LARGE-SCALE BOILER MODELLING WITH CLARA A PROJECT EXPERIENCE

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CONTENT

In cooperation with

CONTENT

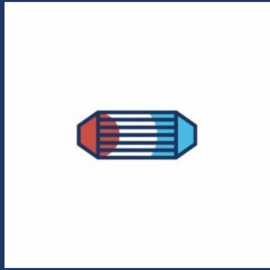
- FVTR Introduction
- LEAG Project Introduction
- Boiler Constructive Overview
- Boiler Model
- Modelling: Problems and Solutions
  - FrictionAtInlet/Outlet between tube bundles and at spray injectors
  - Flue gas recirculation
- Feedback
- First results calibration
- Summary, outlook

In cooperation with

FVTR BACKGROUND

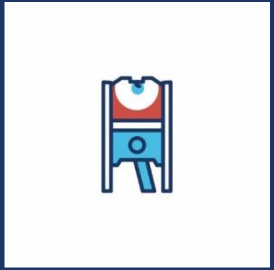
- Founded in 2007
- 22 colleagues
- Engineering services for combustion engines and energy systems
  - Measurement
  - Simulation

Experimental Engine Research



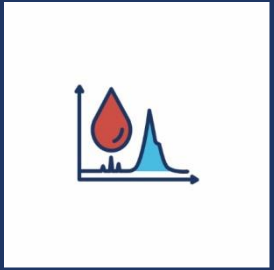
Exhaust Gas Treatment

Fuel Injection Analysis

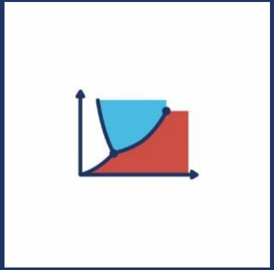


Applied Thermodynamics

Energy System Simulation



Fuels & Lubricants Research



Thermophysical Properties

Training, Studies & Consulting

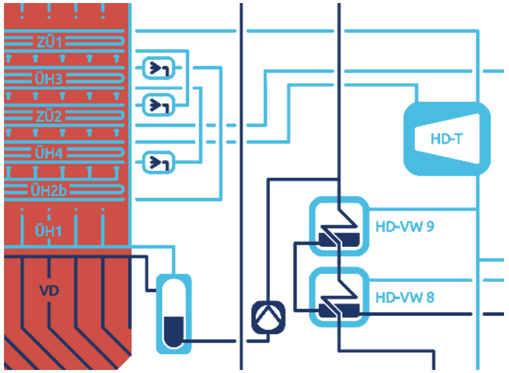
Energy System Simulation

Simulating complex systems for straightforward solutions

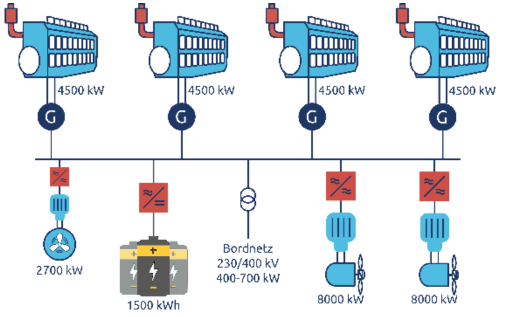
KEY SERVICES

- Modeling of energy sectors and infrastructure
- Dynamic modeling of thermal power plants, maritime energy systems and production processes
- 3D-CFD of combustion and fouling

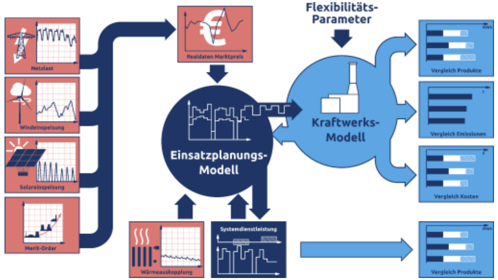
POWER PLANT MODELING



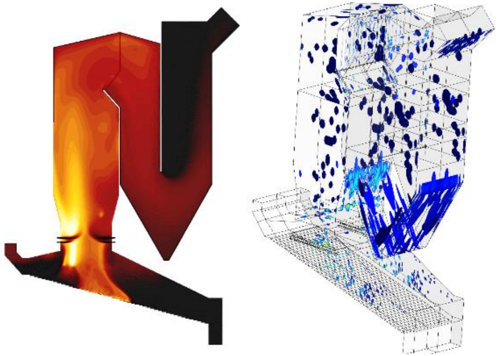
MULTI-ENGINE SYSTEMS



DISPATCH MODELING



PARTICLE DEPOSITION



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LEAG PPOJECT INTRODUCTION

Subject: large lignite power plant

- Operator: LEAG
- Fuel: Lignite
- Live steam approx.: 270 bar / 550 °C
- Hot reheat approx: 60 bar / 580 °C
- District heating: 150 MW_{th}

LEAG PPOJECT INTRODUCTION

Scope of Project

- Development of a detailed dynamic model of the power plant
- Shall be used to accompany:
  - Retrofits of the system
  - Changed components
  - Control optimisation
  - Estimate future wear
- Planned investigations:
  - Improvement of primary and secondary control
  - Faster load changes
  - Reduced component stress

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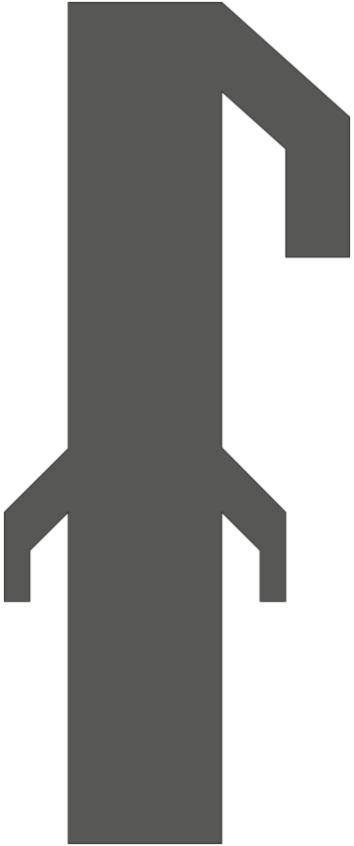
BOILER CONSTRUCTIVE OVERVIEW

General

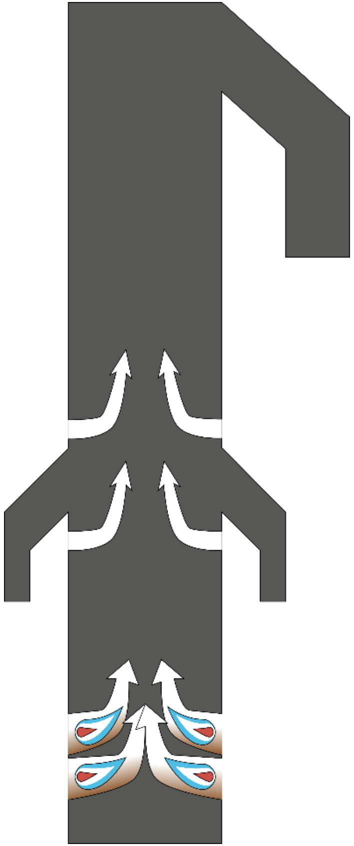
- Height approx. 176 m
- Benson type boiler
- Fuel: lignite (6 -12 MJ/kg)



BOILER CONSTRUCTIVE OVERVIEW

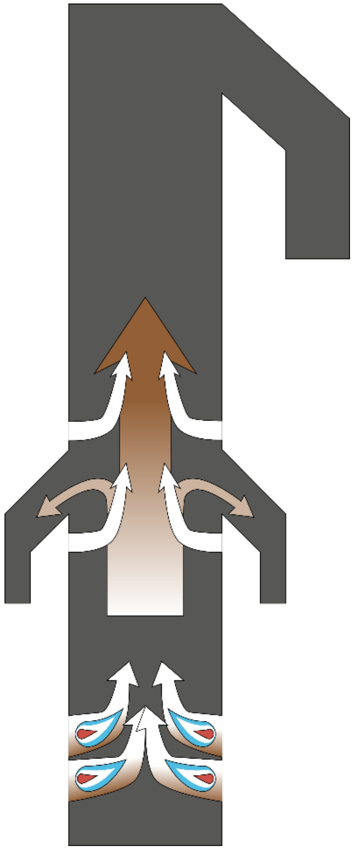
Combustion

- Two burner levels
- Primary air and secondary air



Flue Gas Recirculation

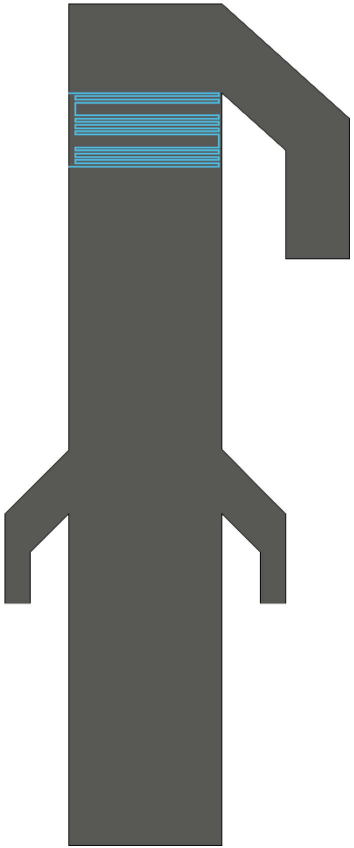
- Recirculated flue gas transports coal
- To dry lignite (water content approach 50 %)
- Approx. 30 % of flue gas flow



BOILER CONSTRUCTIVE OVERVIEW

Economiser

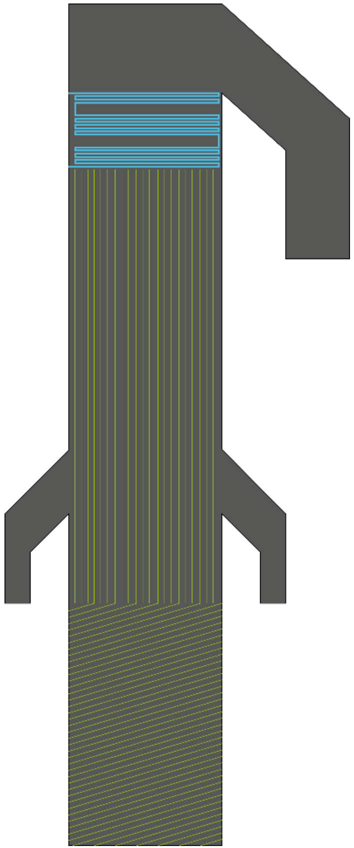
- Upmost convective tube bank



BOILER CONSTRUCTIVE OVERVIEW

Evaporator and Superheater 1

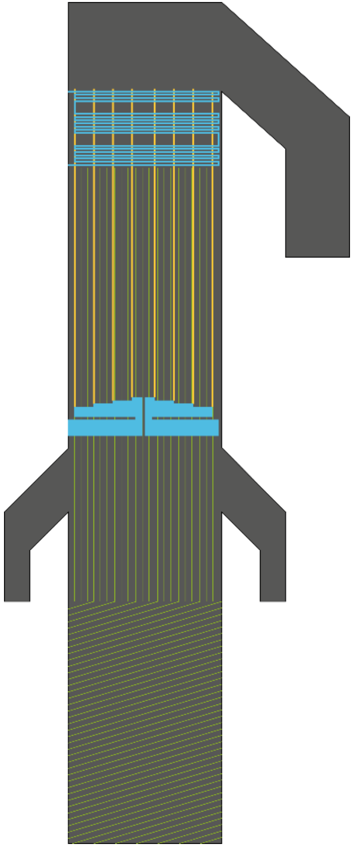
- Finned tube walls
- Helix in lower parts, upper part has straight pipes
- tube walls in convective part constitute superheater 1
- No wall cooling in the height of the eco



BOILER CONSTRUCTIVE OVERVIEW

Superheater 2

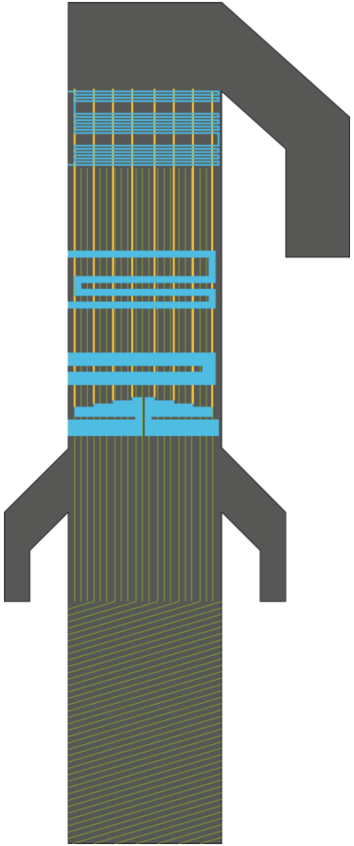
- Carrier tubes
- First tube bundle take radiation from the flame room



BOILER CONSTRUCTIVE OVERVIEW

Superheater 3 and 4

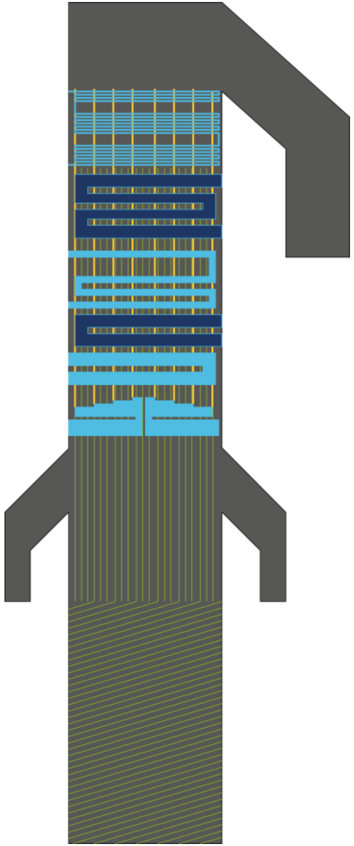
- Convective tube banks



BOILER CONSTRUCTIVE OVERVIEW

Reheat

- Convective tube banks



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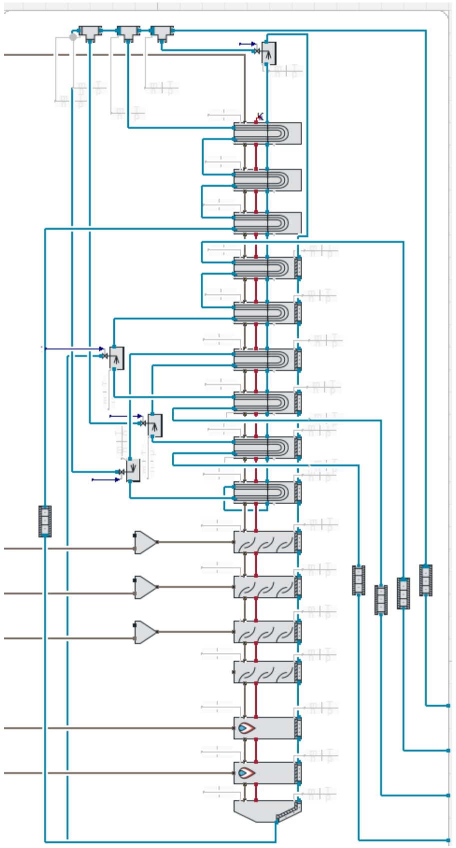
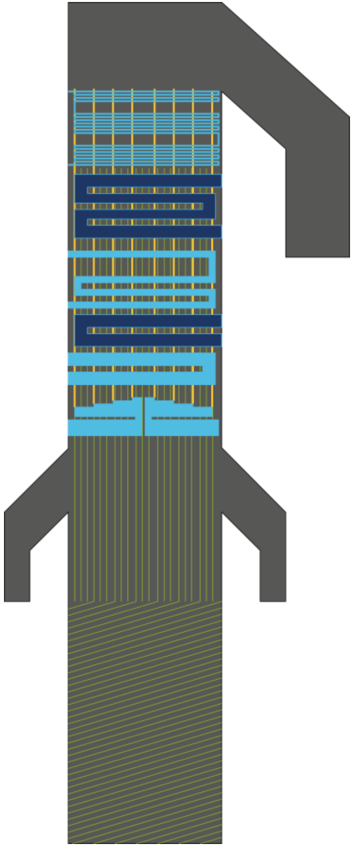
BOILER MODEL OVERVIEW

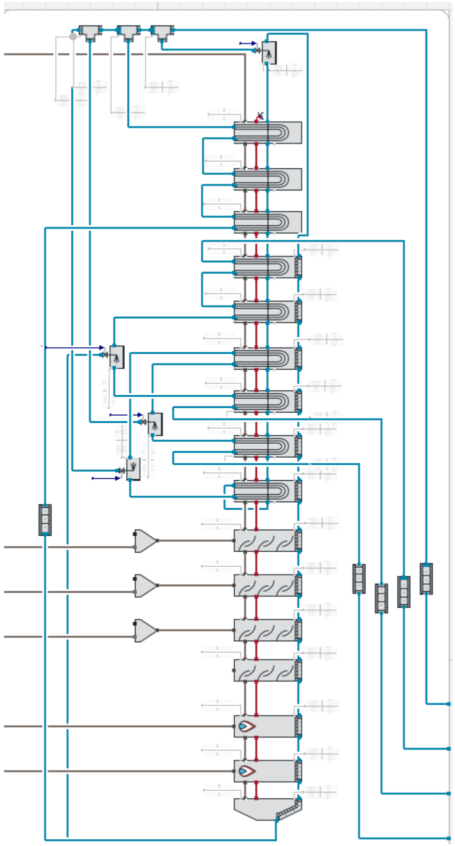


- Included:
  - Risers, downcomers
  - StaCy-based initialisation
- Excluded (for now):
  - Headers
- Precise:
  - Gas side heat transfer
- Coarse:
  - Water side heat transfer
  - Pressure losses



Model Statistics

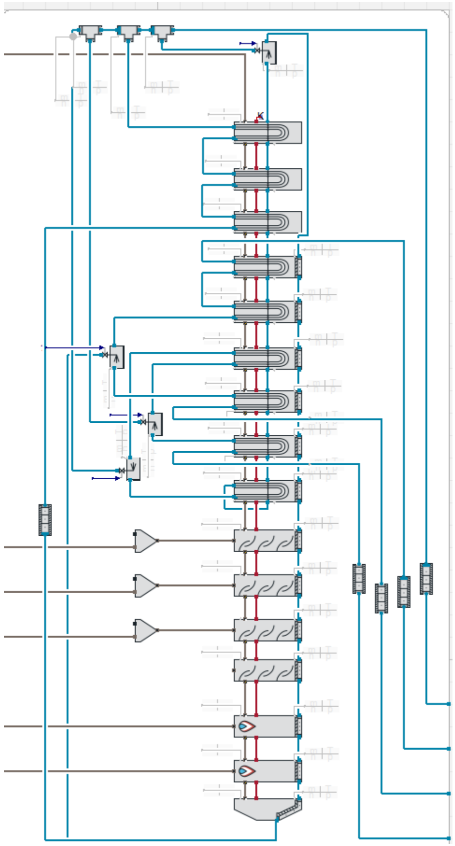
- Translated Model
  Constants: 65580 scalars
  Free parameters: 6943 scalars
  Parameter depending: 25206 scalars
  Outputs: 2 scalars
  Continuous time states: 641 scalars
  Time-varying variables: 23618 scalars
  Alias variables: 17077 scalars
  Assumed default initial conditions: 295
  Number of mixed real/discrete systems of equations: 0



BOILER MODEL DETAILS

Nonlinear systems:

Sizes of nonlinear systems of equations: {20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 3, 3, 10, 2, 20, 20, 20, 3, 3, 10, 3, 2, 2, 20, 5, 3, 3, 10, 2, 2, 4, 10, 3, 10, 3, 2, 2, 3, 2, 2, 3, 3, 10, 2, 2, 10, 2, 2, 3, 10, 2, 2, 3, 4, 20, 3, 3, 3, 3, 10, 2, 10, 2, 2, 10, 2, 2, 2, 6, 2, 2, 3, 8, 2, 2, 3, 8, 2, 2, 2, 8, 3, 2, 2, 8, 3, 2, 2, 8, 3, 2, 2, 8, 3, 2, 3, 15, 2, 2, 7, 7, 7, 3, 3, 3, 3, 3, 3, 7, 2, 10, 2, 10, 2, 2, 10, 2, 2, 3, 7, 7, 7, 7, 7, 10, 2, 10, 10}
Sizes after manipulation of the nonlinear systems: {1, 4, 1, 4, 4}



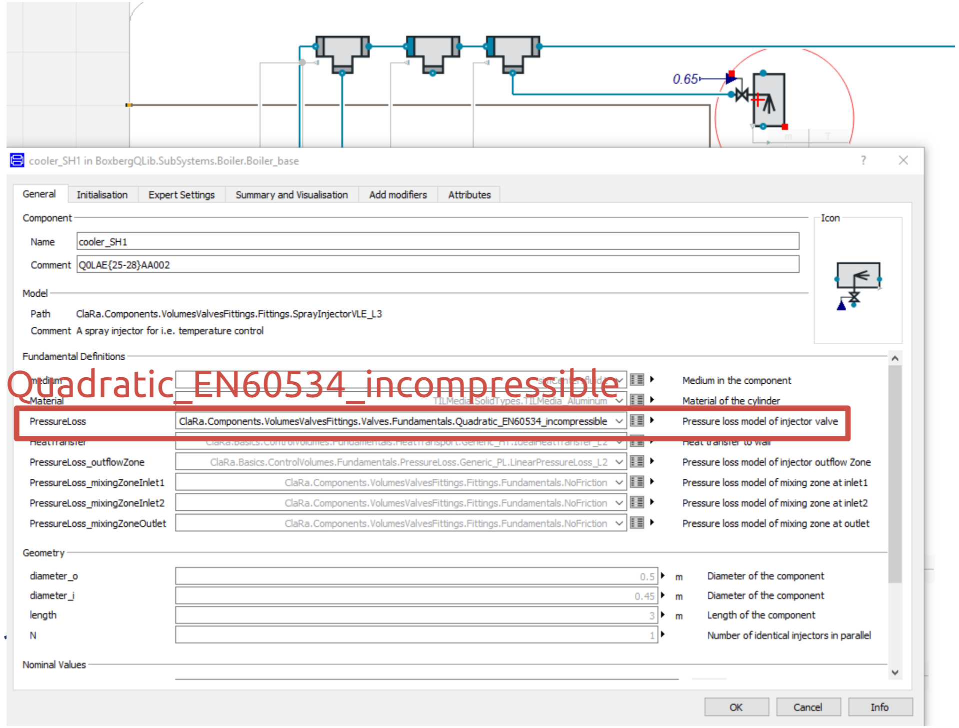
CONTENT

Nonlinear Systems of Size 4

System simulation.nonlinear[130]:

The equation system depends on the following timevarying variables:
boiler.cooler_SH2.mixingZone.h
boiler.cooler_SH2.mixingZone.p
boiler.cooler_SH2.summary.outline.Delta_p
boiler.cooler_SH2.valve.pressureLoss.p_in
boiler.splitIC2.h
boiler.splitIC2.p

Iteration variables:
boiler.cooler_SH2.summary.inlet2.T(start = 288.1
boiler.cooler_SH2.valve.fluidIn.d(start = 0.0)
boiler.cooler_SH2.valve.fluidOut.d(start = 0.0)
boiler.cooler_SH2.valve.fluidOut.T(start = 288.15)



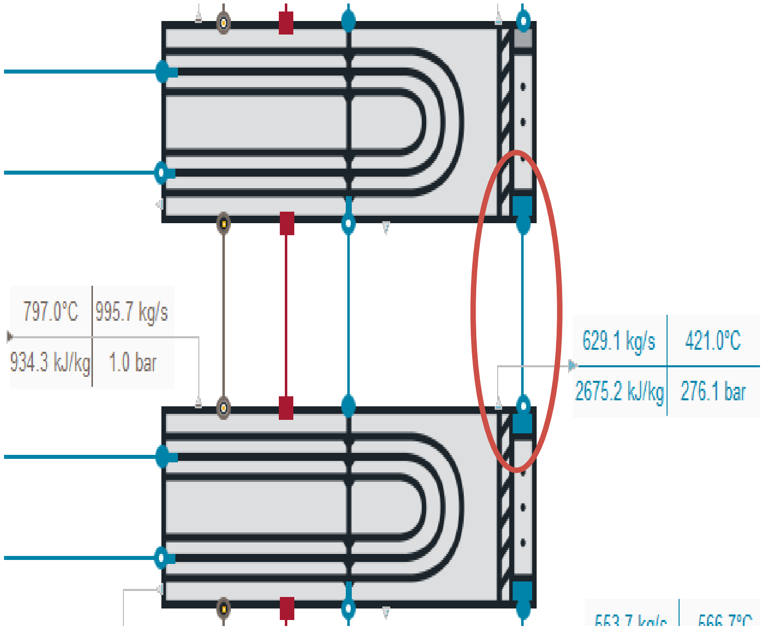
MODELLING: PROBLEMS AND SOLUTIONS

Problems solved: eliminating lots of nonlinear systems of size 2

System simulation.nonlinear[72]:

The equation system depends on the following timevarying variables:
boiler.RH2.pipeFlow_FTW.Delta_p_grav[4]
boiler.RH2.pipeFlow_FTW.h[3]
boiler.RH2.pipeFlow_FTW.iCom.h_in[]
boiler.RH2.pipeFlow_FTW.p[3]
boiler.SH3.pipeFlow_FTW.Delta_p_grav[1]
boiler.SH3.pipeFlow_FTW.h[1]
boiler.SH3.pipeFlow_FTW.p[1]
boiler.SH4.pipeFlow_FTW.p[3]

Iteration variables:
boiler.quadruple10.m_flow(start = boiler.RH2.pipeFlow_FTW.m_flow_nom)
boiler.RH2.pipeFlow_FTW.Delta_p_fric[4](start = 0.0)



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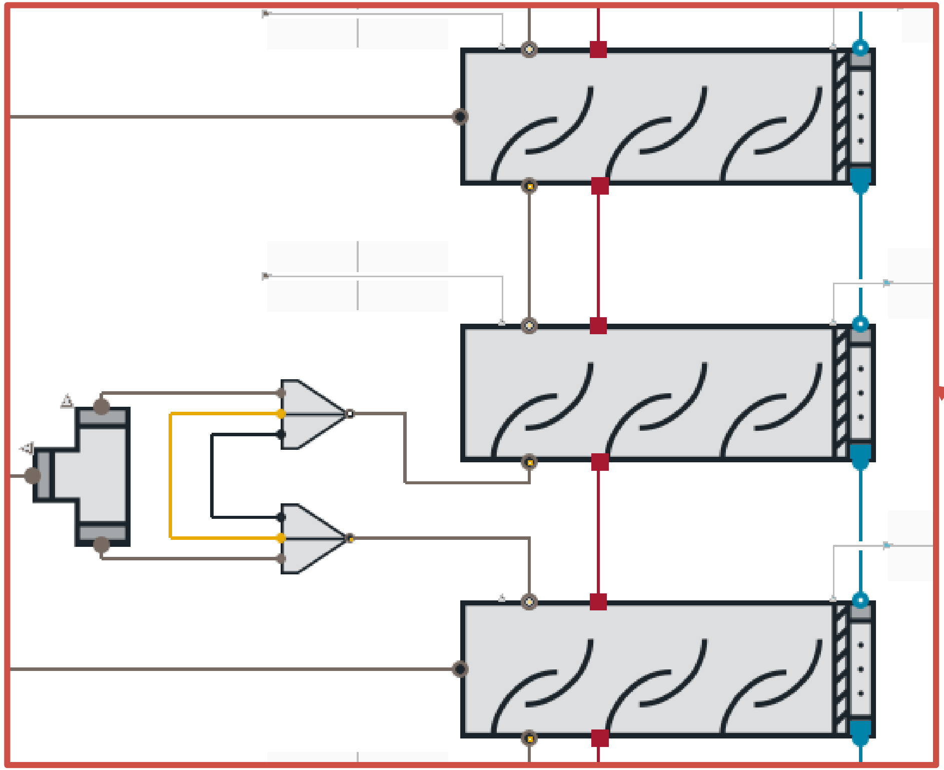
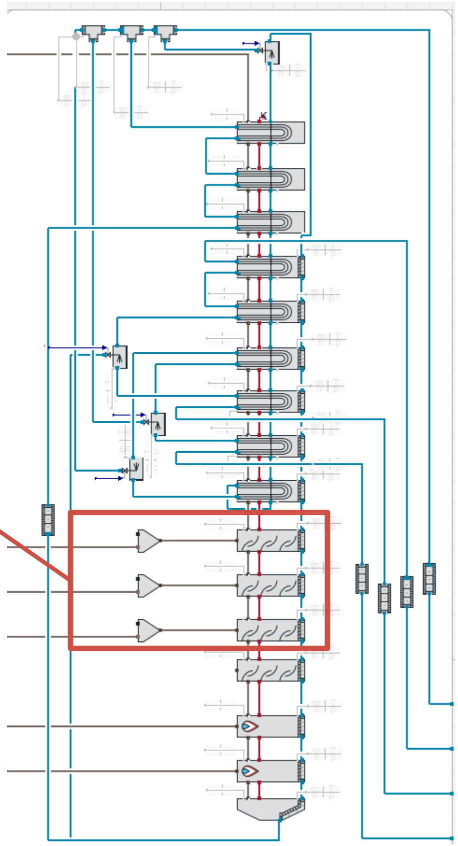
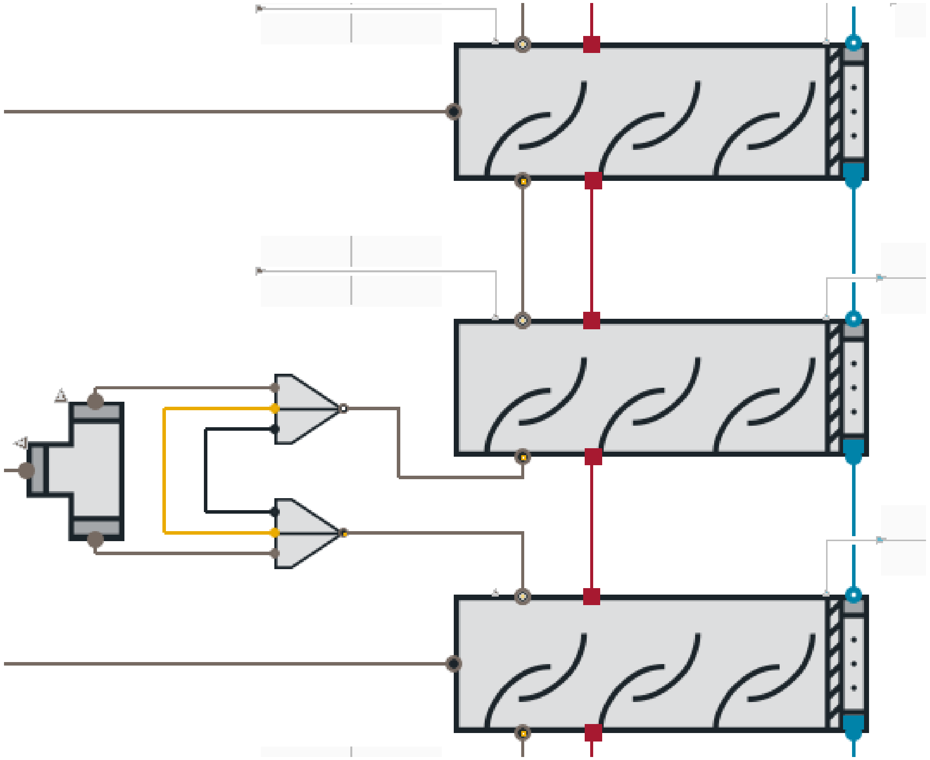




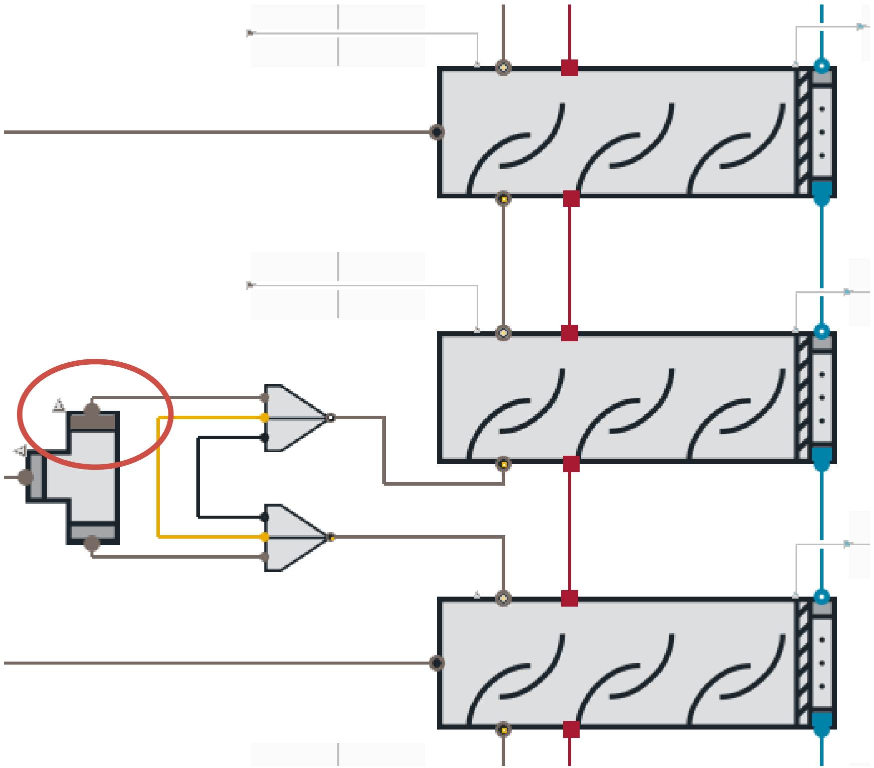
Realisation of Flue Gas Recirculation

- Sizes of nonlinear systems of equations: {20, 20, 20, 20, 20, 20, 1045, 3, 3, 10, 2, 3, 3, 10, 2, 2, 3, 3, 3, 3, 3, 3, 3, 7, 3, 3, 10, 3, 2, 2, 10, 3, 2, 2, 7, 7, 7, 15, 2, 2, 7, 7, 10, 2, 3, 10, 2, 2, 3, 2, 8, 2, 3, 2, 8, 2, 8, 2, 8, 2, 8, 2, 8, 6, 5, 2, 2, 3, 2, 3, 2, 3, 2, 3, 2, 3, 2, 2, 10, 3, 2, 2, 7, 10, 2, 2, 3, 3, 10, 2, 2, 3, 10, 2, 2, 3, 4, 2, 10, 2, 7, 7, 3, 3, 3, 3, 2, 10, 2, 10, 2, 2, 10, 2, 2, 2, 4, 10, 10, 10}
  Sizes after manipulation of the nonlinear systems: {1, 1, 1, 1, 1, 1, 27, 1, 4, 4, 4}



Vary Pressure Losses

Sizes of nonlinear systems of equations: {20, 563, 1045, 2, 3, 3, 3, 3, 10, 2, 2, 3, 8, 2, 2, 5, 2, 6, 10, 2, 3, 8, 2, 2, 2, 8, 2, 3, 2, 8, 2, 3, 3, 3, 10, 2, 2, 2, 8, 2, 3, 10, 2, 2, 3, 10, 3, 2, 2, 3, 2, 10, 2, 2, 8, 2, 3, 3, 3, 10, 2, 2, 10, 2, 2, 3, 10, 2, 2, 3, 4, 3, 7, 7, 3, 3, 3, 3, 3, 3, 7, 7, 3, 3, 10, 2, 2, 3, 3, 10, 2, 2, 4, 10, 7, 15, 2, 2, 10, 7, 7, 7, 7, 2, 10, 2, 10, 2, 2, 10, 2, 2, 3, 10, 2, 3}
Sizes after manipulation of the nonlinear systems: {1, 65, 27, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 4, 1, 1, 1, 1, 4, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 4, 1, 1}



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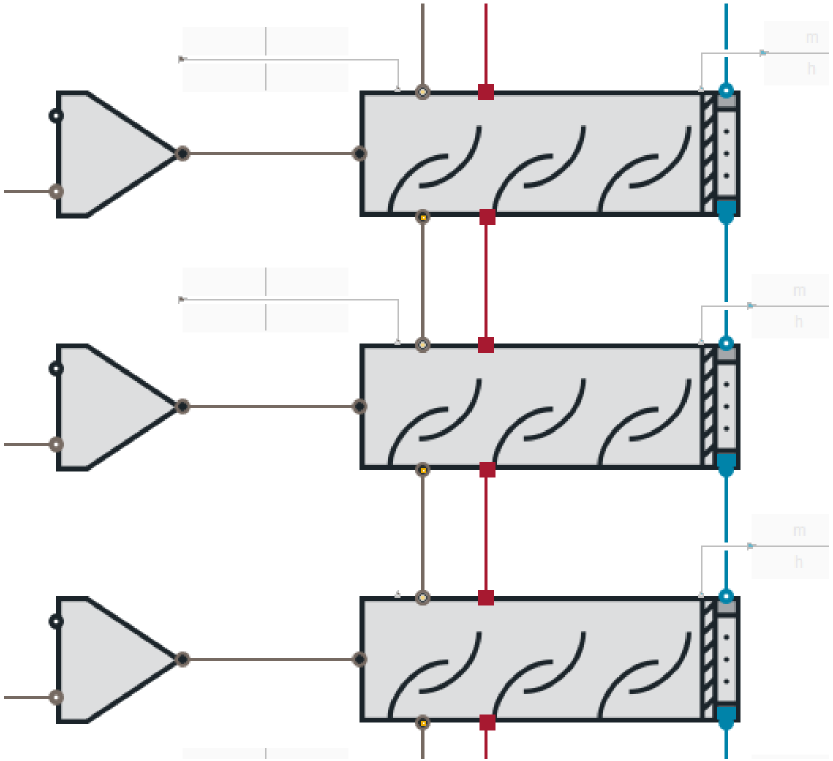

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Feedback

- Model build up of max. complexity is plannable!
- Current options for numeric optimisation of Dymola help to get fast models

- Furnace models are not fully physical w.r.t. balance equations and hydraulics
  - → Makes models less intuitive in its wiring
  - → Problems with reverse flows during initialisation
  - ☺ I solved these problems by try and error of the wiring and strongly reduced initial temperatures at the furnace to prevent reverse flow

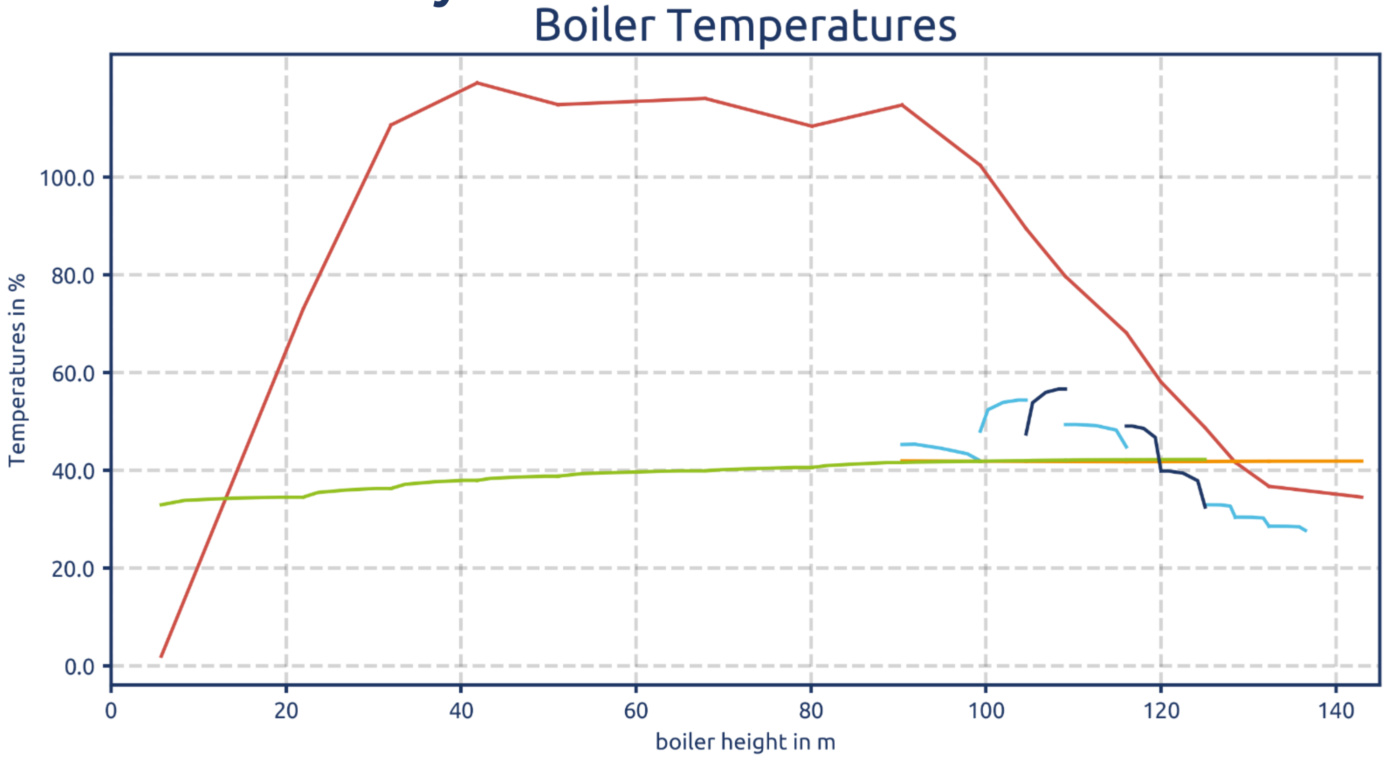
FEEDBACK

Feedback to Giving Feedback

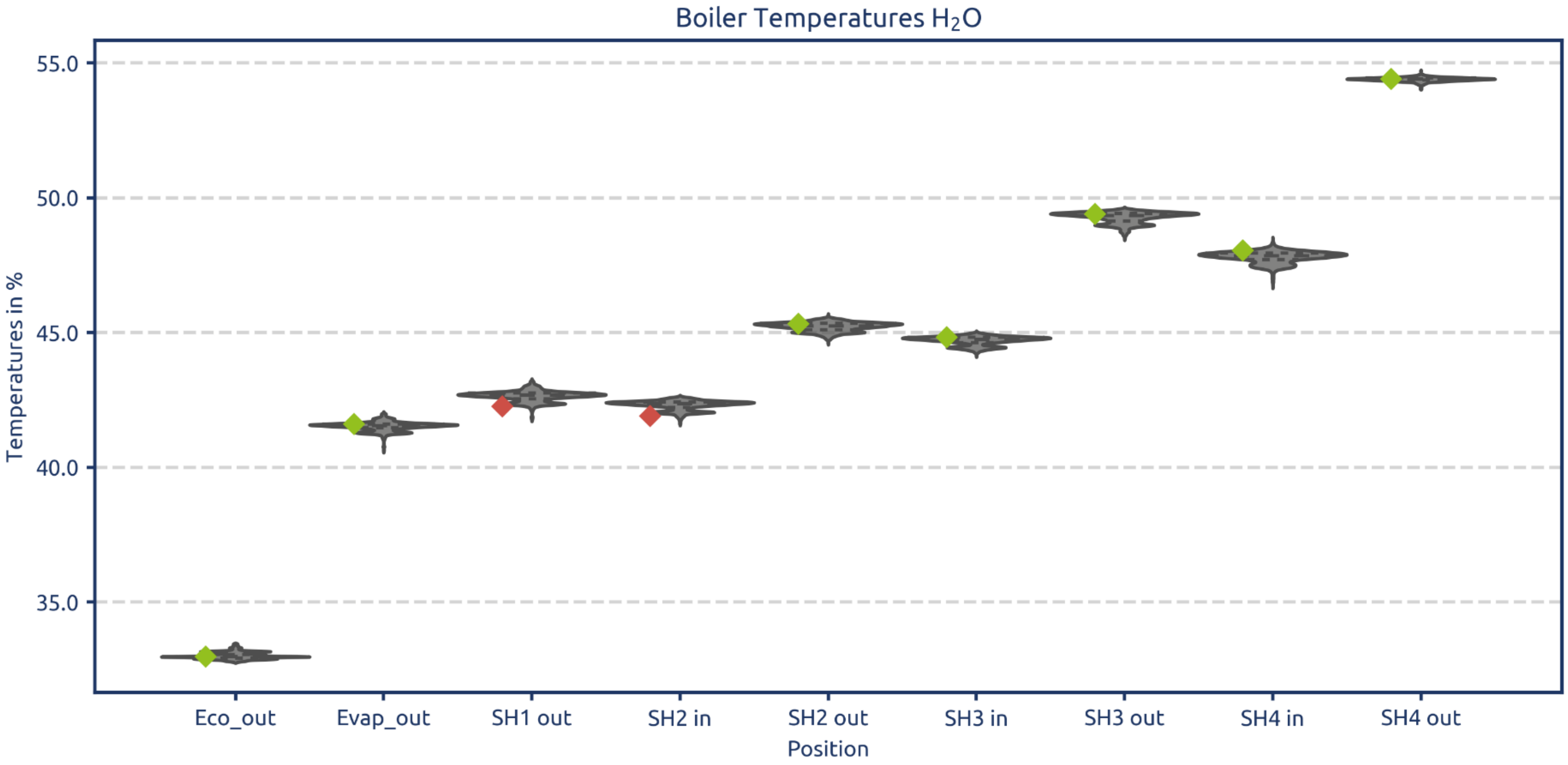
- Very positive!!
- My feedback is already content of ClaRa 1.4.0
- Share your experience as well! It'll improve ClaRa/ClaRa$^+$

CONTENT

First Results for Plausibility Check



FIRST RESULTS CALIBRATION



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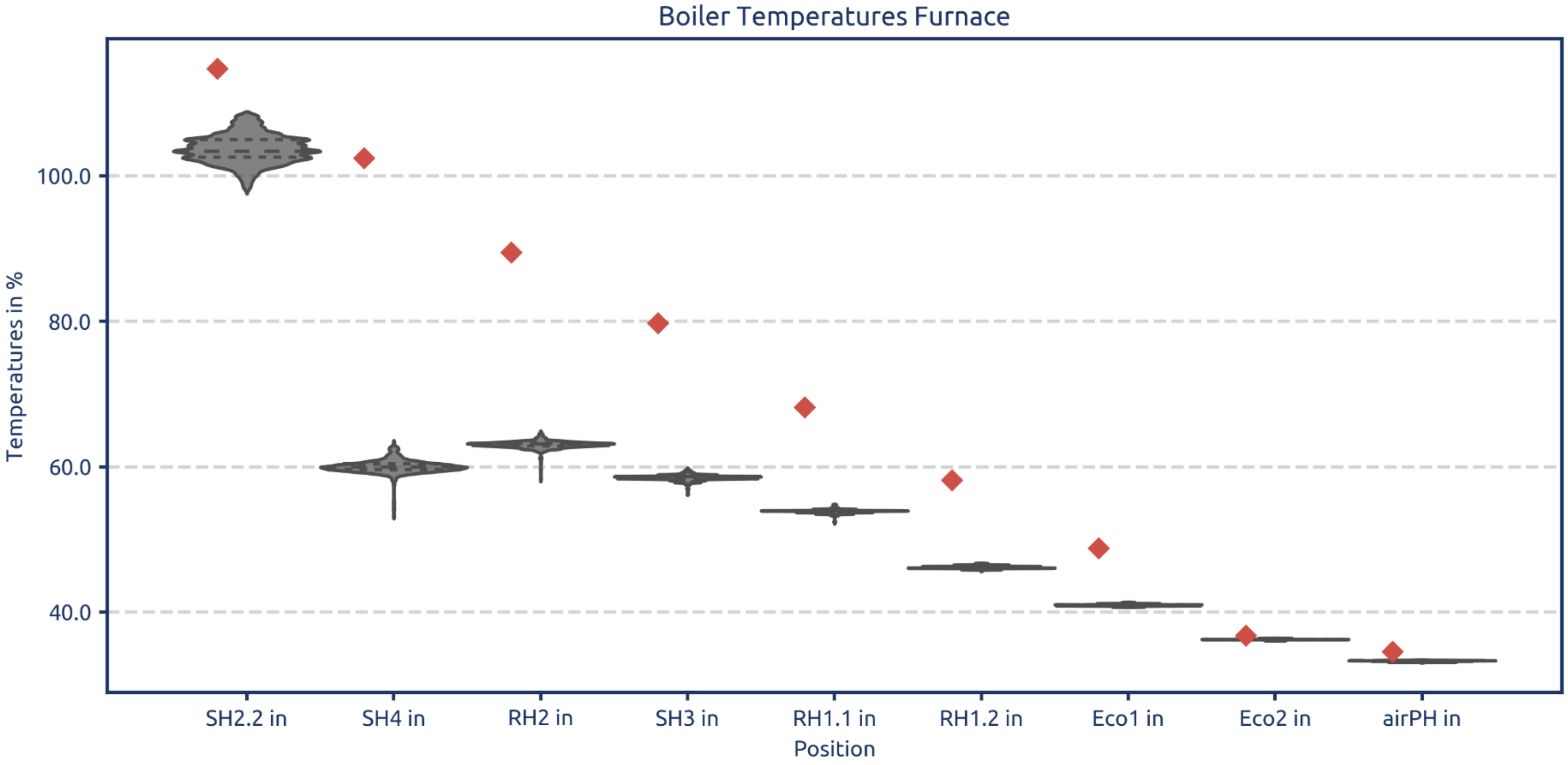

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SUMMARY & OUTLOOK

Summary

- Boiler model prepared for calibration
- Boiler model and water steam cycle models are optimised w.r.t. numerics
- Controls are currently under development by LEAG

Outlook

Calibration of boiler	06/2019
Validation of boiler	08/2019
Validation of water steam cycle	09/2019
Coupling of subsystems with controls	10/2019
Validation of complete system	12/2019
First investigations	From 01/2020

FVTR

Perfecting Energy Conversion

Your research partner for combustion engines and energy systems

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