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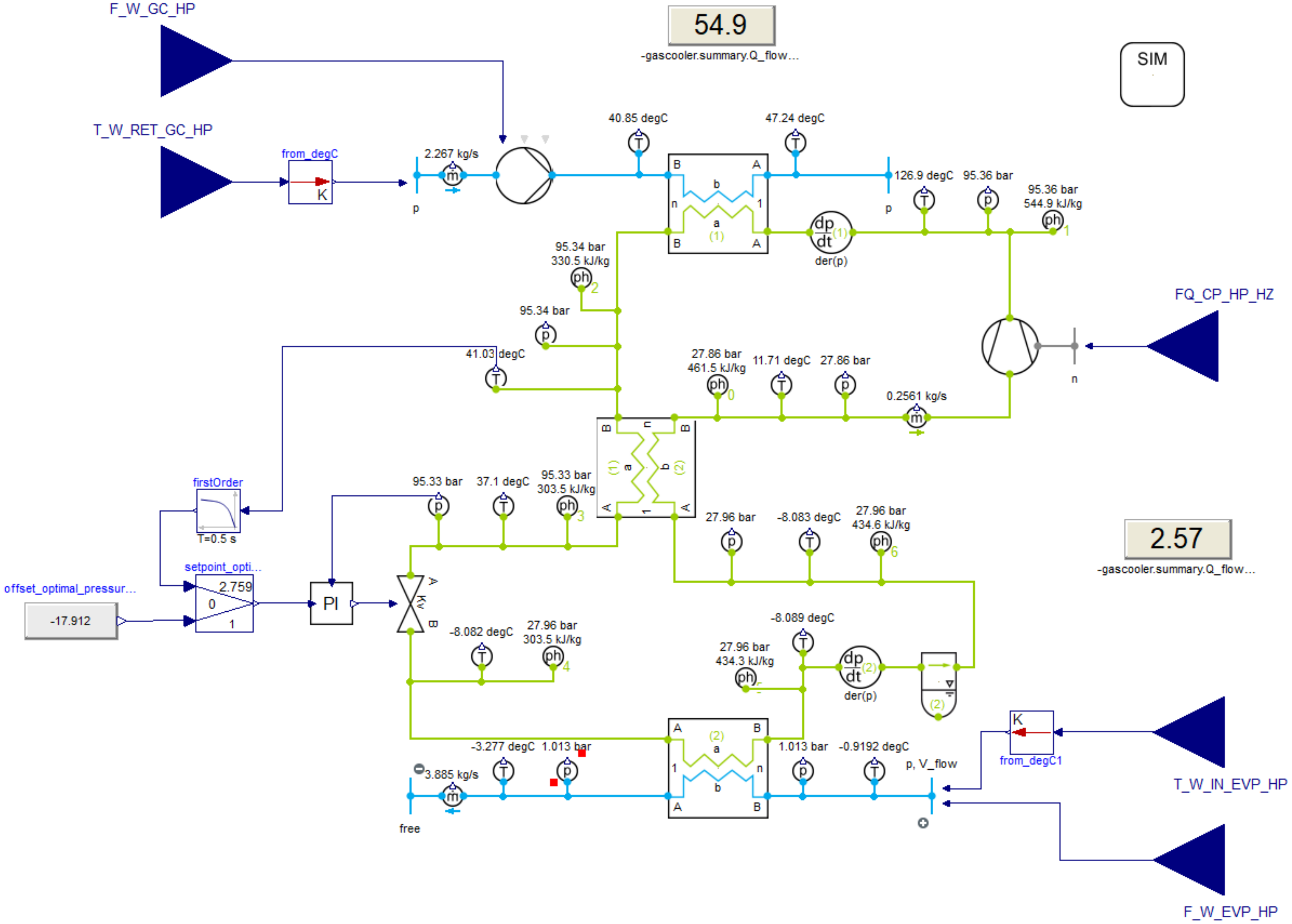

Versatile simulation models of heat pump and refrigeration systems with Dymola

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Why to use a numerical model?

Cost

- Building a test prototype is expensive
- Time saving by running simulations over few seconds

Flexibility and control

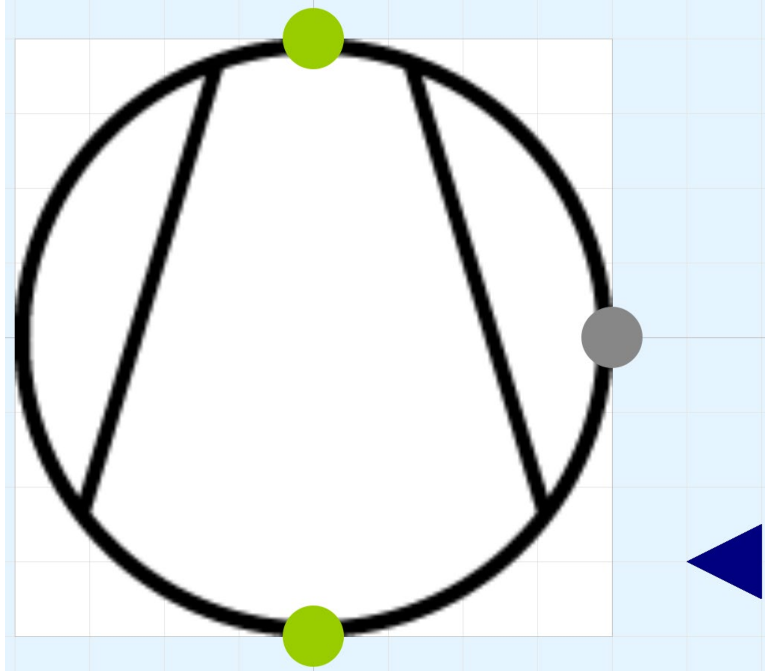
- Parameter variation: possible to “map” the whole spectrum of application
- Simulate complex and/or numerous scenarios
- Reusability of the models: easy scaling and change of subcomponents

Insight and analysis

- Detailed data, which are not always available during tests
- Fault detection/simulation

Versatile language: Modelica

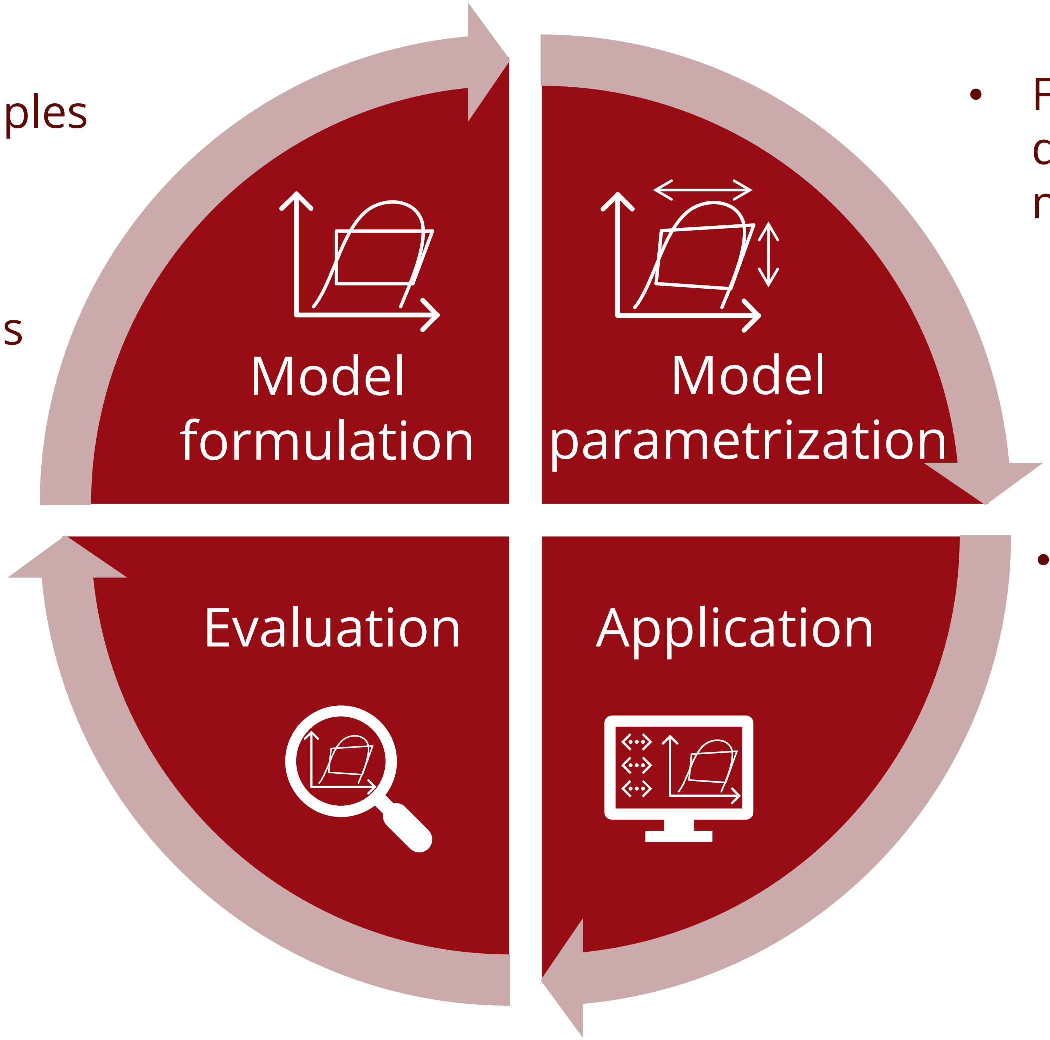
- Multi-domain modelling language
- Object oriented with component approach
- Non-causal
- Open source
- Dynamic modelling
- Graphical and text views



```
model PolynomialCompressor
  "Compressor for which the efficiencies are defined with manufacturers polynomials."
  extends TIL.VLEFluidComponents.Compressors.BaseClasses.PartialEffCompressor;

  import Modelica.Units.Conversions.{to_degC,to_bar};

public
  inner replaceable parameter SmartCO2HP.Components.Compressors.Polynomials
    polynomials constrainedby SmartCO2HP.Components.Compressors.Polynomials
    "Polynomials";

  SI.Temperature To "Saturated suction temperature";
  SI.Temperature Tc "Saturated discharge temperature";
  SI.VolumeFlowRate volumeFlow "Volume flow rate in the compressor";
  SI.MassFlowRate massFlow "Mass flow rate in the compressor";
  SI.VolumeFlowRate sweptVolume "Swept volume";
  SI.Power power "Electrical power consumed by the compressor";
  Real capacity(
    quantity="percentage",
    min=0,
    unit="1",
    displayUnit="%") "Compressor capacity";

equation

  To = to_degC(suctionVLEFluid.VLE.T_v);
  Tc = if polynomials.useDischargePressureForPolynom then to_bar(portB.p) else
    to_degC(dischargeVLEFluid.VLE.T_v);
  capacity = n/50;
  //assuming 100% capacity at 50Hz

  massFlow = 1/3600*capacity*(polynomials.massFlowCoefficients[1] + polynomials.massFlowCoefficients[
    2]*To + polynomials.massFlowCoefficients[3]*Tc + polynomials.massFlowCoefficients[
    4]*To^2 + polynomials.massFlowCoefficients[5]*To*Tc + polynomials.massFlowCoefficients[
    6]*Tc^2 + polynomials.massFlowCoefficients[7]*To^3 + polynomials.massFlowCoefficients[
    8]*Tc*To^2 + polynomials.massFlowCoefficients[9]*To*Tc^2 + polynomials.massFlowCoefficients[
    10]*Tc^3);

  power = capacity*(polynomials.powerCoefficients[1] + polynomials.powerCoefficients[
    2]*To + polynomials.powerCoefficients[3]*Tc + polynomials.powerCoefficients[
    4]*To^2 + polynomials.powerCoefficients[5]*To*Tc + polynomials.powerCoefficients[
    6]*Tc^2 + polynomials.powerCoefficients[7]*To^3 + polynomials.powerCoefficients[
    8]*Tc*To^2 + polynomials.powerCoefficients[9]*To*Tc^2 + polynomials.powerCoefficients[
    10]*Tc^3);

  //Isentropic efficiency
  effIsEff = (isentropicDischargeVLEFluid.h - suctionVLEFluid.h)*massFlow/power;
  isEff = effIsEff;

  //Volumetric efficiency
  volumeFlow = massFlow/suctionVLEFluid.d;
  sweptVolume = displacement*n;
  volEff = volumeFlow/sweptVolume;

end PolynomialCompressor;
```

General Modelling Procedure

- Formulation of physical principles
- Implementation as numerical model
- Structured libraries available
- Generic and adaptable models



Model formulation

Model parametrization

Evaluation

Application

- Fitting models to historical data, detailed simulations or online measurements

- Evaluation if simulation results are satisfying
- Derivation of adjustments in formulation, parametrization, application

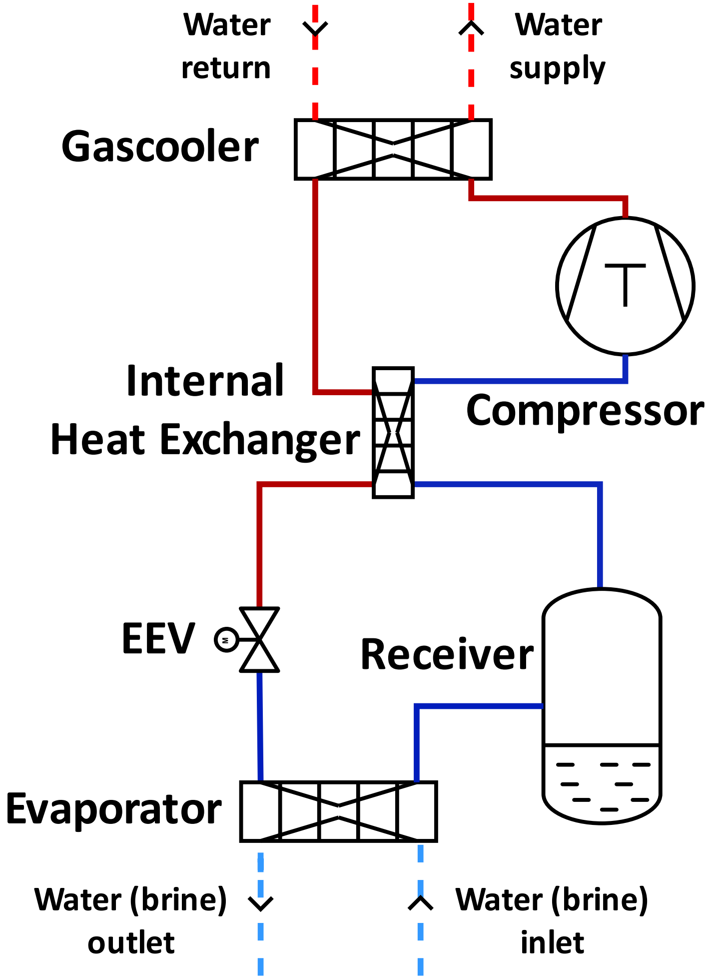
- Simulation of models for different purposes
  - What-if-analysis
  - System & component design
  - Benchmarking
  - Fault detection & diagnosis
  - System control

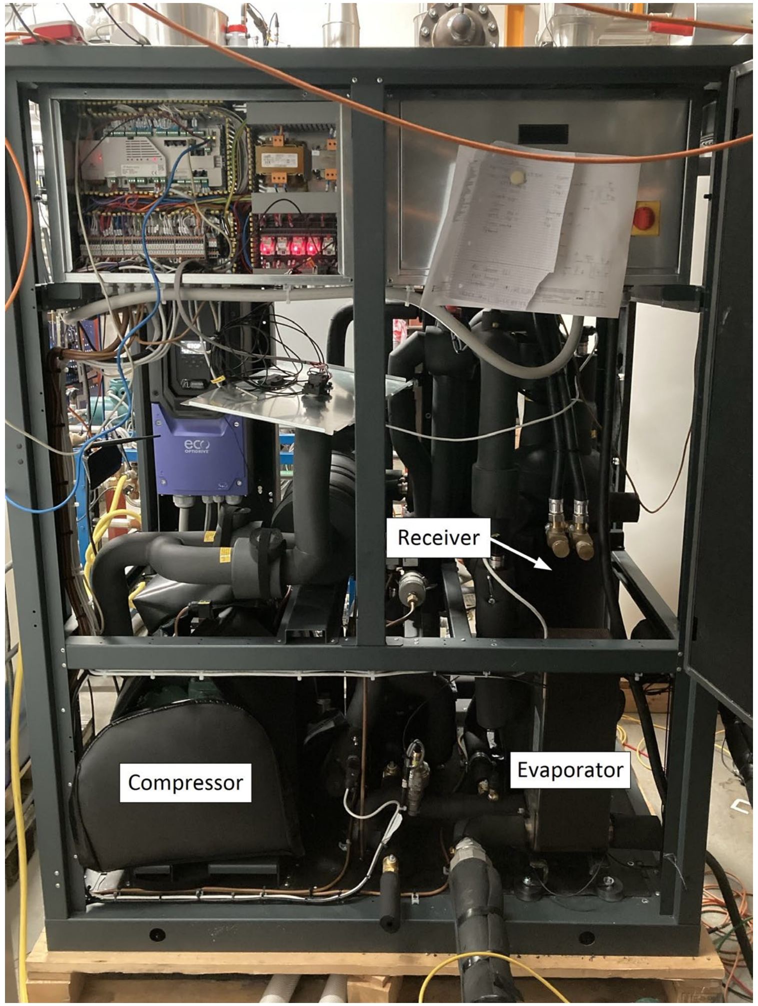
The SmartCO2HP project

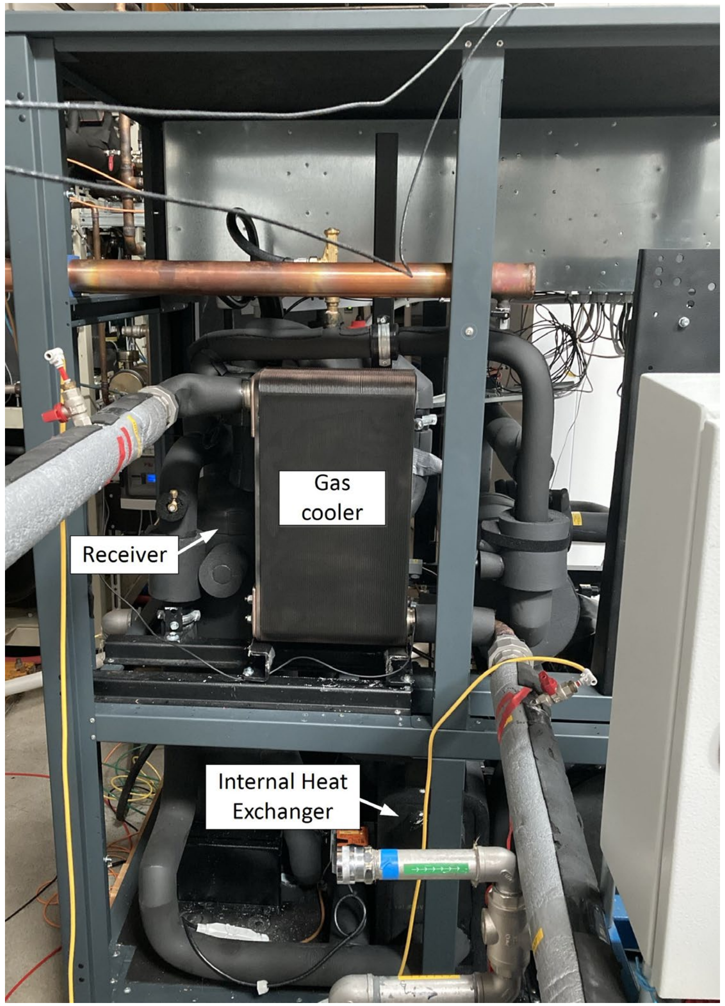
- Develop a CO2 heat pump in the range 20 kW to 200 kW
- Online monitoring of the heat pump
- Water-to-water and air-to-water
- Receives funding from EUDP

SMART CO_2 HEAT PUMP

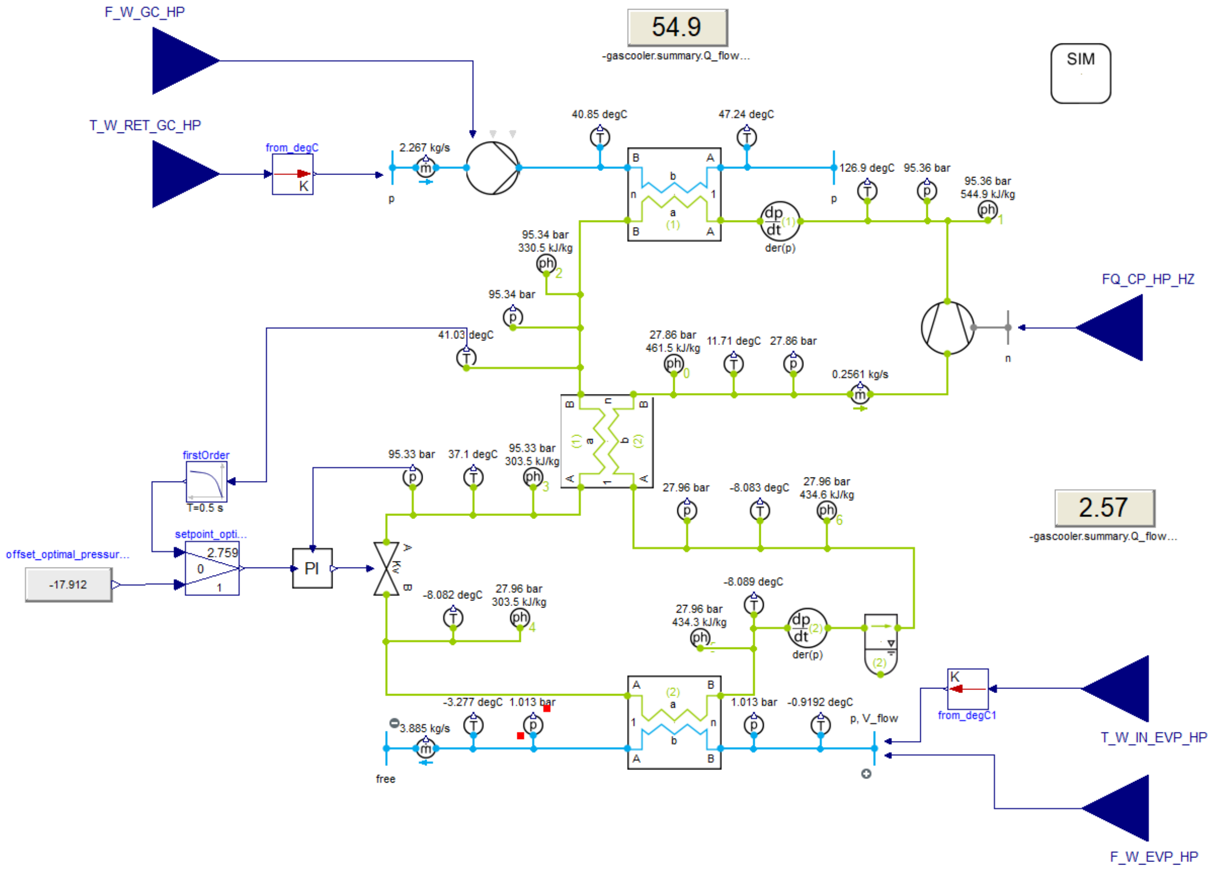
Water-to-water heat pump







Model



Yang L, Li H, Cai SW, Shao LL, Zhang CL. Minimizing COP loss from optimal high pressure correlation for transcritical CO2 cycle. Applied Thermal Engineering.

Components

- Plate heat exchangers from TIL Suite, calibrated with measurements data
- Compressor adapted from TIL Suite, but using polynomials following EN12900
- Simple correlation for optimal pressure

  → potential for more realistic control

Inputs

- Temperature and flow in the gas cooler
- Temperature and flow in the evaporator
- Speed at compressor

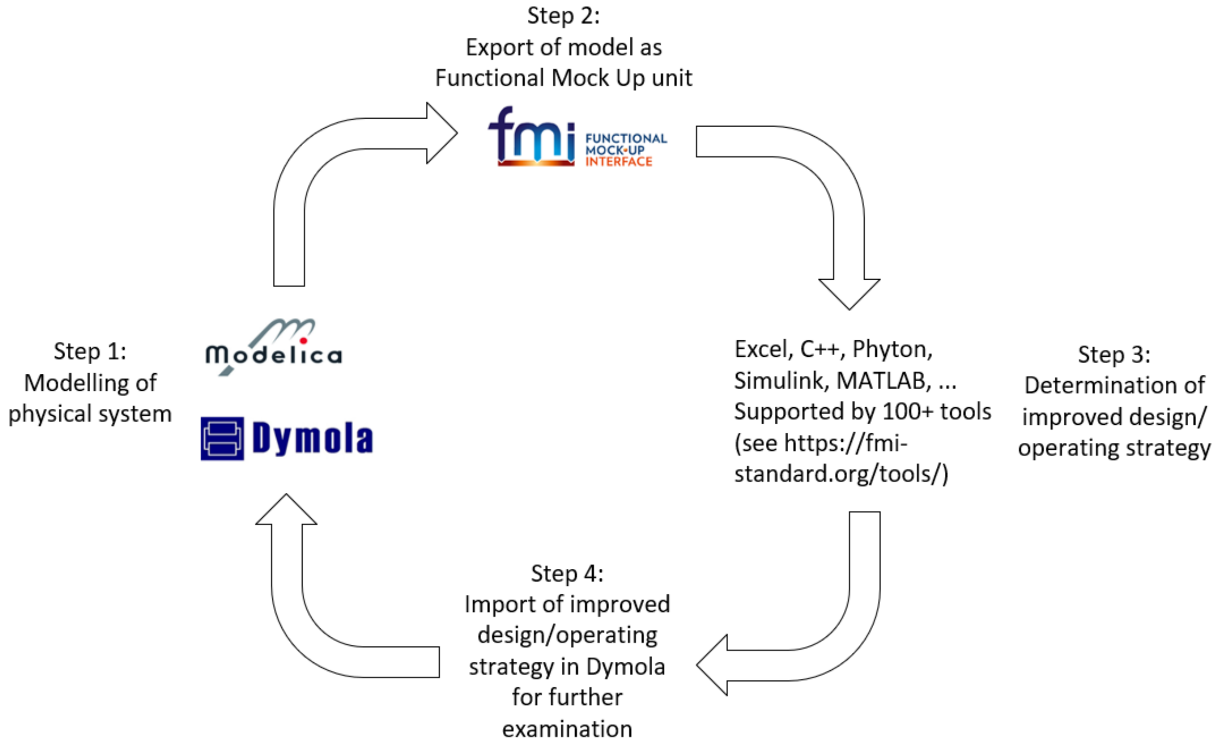
  → Can also run after setpoint on supply temperature

From model to results

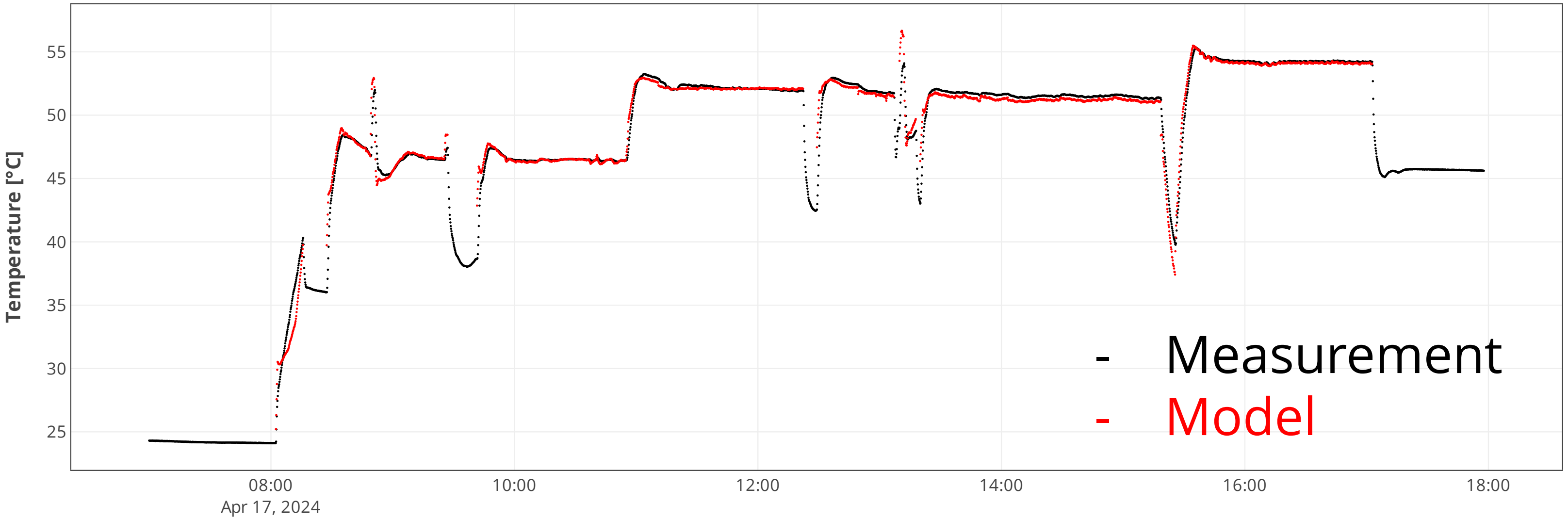
1. The model is built in Dymola
2. The model is exported as an FMU (Functional Mockup-Unit)

   FMU is a single zipped file (*.fmu) containing a description of interface data, functionality (code), calculation algorithm, and eventually additional information (documentation, tables/etc.)

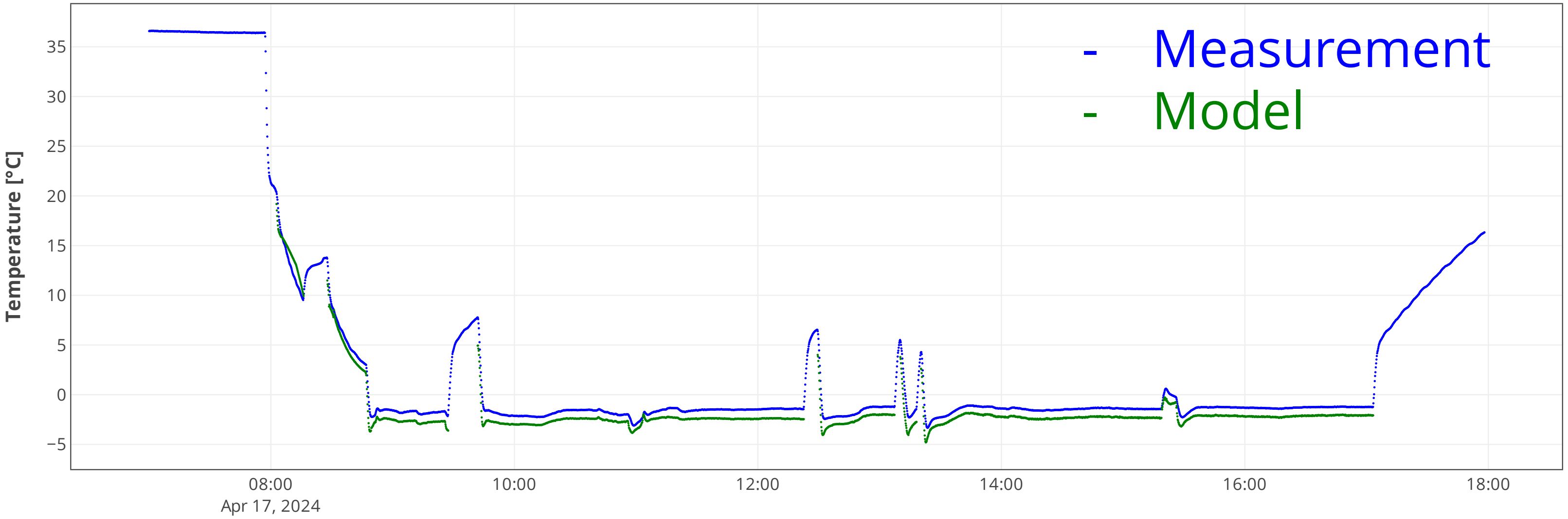
3. The FMU is run in Python with measured data (inputs of the model)
4. The measurements and calculations are compared and the model is improved



Results

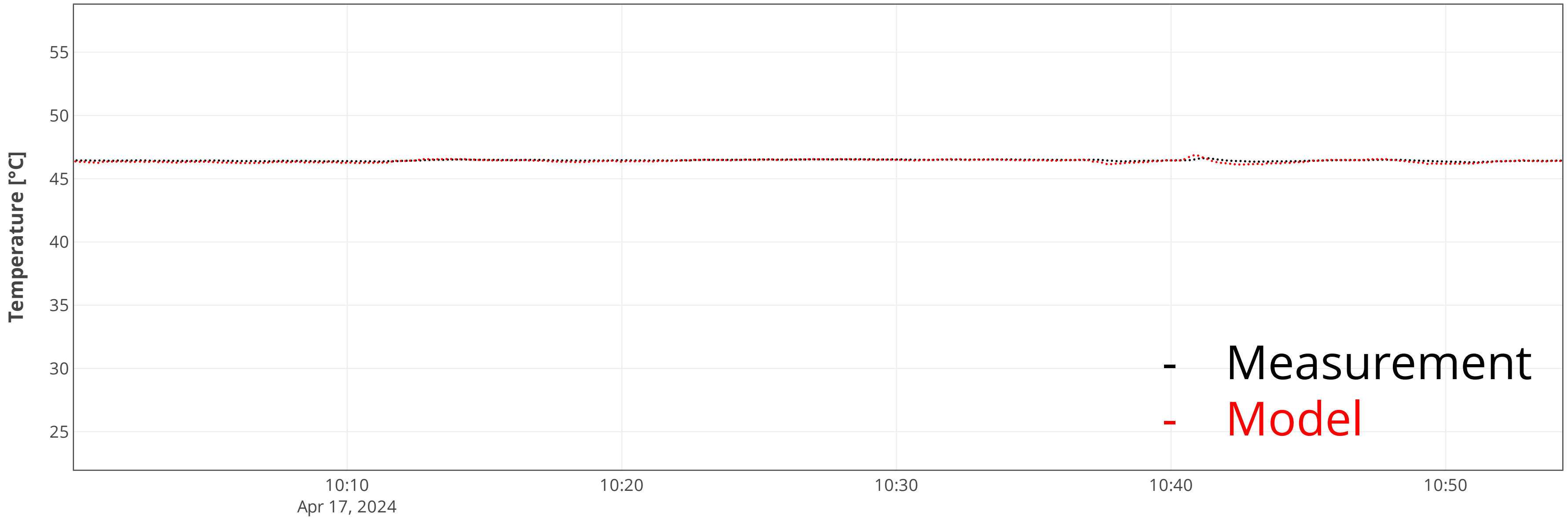


Water temperature out of the gas cooler

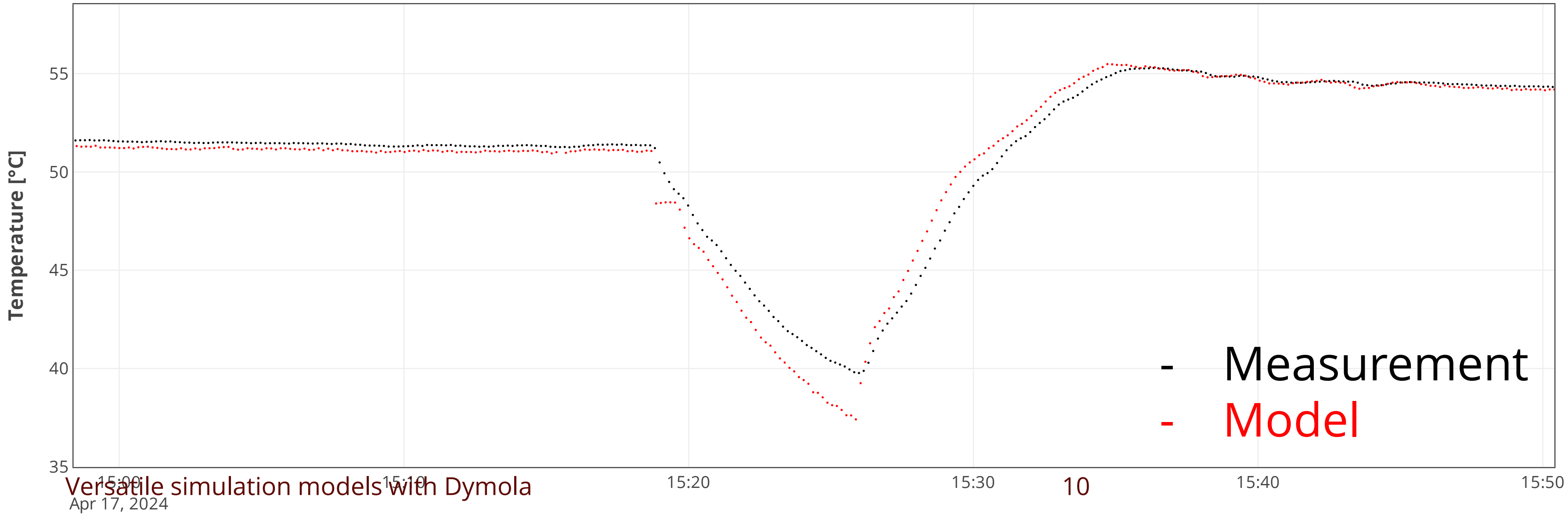


Brine temperature out of the evaporator

Results

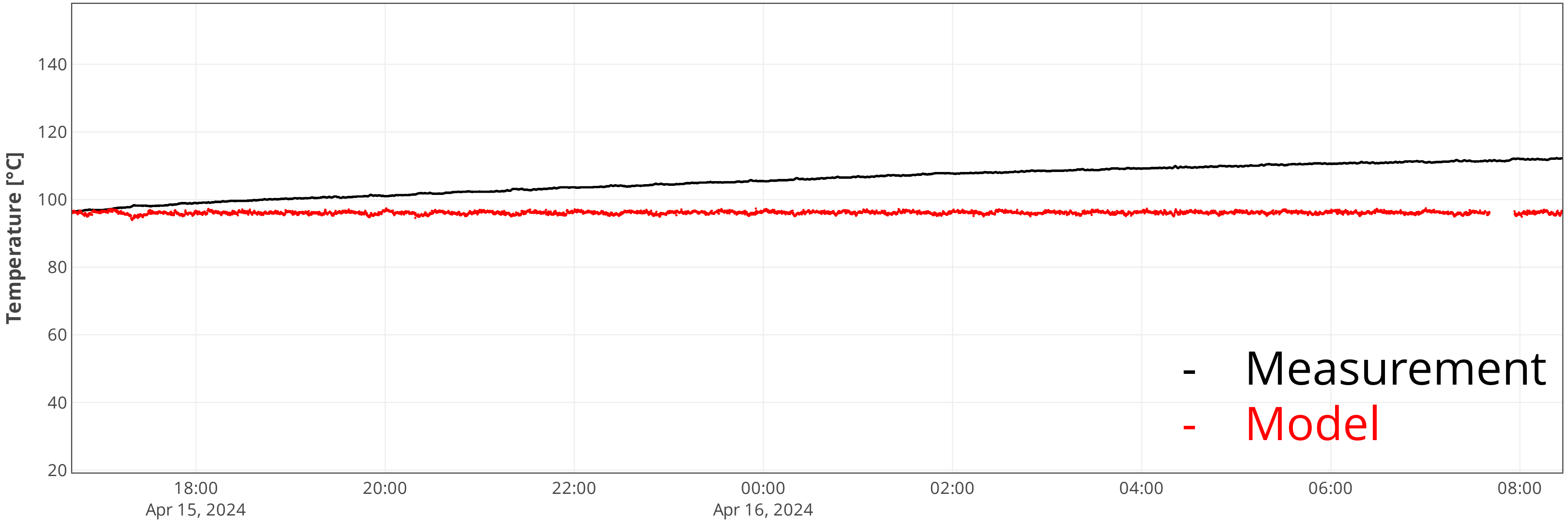


Steady state operation

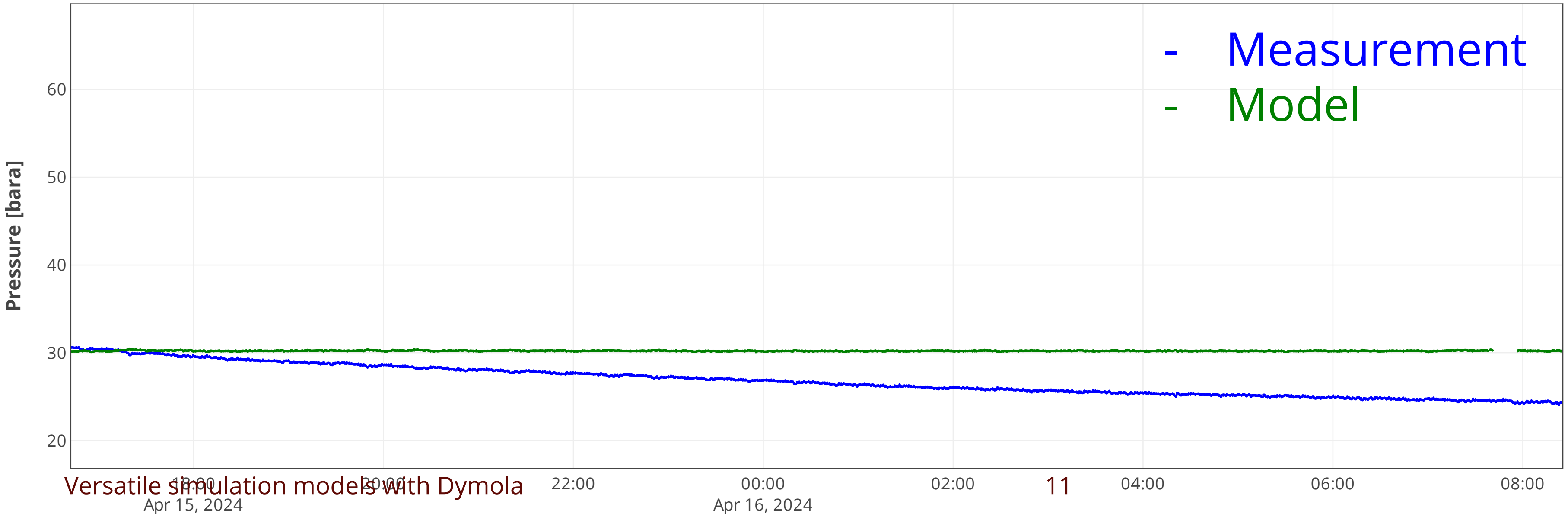


Change of the compressor speed from 66 Hz to 40 Hz, then to 66 Hz again

Results

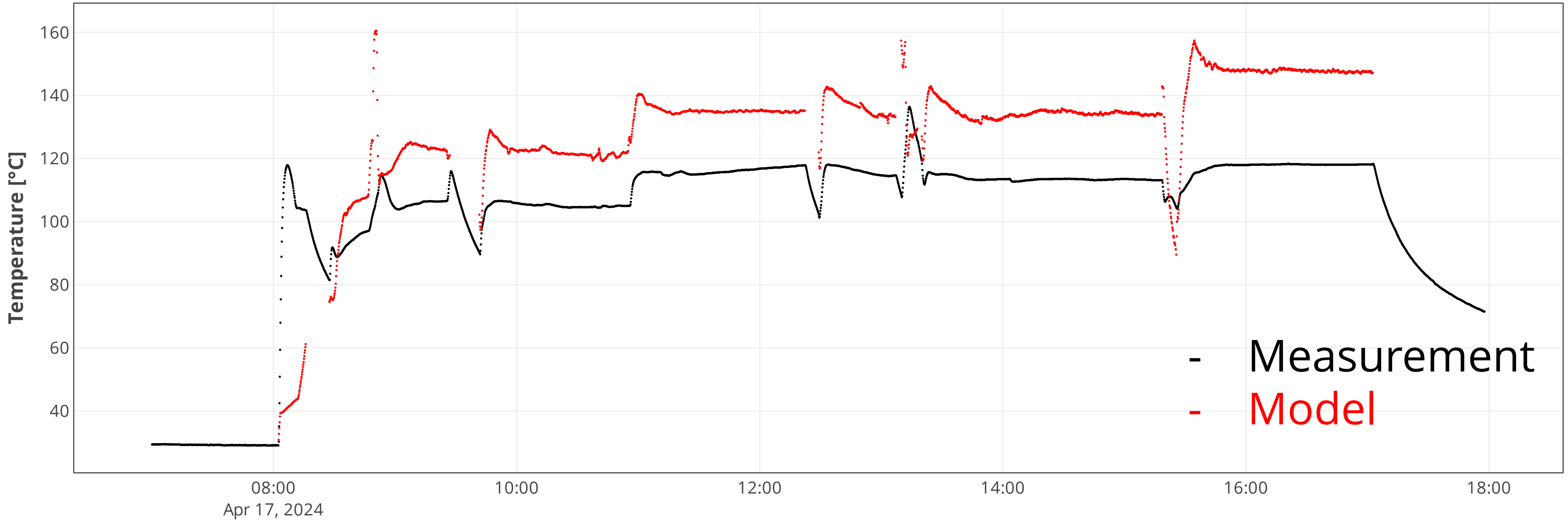


Discharge temperature



Suction pressure

Improvements to the model



Discharge temperature

- The model gives a much higher discharge temperature than measured
- Hypotheses:
  - Heat losses at the compressor not considered
  - Oil management is not present in the model

Future work

- Connect the model and run it parallel to the measurements

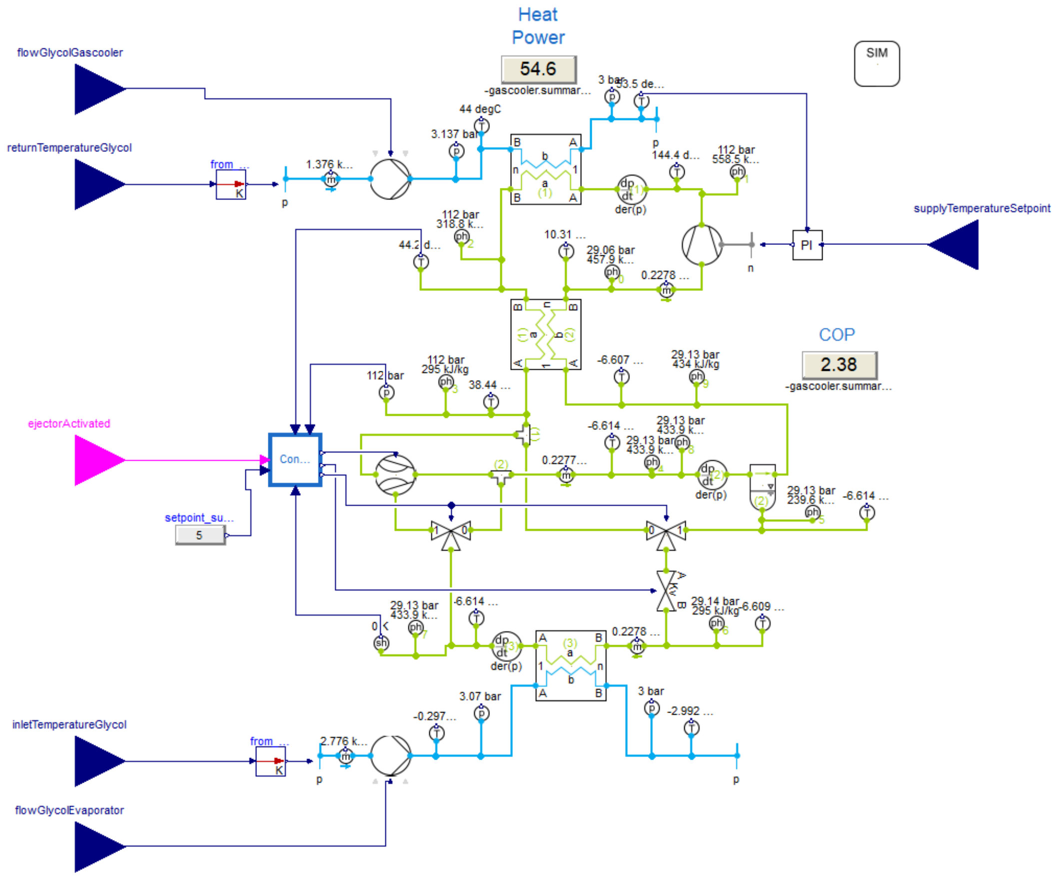
  → has already been done with a non calibrated model for trial

- Add the possibility to run with ejector

  → model ready but controls need to be finetuned

- Adapt the model for air-to-water unit

  → integrate and model the defrost strategies



Conclusion

Modelling of heat pumps and refrigeration systems with Dymola is a fast and efficient way to:

- Accurately estimate the performance of a system
- Conduct tests with limited test resources (test used for calibration)
- Better understand the system and detect faults
- Optimize the operation of the system by adapting the control strategies on a “virtual test bench”

Questions and answers

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