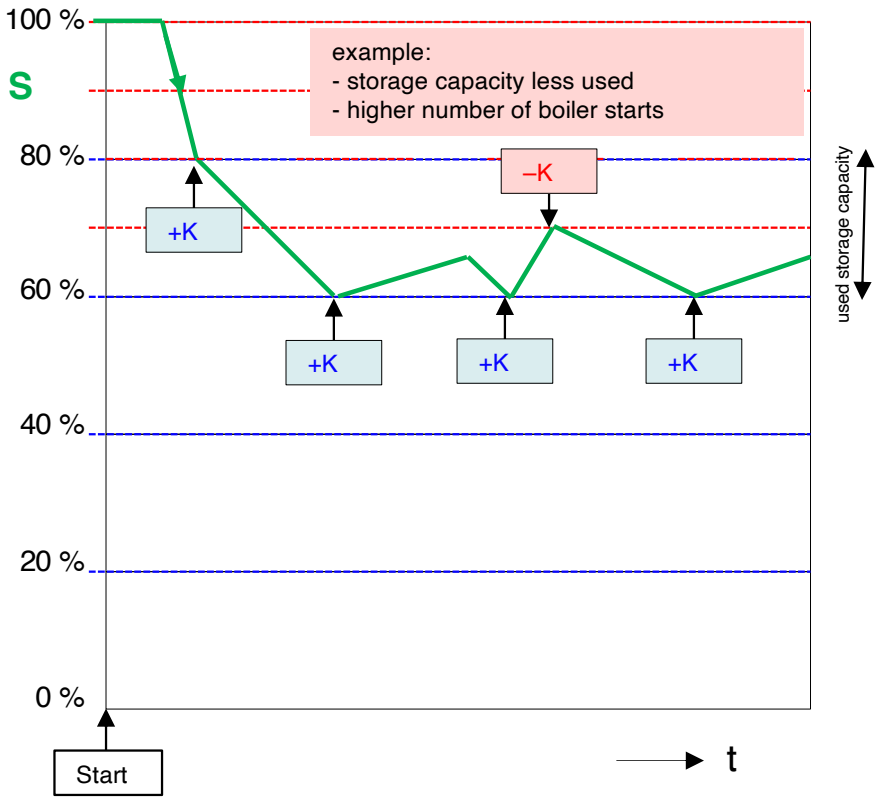
A: individual conditions, fixed for each boiler

for limited number of boilers
expansion causes need for new control concept



B: general conditions, (thus dynamic)

for unlimited number of boilers
expansion of heat pland without need of adaptations



Example without load modulation

1. Introduction and aim
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Investigated plants	Plant 1	Plant 2	Plant 3
Fuel	Wood chips	Wood pellets	Wood pellets
Number of wood boilers	4	3	2

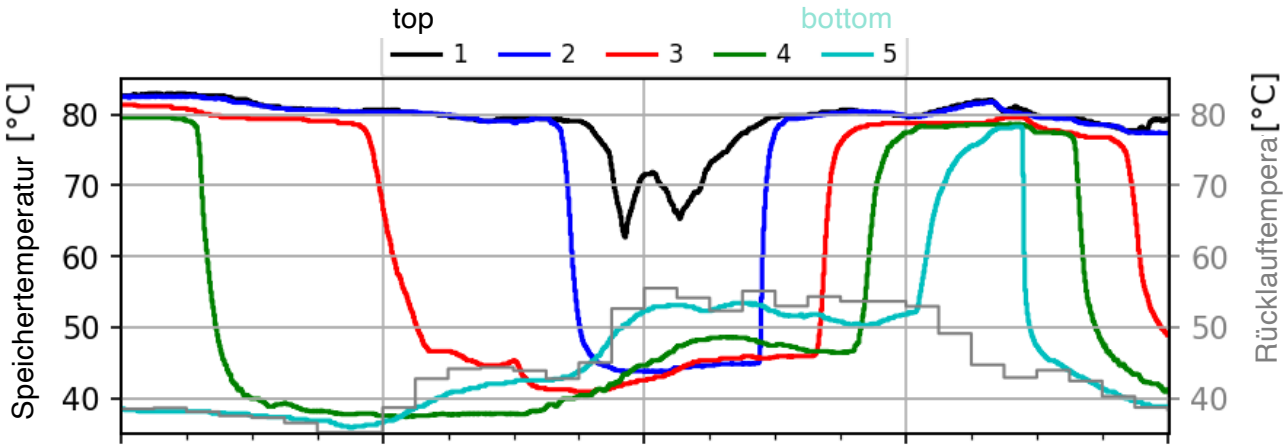
Investigated plants	Plant 1	Plant 2	Plant 3
Fuel	Wood chips	Wood pellets	Wood pellets
Number of wood boilers	4	3	2
Installed capacity	1‘320 kW 4 x 330 kW	260 kW 100 kW / 80 kW / 80 kW	170 kW 2 x 85 kW
Full load hours	ca. 2000 h/a	ca. 1600 h/a	ca. 3200 h/a
Storage capacity at ΔT 40 K - at nominal load - for 2/3 of installed capacity	 46 min 69 min	 73 min 110 min	 68 min 102 min
Control concept	Phase 1: Type B (general condiitions) Phase 2: Type A (individual condiitions)	Type A (individual conditions)	for two boilers Type A = Type B
Storage status S	Variant 5 20 °C – 80 °C	Variant 4 30 °C – 80 °C	Variant 4 40 °C – 80 °C
Load control Modulation range	all boilers 50 % - 100 %	one boiler 40 % - 100 %	all boilers 35 % - 100 %

recommendation > 60 min: ok

Usual de-ashing intervall 12 h of operation

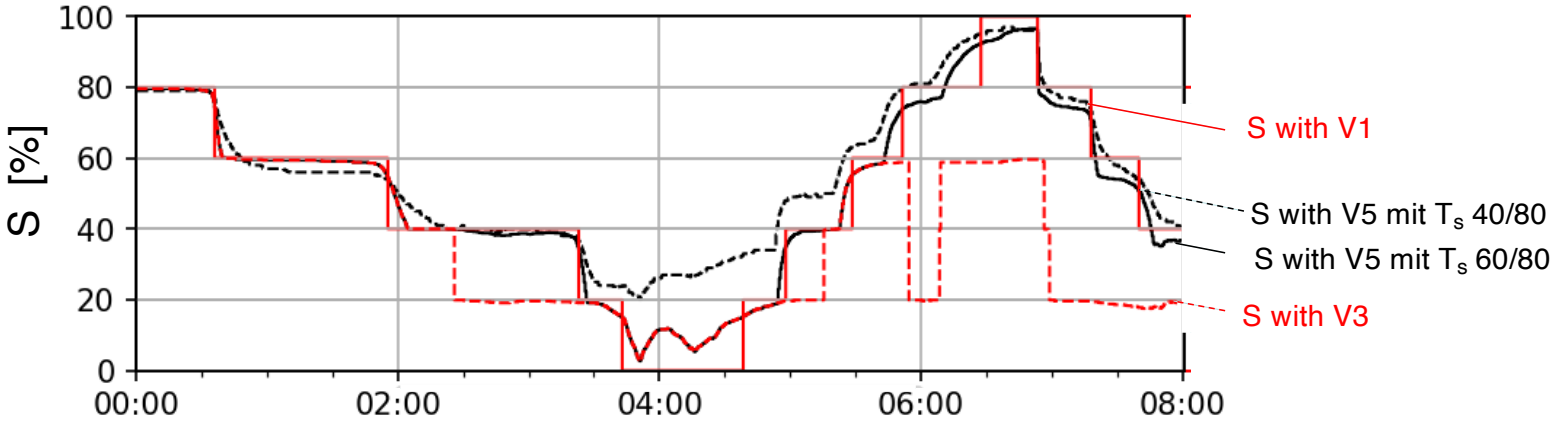
Comparison of effect of definition of Storage status S

Measurement
of storage temperature



Calculated
Storage status S
by different variants:

- V1 step-wise but ok
- V5 smoother
- V3 missleading



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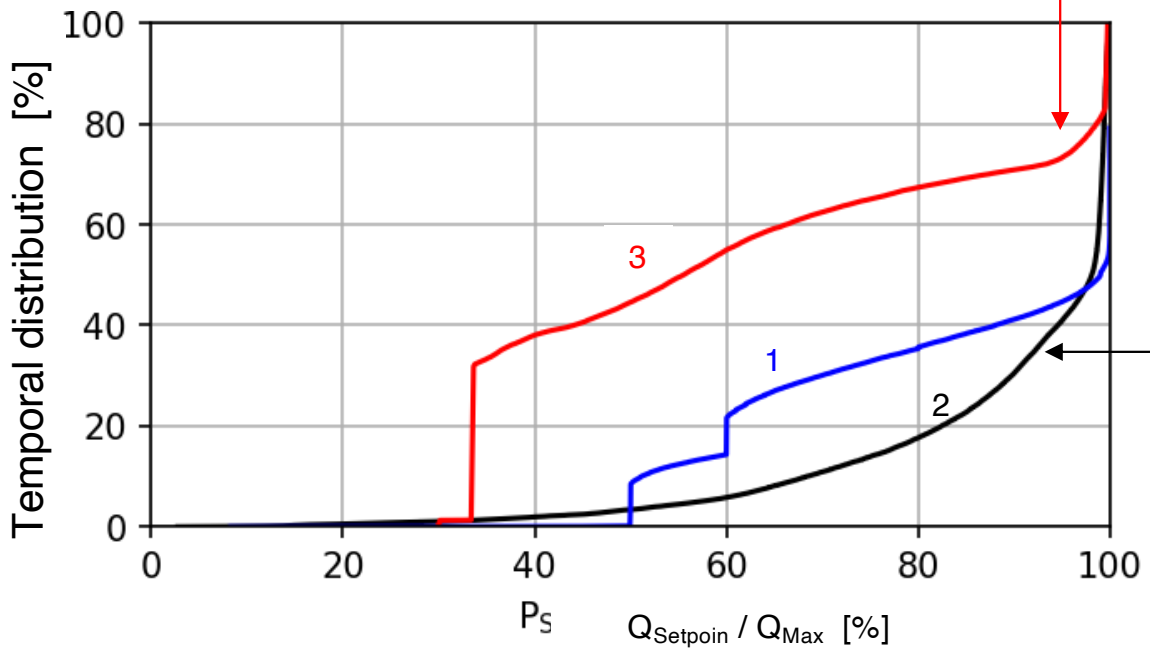
Load modulation of the investigated plants

Modulation of boilers (here 2) is in use for more than 70% of time, hence the potential is exhausted



Potential of modulation is rarely used since one boiler is modulated only

Results: Number of annual starts

Phase 1: original control concept. Phase 2: modified control concept. *Extrapolation.

	Number of boilers	Phase and control concept	Annual starts of the heating plant	Annual starts per boiler
Plant 1	4	Phase 1 concept B general conditions	2469	617

Results: Number of annual starts

Phase 1: original control concept. Phase 2: modified control concept. *Extrapolation.

	Number of boilers	Phase and control concept	Annual starts of the heating plant	Annual starts per boiler
Plant 1	4	Phase 1 concept B general conditions	2469	617
		Phase 2 concept A individual conditions	1377*	344*

Optimization of control:
1. by avoidance of gaps in heat production
2. avoidance of simultaneous boiler charging
3. control concept by "individual conditions"

Results: Number of annual starts

Phase 1: original control concept. Phase 2: modified control concept. *Extrapolation.

	Number of boilers	Phase and control concept	Annual starts of the heating plant	Annual starts per boiler
Plant 1	4	Phase 1 concept B general conditions	2469	617
		Phase 2 concept A individual conditions	1377*	344*
Plant 2	3	–	1835	611
Plant 3	2	–	2060	1030

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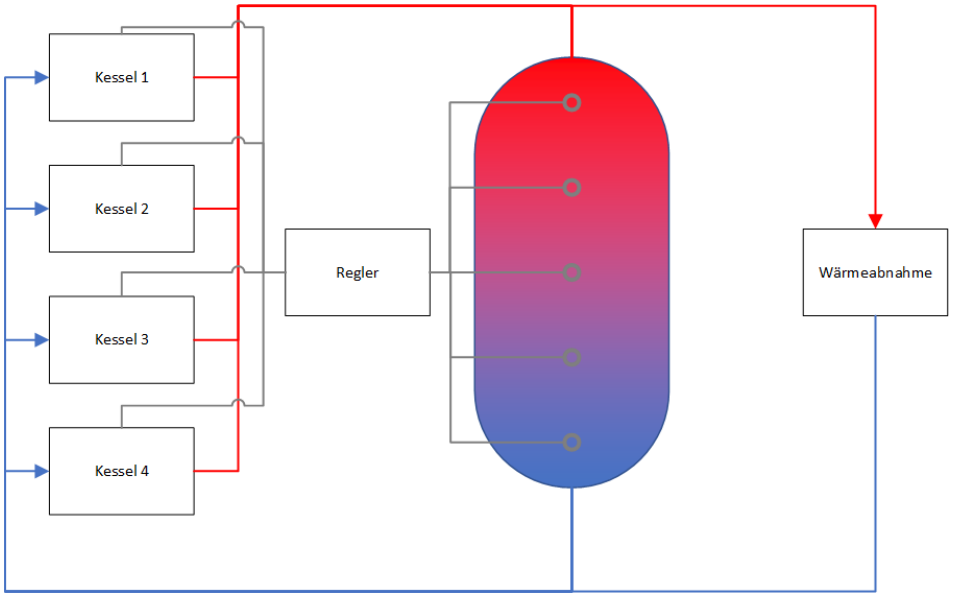
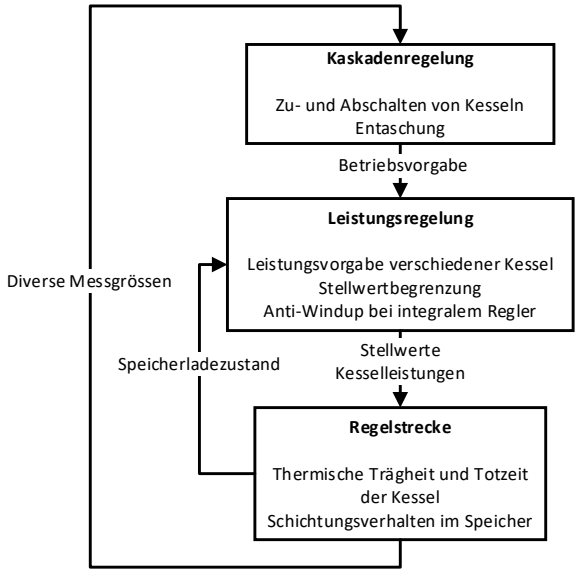
Model:

Plant layout



Control concept



Method: Energy balance calculated to cover the heat demand (which is a function of time)

- in 1 minute steps
- during 24 hours profile for four seasons
- during 365 days in a year
- modeling in Matlab

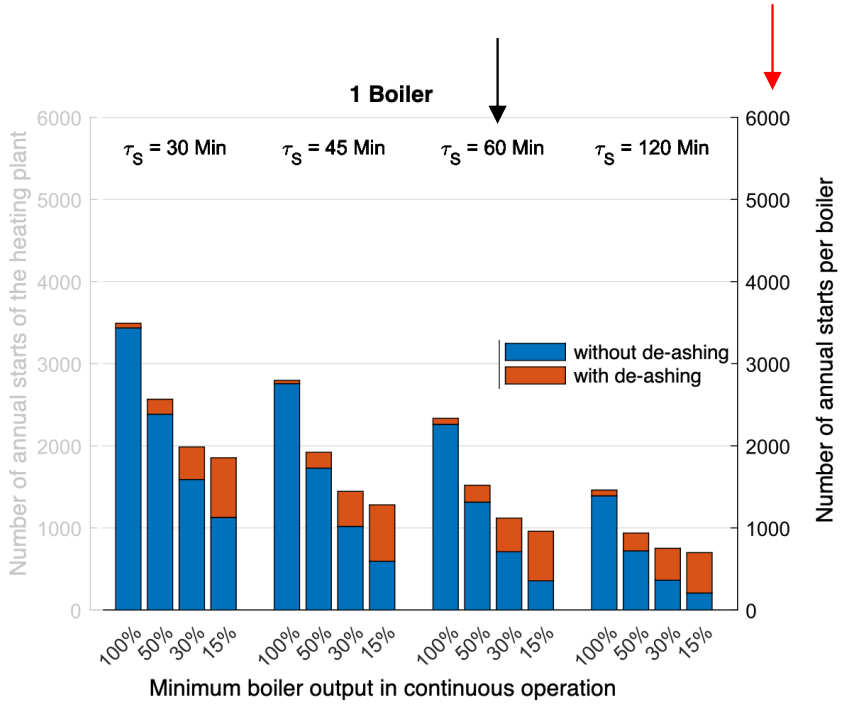
Parameters:

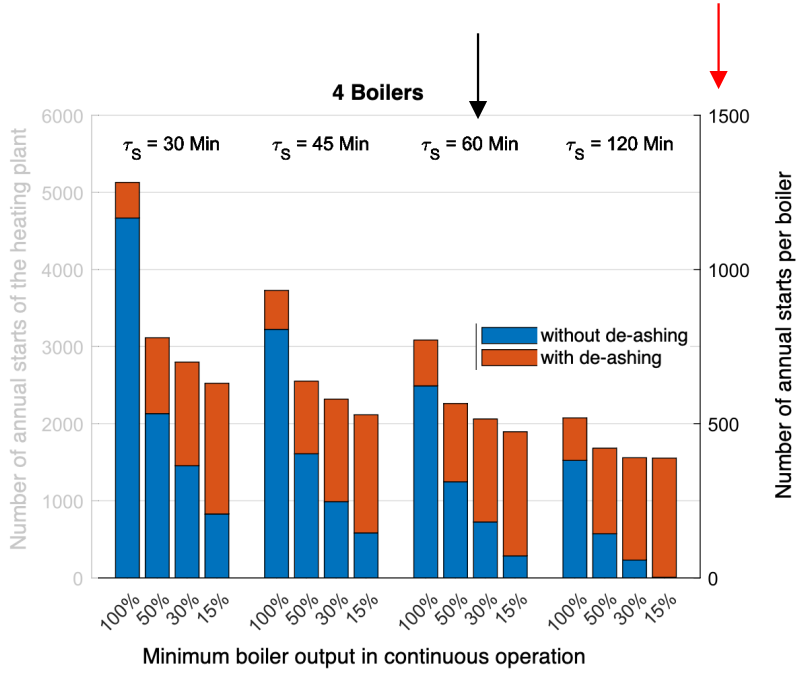
- number of boilers 1 / 2 / 3 / 4 and more
- heat storage capacity 0 / 0.5 / 1 / 2 / 4 hours
- definition of Storage status S and control concept

Result 1:

Number of Starts

- Cascades
  - increase the total number of starts, which is not relevant for the total emissions, and
  - reduce the number of starts per boiler (which is relevant for the total emissions)
- Heat storage capacity of 1 hour is confirmed as reasonable standard
- Load modulation from 50% or less reduces start-ups significantly (more than storage increase)
- For modulating boilers, the number of starts is dominated by the de-ashing stops





Result 2:

Options to meet minimum load requirement of 12 hours continuous operation per day

Figure in table = Fossil share needed

Thus 0 % = fulfilled without fossil boiler

Modulation range of wood boilers	Number of wood boilers			
	1	2	3	4
100 %	97 %	27 %	17 %	12 %
90%–100 %	66 %	24 %	16 %	11 %
80%–100 %	53 %	22 %	15 %	11 %
70%–100 %	44 %	20 %	13 %	3 %
60%–100 %	35 %	18 %	12 %	0 %
50%–100 %	26 %	16 %	2 %	0 %
40%–100 %	19 %	14 %	0 %	0 %
30%–100 %	13 %	0 %	0 %	0 %
20%–100 %	10 %	0 %	0 %	0 %
10%–100 %	0 %	0 %	0 %	0 %

- Load modulation from 50 % or less is crucial to avoid unfavourable boiler operation
- Cascades with at least 2 but preferably 3 boilers enable favourable operation

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Conclusions

1. Cascade systems are suited for a fossil-free heat generation
   and to fulfill the requirements on low load and limit of starts (if counted per boiler)

2. To fulfill the requirements,

   - a heat storage of 1 full load hour is recommended and

   - for three boilers, a load modulation from 50 % is needed
     for two boilers, a load modulation from 30 % is needed

3. Starts due to automatic de-ashing often contribute to 50 % of the starts.
   Hence optimization to anticipate de-ashing and to extend the intervals are recommended.

4. The control concept has a significant influence on the number of starts.
   - Investigated plants had 600 annual starts per boiler and more
   - Optimization of the control concept reduced the starts to 350 per boiler

Acknowledgments

Team: Adrian Lauber, Verenum (Monitoring)
Felix Schumacher, HSLU (Modelling)
Jürgen Good, Verenum & QM

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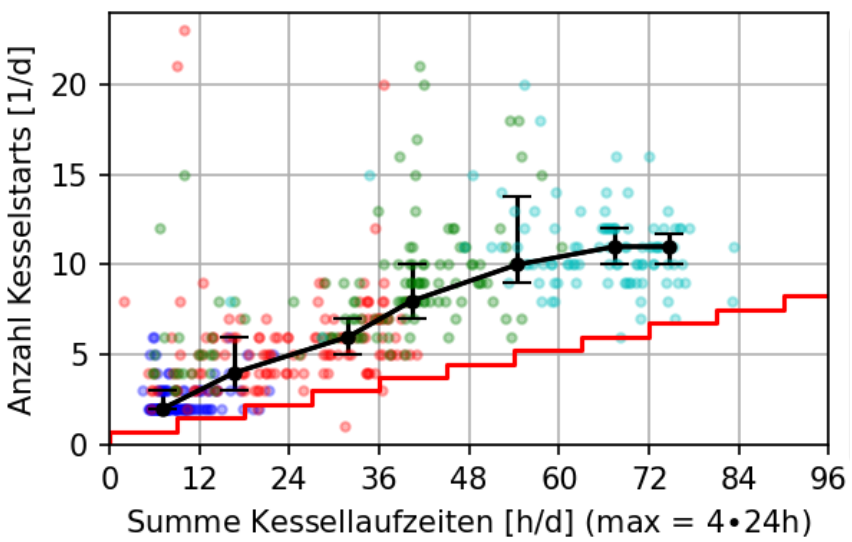
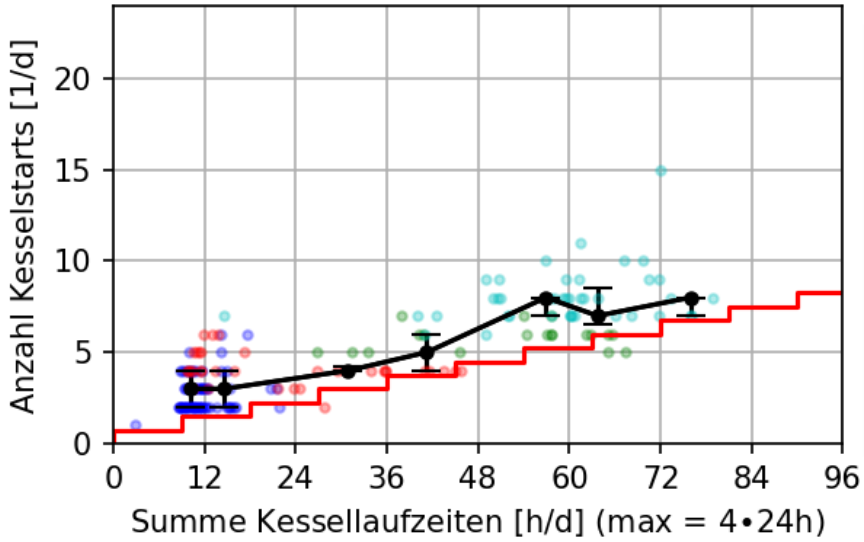
The End

Number of boiler starts for plant 1

Phase 1 (control by general conditions)



Phase 2 after adaptation of control concept to individual conditions



Maximum number of boilers in operation:
blue = 1, red = 2, green = 3, turquoise = 4.
Black: median and quartiles.
Red line: Starts due to ash removals

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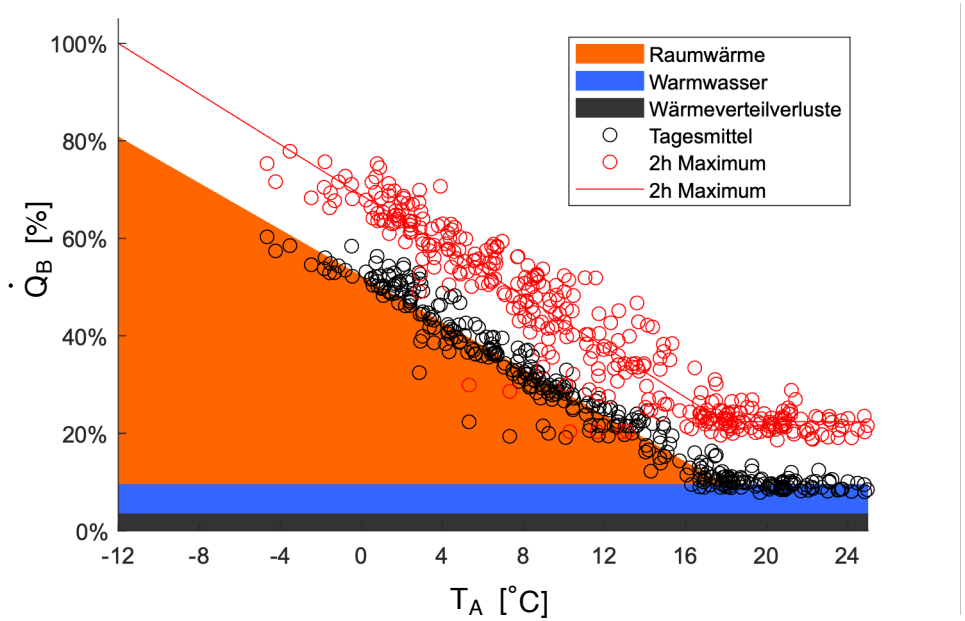
Example of heat demand profile: district heating network of plant 1

Daily heat demand
as functiion of ambient temperature



Ambient temperature

–> Data used to model one year as function of ambient temperature