

Development of BTMS control algorithm using KULI / MATLAB co-simulation

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BSPL 1

SEMS'23

BSPL

DESIGN

Support in design space for cooling

Calculation of selected solution

CFD Simulation of cover grills / airducting

Control algorithms

PROTOTYPING

Quick prototype delivery

Support in installation

Installation check (approval)

Quick response

VALIDATION

Support in validation planning

Measurements

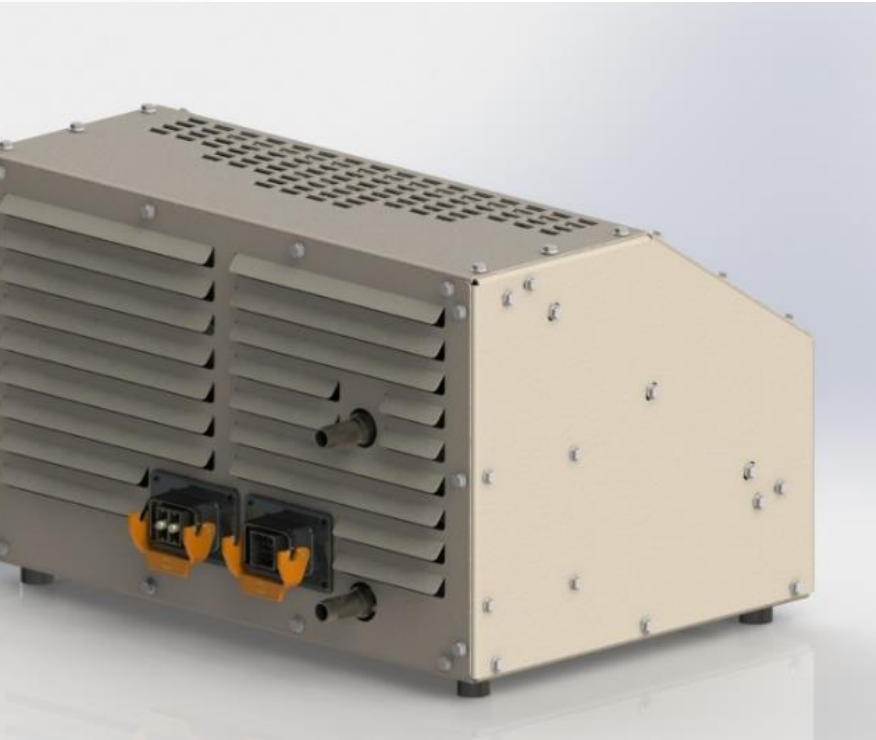
Analysis and reporting

PRODUCTION

Series deliveries

Flexible planning

BSPL battery thermal comfort products



AG01 series – Off-highway



AC07 series – On-highway



AG02 series – Off-highway

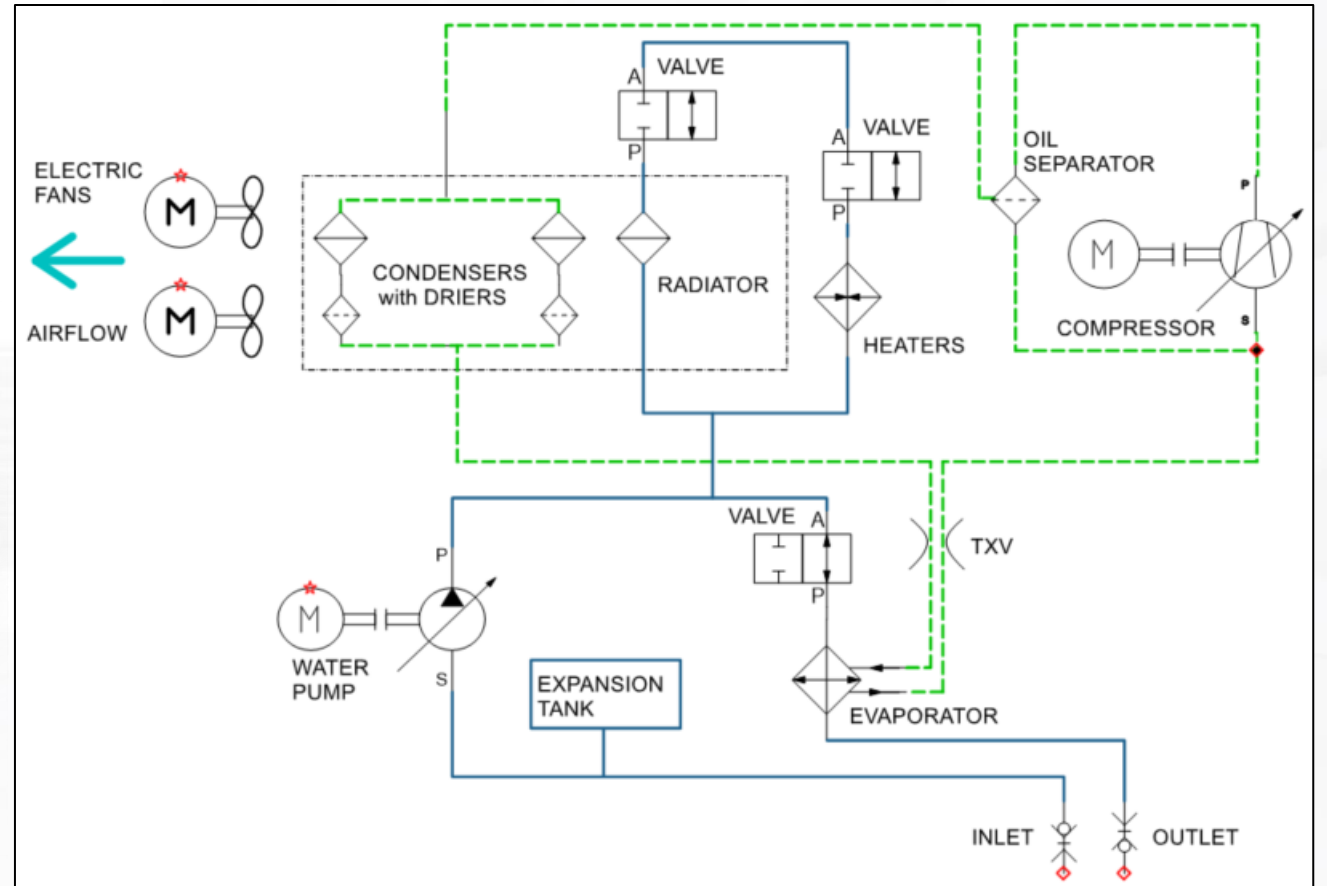


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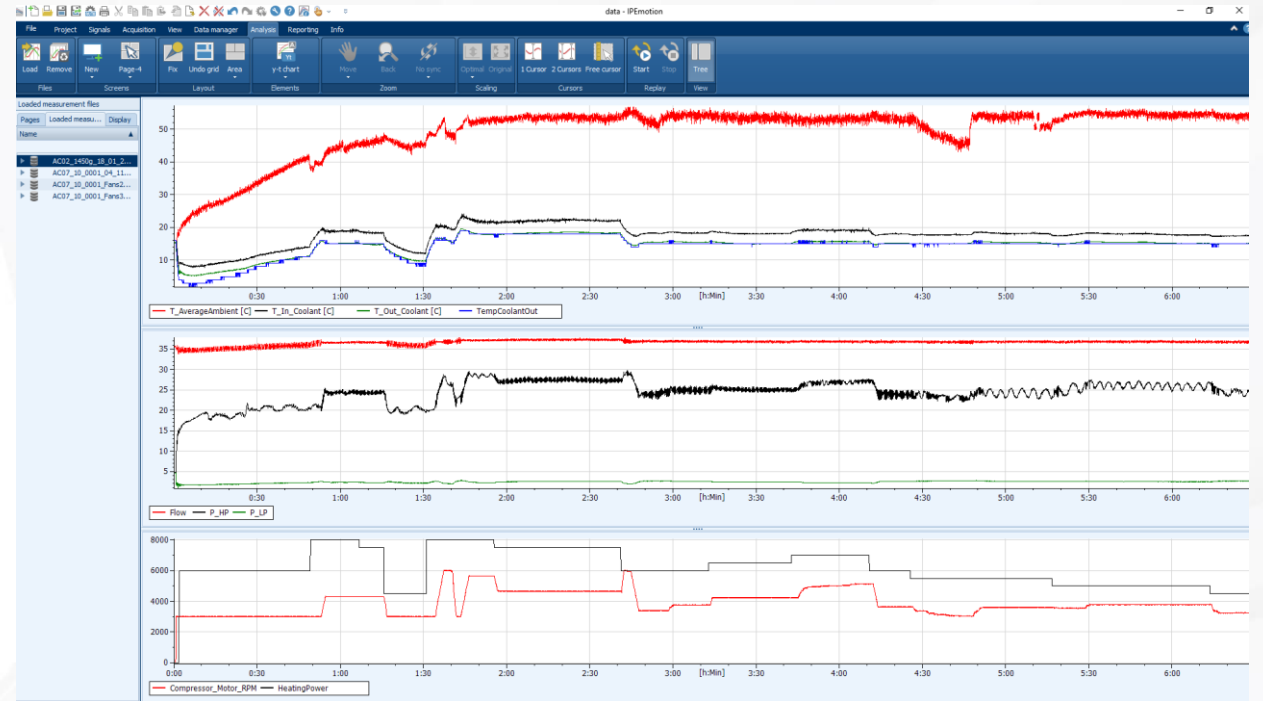
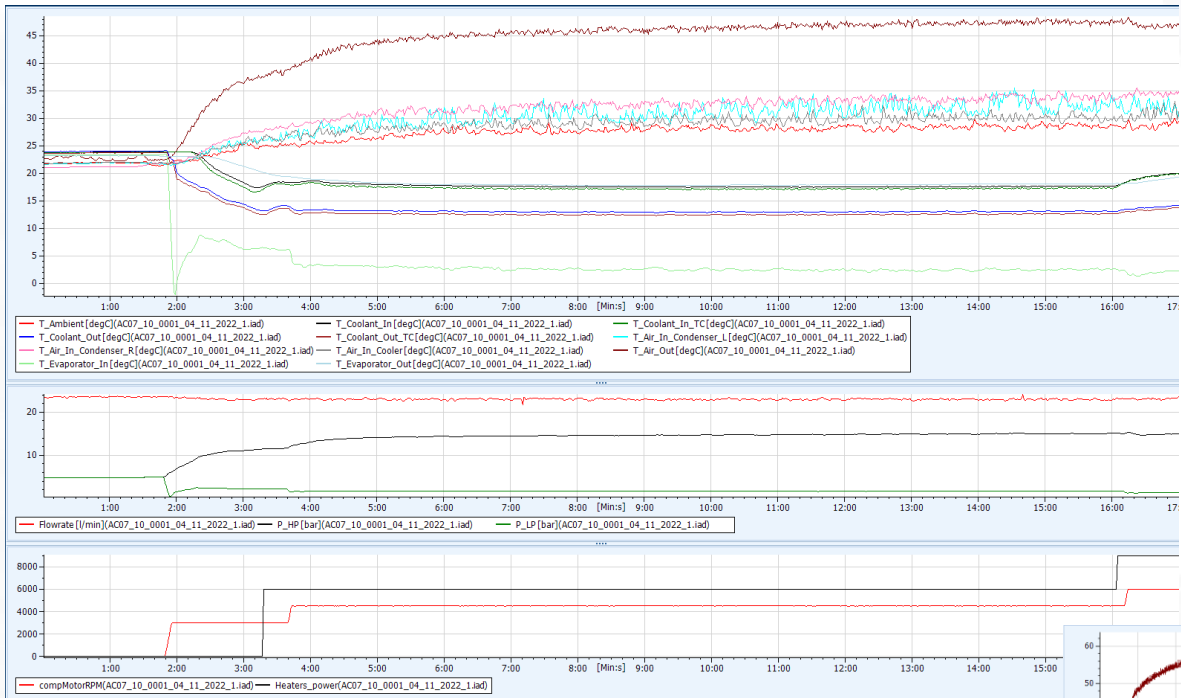
KULI

AC07 configuration

- Active cooling based on refrigerant cycle
- Passive cooling based on coolant to air heat exchanger
- Heating based on electric heater



Test results

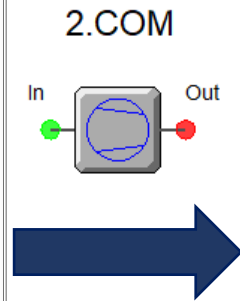
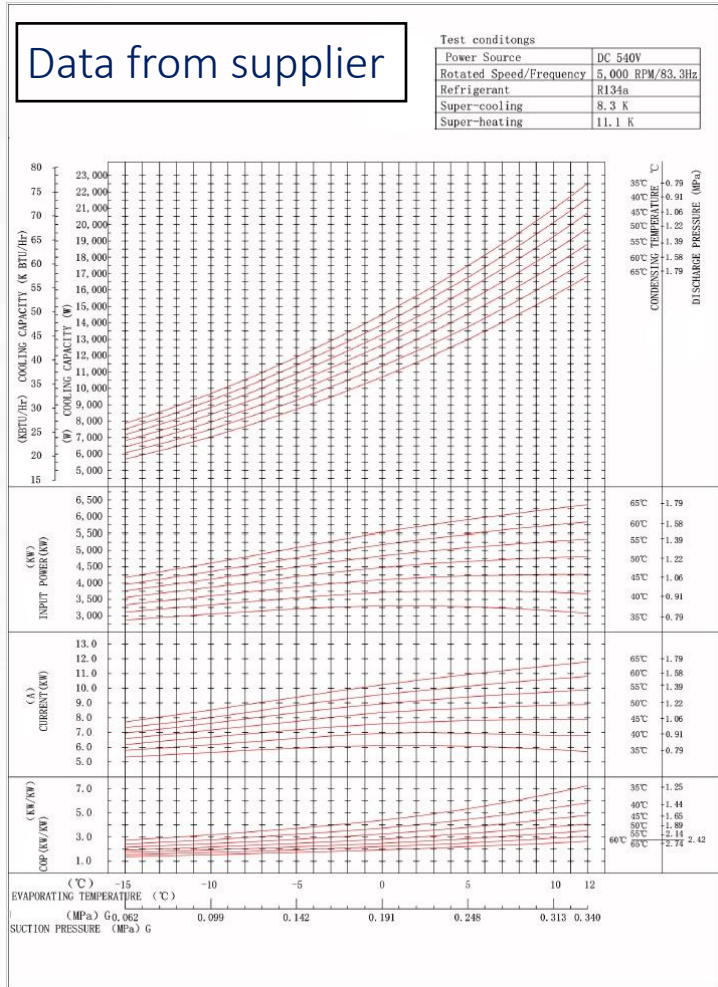


Tests in few steps:

- Component verification
- BTMS parameters at different conditions with manual control
- BTMS control algorithm in automatic mode



First step of KULI model – component models



Data needed in KULI

Compressor [BM80_comp_ac_test_BW_2_1.kulicom]

File Extras

General data Charac. curves Control characteristic

Characteristic curves based model Analytical based model

Unit of compressor speed: 1/min

3D Data

Pressure ratio: 3.96

Compressor speed	Volumetric efficiency [-]	Isentropic efficiency [-]
3000	0.919	0.618
4000	0.924	0.6255
5000	0.929	0.627
6000	0.936	0.625

char. curve interpolation: Linear

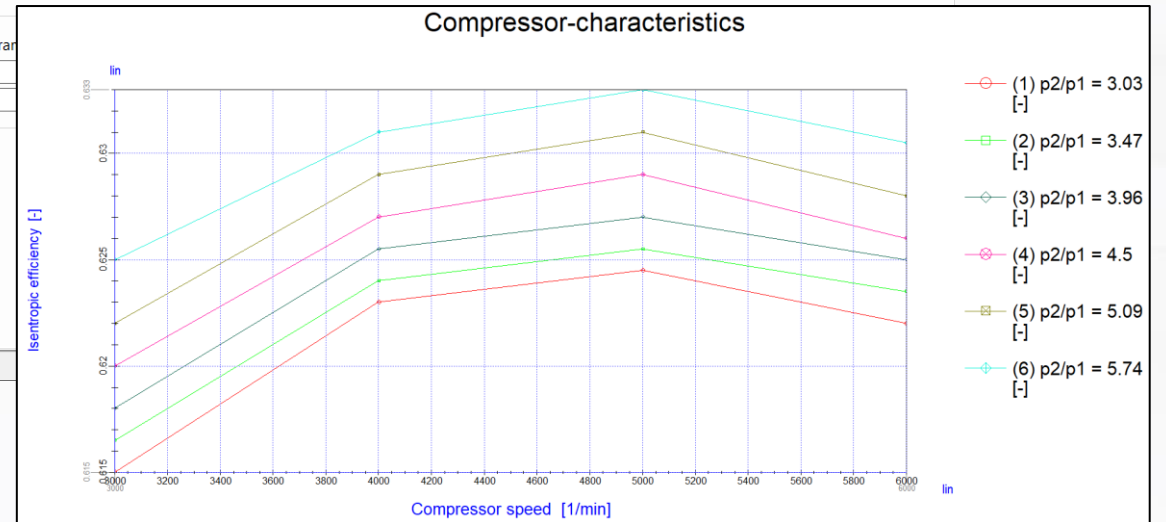
Extrapolation: Allow Extr

Volumetric efficiency

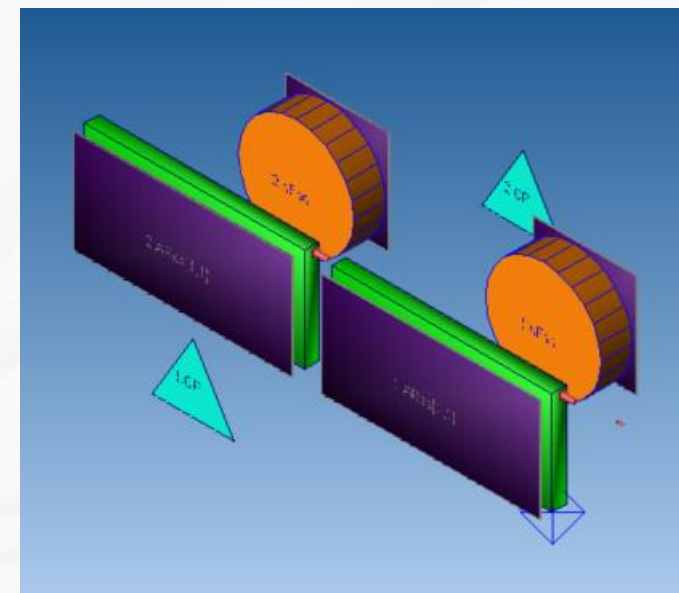
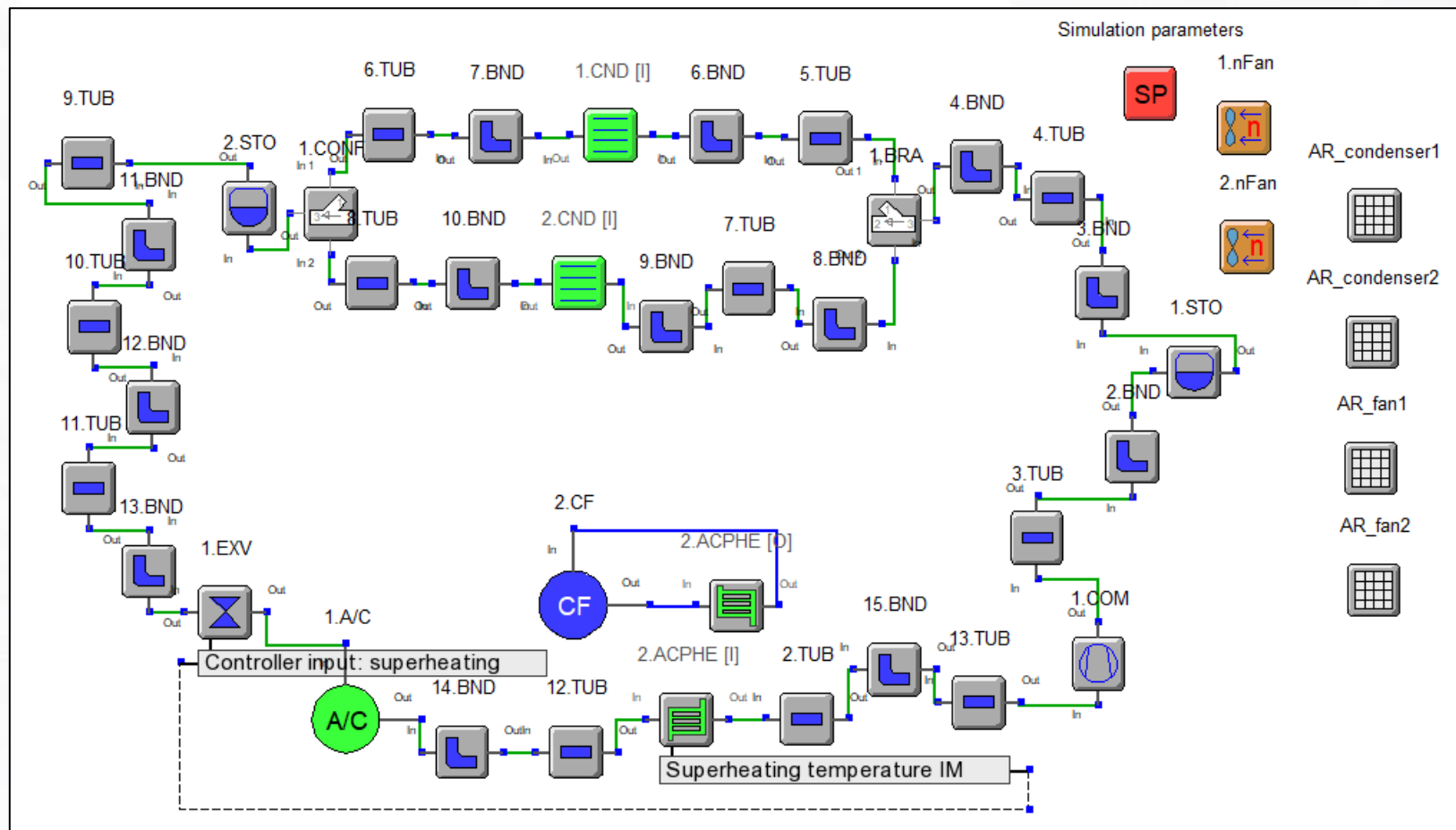
Input the mechanical efficiency parameters

Coefficient c1	0.872821
Coefficient c2	0.177669

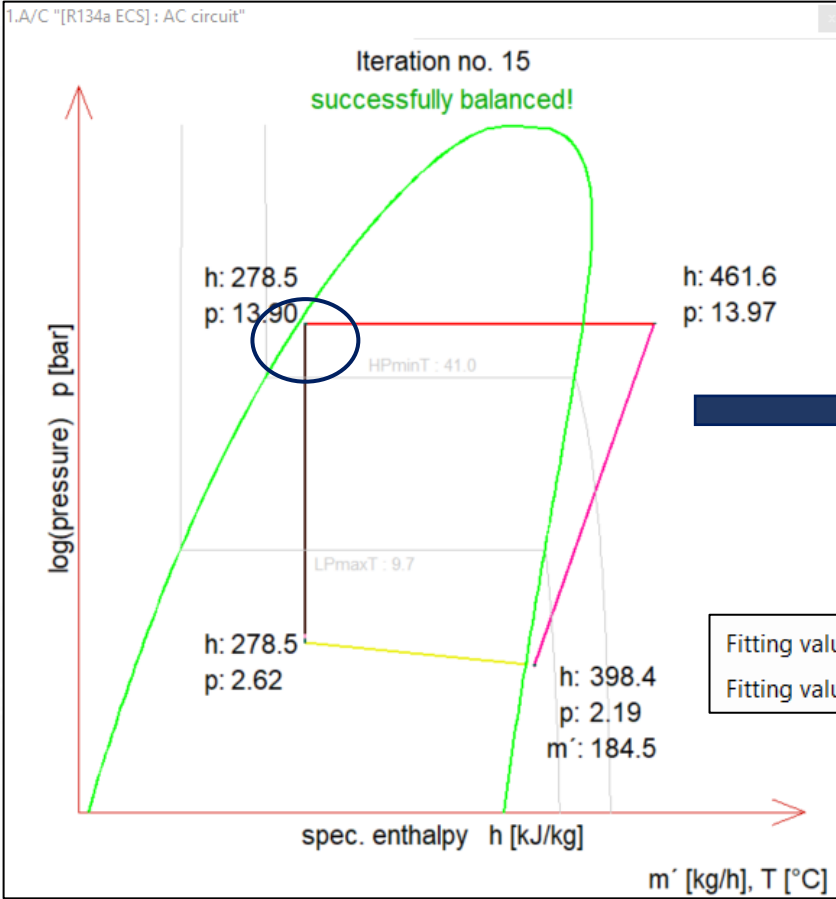
Ready



Model of AC circuit only



Example of results for model of AC circuit



Condenser (Condenser_BW.nd)

File Extras

General data Connections Geometric properties Inner side Geometric properties Outer side Outer flow Adjustment

Inner flow (refrigerant)

Geometry of Tube

Number of pipe rows: 1

Wall Thickness (mm): 0.3

Examples

- 1 Pipe Row; 4 Pipe Rows
- 2 Pipe Rows; 2 Fins/Pipe
- 2 Pipe Rows; 4 Fins/Pipe

Geometry of Pipe

Circular Non circular

Pipe cross-section [mm²]: 79.5

Wetted perimeter [mm]: 176.6

Inner tube height [mm]: 2.4

Pipe roughness [mm]: 0.002

Fin not divided

No. of longitudinal fins n [-]: 22

Fin thickness s [mm]: 0.1

$s/n = 2$

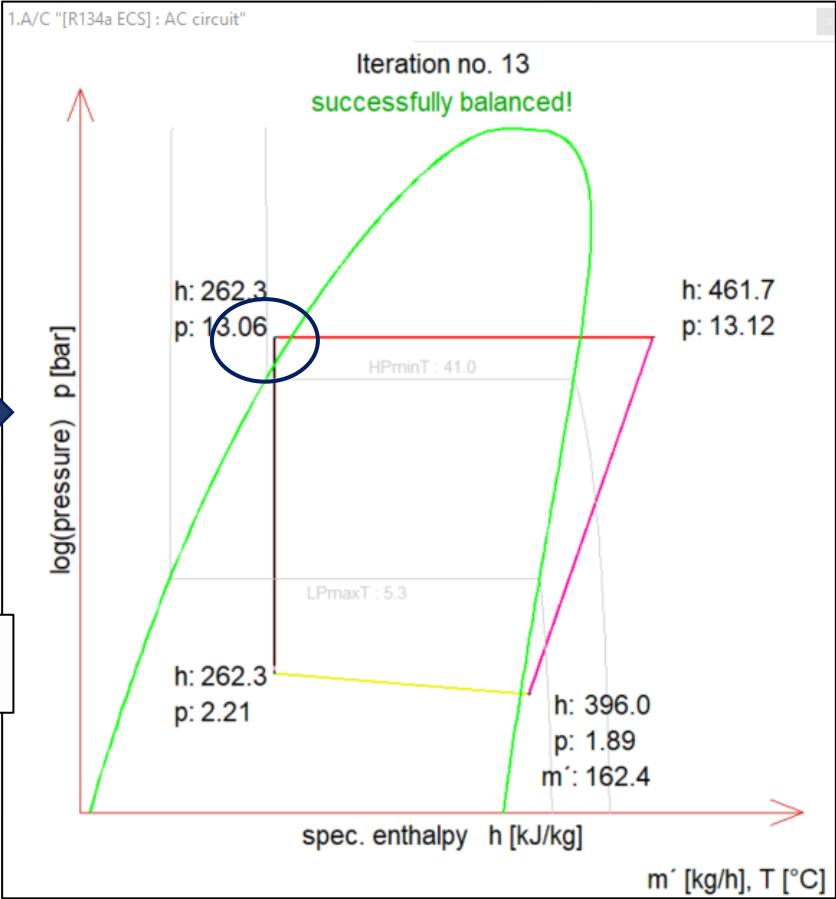
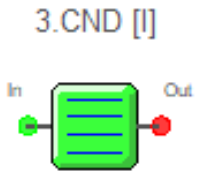
Input ref. side heat transfer area [m²]

Fitting value for inside heat transfer [-]: 0.6

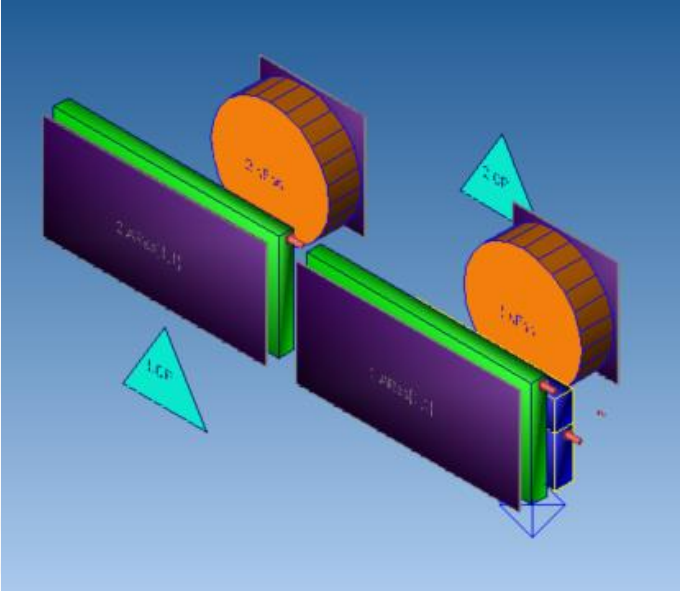
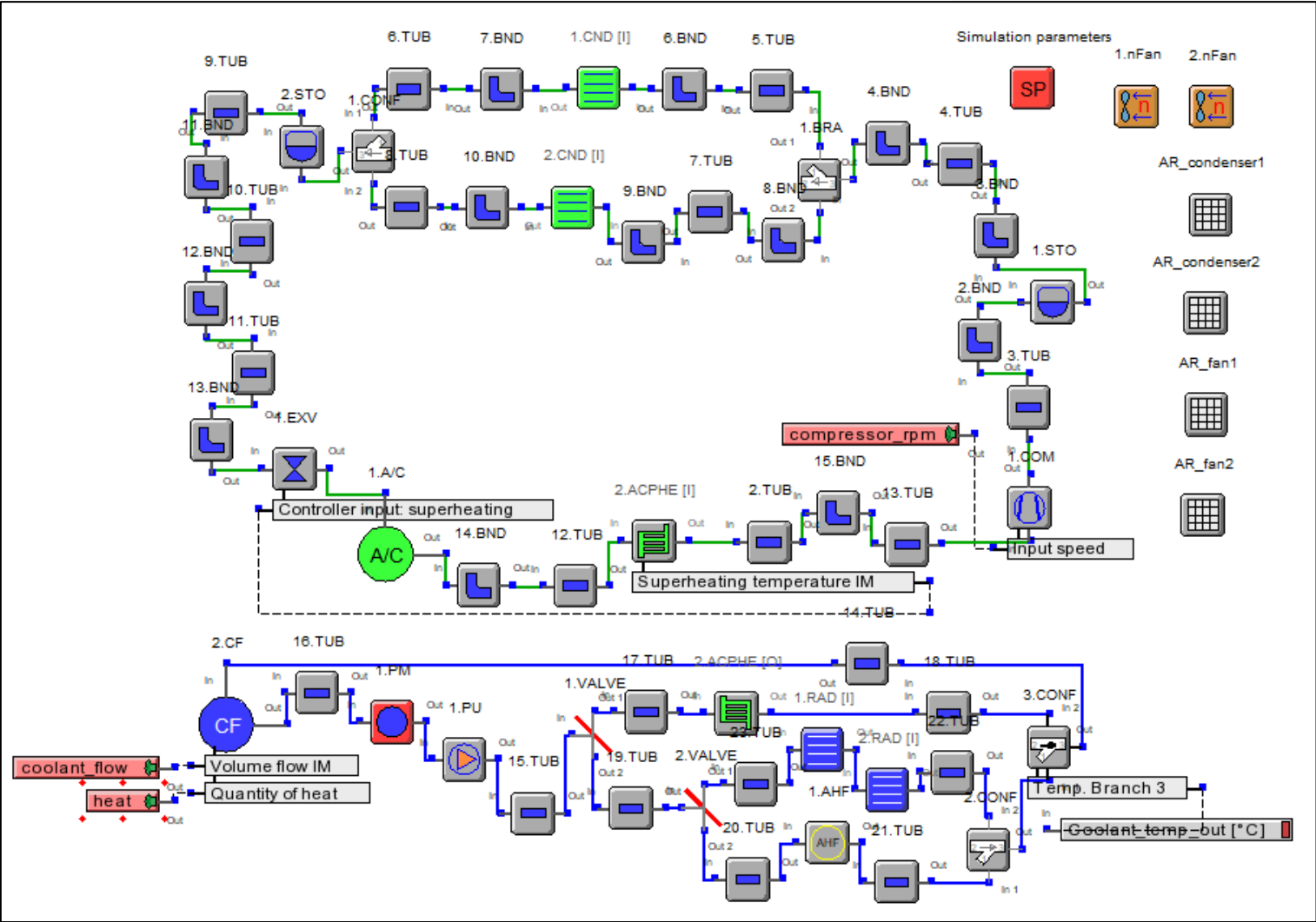
Fitting value for inside pressure loss [-]: 1

Fitting value for inside heat transfer [-] 0.6

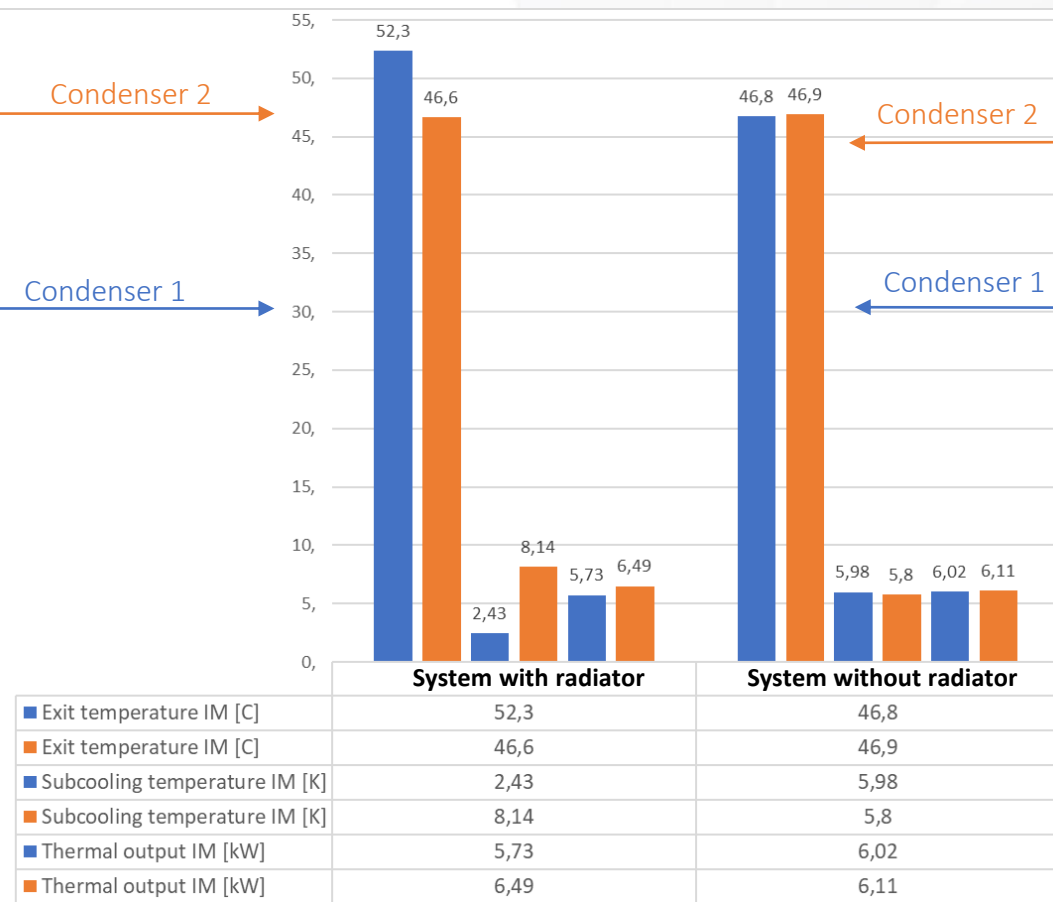
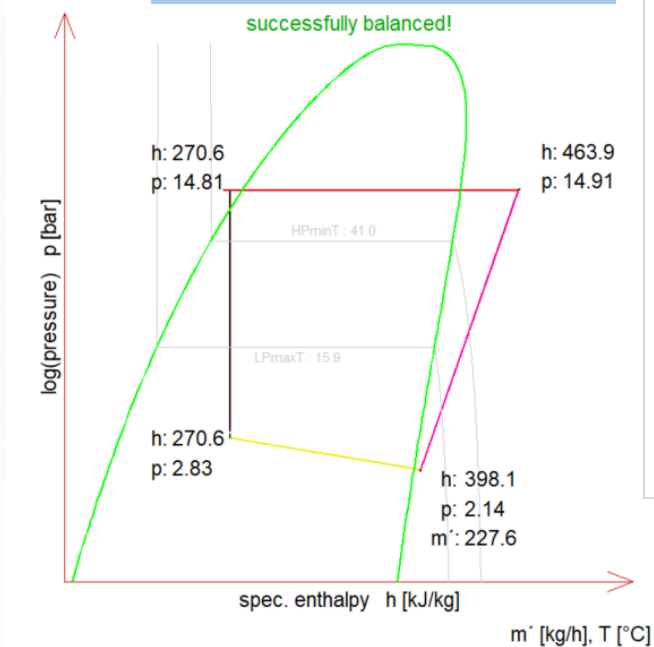
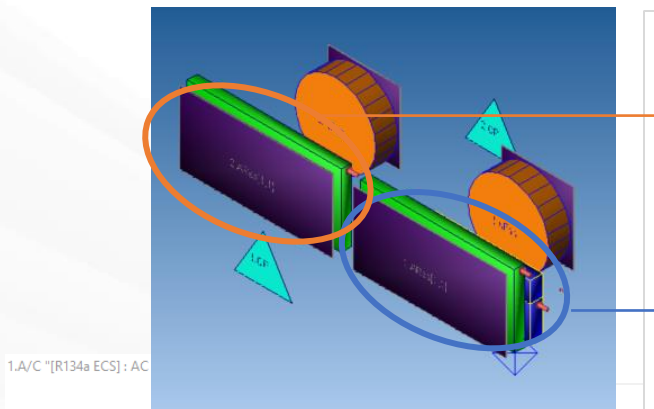
Fitting value for inside pressure loss [-] 1



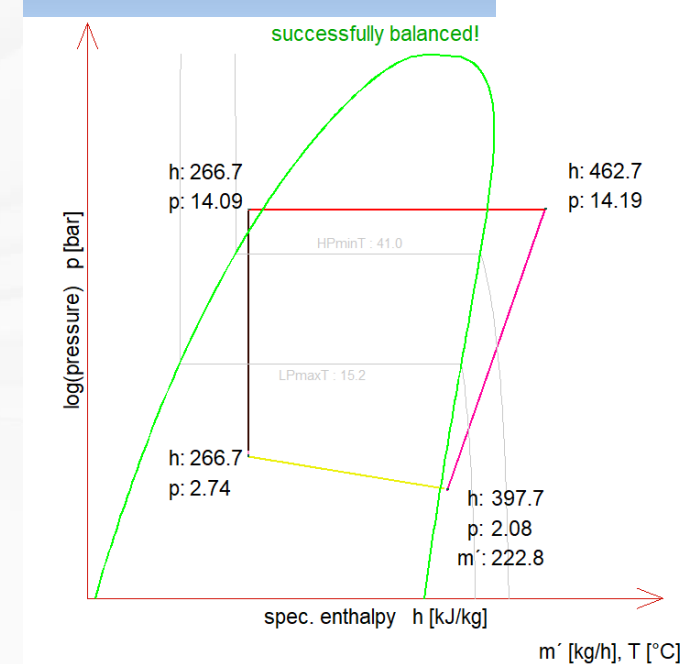
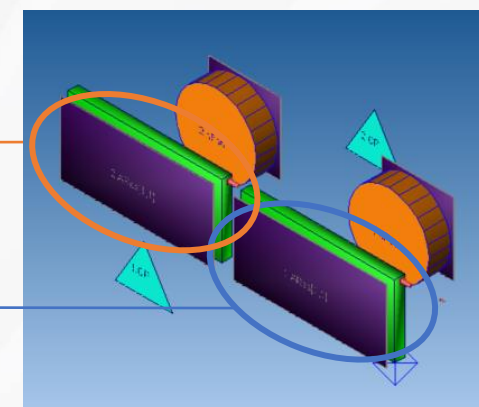
Model of whole BTMS circuit



Model of whole BTMS vs AC circuit



PHE evaporator	Superheating temperature	K	5,2	3,3
	Entry vapour quantity	-	0,37	0,35
	Thermal output	kW	8,06	8,01
	Entry temperature OM	°C	16,8	15,9
	Exit temperature OM	°C	10,8	9,9



PHE evaporator

AC Plate Heat Exchanger (chiller_BBLASx70_BW_4kuliaphe)

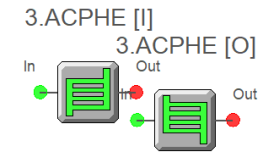
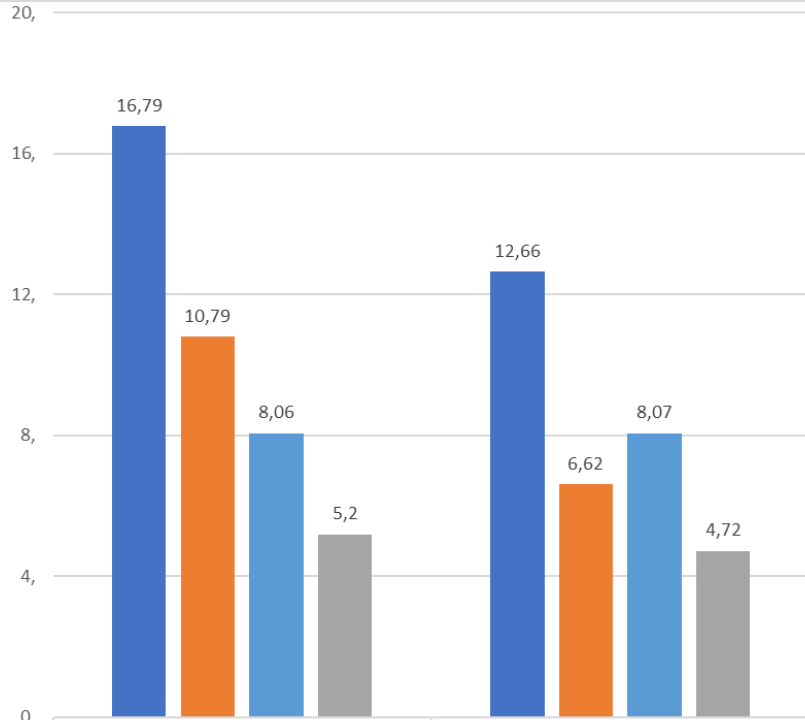
File Extras

General data Configuration Measured data

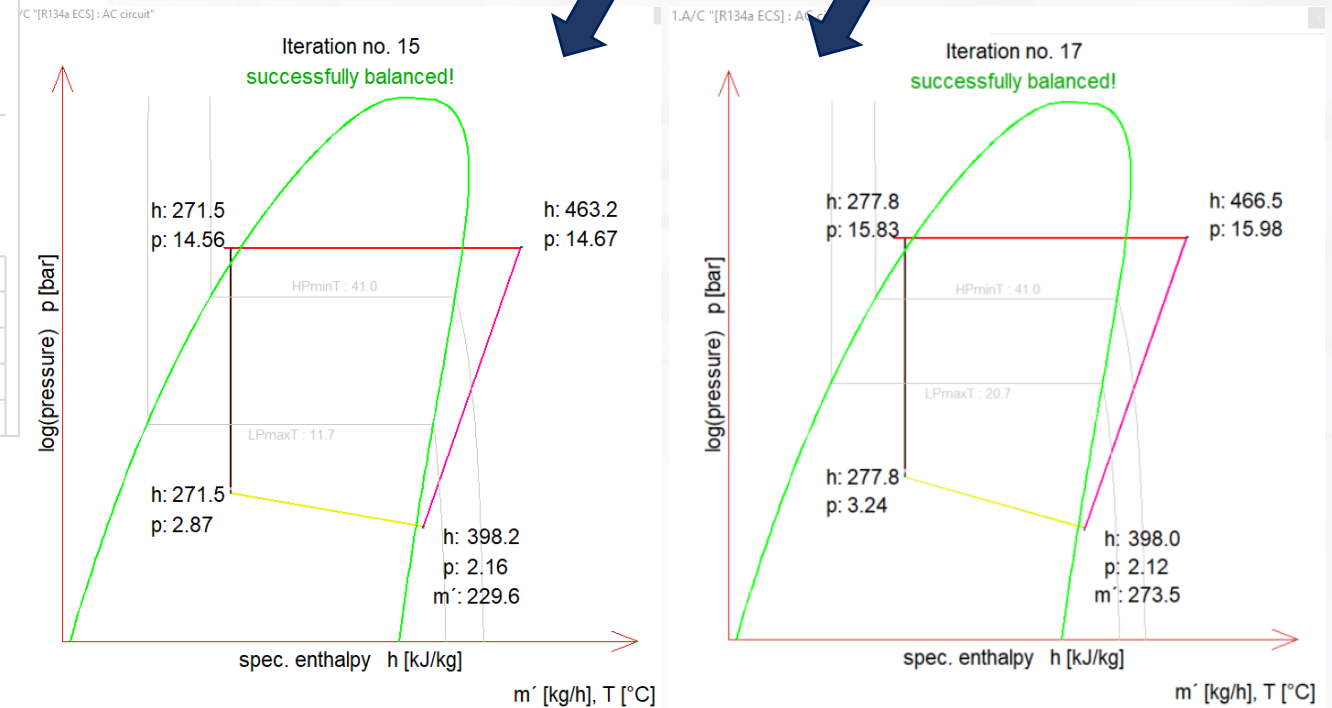
Heat definition by
 Exchanged heat (abs)

Inner flow rate [kg/s]	Outer flow rate [kg/s]	Exchanged heat (abs) [kW]	Inner pressure drop [kPa]	Outer pressure drop [kPa]	Inner entry enthalpy [kJ/kg]	Inner entry pressure [bar]	Outer entry temperature [°C]	Outer entry pressure [hPa]	Error Exchanged Heat [%]	Error Inner Pressure Drop [%]	Error Outer Pressure Drop [%]
0.035	0.358906	5.26339	13.5988	12.1152	260	4	30	1200	5.65175	-54.8932	-0.0730544
0.05	0.484523	7.51913	22.5409	20.955	260	4	30	1200	3.85868	-29.8681	0.121375
0.065	0.61014	9.77486	33.2591	31.8936	260	4	30	1200	-6.82171	0.469619	0.00479788
0.08	0.717812	12.0306	45.5272	42.9386	260	4	30	1200	-20.5085	30.2064	-0.0579375

PHE evaporator



	Outer entry temp. 30 deg C	Outer entry temp. 25 deg C
Coolant entry temperature [C]	16,79	12,66
Coolant exit temperature [C]	10,79	6,62
Thermal output [kW]	8,06	8,07
R134a Superheating temp. [K]	5,2	4,72

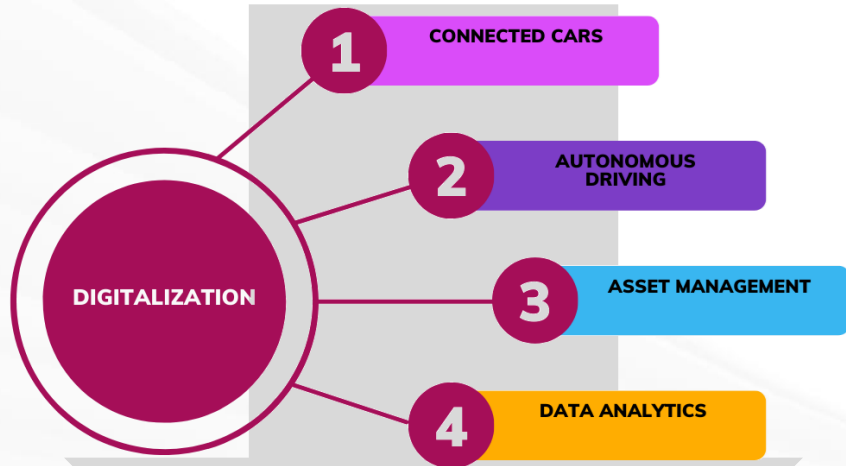




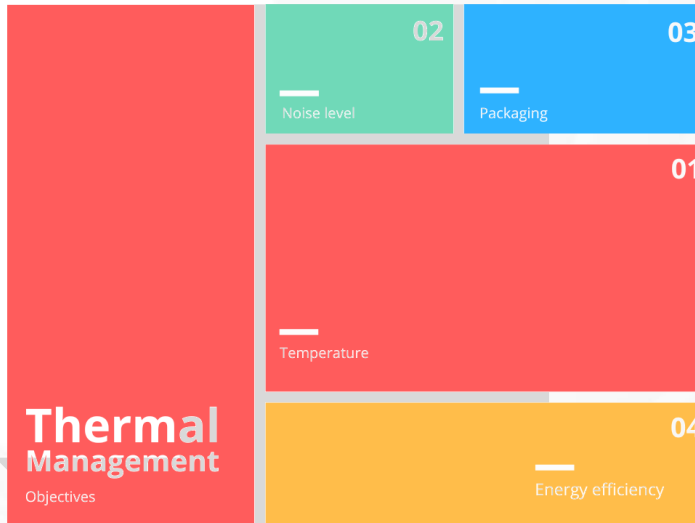
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MATLAB & SIMULINK

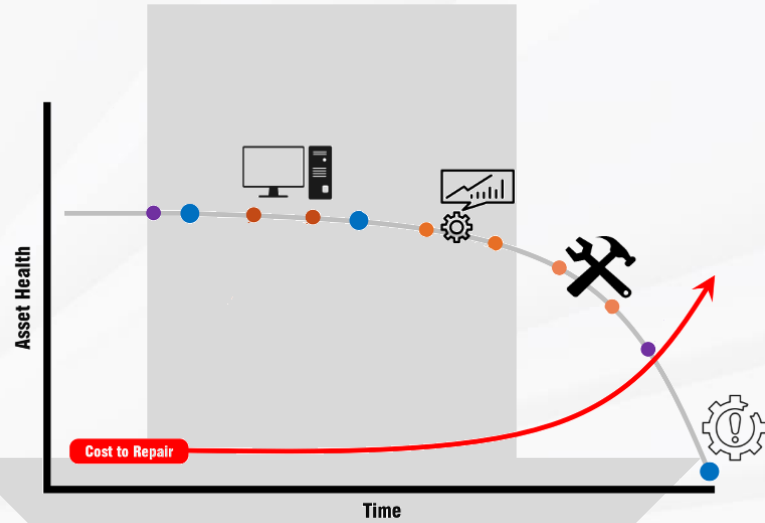
Why KULI + Matlab & Simulink



„Softwareization”



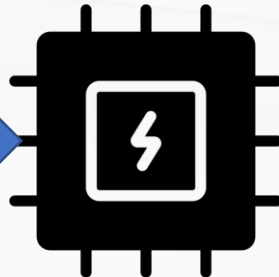
Complex requirements



Additional features

Matlab toolbox

Code generation



Our approach

1. Function

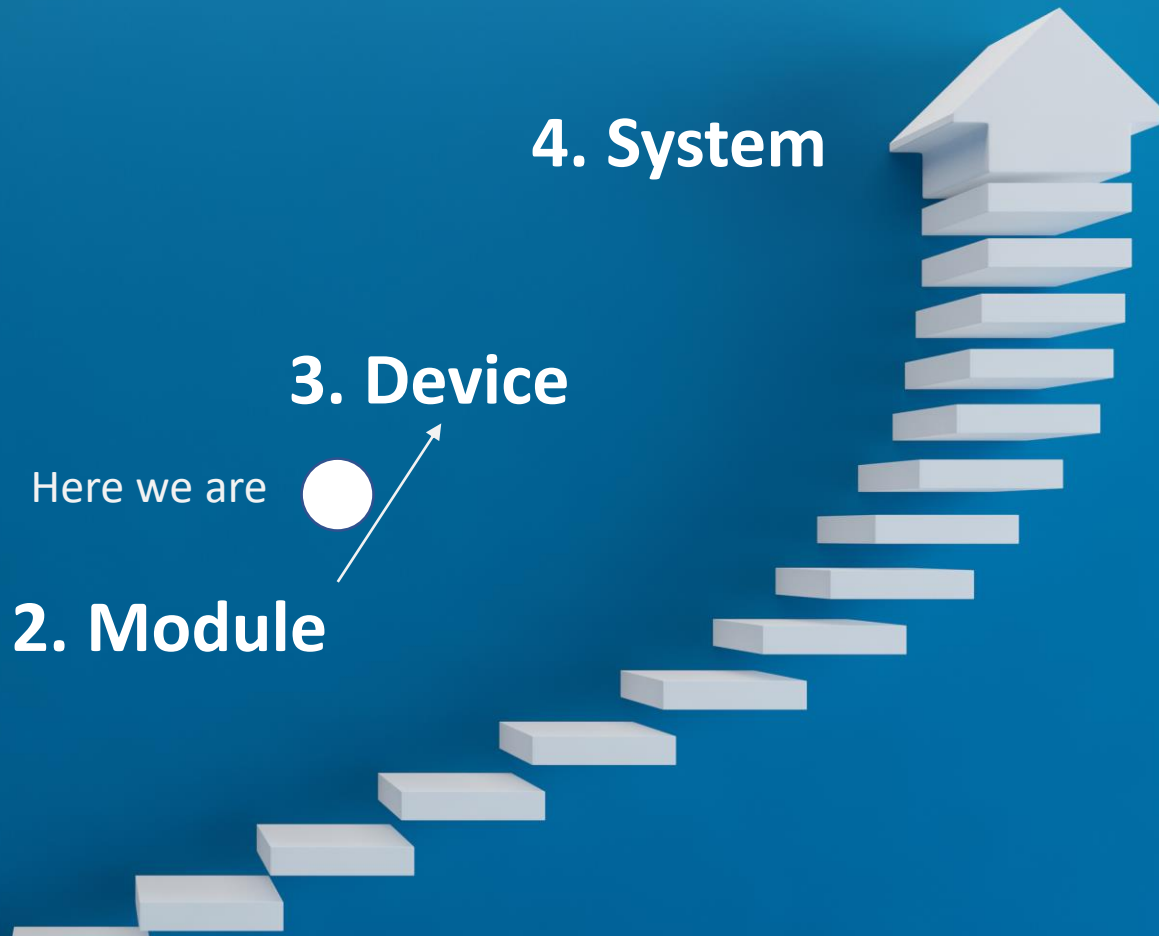
2. Module

Here we are



3. Device

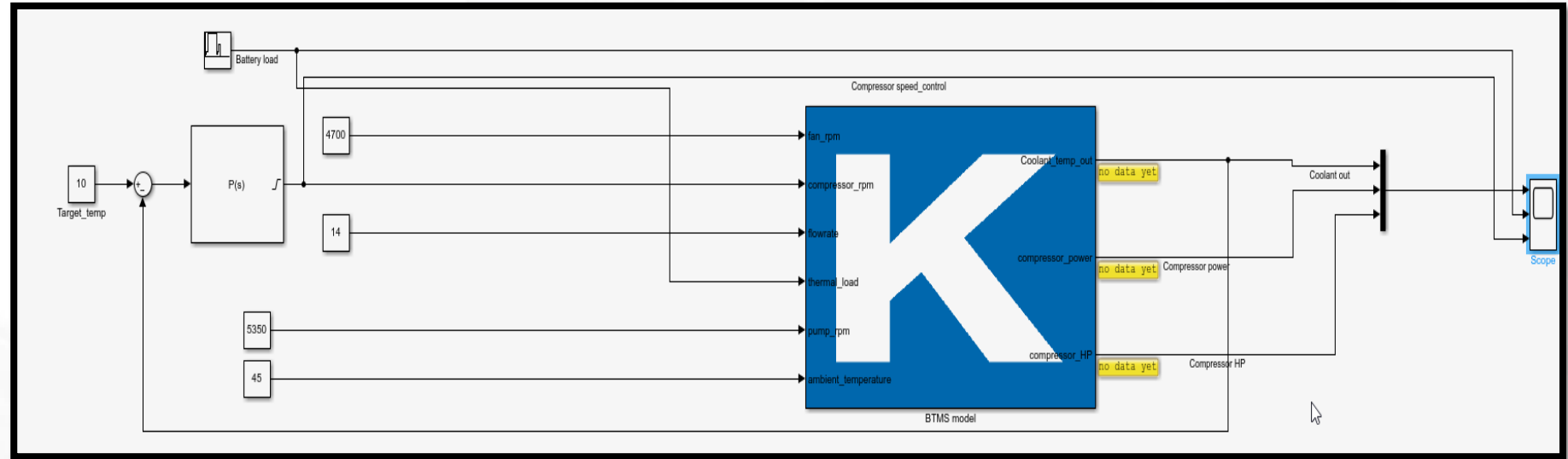
4. System



FMU & Simulink setup

- Inputs

- Fan RPM
- Compressor RPM
- Pump Flowrate
- Thermal load
- Ambient temperature



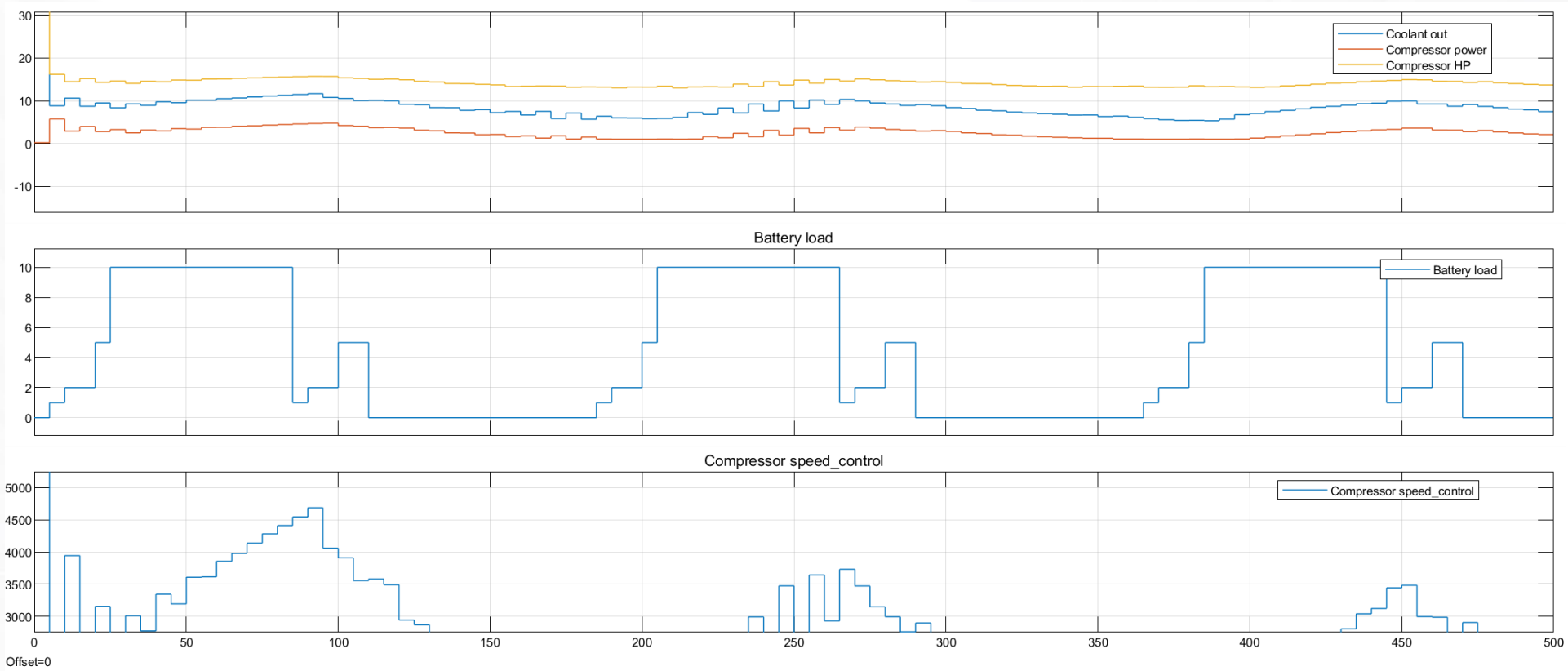
- Outputs

- Coolant outlet temperature
- Compressor power consumption
- HP Pressure

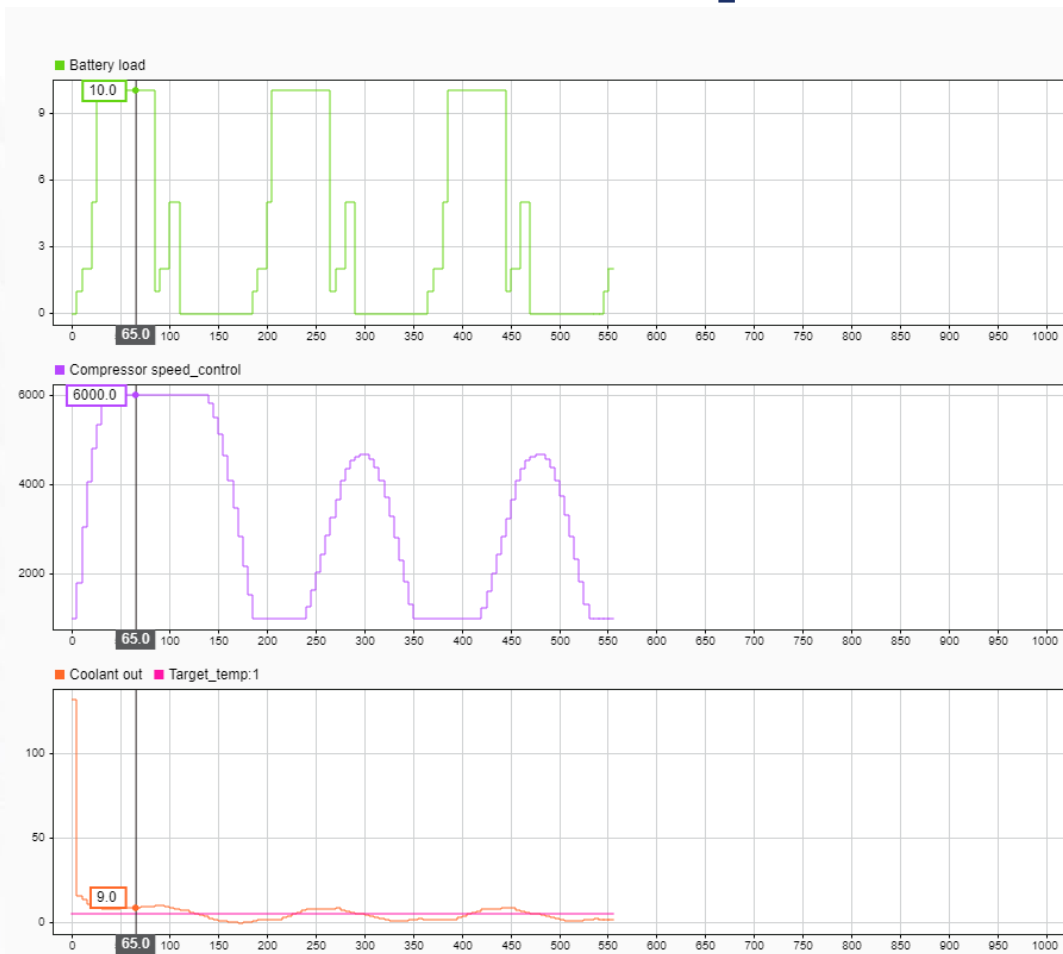
Focus on Active cooling



Control example – P

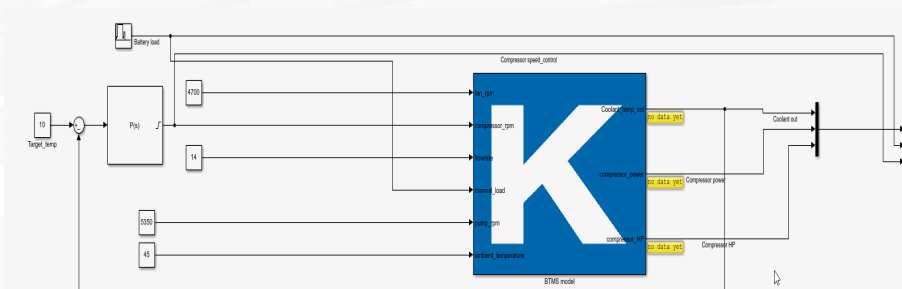
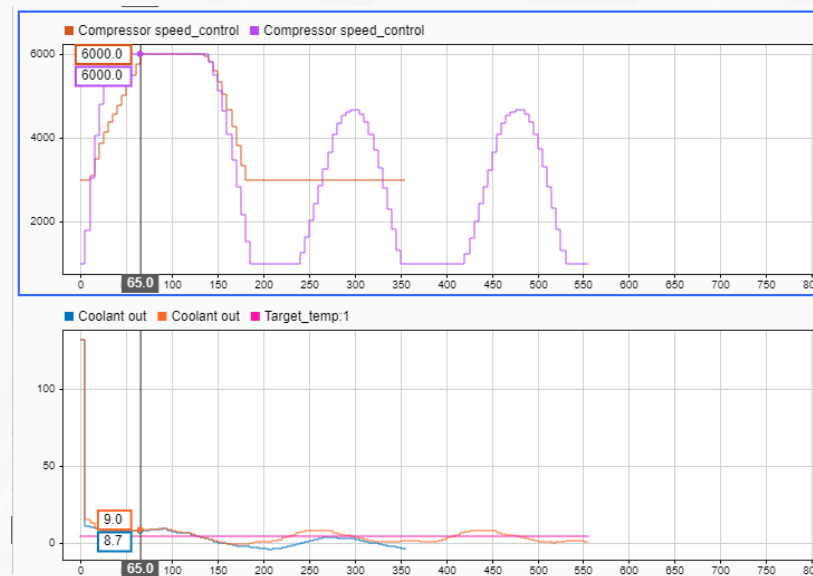


Control example – PI

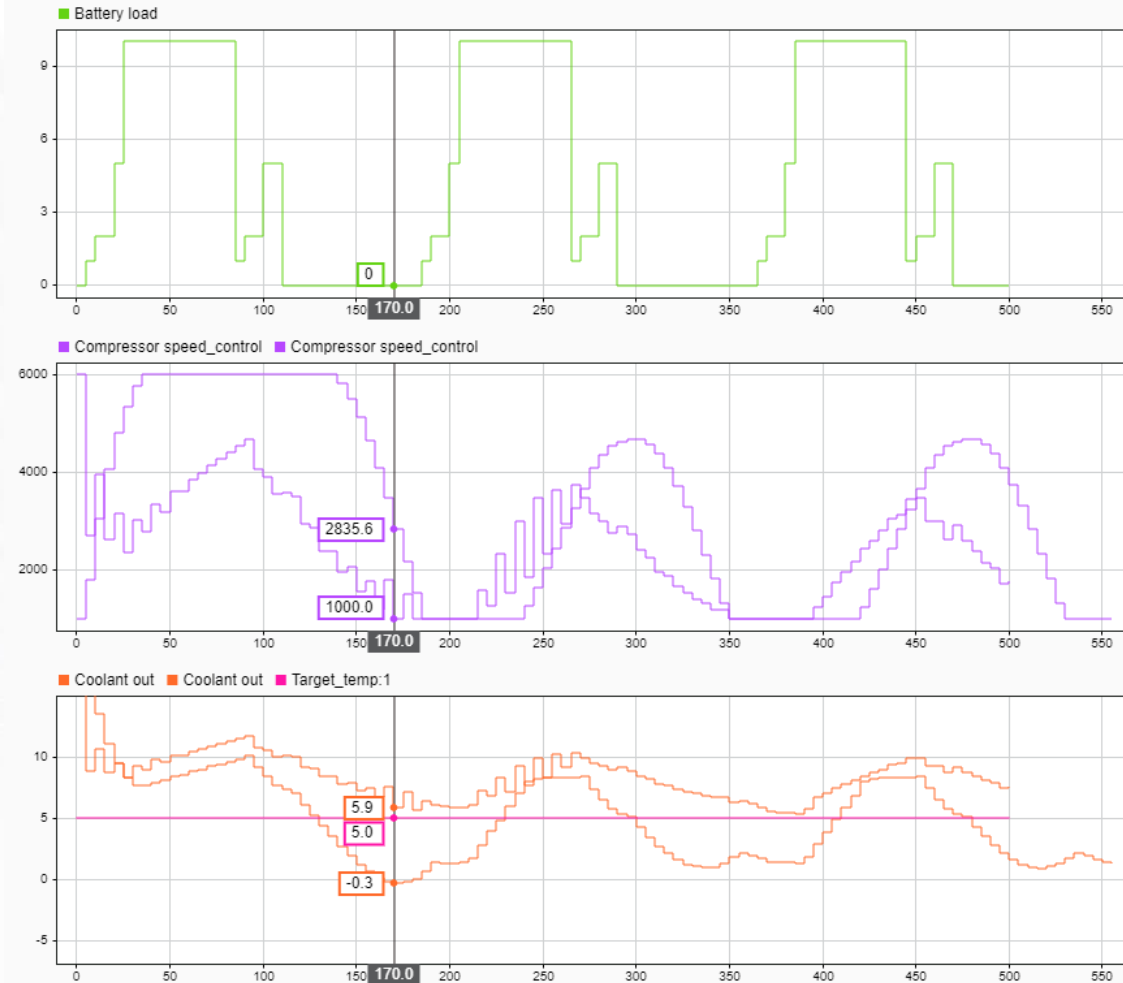


Max dT = 3K

Parameter impact analysis



Comparison



```
#include <stdlib.h>
#include <stdio.h>
#include <stdbool.h>

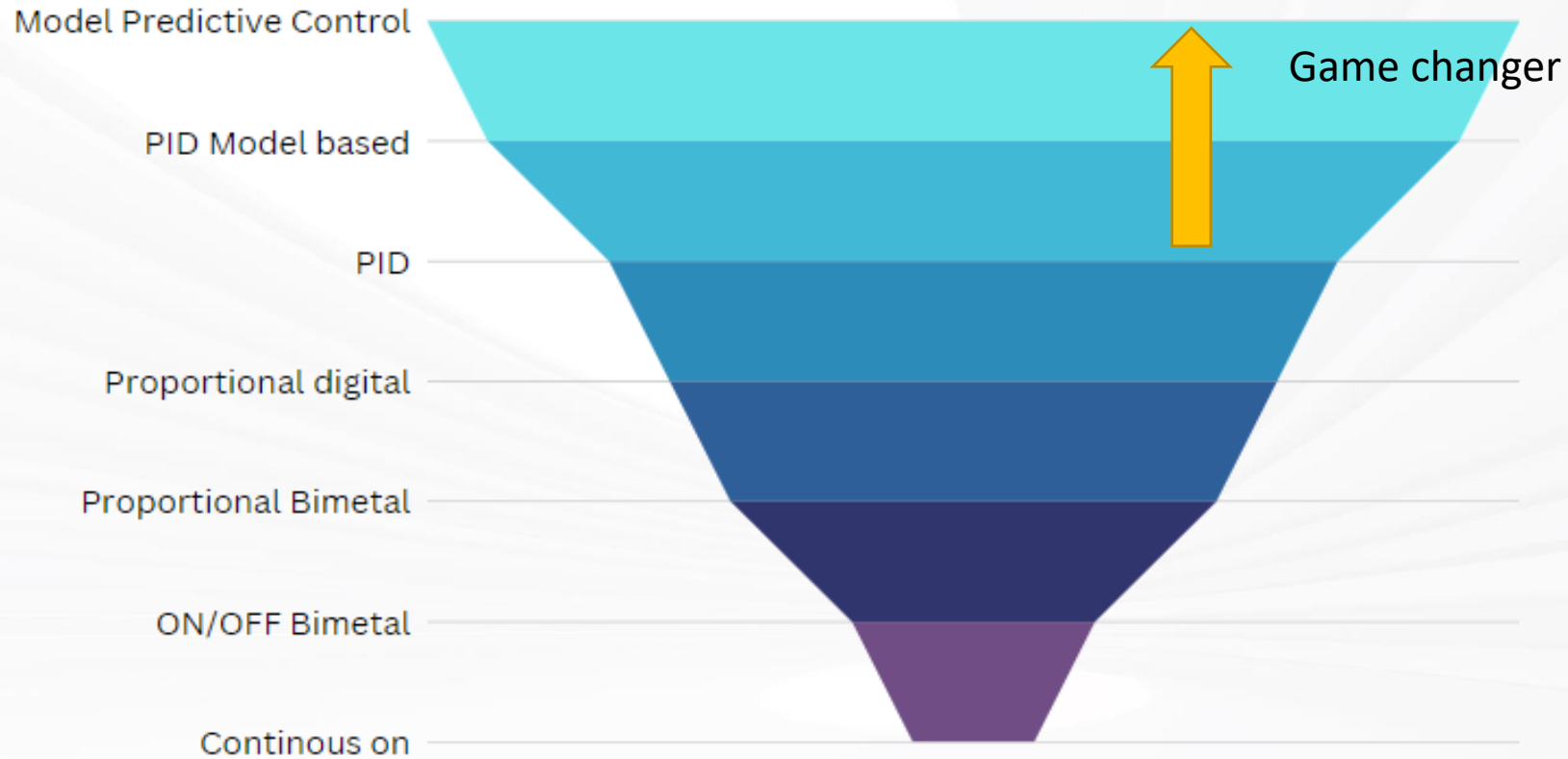
struct stats { int count; int sum; int sum_squares; };

void stats_update(struct stats * s, int x, bool reset) {
    if (s == NULL) return;
    if (reset) * s = (struct stats) { 0, 0, 0 };
    s->count += 1;
    s->sum += x;
    s->sum_squares += x * x;
}

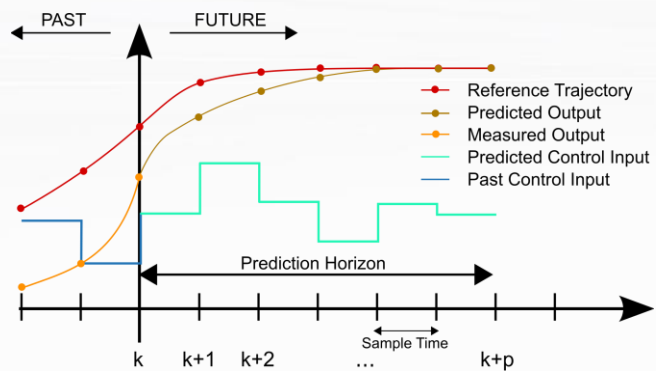
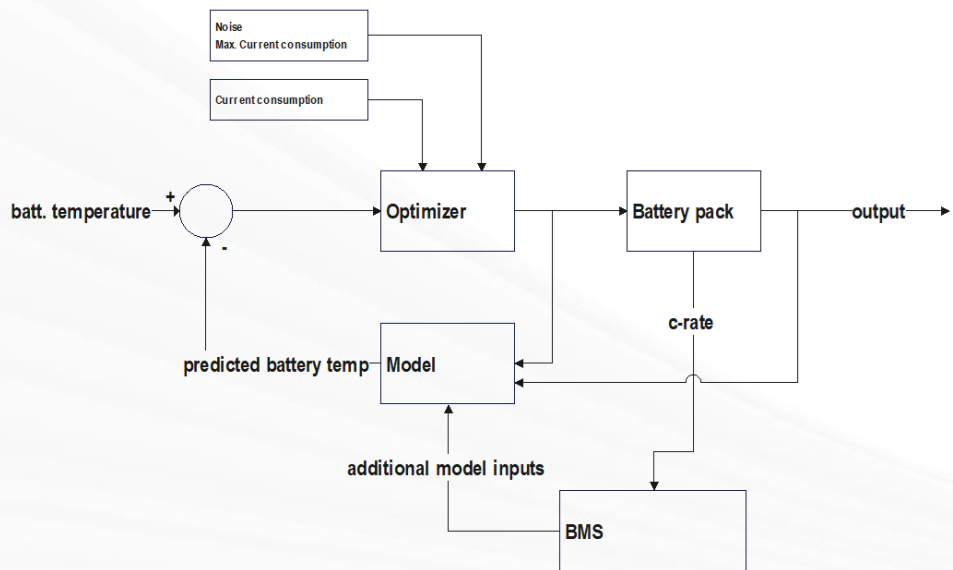
double mean(int data[], size_t len) {
    struct stats s;
    for (int i = 0; i < len; ++i)
        stats_update(&s, data[i], i == 0);
    return ((double)s.sum) / ((double)s.count);
}

void main() {
    int data[] = { 1, 2, 3, 4, 5, 6 };
    printf("MEAN = %lf\n", mean(data, sizeof(data) / sizeof(data[0])));
}
```

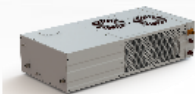
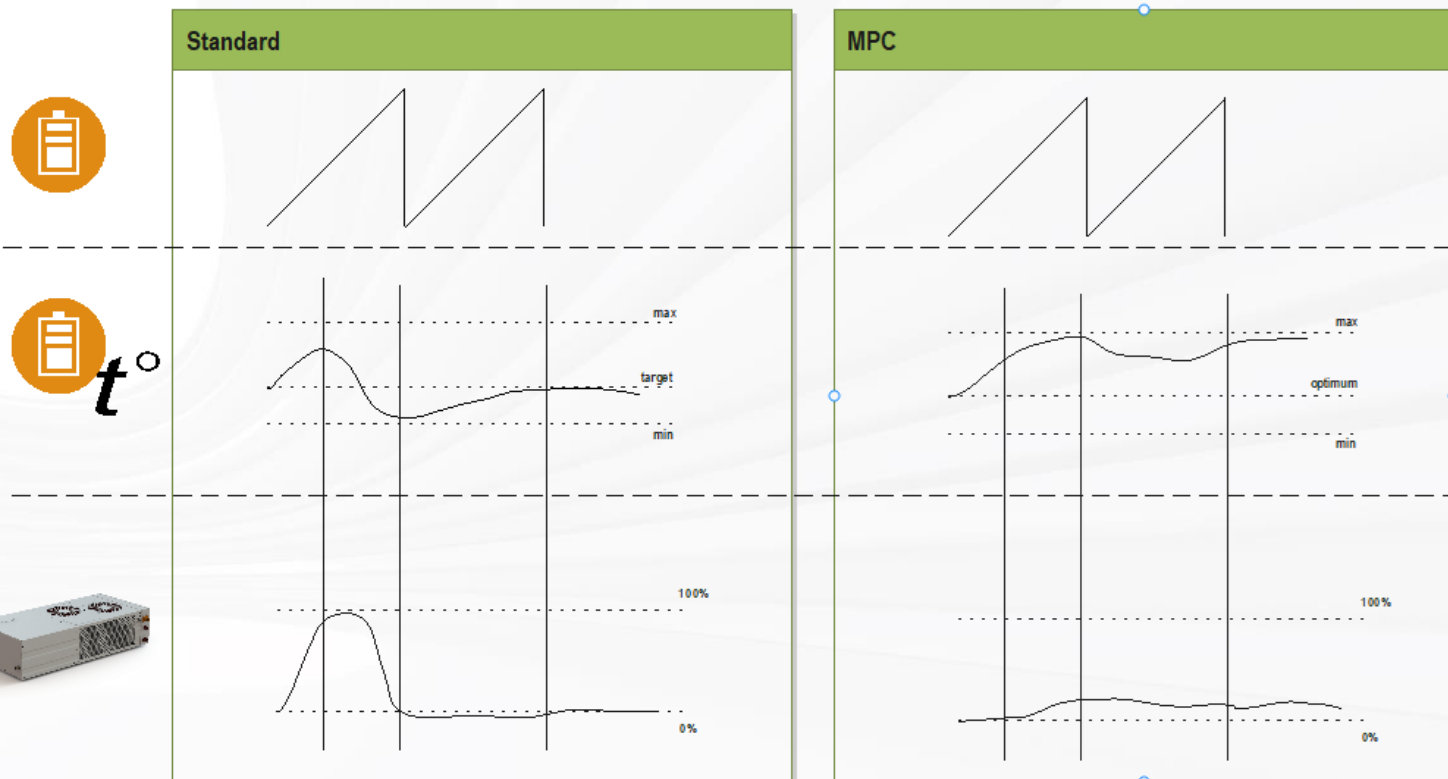
Controls evolution



Future BTMS controls



Potential operation comparison



Short Summary & Thank you!