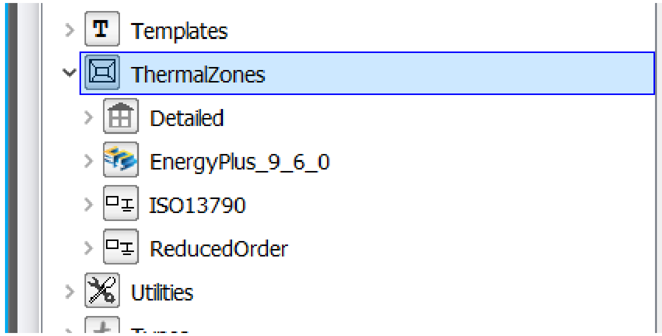
Modelica-based simulation of building and district energy systems

Session 8/9: Hands-on training / Air-based cooling system

Alessandro Maccarini

SESSION 8/9 – Detailed and simplified models of thermal zones

The Buildings library currently includes four different approaches to model thermal zones:



1. Detailed thermal zone (*ThermalZones.Detailed*)
    - Conduction through walls/roof/floor (1D discretization)
    - Solar radiation on exterior surfaces and windows
    - Interior radiation exchange
    - Surface convection based on temperature difference and surface orientation

2. Spawn of EnergyPlus (*ThermalZones.EnergyPlus_9_6_0*)
    - Allows to simulate HVAC and control systems in Modelica coupled to the EnergyPlus envelope model
    - You need to download and install EnergyPlus

3. Reduced-order model based on ISO13790 Standard (*ThermalZones.ISO13790*)
    - Based on a thermal network consisting of five resistances and one capacitance (5R1C). The models are based on the ISO 13790:2008 Standard.

4. Reduced-order model based on German Guideline VDI 6007 (*ThermalZones.ReducedOrder*)
    - Based on a thermal network consisting of seven resistances and two capacitances (7R2C).

SESSION 8/9 – Detailed and simplified models of thermal zones

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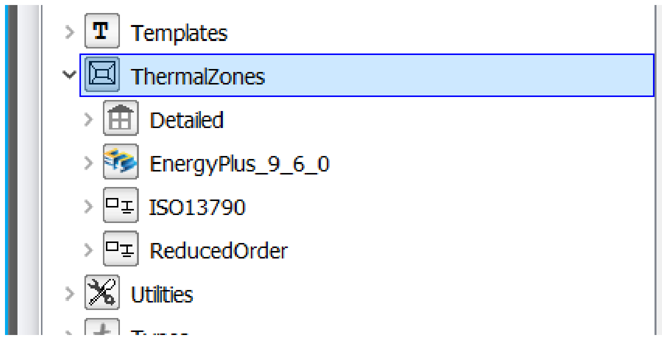

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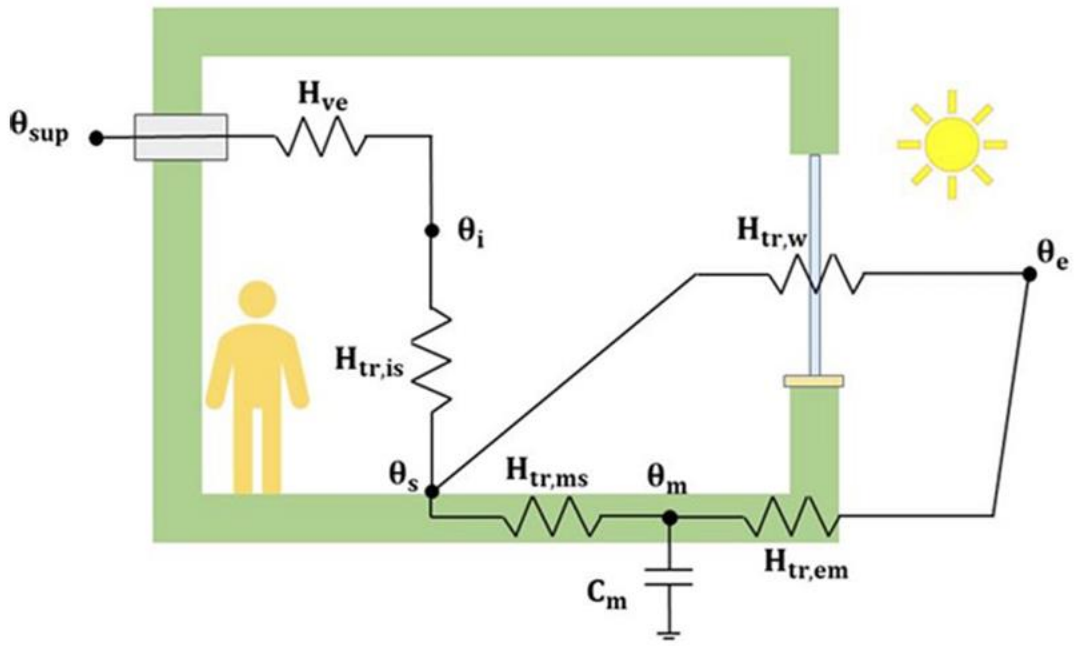
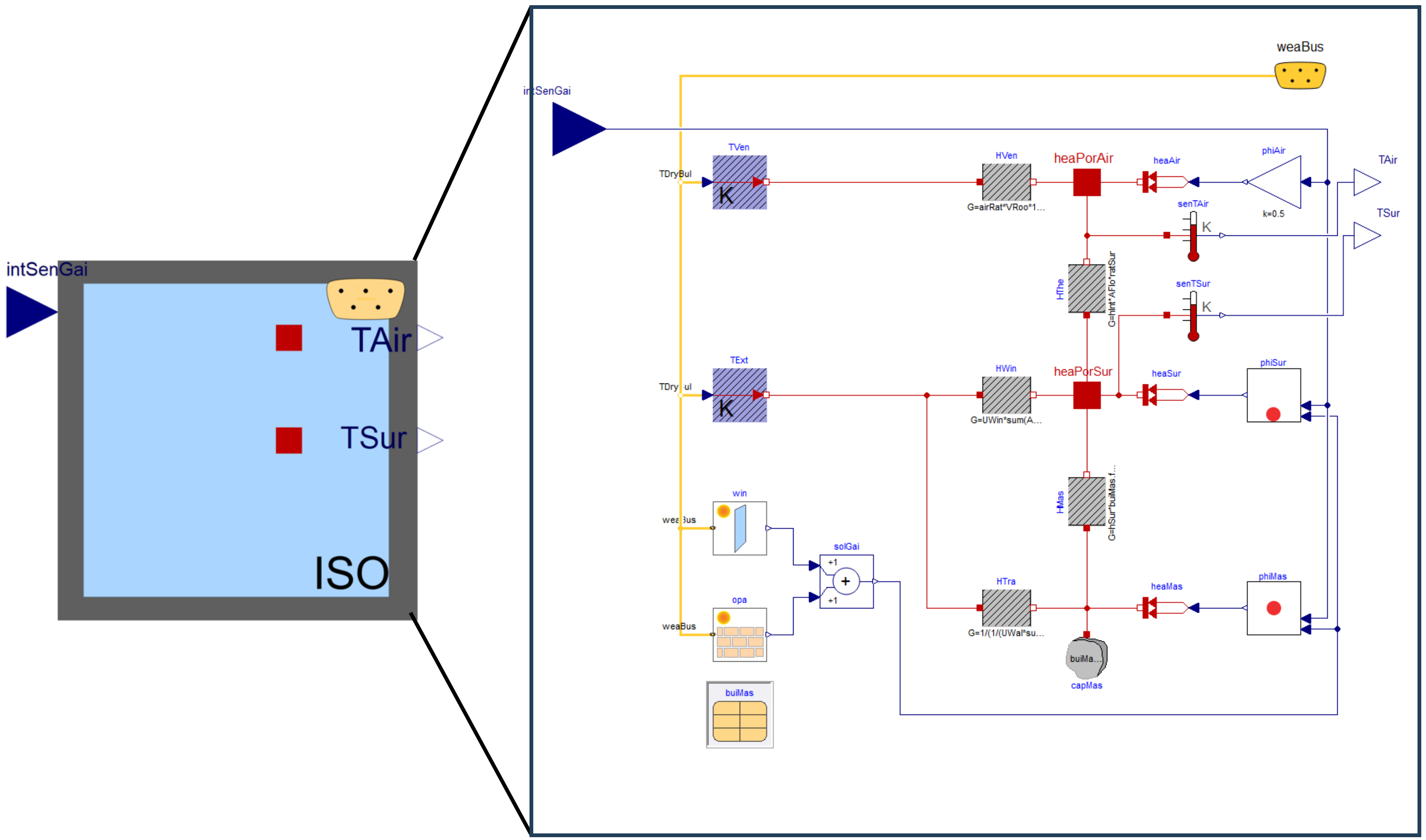
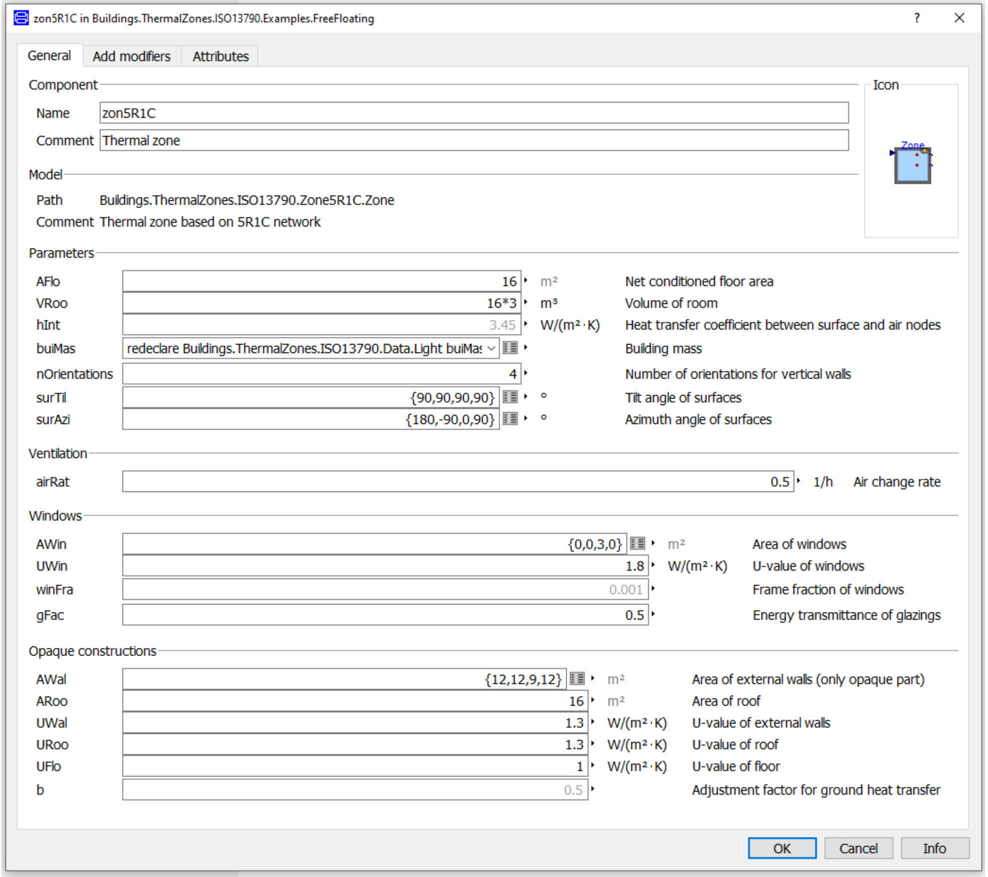
SESSION 8/9 – The ISO13790 thermal zone model

- Lumped-capacity simplified building model
- 5 resistances and 1 capacity used to reproduce the transient thermal behavior of buildings
- The thermal zone is modeled with three temperature nodes:
  - Indoor air temperature θ_i
  - Envelope internal surface temperature θ_s
  - Zzone's mass temperature θ_m
- The thermal capacity C_m includes the thermal capacity of the entire zone
- The resistances represent:
  - Heat transfer through ventilation (H_{ve})
  - Heat transfer through windows ($H_{tr,w}$)
  - Heat transfer through walls (split in $H_{tr,em}$ and $H_{tr,ms}$)
  - Heat transfer between internal surfaces and air ($H_{tr,is}$)



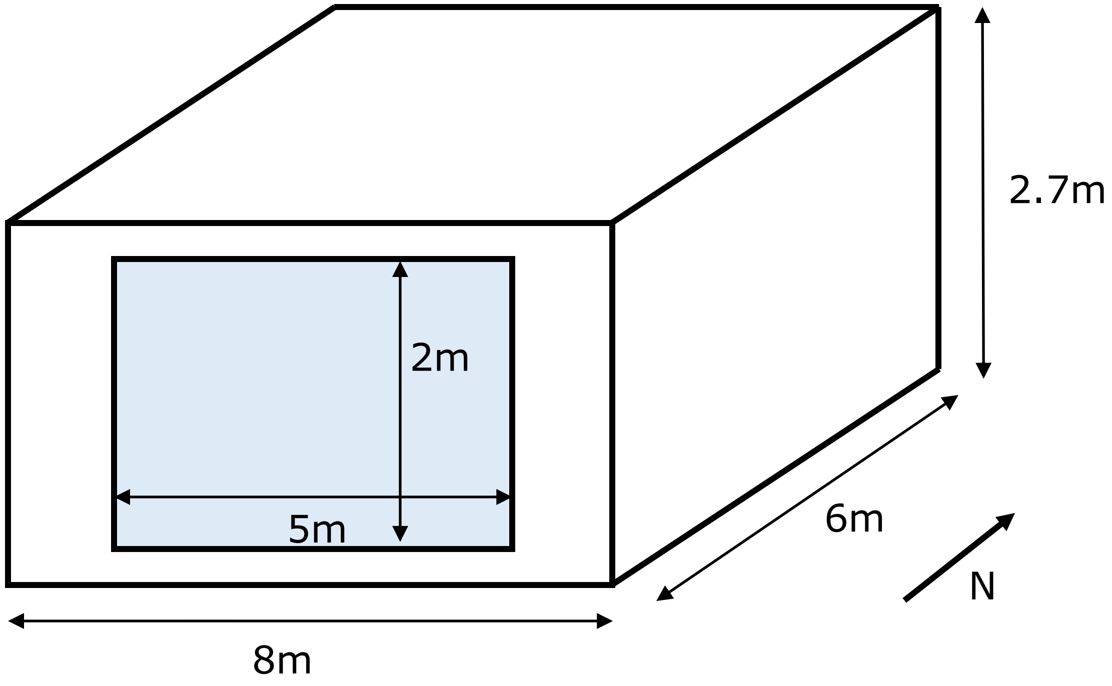
SESSION 8/9 – The ISO13790 thermal zone model





SESSION 8/9 – The ISO13790 thermal zone model

GOAL: To create a model of a room using the ISO13790 model, and simulate for 4 summer days (from day 145 to 149)



- List of input parameters:
  - Heat transfer coefficient 3.45 W/m2K
  - Building mass medium
  - Air change rate 0.4 1/h
  - U-values:
    - Walls 0.2 W/m2K
    - Roof 0.15 W/m2K
    - Floor 0.1 W/m2K
    - Window 1.8 W/m2K
  - g-factor window 0.6
  - Frame ratio 0.01
  - Ground factor 0.5
- Sensible heat gains of 10 W/m^2 (latent = 0)
- All six surfaces are exposed to the outdoor environment
- Weather file of Chicago O'Hare

Tip: Azimuth for orientations:
- North 180°
- East -90°
- South 0°
- West 90°

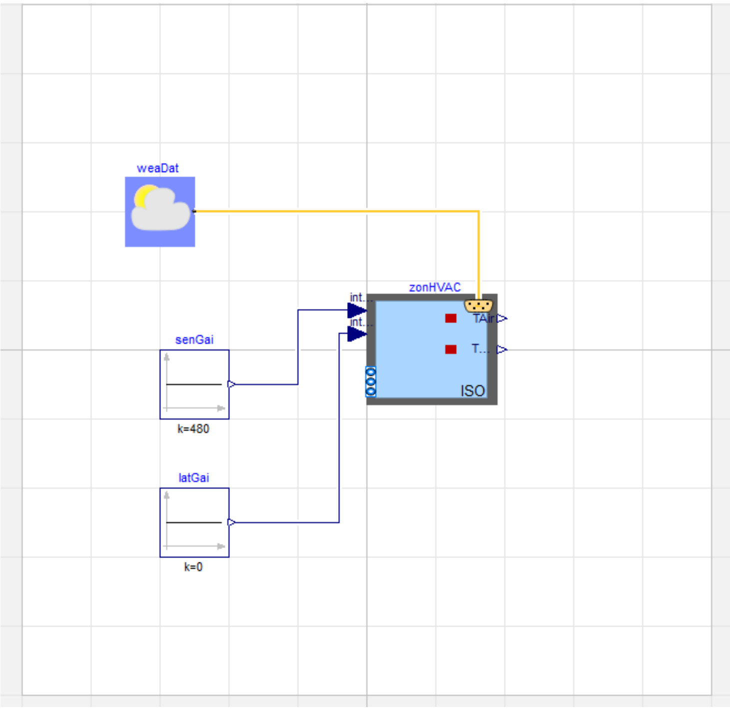
SESSION 8/9 – The ISO13790 thermal zone model

STEP 1: Create the thermal zone

1. Create a new package **CoolingSystem**
2. Create a new package called **Components** inside CoolingSystem
3. Create another new package called **Experiments** inside CoolingSystem
4. Create a new model **Experiment1** inside Experiments
5. In Experiment1, drag and drop the following models:

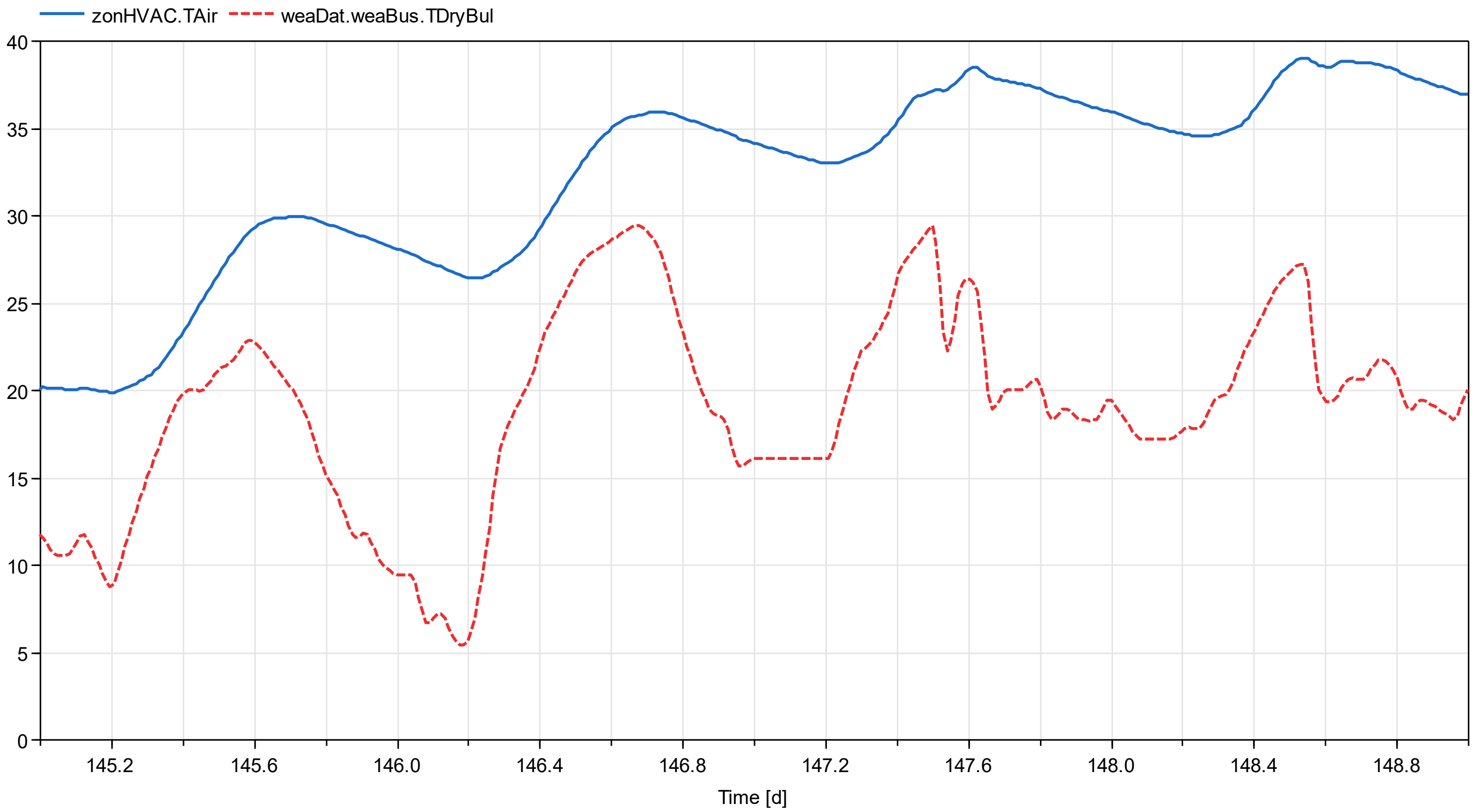
   - `Buildings.ThermalZones.ISO13790.Zone5R1C.ZoneHVAC (1)`
   - `Modelica.Blocks.Sources.Constant(2)`
   - `Buildings.BoundaryConditions.WeatherData.ReaderTMY3 (1)`

5. Connect the components according to the figure on the right.
6. Assign the values of the parameters according to previous slide. Parameters with multiple values (e.g. areas, azimuth) should be inserted between curly brackets and separated by commas. Note that the weather file can be selected by clicking on *FilNam* in the weather data reader and search in the Buildings library folder at ../Resources/weatherdata
7. Simulate the model for 4 summer days (from day 145 to 149) Simulate the model for 4 summer days (from day 145 to 149)
8. Plot the air temperature in the room and the outdoor air temperature



SESSION 8/9 – The ISO13790 thermal zone model

Results – Experiment1



The peak inside air temperature is around 40°C!

Since it looks like our outdoor air temperature is always less than our room air temperature, this will help us cool down the room

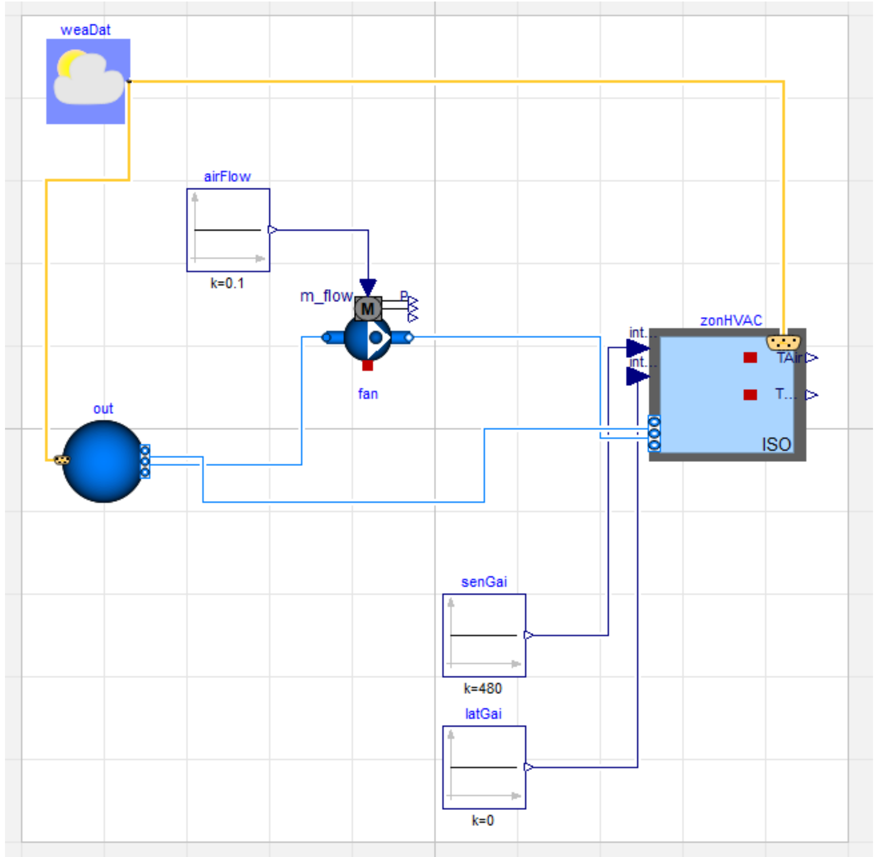
Let’s add a fan and blow some outdoor air into the room

SESSION 8/9 – The ISO13790 thermal zone model

STEP 2: Create a simple ventilation system to cool down our room

1. Duplicate Experiment1 and create a new model called **Experiment2** inside Experiments
2. In Experiment2, add the following models:
    - `Buildings.Fluid.Movers.FlowControlled_m_flow (1)`
    - `Modelica.Blocks.Sources.Constant (1)`
    - `Buildings.Fluid.Sources.Outside (1)`
3. Connect the components according to the figure
4. Assign the following values to the parameters:

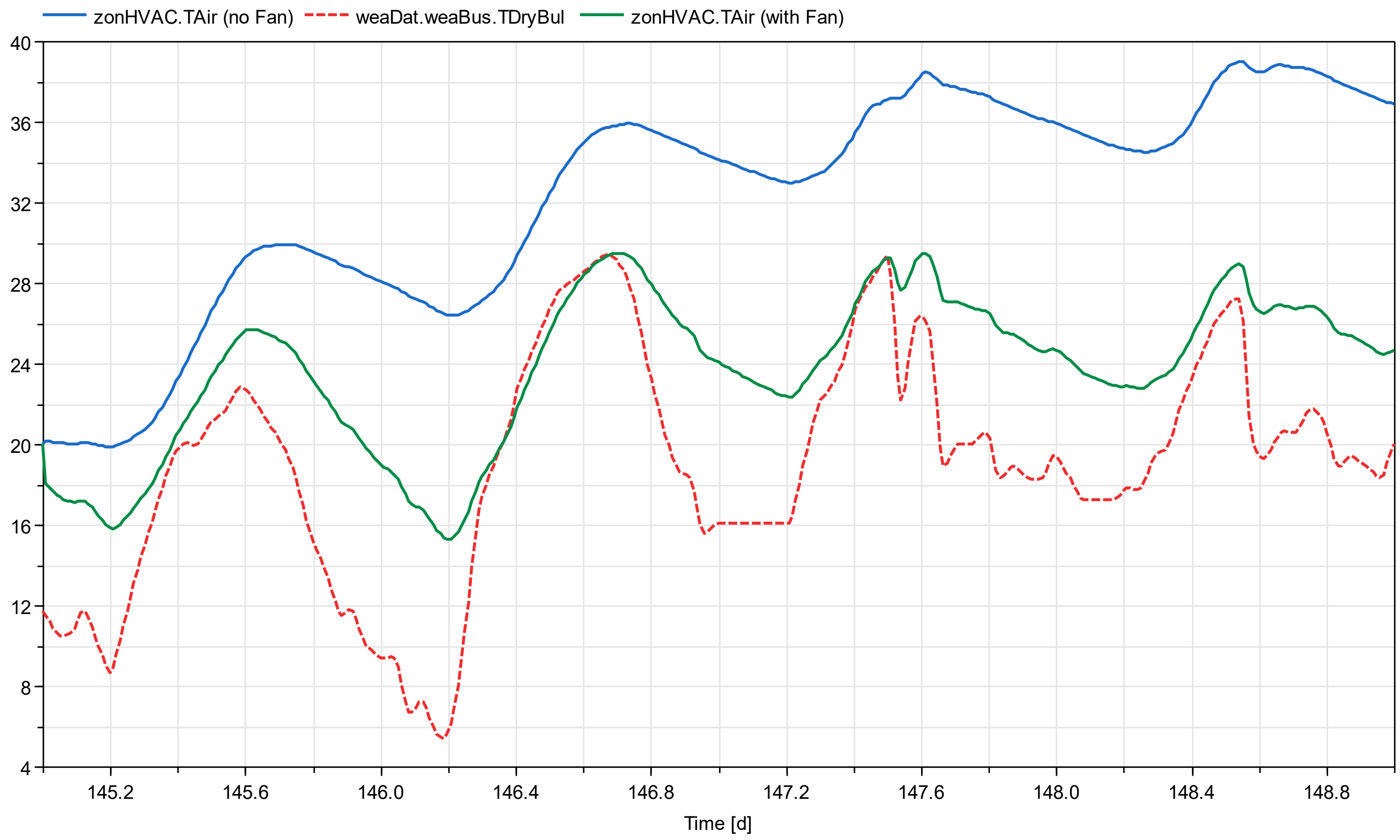
Component	Parameter	Value
airFlow	k	0.1
Out	Medium	Air
fan	Medium	Air
	AddPowerToMedium	False
	m_flow_nominal	0.1



5. Simulate the model for 4 days (from day 145 to149)
6. Plot the (new) room air temperature and compare with the previous results (with no fan).

SESSION 8/9 – The ISO13790 thermal zone model

Results – Experiment2



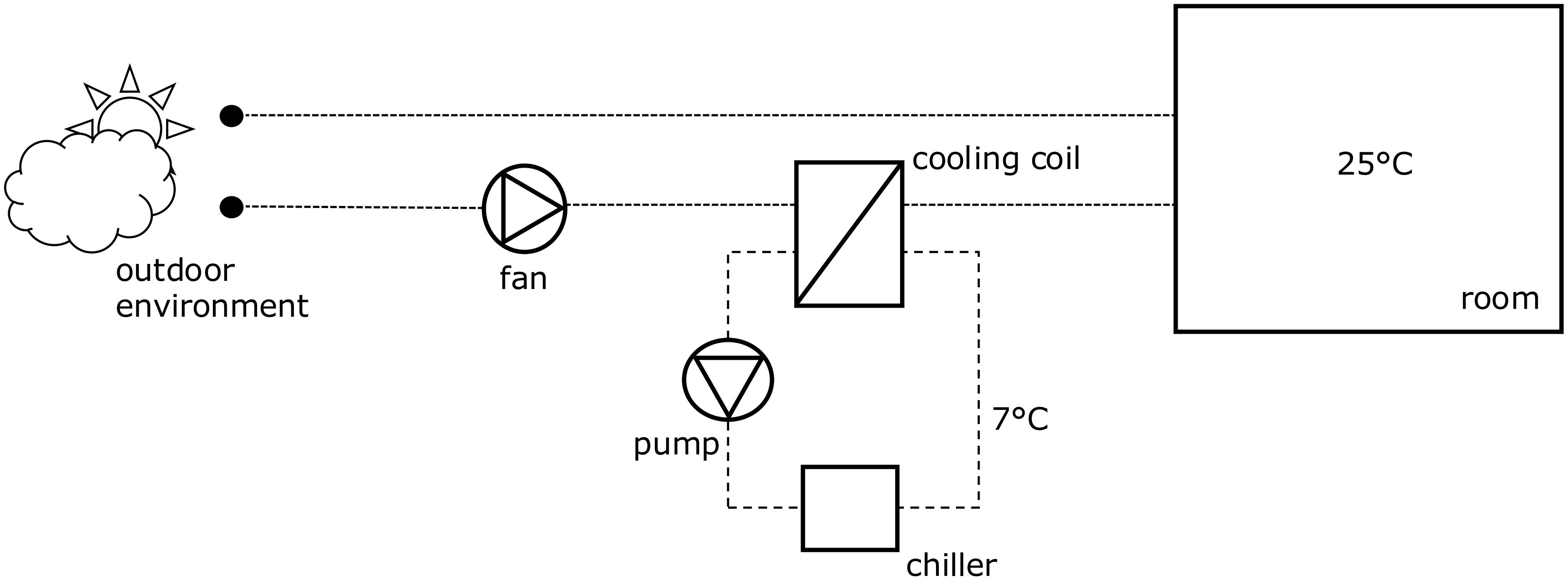
We managed to cool down our room, but the peak temperature reaches around 30°C…

Let's add a cooling system!

SESSION 8/9 – Cooling system

STEP 3: To build a more detailed cooling system

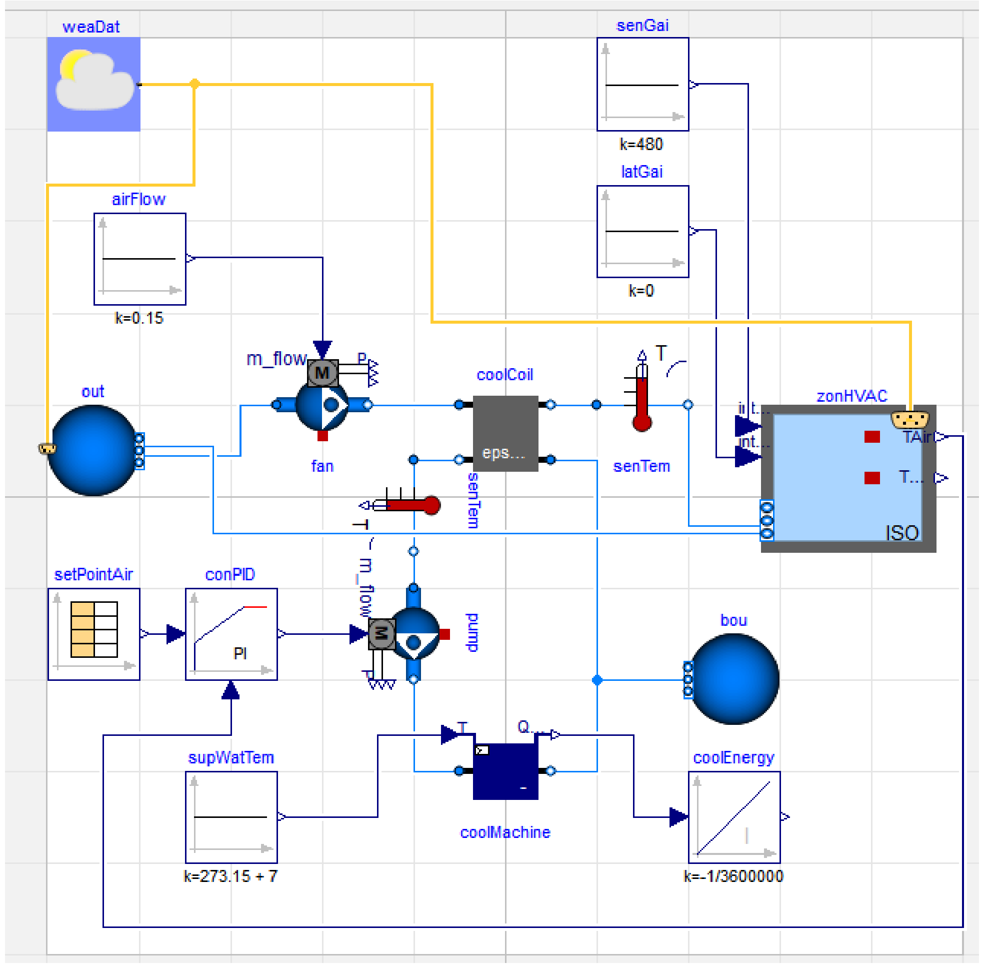
In this part, you will:
1. Implement a cooling system model that includes a fan, cooling coil, ideal chiller and a thermostat control to maintain the room air temperature according to a set-point
2. Make a more realistic chiller model based on COP curve
3. Adjust the room air temperature set-point to simulate a demand-response event and compare the cooling power profile to the case without the demand-response event.
4. (optional) Add a heating system that keeps room temperature above 20°C



SESSION 8/9 – Cooling system

STEP 3: To build a more detailed cooling system

1. Duplicate Experiment2 create a new model **Experiment3**. Drag and drop the following models:
    - `Modelica.Blocks.Sources.Constant (1)`
    - `Buildings.Fluid.HeatExchangers.SensibleCooler_T (1)`
    - `Buildings.Controls.Continuous.LimPID (1)`
    - `Modelica.Blocks.Sources.CombiTimeTable (1)`
    - `Buildings.Fluid.Sensors.TemperatureTwoPort (2)`
    - `Buildings.Fluid.HeatExchangers.ConstantEffectiveness (1)`
    - `Buildings.Fluid.Movers.FlowControlled_m_flow (1)`
    - `Buildings.Fluid.Sources.Boundary_pT (1)`
    - `Modelica.Blocks.Continuous.Integrator (1)`



2. Connect the components according to the figure
3. Assign values to parameters according to the tables in the next slides
4. Simulate the model from day 145 to day 149
5. Plot the room air temperature
6. How much energy is used by the cooling system?

`Buildings.Fluid.HeatExchangers.ConstantEffectiveness`

Parameter name	value
Medium1	Moist air
Medium2	Water
eps	0.8
m1_flow_nominal	0.15
m2_flow_nominal	0.15
dp1_nominal	0
dp2_nominal	0

`Buildings.Fluid.Sensors.TemperatureTwoPort` (in the air circuit)

Parameter name	value
Medium	Moist air
m_flow_nominal	0.15

`Buildings.Fluid.Sensors.TemperatureTwoPort` (in the water circuit)

Parameter name	value
Medium	Water
m_flow_nominal	0.15

`Buildings.Controls.Continuous.LimPID`

Parameter name	value
Controller type	PI controller
k	0.1
Ti	120
yMax	2
reserveActing	Deselected

`Buildings.Fluid.HeatExchangers.SensibleCooler_T`

Parameter name	value
Medium	Water
Qmin_flow	-2800
m_flow_nominal	0.15
dp_nominal	0

`Modelica.Blocks.Sources.CombiTimeTable`

Parameter name	value
table	[0,273.15+25]
smoothness	ConstantSegments
extrapolation	HoldLastPoint

`Buildings.Fluid.Sources.Boundary_pT`

Parameter name	value
Medium	Water

`Buildings.Fluid.Movers.FlowControlled_m_flow`

Parameter name	value
addPowerToMedium	Deselected
nominalValuesDefineDefaultPressureCurve	Selected
m_flow_nominal	0.15

`Modelica.Blocks.Continuous.Integrator`

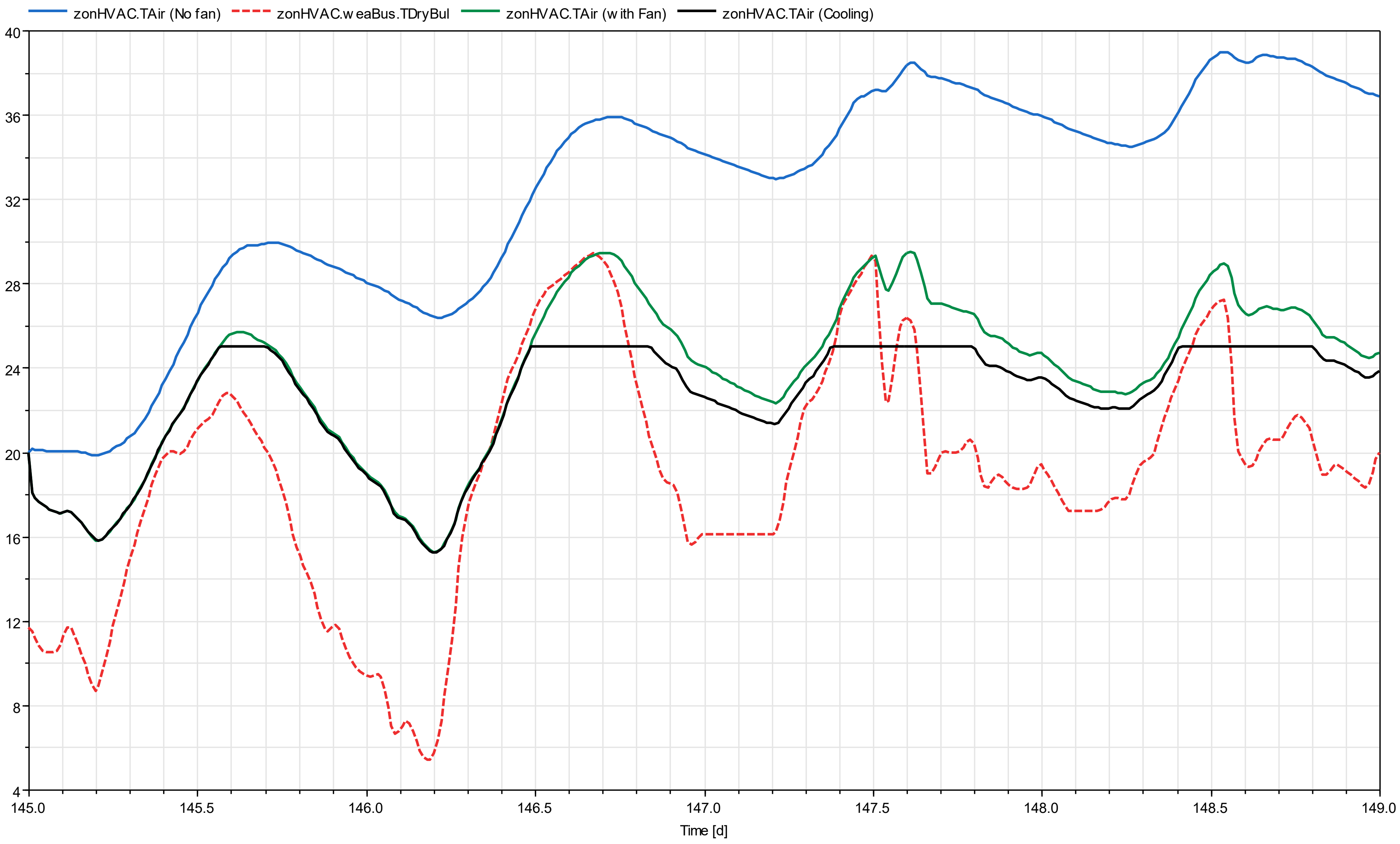
Conversion from Joule to kWh

Parameter name	value
k	-1/3600000

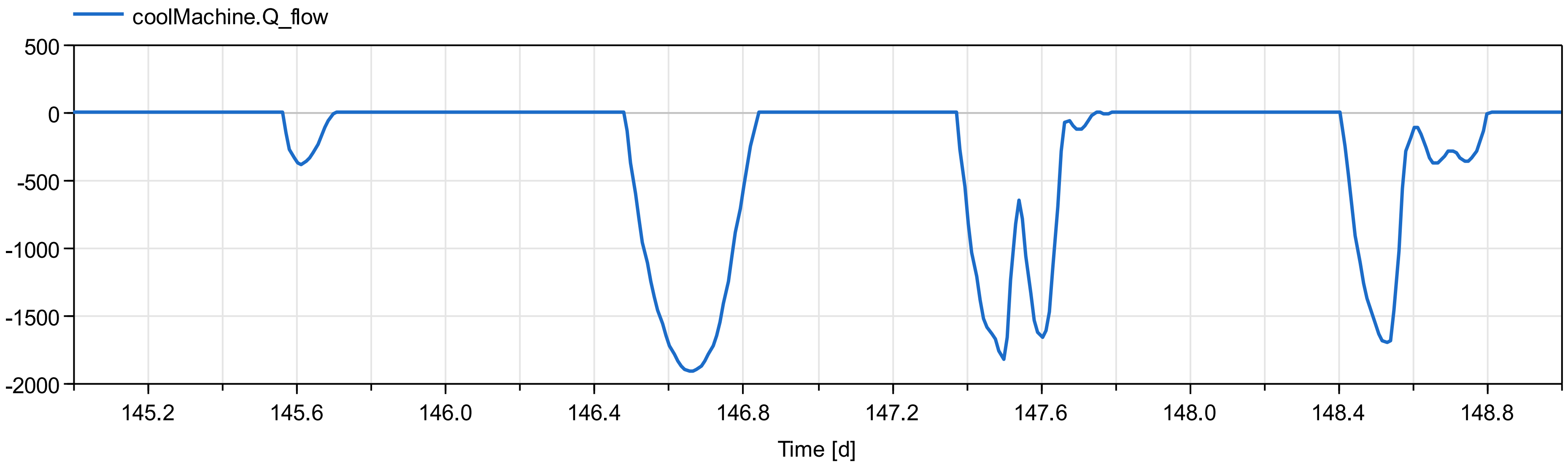
SESSION 8/9 – Cooling system

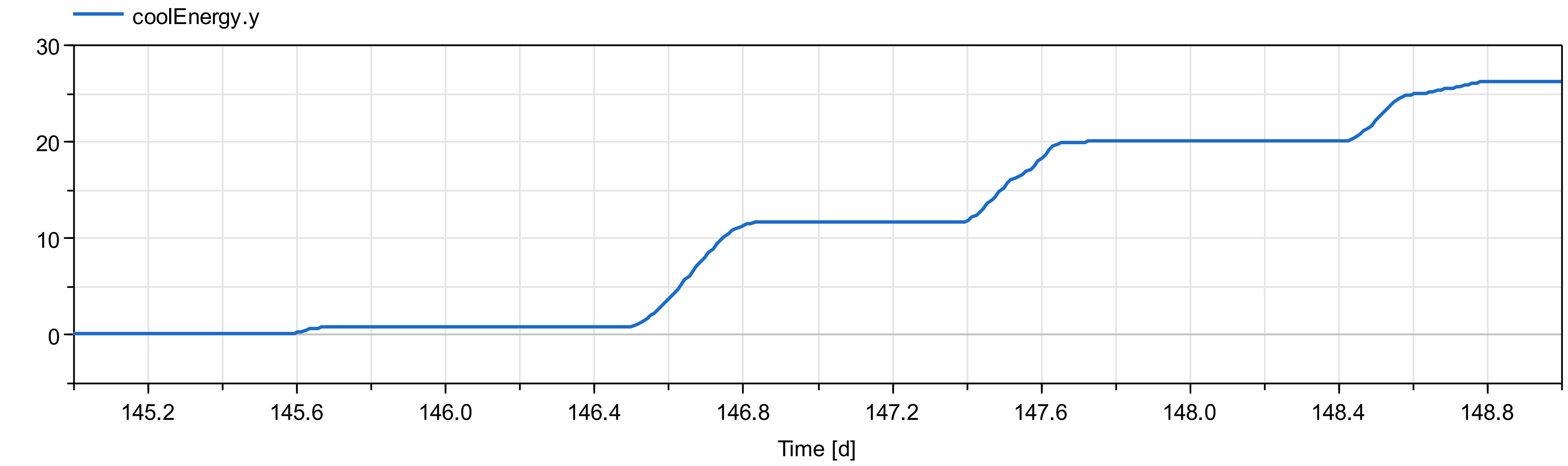
Conversion from
Joule to kWh

SESSION 8/9 – Cooling system



SESSION 8/9 – Cooling system





The system uses around 26 kWh for cooling

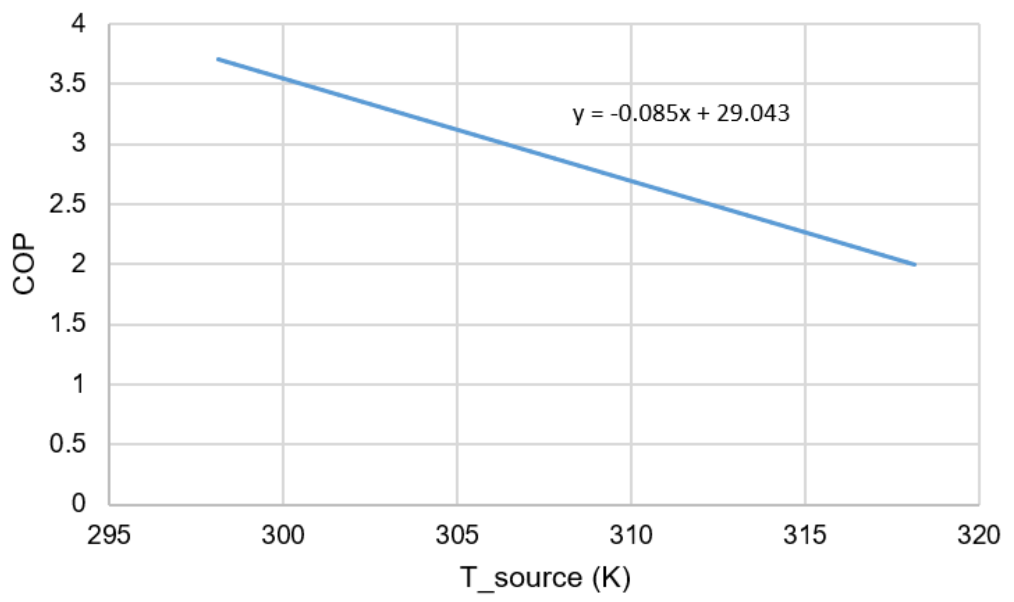
SESSION 8/9 – Cooling system

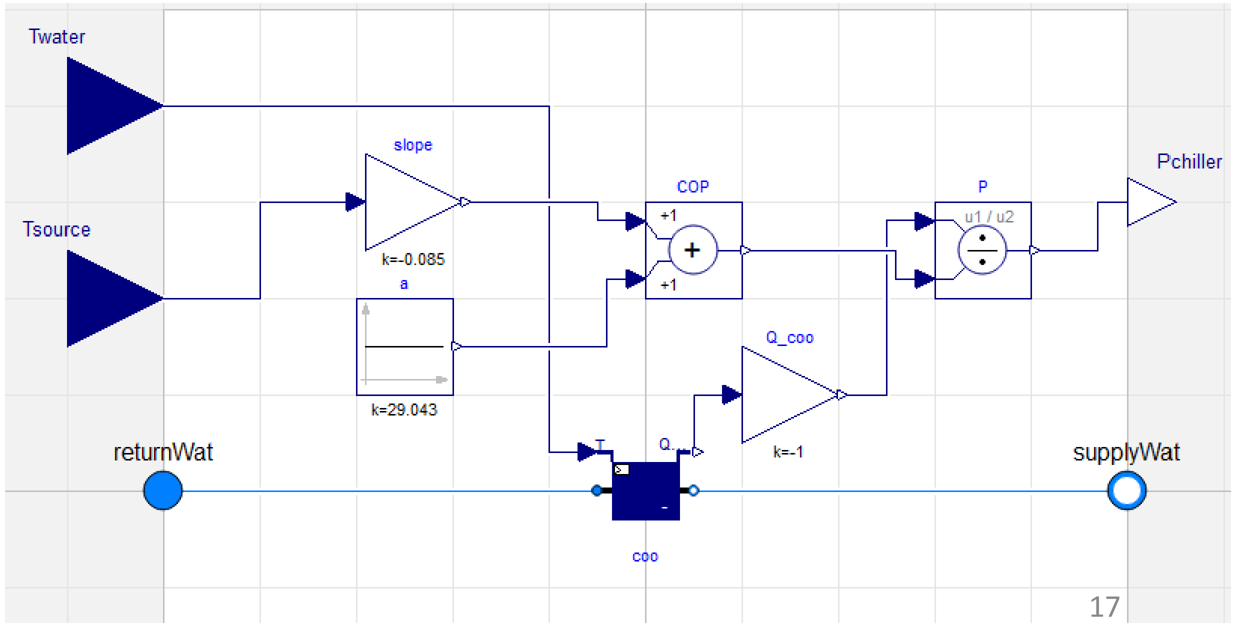
STEP 4: Let's transform our ideal cooling machine into an electrical chiller. Let's use a simple COP curve.

1. Create a new package **Components** and a model **Chiller**
2. Drag and drop the following models:
   - `Modelica.Blocks.Sources.Constant (1)`
   - `Buildings.Fluid.HeatExchangers.SensibleCooler_T (1)`
   - `Modelica.Blocks.Interfaces.RealOutput (1)`
   - `Modelica.Blocks.Interfaces.RealInput (2)`
   - `Modelica.Fluid.Interfaces.FluidPort_a (1)`
   - `Modelica.Fluid.Interfaces.FluidPort_b (1)`
   - `Modelica.Blocks.Math.Gain (2)`
   - `Modelica.Blocks.Math.Add (1)`
   - `Modelica.Blocks.Math.Division (1)`
3. Connect the components according to the figure
4. Assign values to parameters

Component	Parameter	Value
slope	k	-0.085
a	k	29.043
Q_coo	k	-1
coo (same as before)		
supplyWat	Medium	water
returnWat	Medium	water

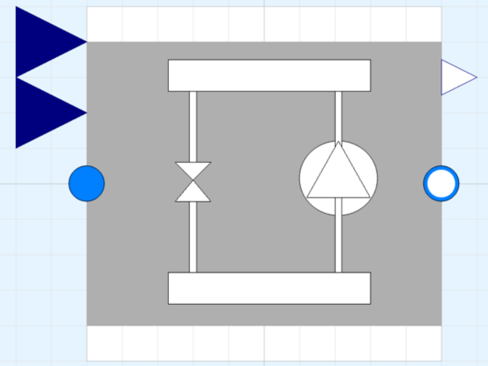
Tsup,water = 7°C



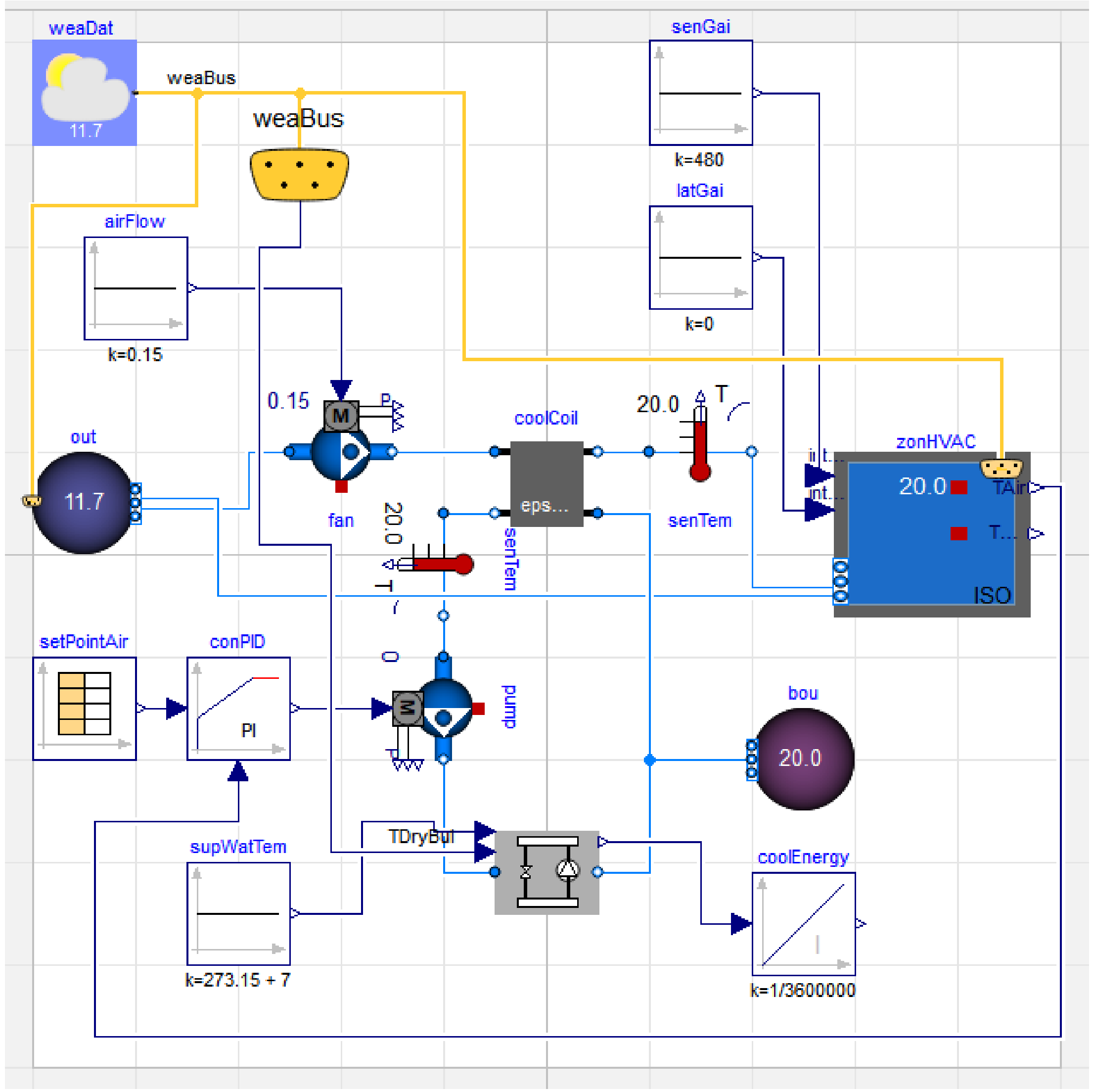


SESSION 8/9 – Cooling system

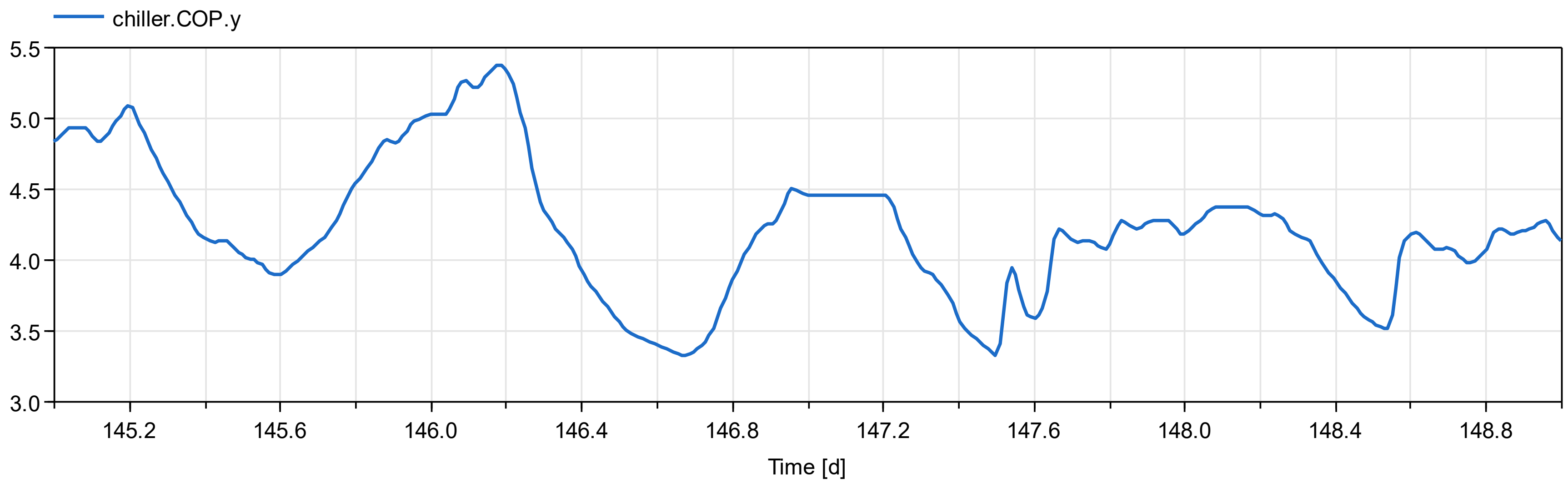
5. Go to icon view and draw a simple icon of a chiller

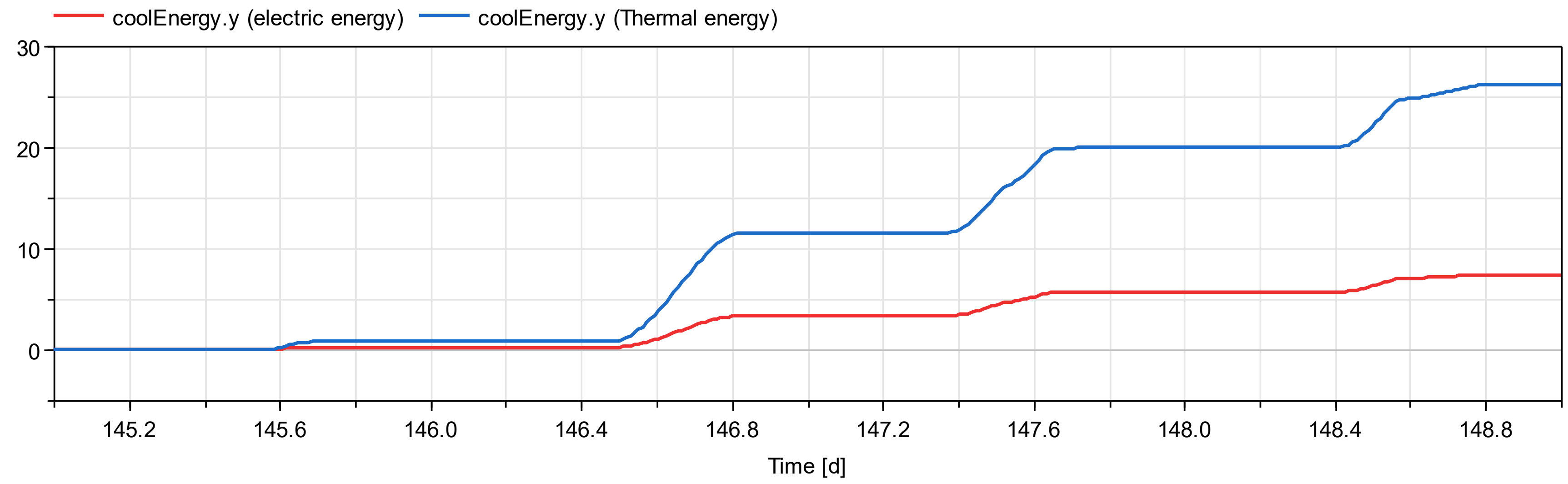


6. Duplicate Experiment3 and create a new model **Experiment4**
7. Replace the ideal cooling machine with the chiller
8. Add *Buildings.BoundaryConditions.WeatherData.Bus*
9. Connect the components according to the figure.
10. Note that the *Tsource* is outside air temperature
11. Simulate the model from Day 145 to 149 and plot the
12. electric power and COP



SESSION 8/9 – Cooling system



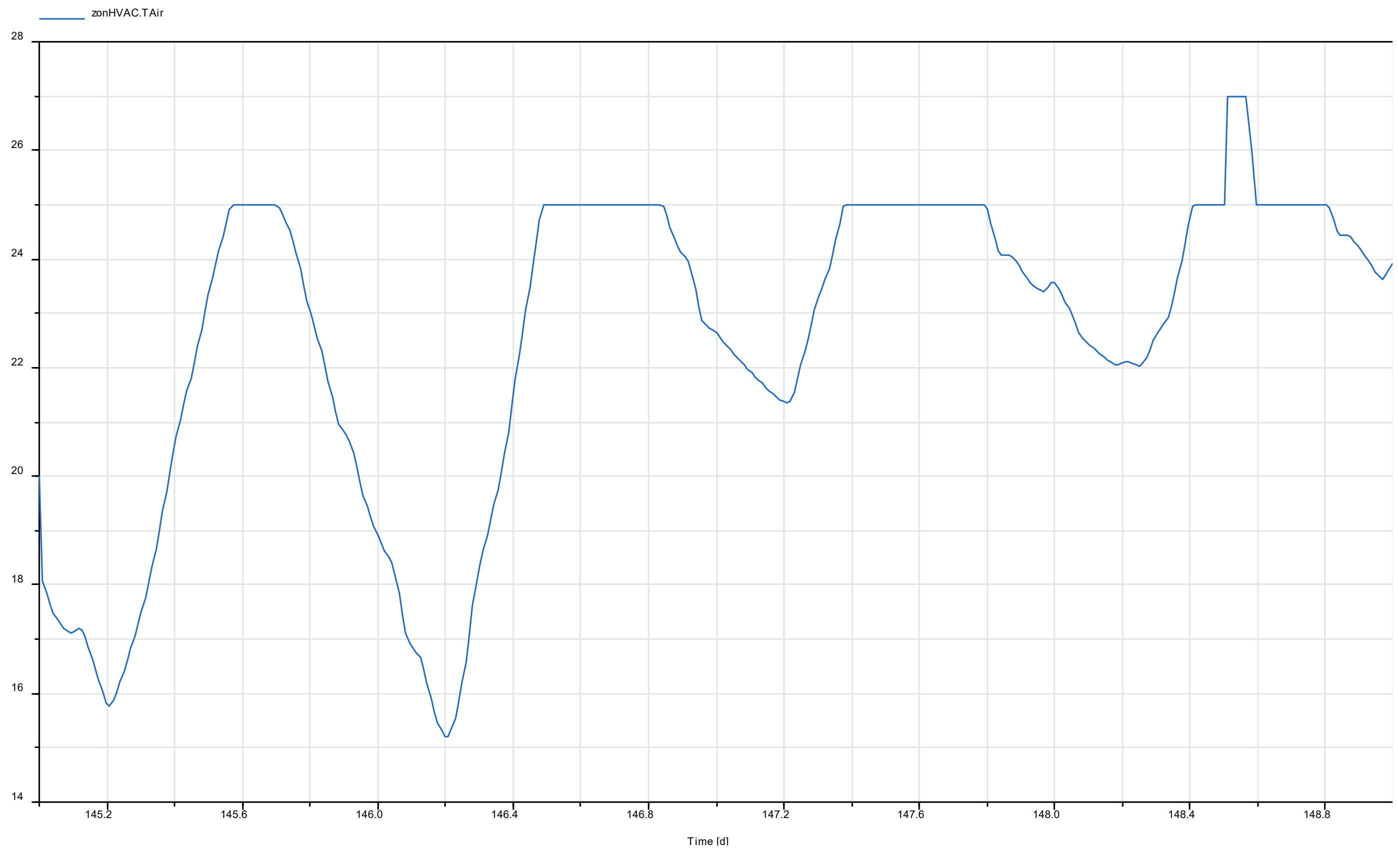


SESSION 8/9 – Cooling system

Demand-response event

- Cooling set point = 27 degC

between 12:00-14:00 on Day 148



OPTIONAL exercise (if you have time…) Add a heating system to keep indoor air temperature within 20 degC and 25 degC at any time. Use the radiator model previsouly developed and a PI controller