

Model-Based Controller Design for Heat Pumps

S. Rauscher, TLK Energy GmbH

ThermoSim 2022

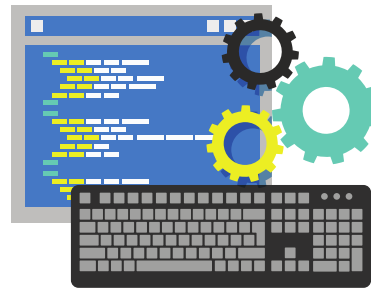
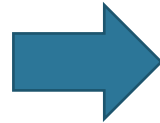
5th October 2022

WHY USE MODEL-BASED CONTROLLER DESIGN?

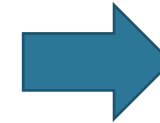
Classic approach to design a controller:



Write controller specification



Program controller code



Test controller on test bench



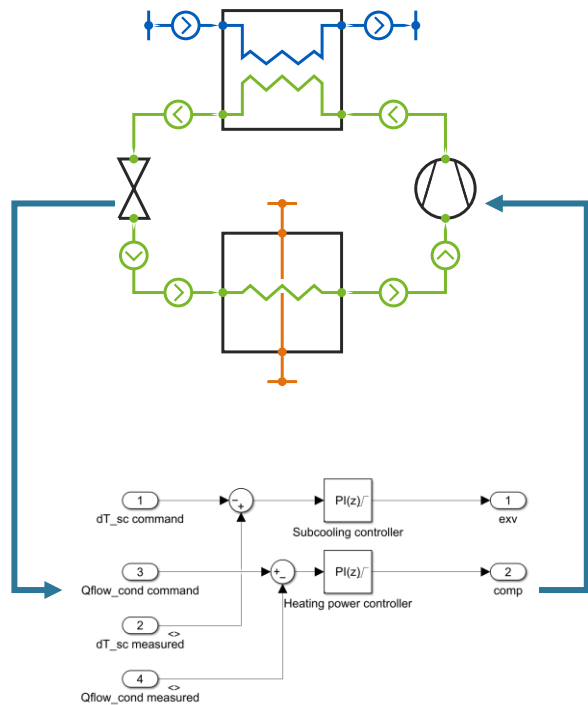
Error?

Classic approach is time consuming and expensive but widely used in refrigeration industry

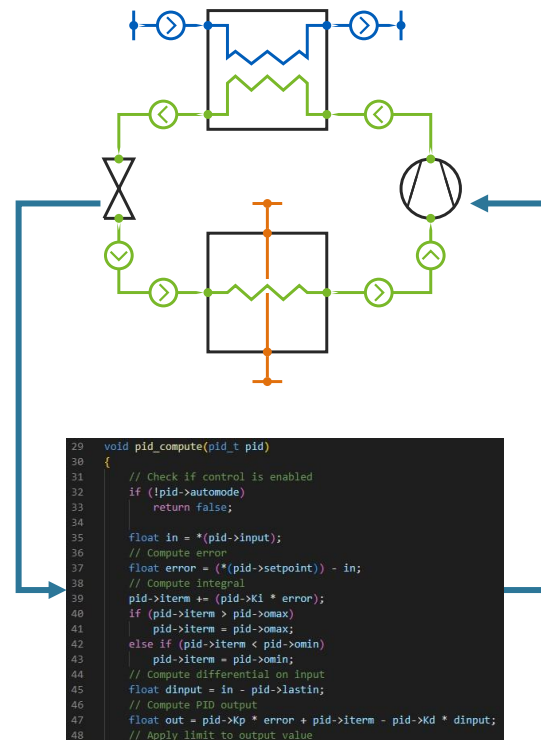
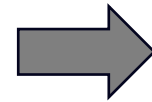
Picture source: © eakrinr / 123RF.com

WHAT IS MODEL-BASED CONTROLLER DESIGN?

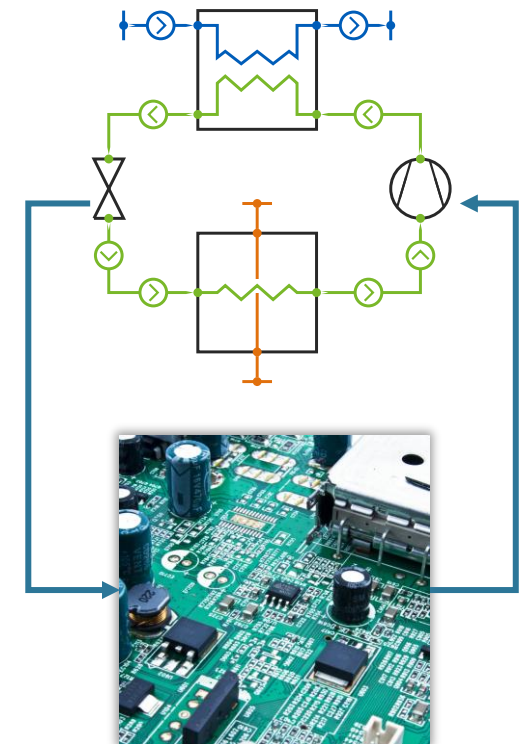
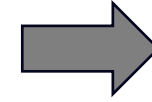
Design process, where different **design steps of a controller** are tested with a **model of the plant**:



Model-in-the-Loop (MiL)



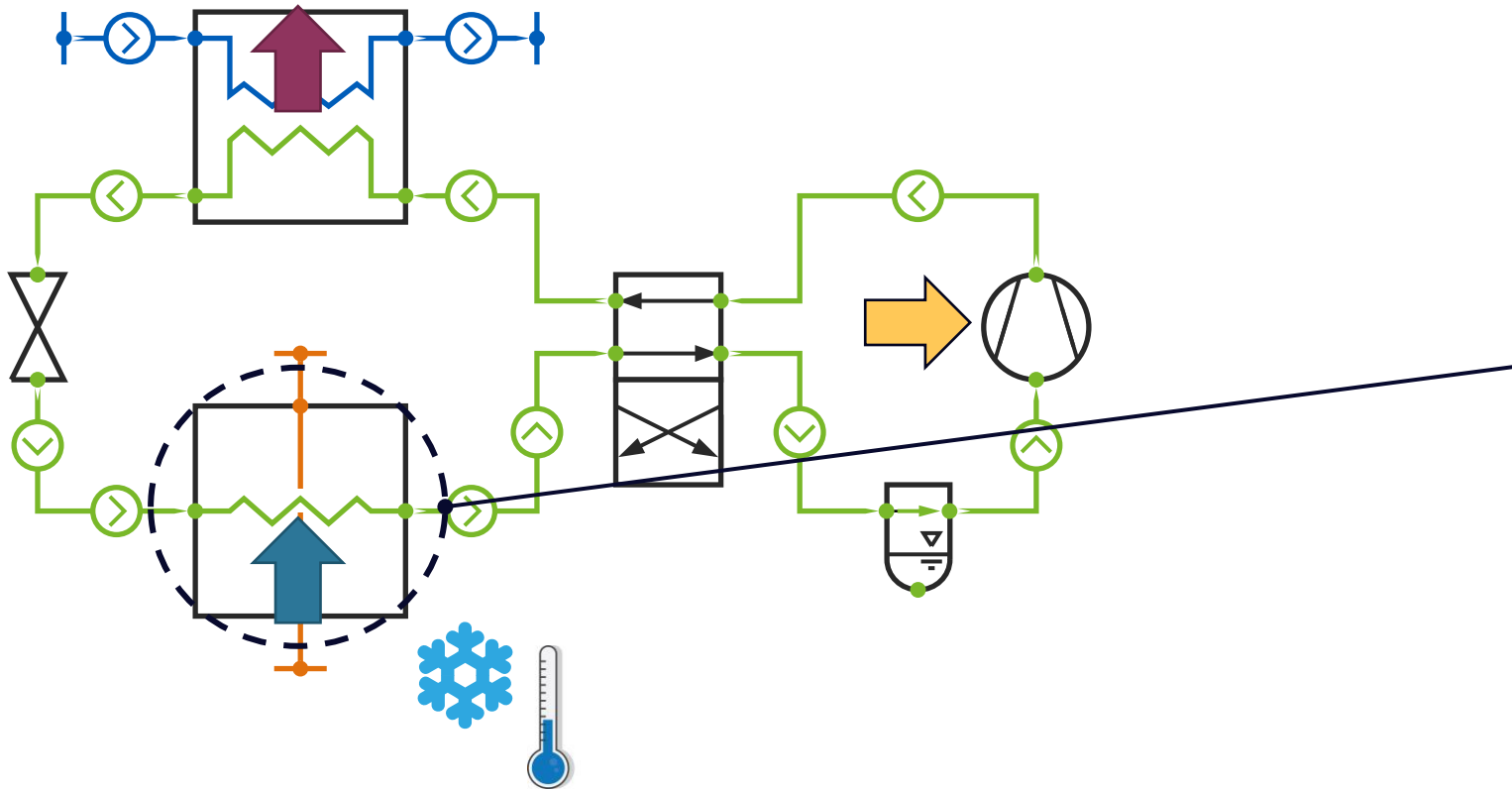
Software-in-the-Loop (SiL)



Hardware-in-the-Loop (HiL)

Picture source: © photoraidz / 123RF.com

EVAPORATOR FROSTING OF AN AIR-WATER-HEAT PUMP

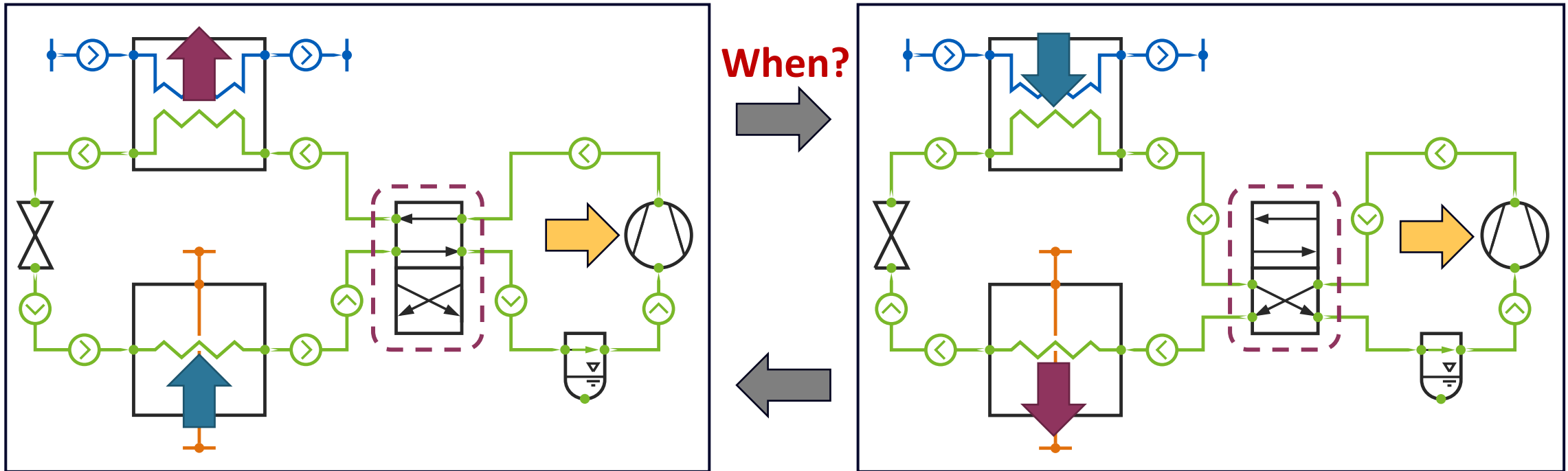


Evaporator frosting **lowers the COP** and can make the heat pump **cycle collapse**

Picture source: © eutoch / 123RF.com

EVAPORATOR DEFROSTING USING THE 4-WAY-VALVE

To defrost the evaporator, the heat pump cycle is turned around:

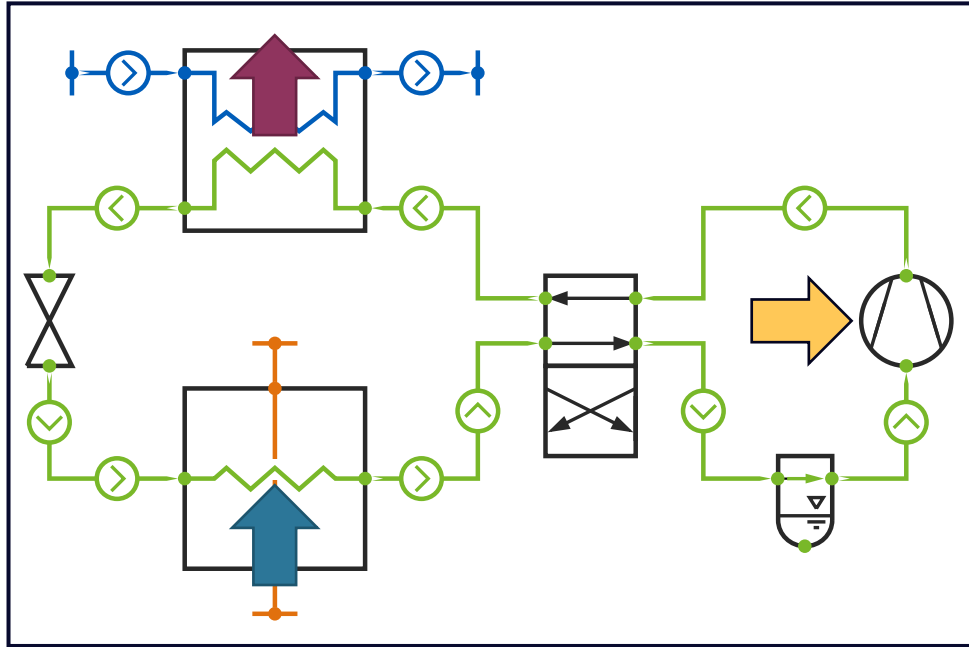


Normal Operation

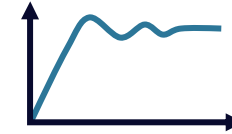
Evaporator Defrosting

Model-based controller design to develop a defrosting trigger

MODEL OF PLANT: MODELICA AND TIL-SUITE



- Dynamic system



- Flow reversal

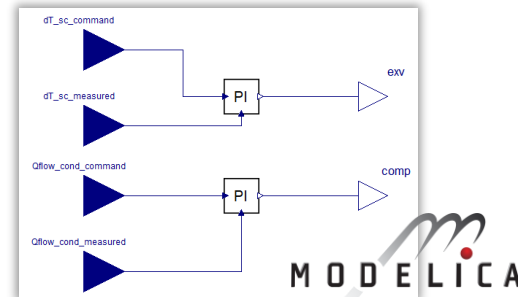


- Zero mass flow rate

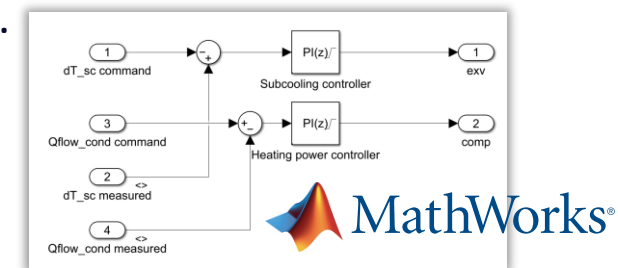
$$\dot{m} = 0$$



1.

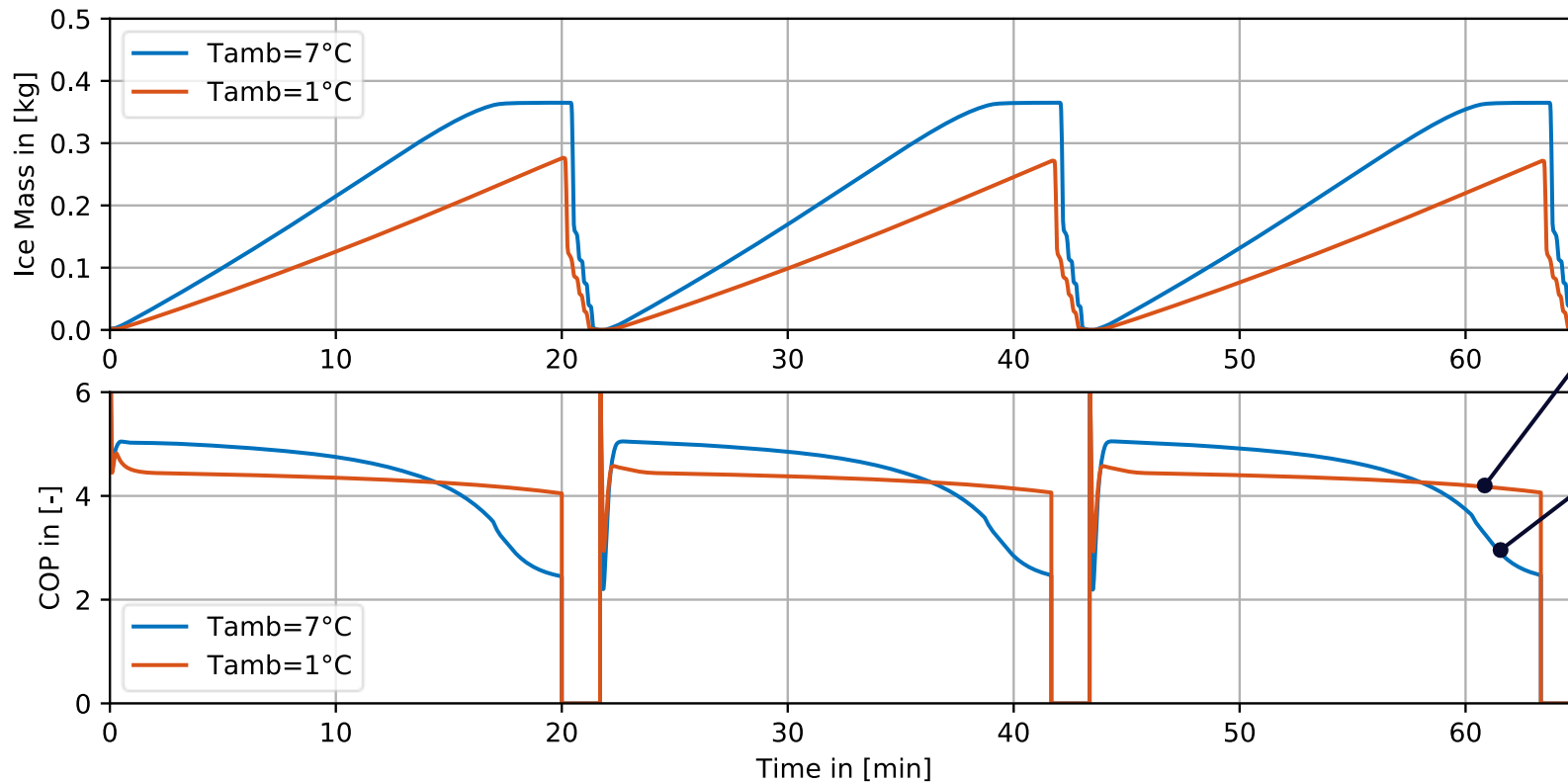


2.



DEFROSTING-TRIGGER: TIME-BASED APPROACH

Time-Based Defrosting:
Defrosting is triggered every 20 minutes



$T_{amb} = 1^{\circ}\text{C}$:
Defrosting is triggered too often

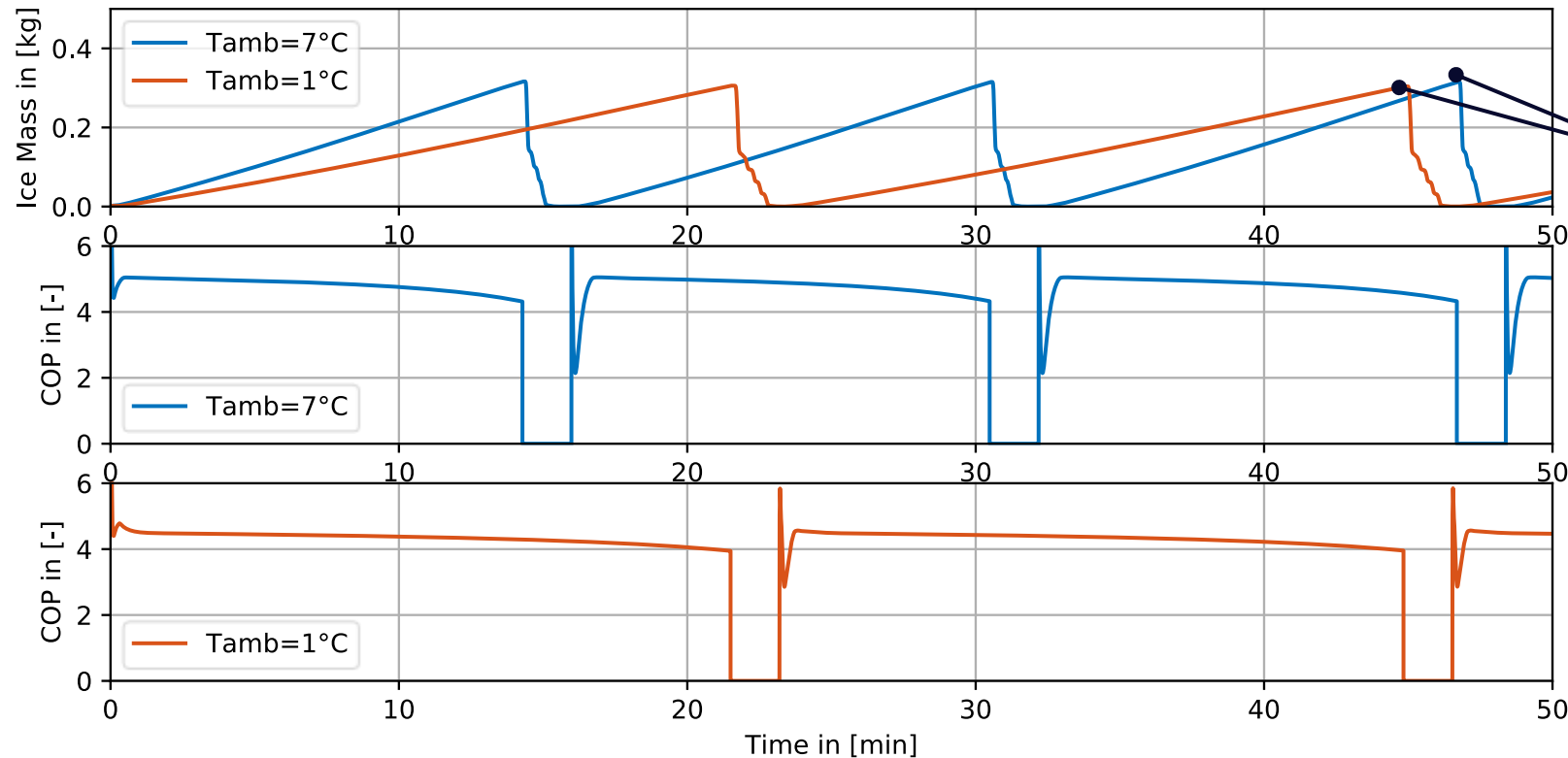
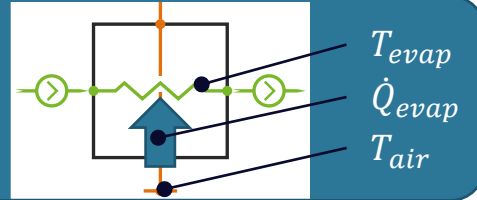
$T_{amb} = 7^{\circ}\text{C}$:
Defrosting is triggered too rarely

Time-based defrosting is **inefficient**,
since influence of ambient
conditions is not considered.

DEFROSTING-TRIGGER: EVAPORATOR CAPACITY PER TEMPERATURE DIFFERENCE

Evaporator capacity per temperature difference:

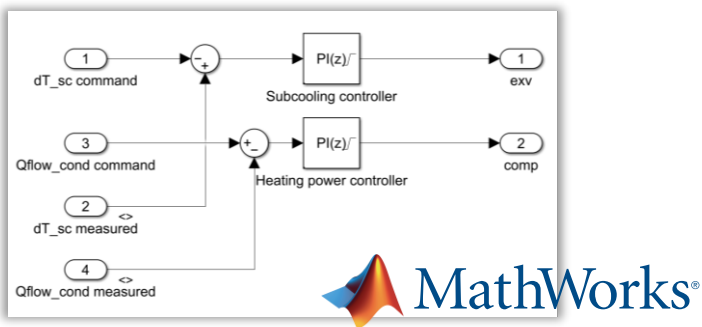
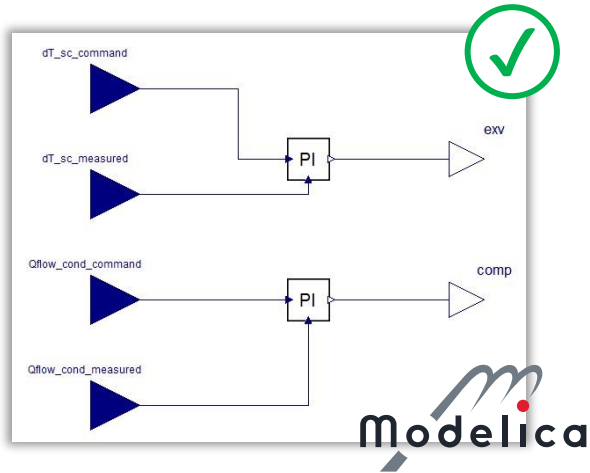
Defrosting is triggered if $\Psi = \frac{\dot{Q}_{evap}}{T_{air} - T_{evap}} < \Psi_{limit}$



Defrosting is triggered at different times

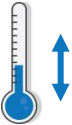
Defrosting is triggered with respect to different ambient conditions and is therefore **more efficient**.

MiL IN MODELICIA: SUCCESSFULLY DEVELOPED A PROTOTYPICAL DEFROSTING TRIGGER



MiL in Modelica:

- Prototypical implementation of controller
- Defrosting trigger that can react to different ambient conditions

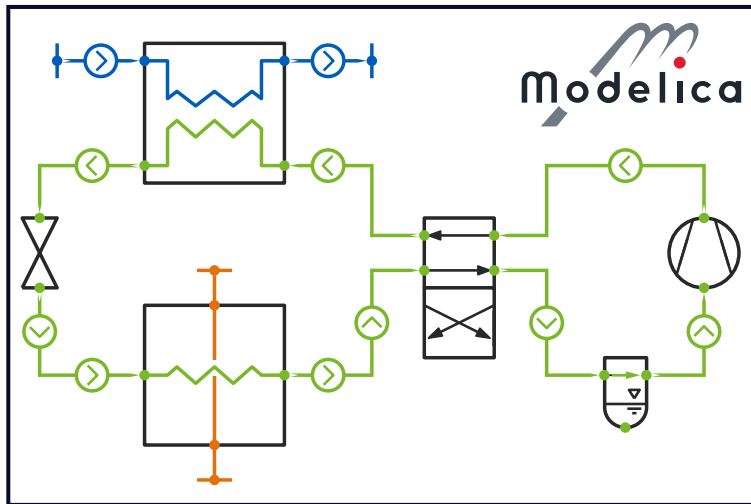


MiL in Simulink:

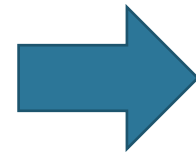
- Established tool to develop controller code
- Great support for code generation

WORKFLOW TO USE PLANT MODEL IN SIMULINK

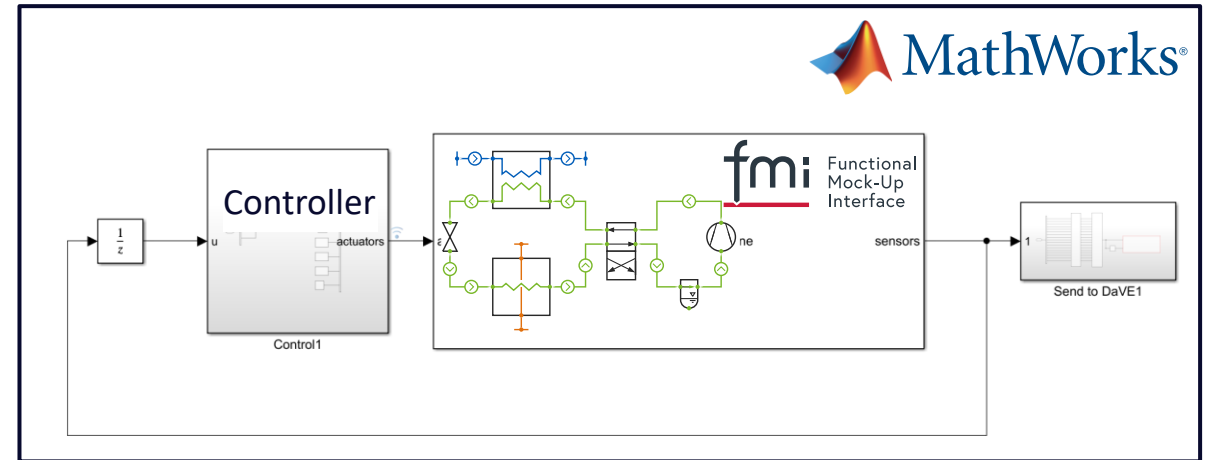
Modelica is very well suited to model dynamic systems. Therefore:



Plant model

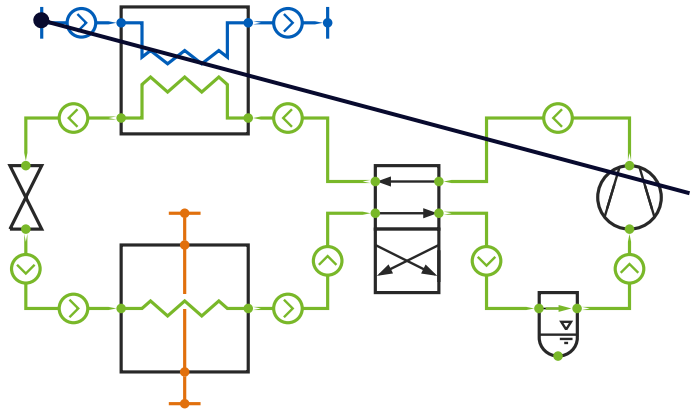


Export as FMU

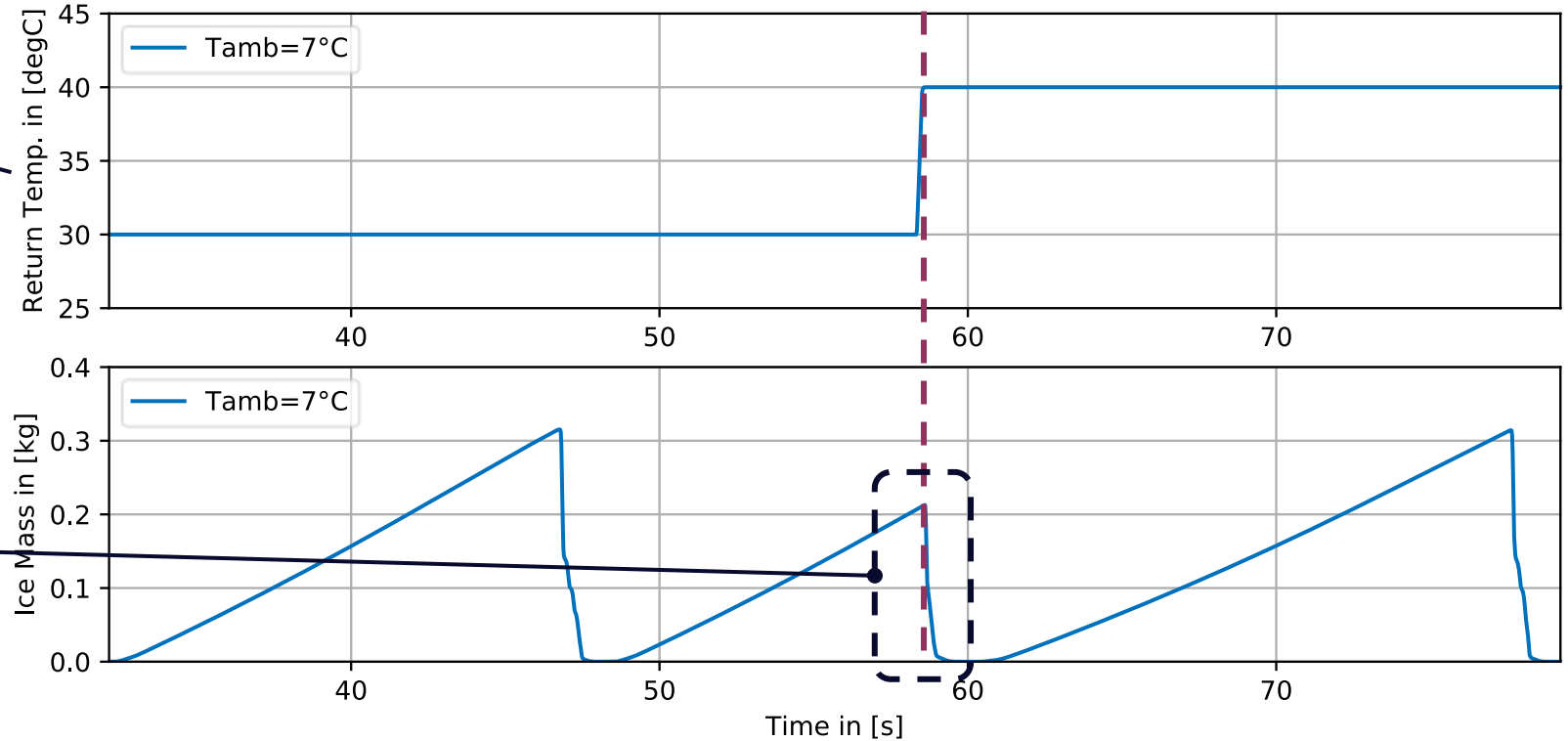


Build in support for FMU-import in Simulink

MIL IN SIMULINK: TEST OF DEFROSTING TRIGGER



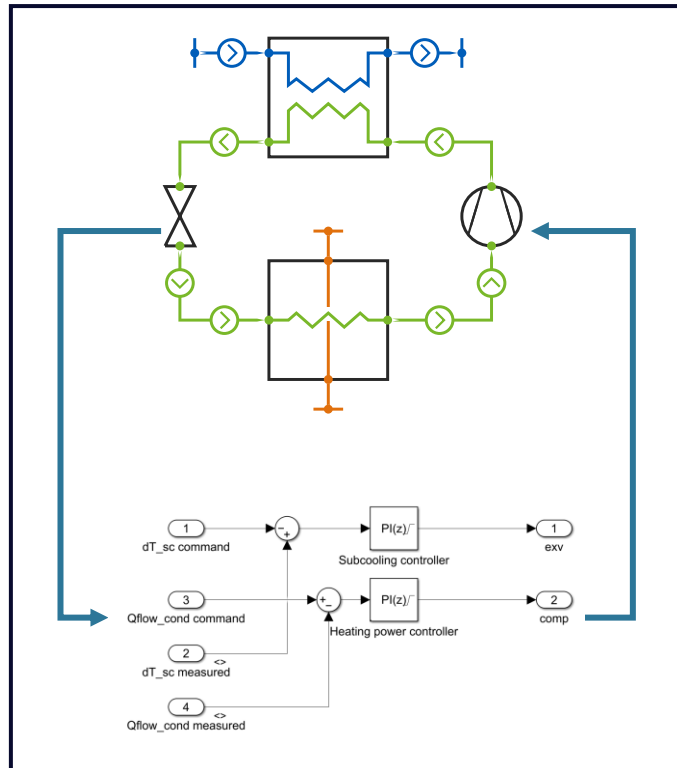
Defrosting is triggered too early



Explanation:

Increased return temperature lowers \dot{Q}_{cond} and \dot{Q}_{evap} \rightarrow Ψ drops below threshold \rightarrow Defrosting is triggered too early

MiL: UNEXPECTED BEHAVIOR WAS FOUND IN AN EARLY DESIGN STAGE



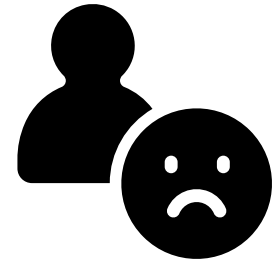
Identified unexpected behavior of defrosting trigger

Without MiL, the unexpected behavior would have been noticed...



... at the test bench.

or



... at the customer.

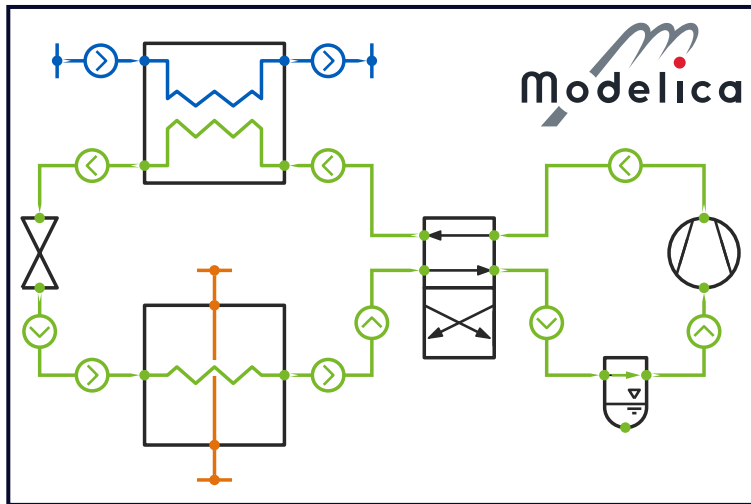


Messed up development schedule

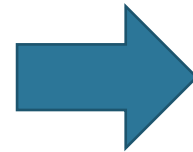
Picture source: © eakrinr / 123RF.com

NEXT STEP: FURTHER TESTS OF CONTROLLER ON HiL-SYSTEMS

Modelica model can be used on HiL-Systems:



Plant model



Export as FMU
fmi Functional Mock-Up Interface



HiL systems, for example by Speedgoat, dSpace or National Instruments

- Test of I/O communication
- Test of compiled code

Picture source: Speedgoat GmbH, <https://www.speedgoat.com/>

MODEL-BASED CONTROLLER DESIGN SAVES DEVELOPMENT TIME

- Controller is designed with a model of the plant
- With MiL, SiL and HiL, the controller can be tested in different development stages
- FMI standard allows...
 - ... to develop the plant model in the ideal environment
 - ... a consistent use of the same plant model

THANK YOU FOR YOUR ATTENTION

Stefan Rauscher, M.Sc.
stefan.rauscher@tlk-energy.de

TLK ENERGY GMBH
Telefon: +49 241 412 50 645
E-Mail: info@tlk-energy.de
Web: www.tlk-energy.de