AES_Project_2021_2022

Politecnico di Milano

Automation and Control Engineering

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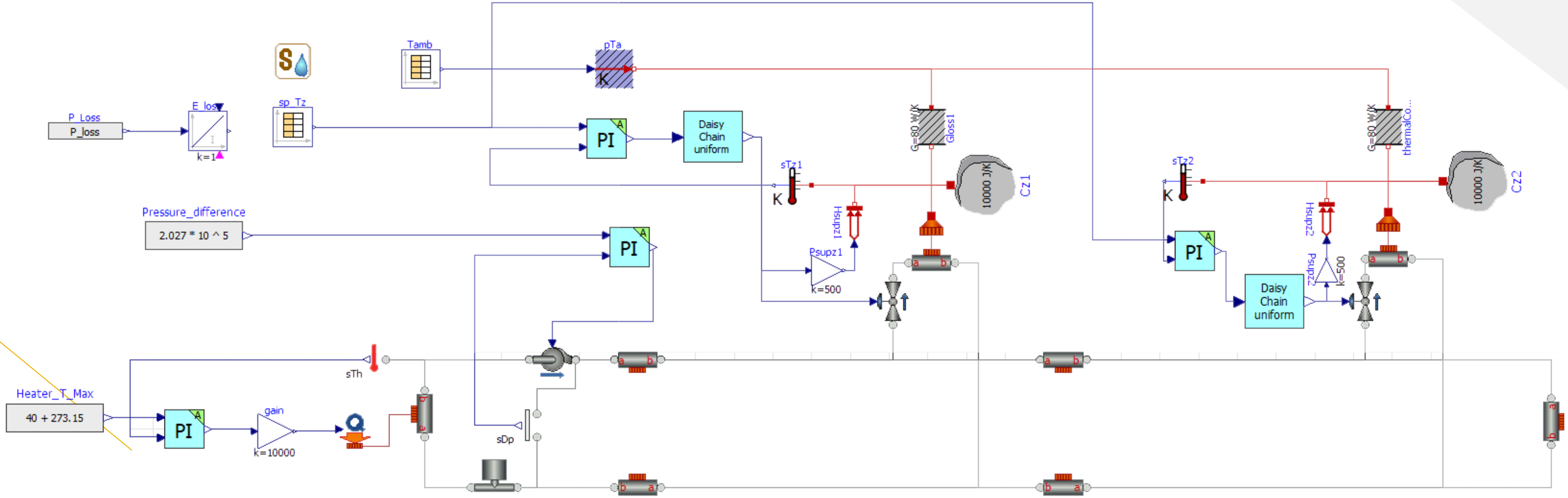
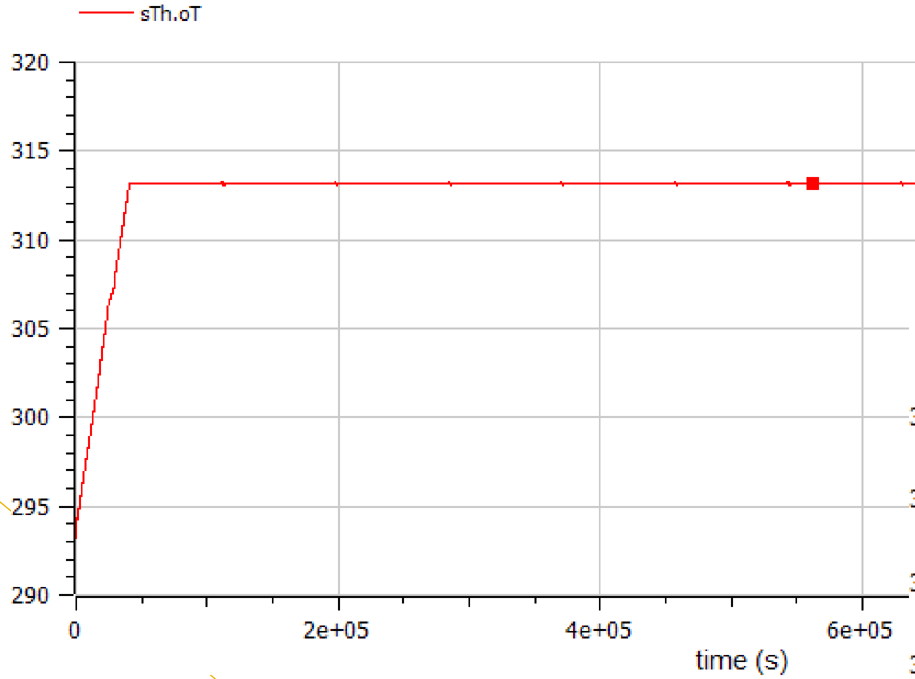
Controlled system

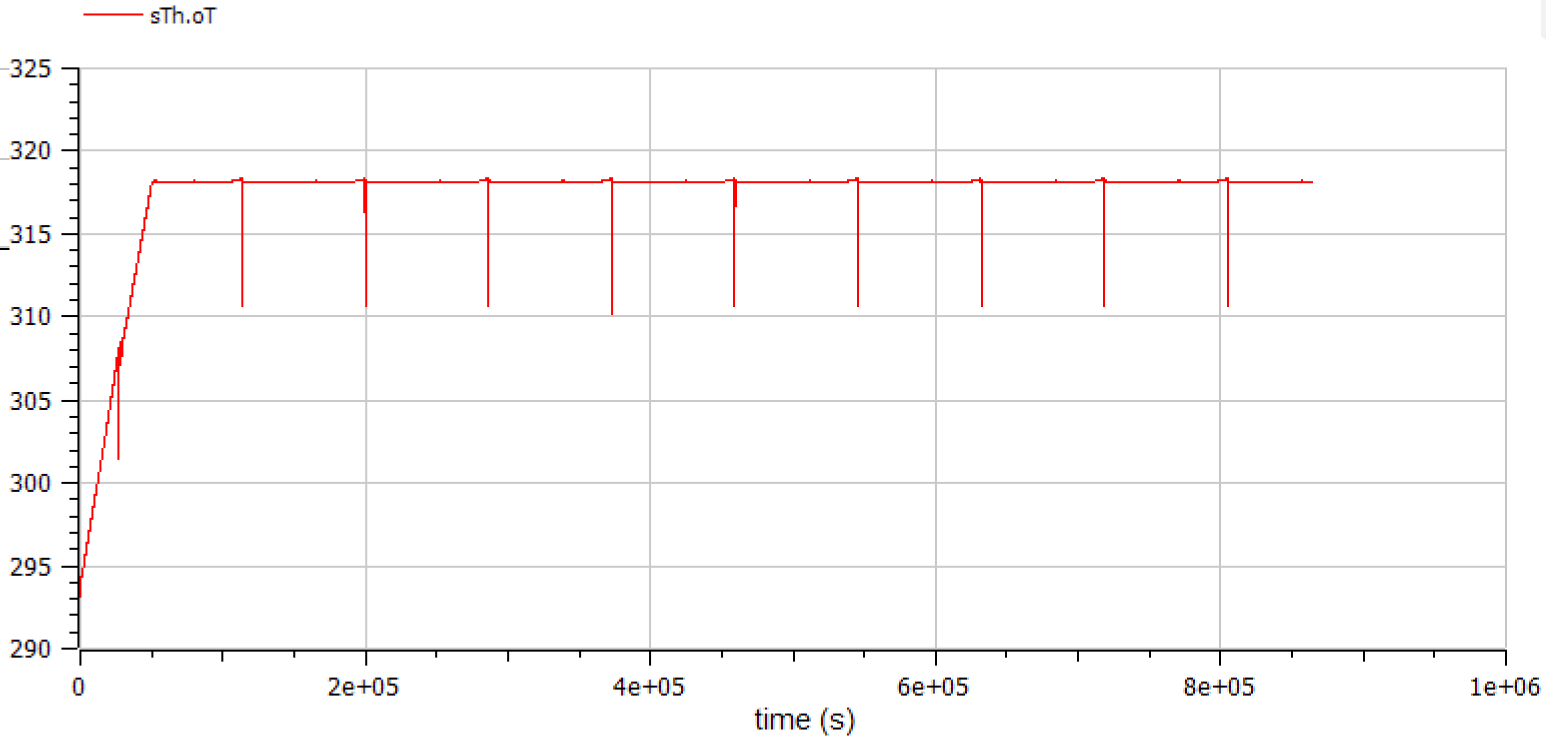


Heater model and tracking

- Energy balance $c\rho V\dot{T}_h = K_h u + wc(T_c - T_h)$ → $T_h(s) = \frac{K_h/cw}{1+s\frac{\rho V}{w}} \cdot u + \frac{T_c}{1+s\frac{\rho V}{w}}$
- V: total volume of water in the network, $w_n = 0.5\frac{kg}{s}$ nominal flow rate
- Select experimentally a wc → wc $= 0{,}008\ rad/s$ (good tradeoff)
- $Ti = 4{,}7517 \cdot 10^3$
- $K = 8{,}287$

Heater Temperature

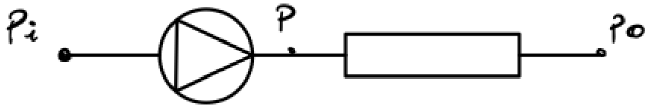


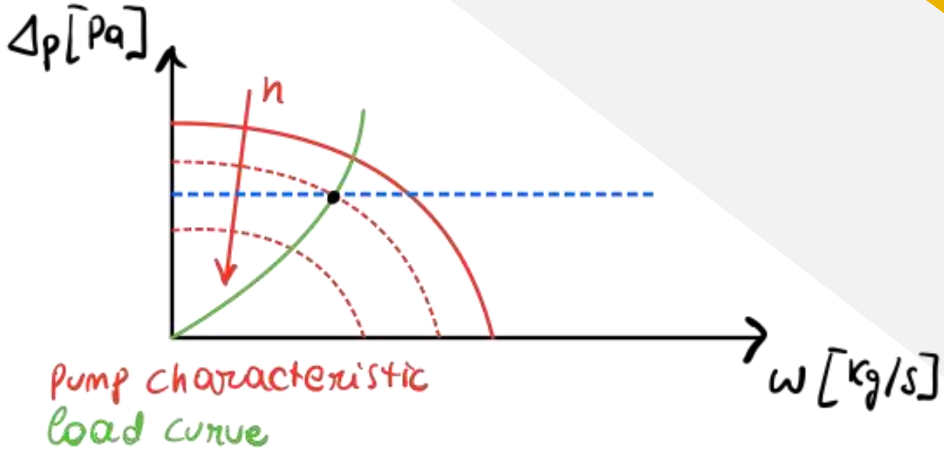


Pump model

- Pump: $\Delta \mathrm{p} = H_0(\mathrm{n}) - H_1(n)w^2 \rightarrow \Delta \mathrm{p} = 6 \cdot 10^3 n - 666{,}7nw^2$
- Pipe Network : $\Delta \mathrm{p} = K_L \rho w^2 \rightarrow \Delta \mathrm{p} = 4 \cdot 10^7\, w^2$
- Flow rate assumed equal in the whole network → Assumption

$$\begin{cases} p - p_i = 6 \cdot 10^5\, n - 666{,}7 \cdot n w^2 \\ p - p_o = 4 \cdot 10^7\, w^2 \end{cases}$$





- EQUILIBRIUM
  - Compute the equilibrium point for n, by imposing Δp = $2{,}027 \cdot 10^5\, Pa \rightarrow \bar{n} = 0.338$

Pump Model

- Linearization

$$\Delta p = \frac{6 \cdot 10^5 n}{1 + \frac{666{,}7}{4 \cdot 10^7} n} = \frac{24 \cdot 10^{12} n}{4 \cdot 10^7 + 666{,}7 n} = \frac{a n}{b + c n}$$

$a = 24 \cdot 10^{12}$
$b = 4 \cdot 10^7$
$c = 666{,}7$

$$\delta p = \left. \frac{a(b+cn) - anc}{(b+cn)^2} \right|_{\bar{n}} \delta n = \frac{a(b+c\bar{n}) - a\bar{n}c}{(b+c\bar{n})^2} \delta n \Rightarrow \delta p \simeq 6e5\, \delta n$$

«Albegraic model» → Hydraulics dynamics much faster than temperature, can be neglected

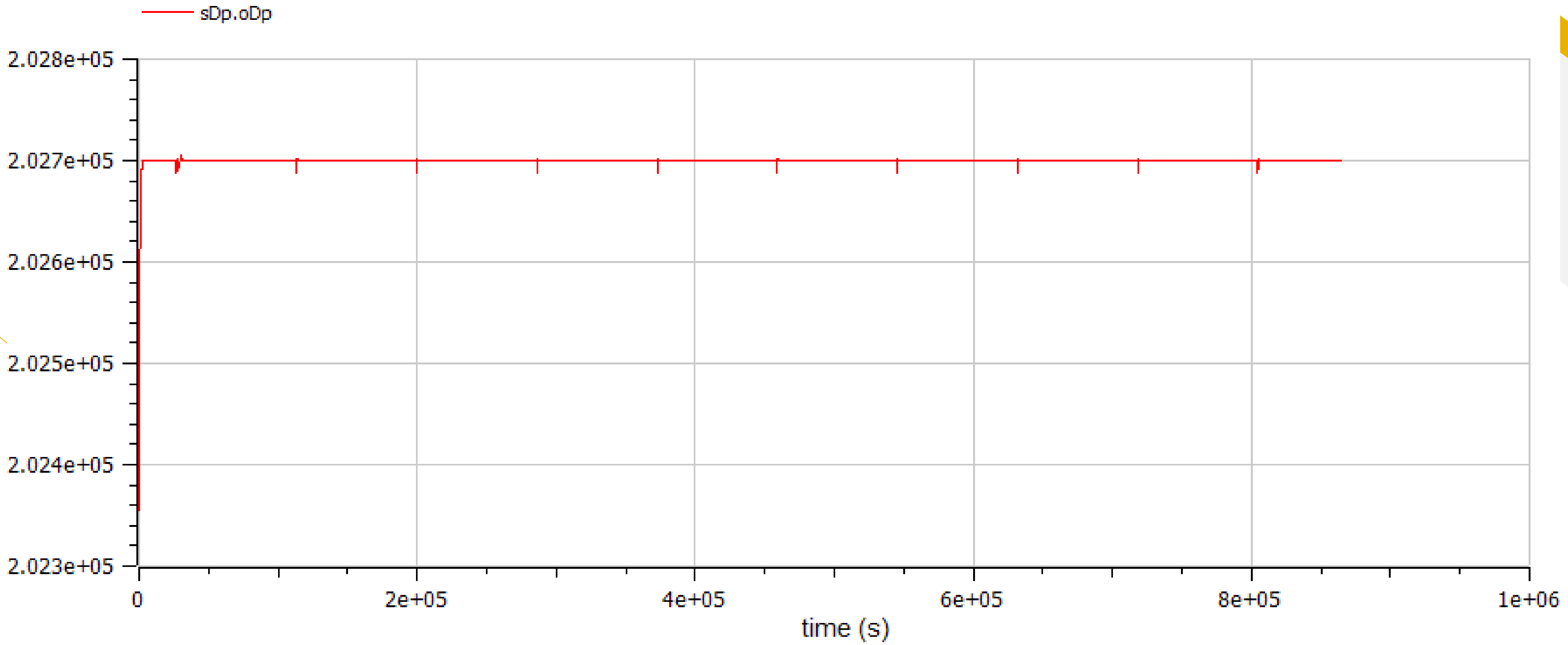
(in reality: $G(s) = \frac{\mu}{1+s\tau}$ with τ very small)

Use a PI = $\frac{K(1+sTi)}{sTi}$ → $L(s) = \frac{k_L*(1+sTi)}{s(1+s\tau)}$ → dominant closed loop pole at 1/Ti

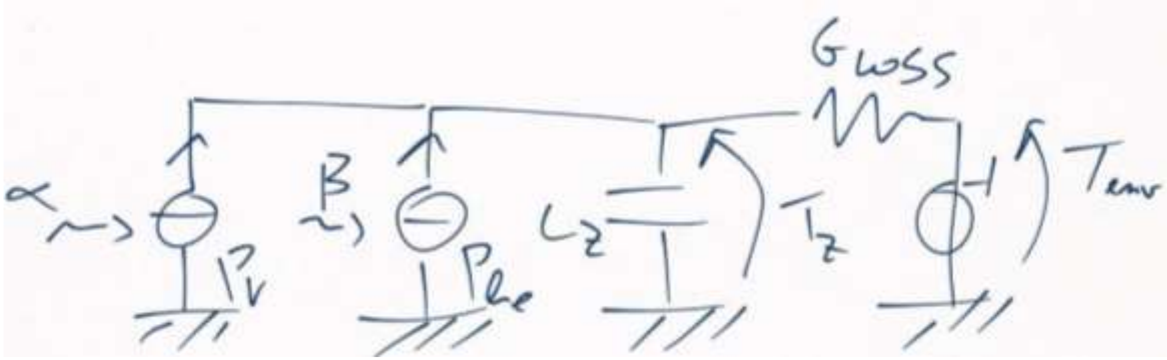
Design choices: Ta = 2500s → Ti = 500s (system settles quickly)

K = 0,001 (to reduce oscillations)

Pump Control



Zones model



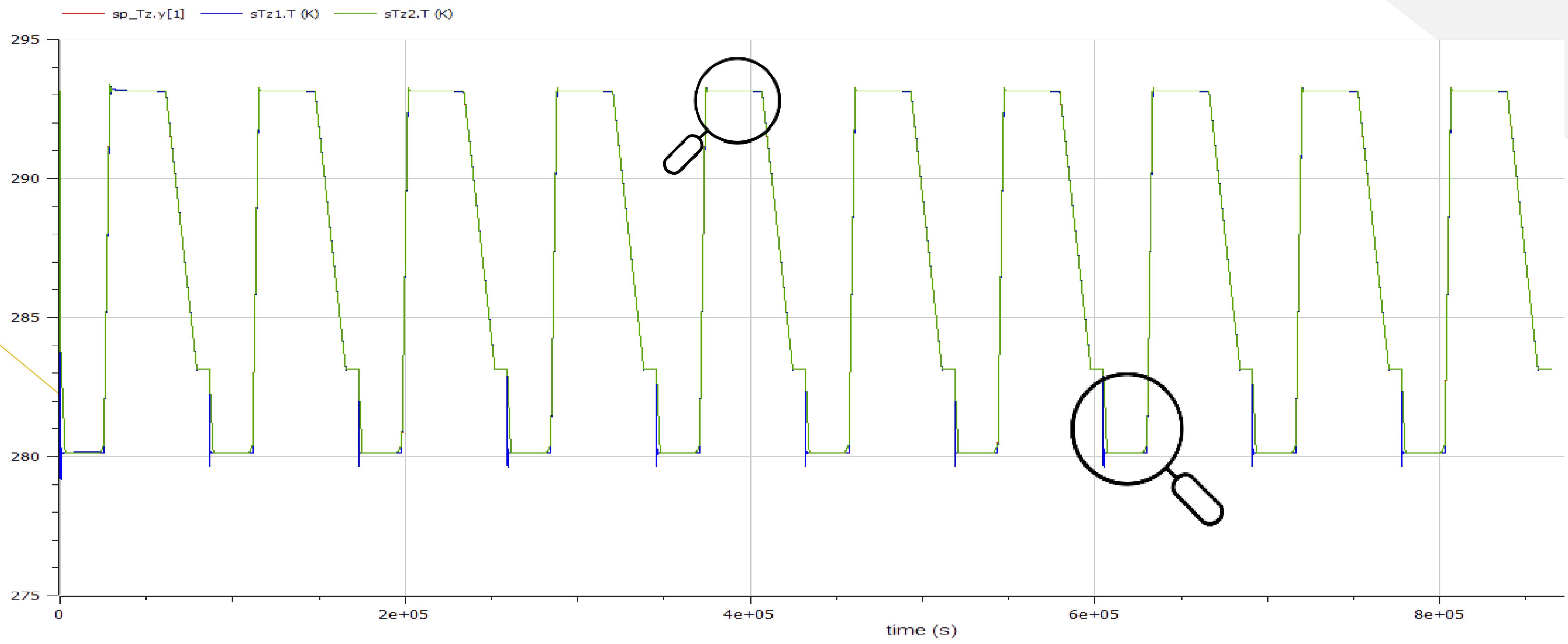
$$\begin{cases} \alpha \in [0,1] \\ \beta \in [0,1] \end{cases}$$

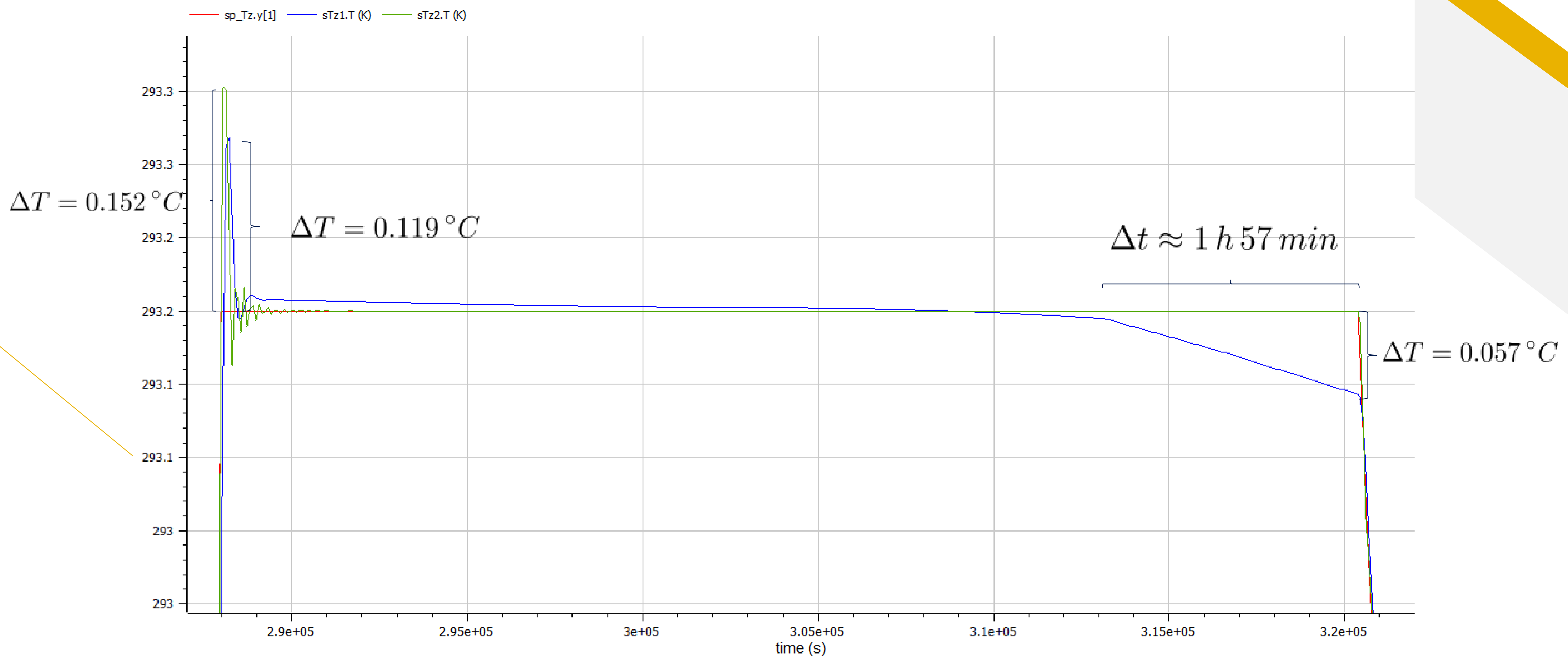
$$c_z \dot{T}_z = \beta K_{he} + \alpha G(T_{Grid} - T_z) - G_{Loss}(T_z - T_{env})$$

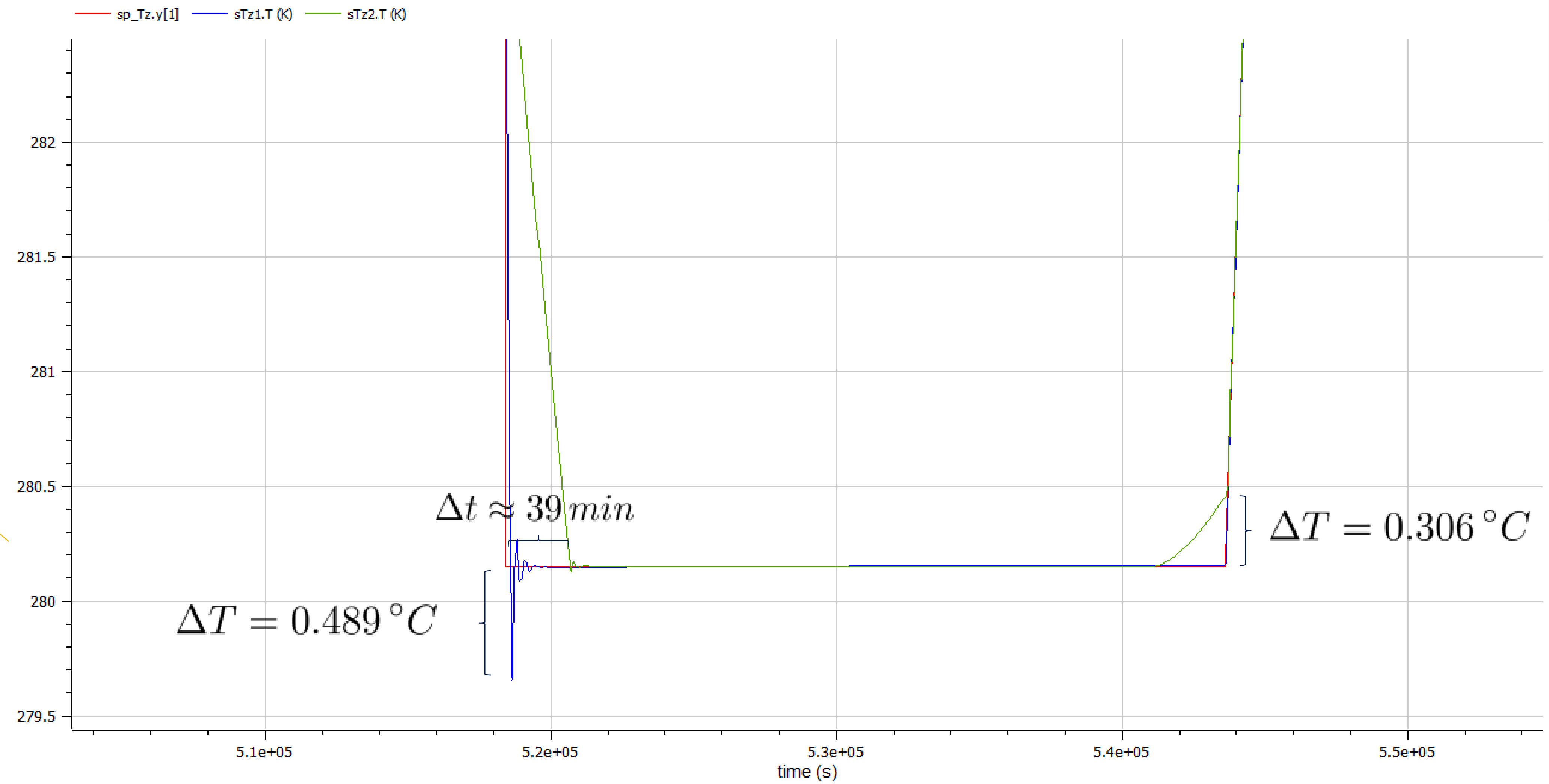
$$\begin{cases} \bar{\alpha} = 0.5 \\ \bar{\beta} = 0 \\ \bar{T}_z = \frac{\bar{\beta} K_{he} + \bar{\alpha} G T_{Grid} + G_{Loss} T_{env}}{\bar{\alpha} G + G_{loss}} \end{cases}$$

$$\delta \bar{T}_z = \left[-\frac{\bar{\alpha} G}{c_z} - \frac{G_{\text{Loss}}}{c_z} \right] \delta T_s + \left[\frac{G}{c_z} \left(T_{\text{Grid}} - \bar{T}_z \right) \; \frac{K_{\text{he}}}{c_z} \right] \begin{bmatrix} \delta\alpha \\ \delta\beta \end{bmatrix}$$

Zones set point tracking



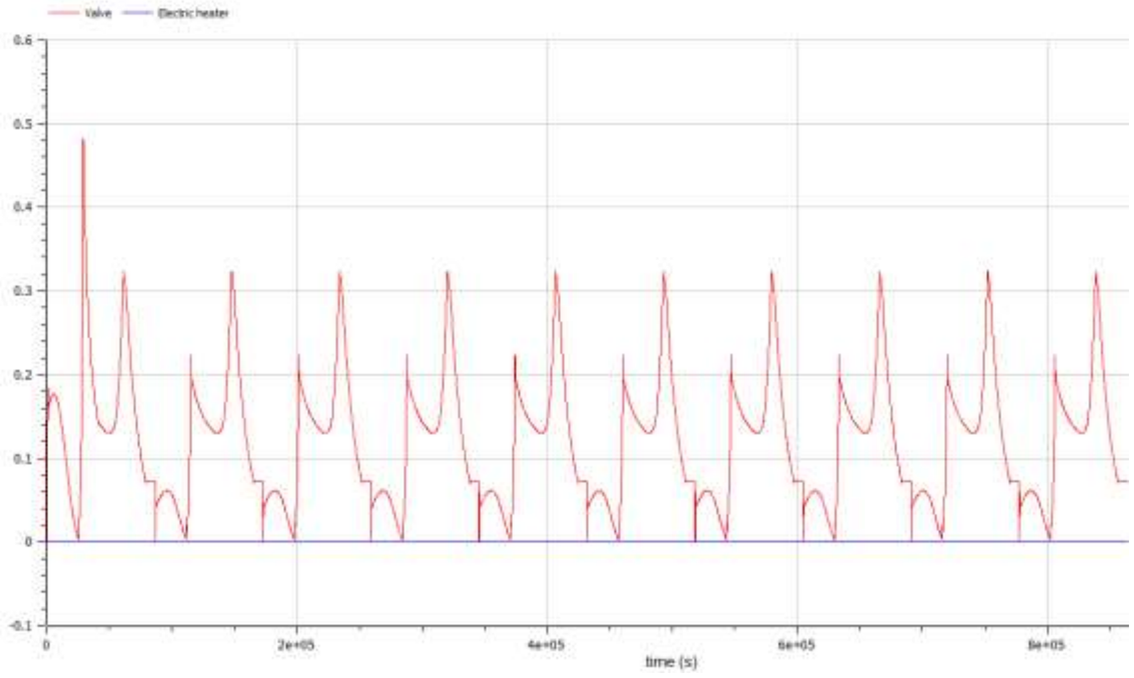

sp_Tz.y[1]
sTz1.T (K)
sTz2.T (K)
293.3
293.3
293.2
293.2
293.1
293.1
293
293
2.9e+05
2.95e+05
3e+05
3.05e+05
3.1e+05
3.15e+05
3.2e+05
time (s)
$\Delta T = 0.152\,^{\circ}C$
$\Delta T = 0.119\,^{\circ}C$
$\Delta t \approx 1\,h\,57\,min$
$\Delta T = 0.057\,^{\circ}C$

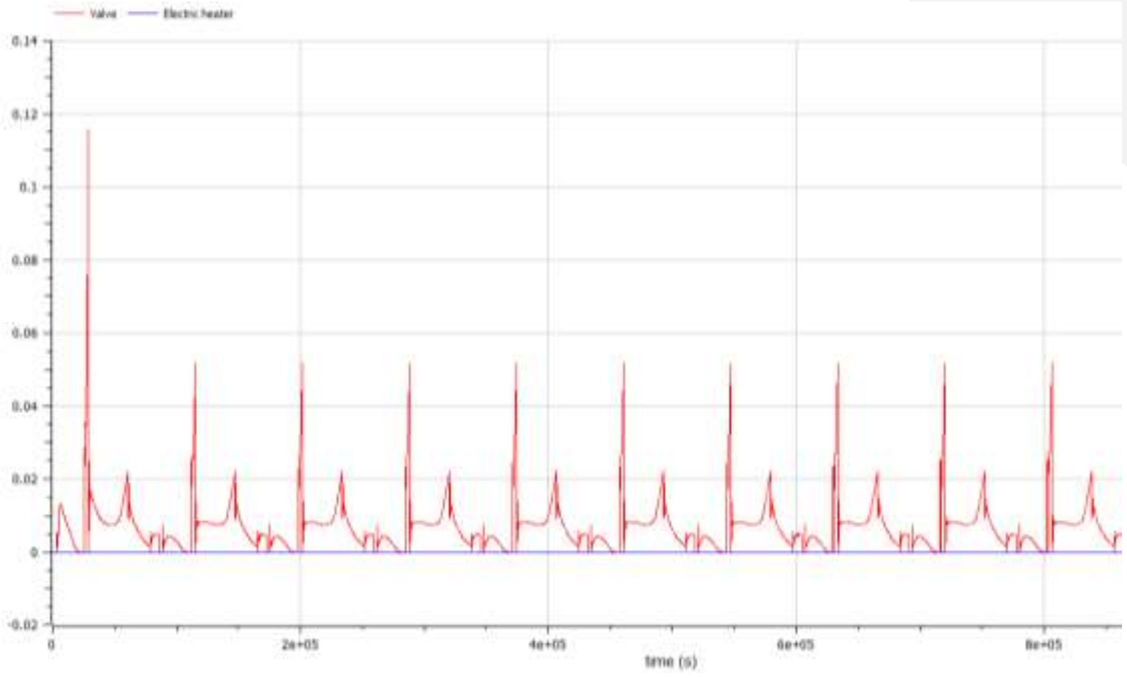


sp_Tz.y[1]
sTz1.T (K)
sTz2.T (K)
282
281.5
281
280.5
280
279.5
5.1e+05
5.2e+05
5.3e+05
5.4e+05
5.5e+05
time (s)
$\Delta t \approx 39\, min$
$\Delta T = 0.489\,^{\circ}C$
$\Delta T = 0.306\,^{\circ}C$

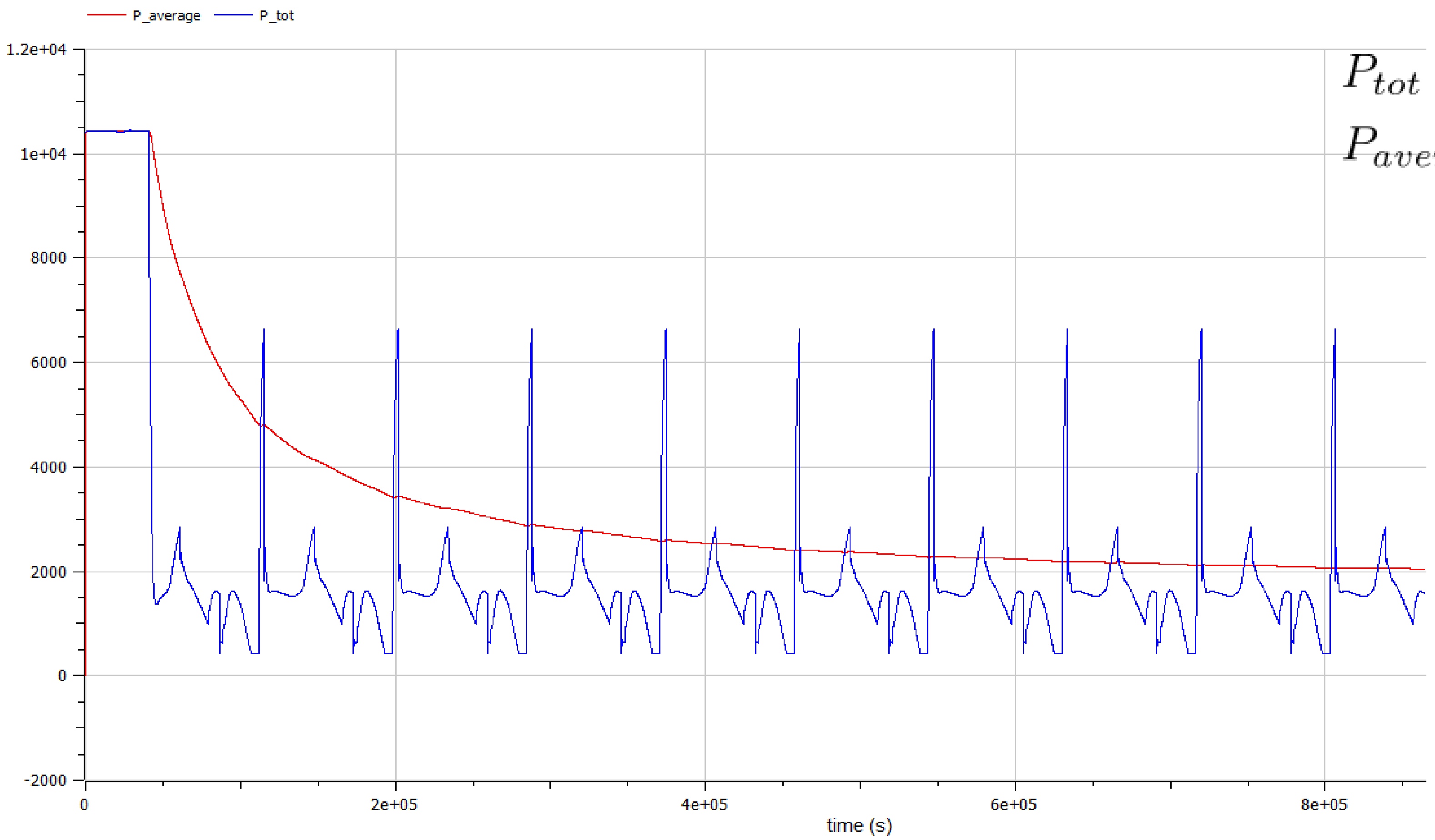
Control signals of each actuator

$$\begin{cases} \alpha \in [0,1] \\ \beta \in [0,1] \end{cases}$$





Power consumption

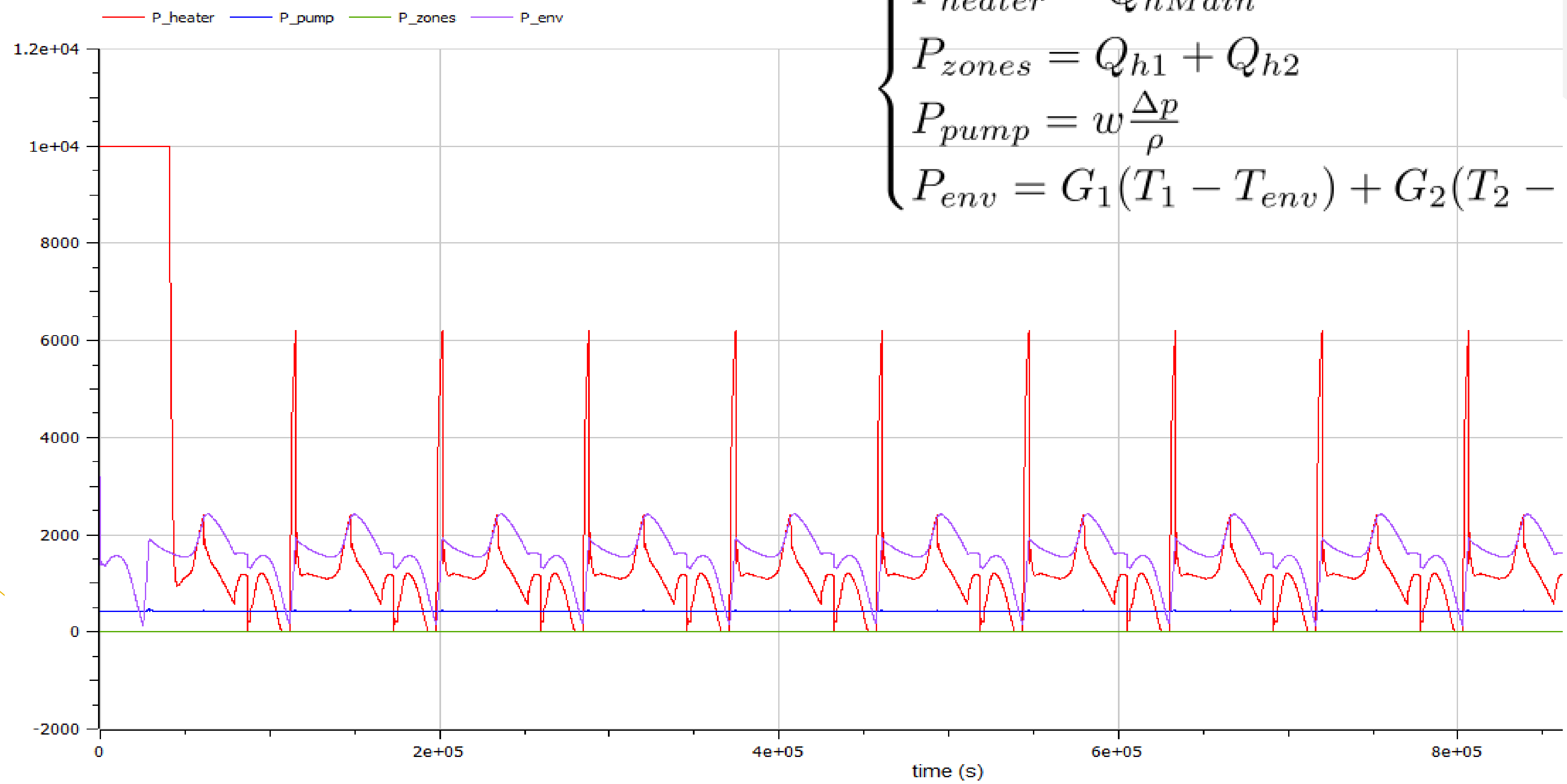


$$P_{tot} = P_{pump} + P_{heaters}$$

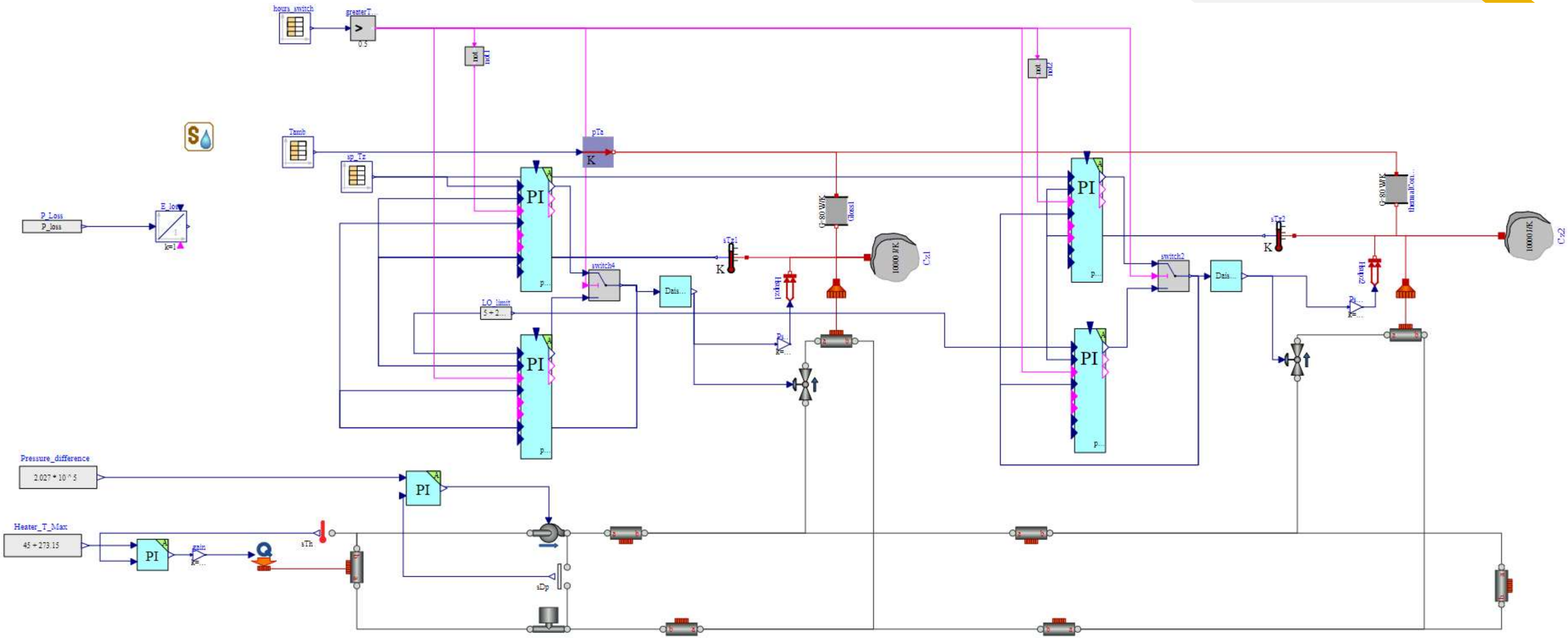
$$P_{average} \rightarrow 2043.9\ \mathrm{W}$$

Individual power consumptions

$$
\begin{cases}
P_{heater} = Q_{hMain} \\
P_{zones} = Q_{h1} + Q_{h2} \\
P_{pump} = w\frac{\Delta p}{\rho} \\
P_{env} = G_1(T_1 - T_{env}) + G_2(T_2 - T_{env})
\end{cases}
$$



Model with the implementation of Day-Night Control



Components of the logic switching system:

Componente

Nome: hours_switch

Class

Percorso: Modelica.Blocks.Sources.CombiTimeTable

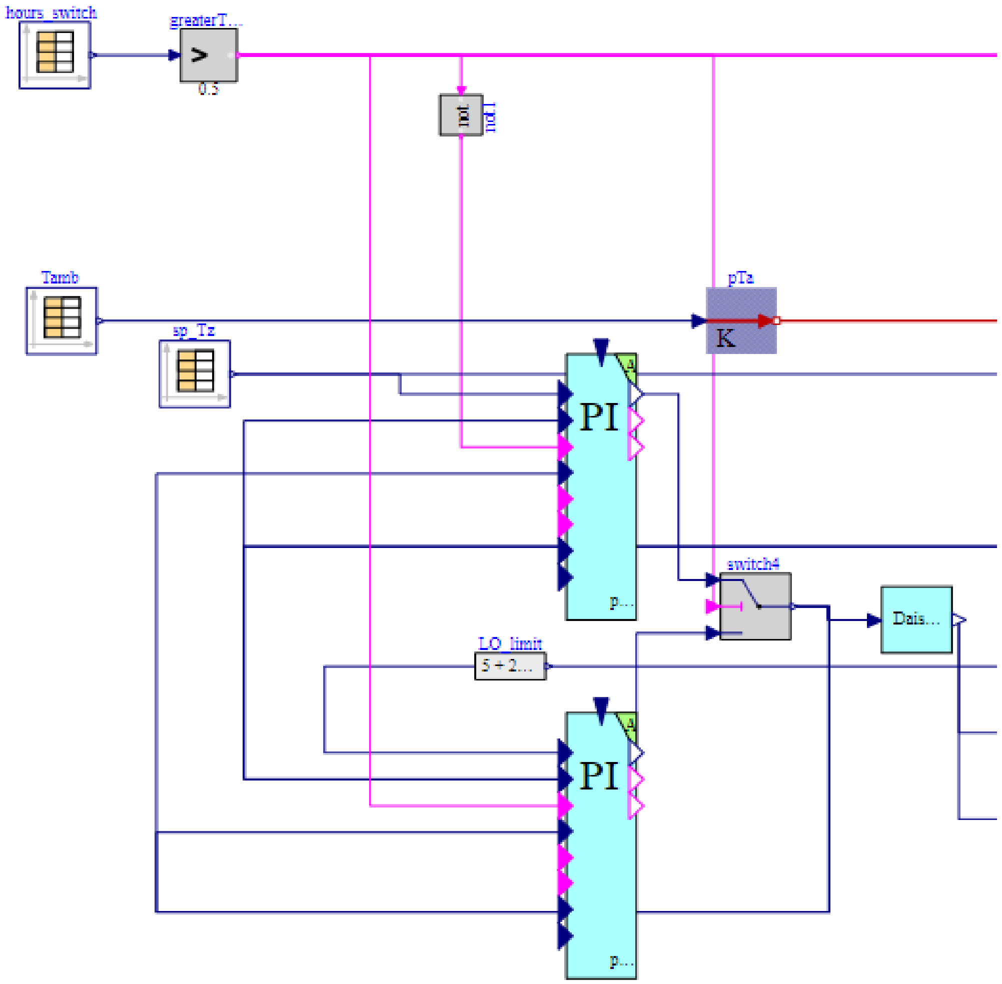
Commento: Table look-up with respect to time and linear/periodic extrapolation methods

Table data definition

tableOnFile	false
table	[0, 0; 7.5, 1; 22, 0; 24, 0]
tableName	"NoName"
fileName	"NoName"
verboseRead	true

Table data interpretation

columns	2:size(table, 2)	
smoothness	Modelica.Blocks.Types.Smoothness.ConstantSegments	
extrapolation	Modelica.Blocks.Types.Extrapolation.Periodic	
timeScale	3600	s
offset	{0}	
startTime	0	s
shiftTime	startTime	s
timeEvents	Modelica.Blocks.Types.TimeEvents.Always	
verboseExtrapolation	false	



Componente

Nome: pI_z1D

Class

Percorso: AES.ControlBlocks.AnalogueControllers.PI_awfb_full

Commento:

Parameters

K	0.07692
Ti	76.92

Componente

Nome: pI_z2D

Class

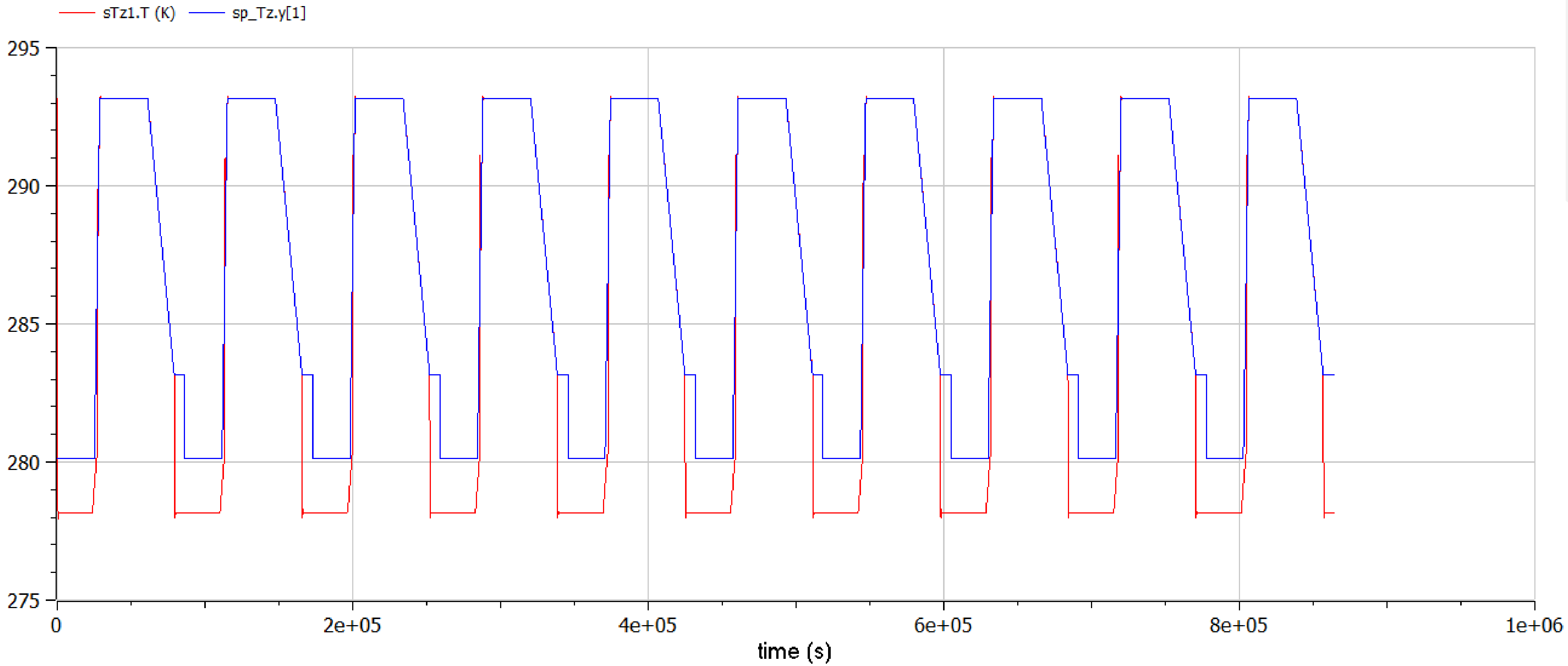
Percorso: AES.ControlBlocks.AnalogueControllers.PI_awfb_full

Commento:

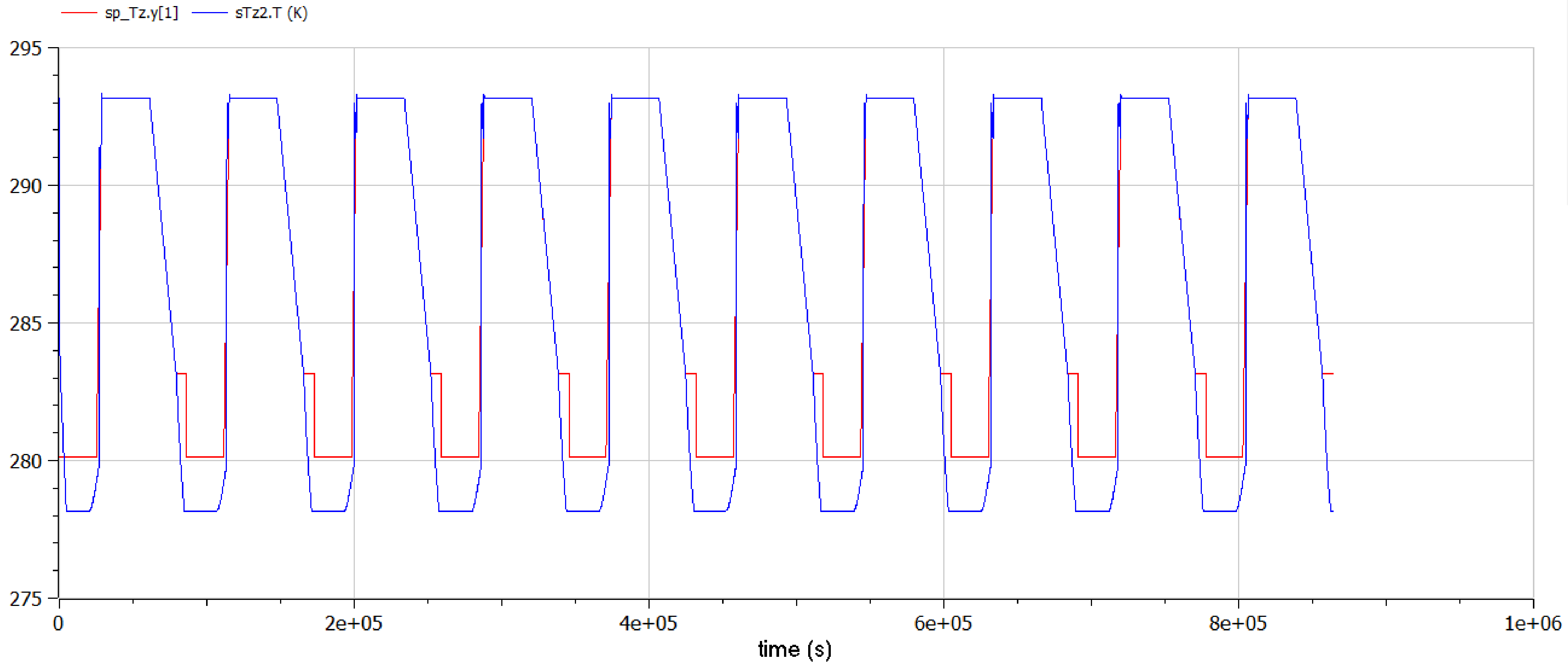
Parameters

K	0.3846
Ti	76.92

Temperature tracking of zone 1

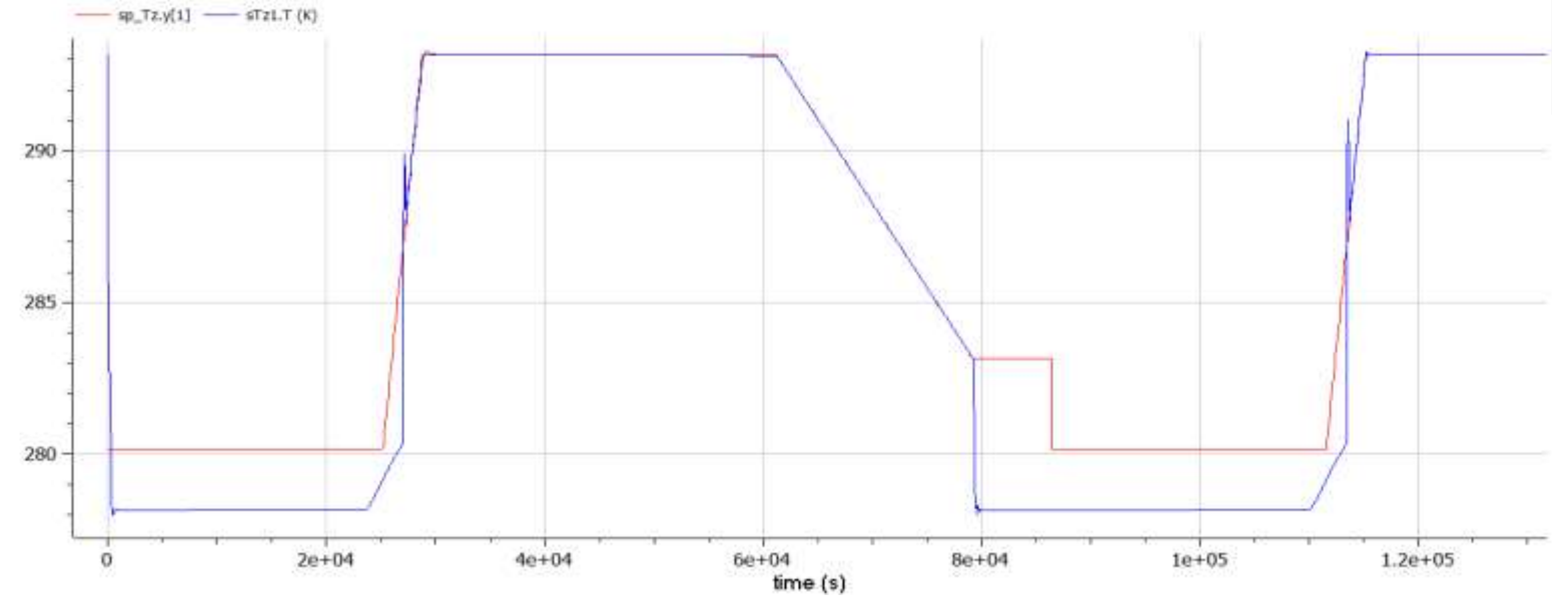


Temperature tracking of zone 2

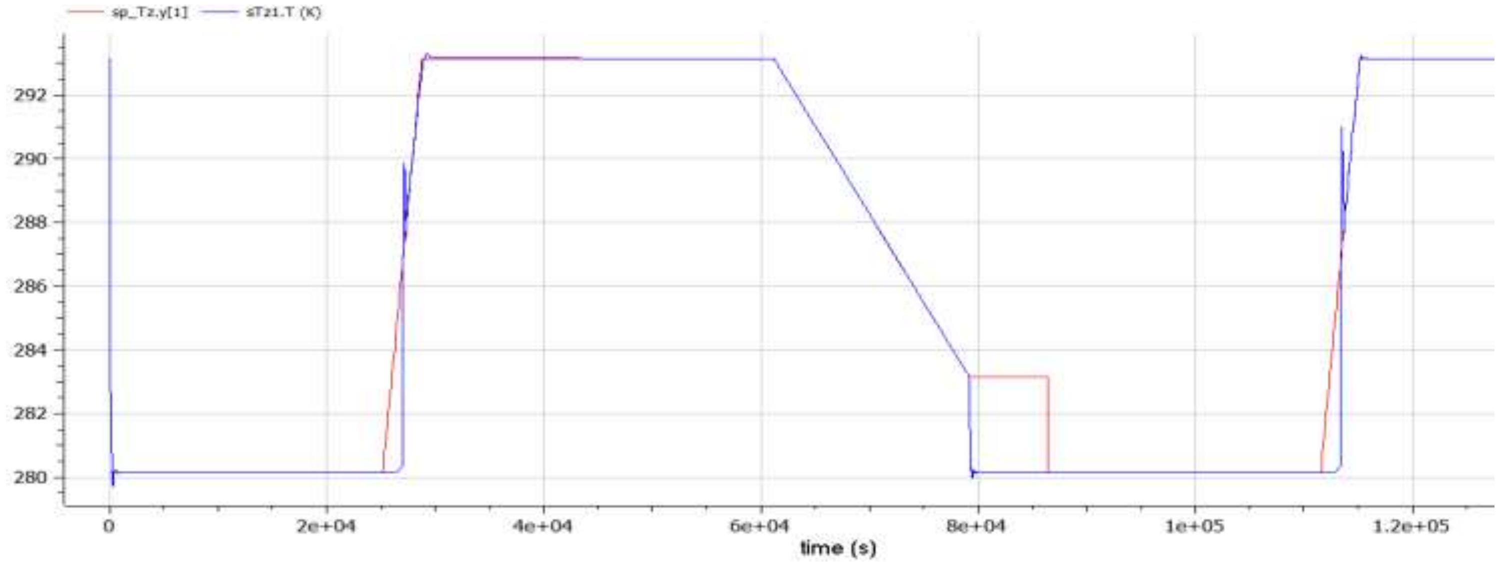


Zone 1 Temperature tracking with different low limits

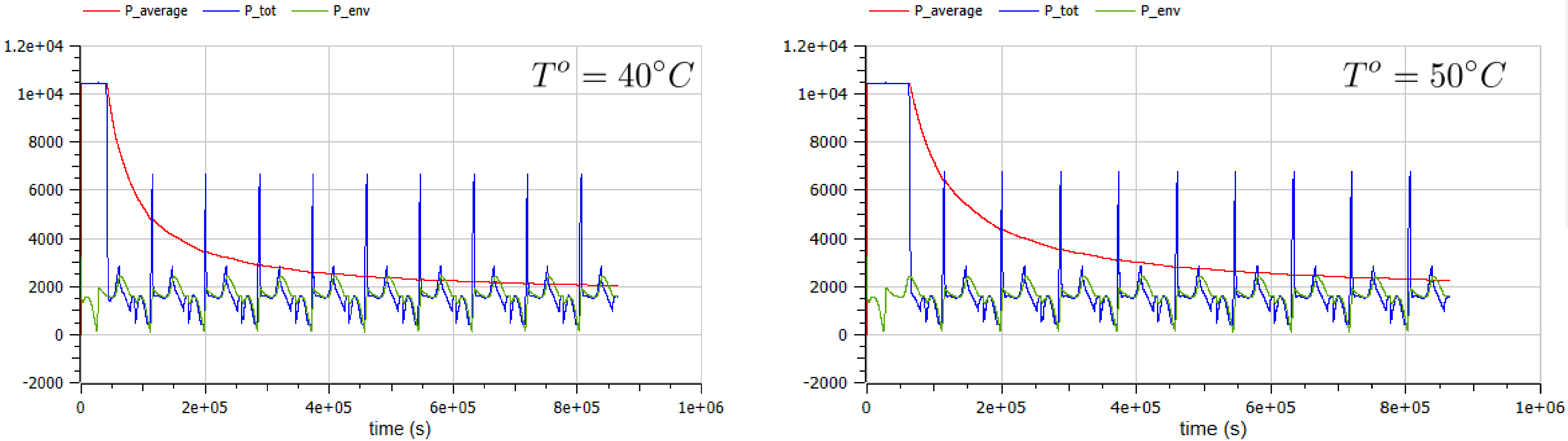
Low limit= 5+273,15K



Low limit= 7+273,15K



Power consumption with different outlet temperatures in day mode

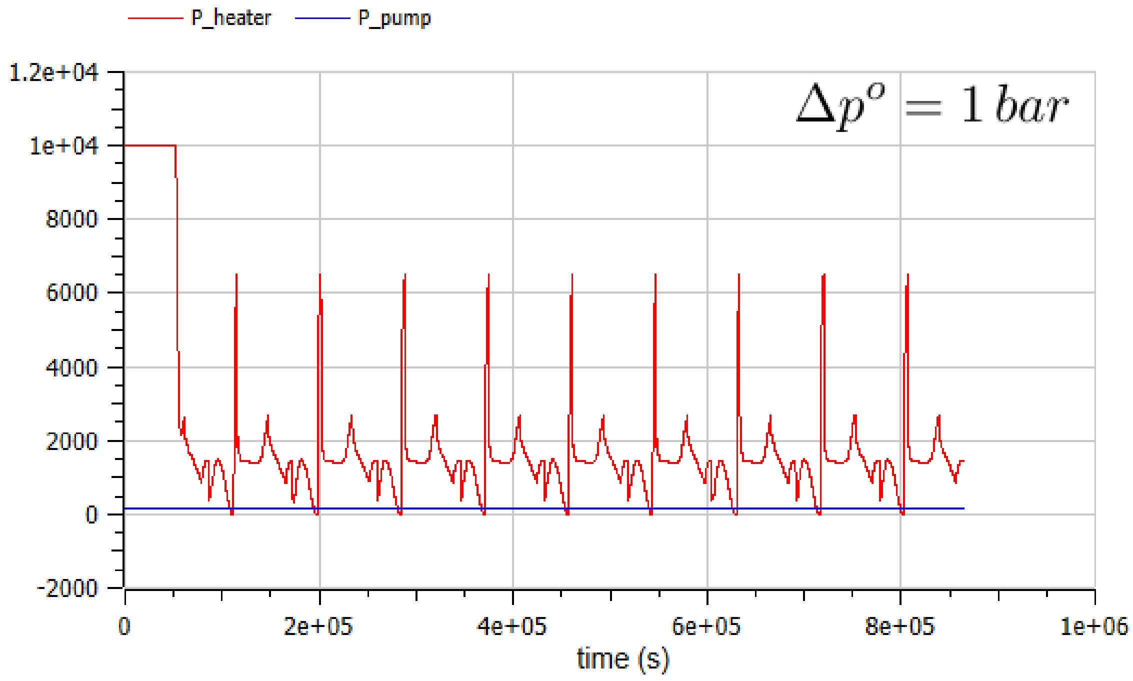


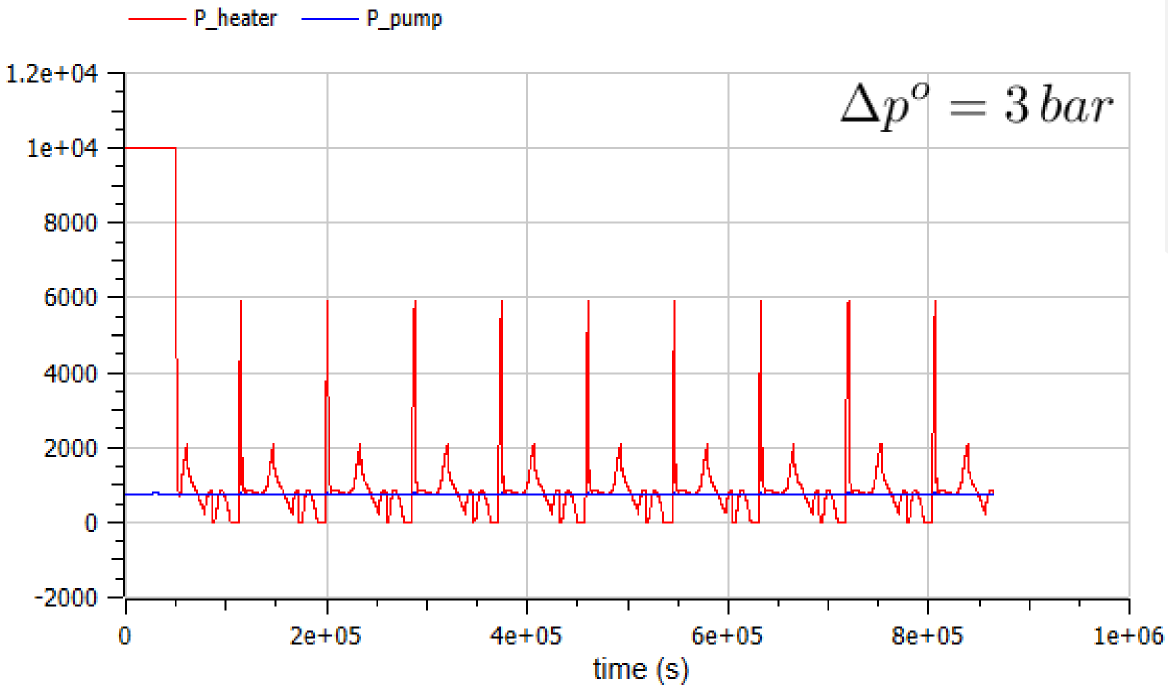
If I change the reference outlet temperature of the heater, while keeping the reference pressure constant,I get the following power consumption diagrams,

$$T^o \uparrow \Rightarrow P_{average} \uparrow$$

where $P_{average} = \frac{\int_0^t P_{tot}}{t}.$

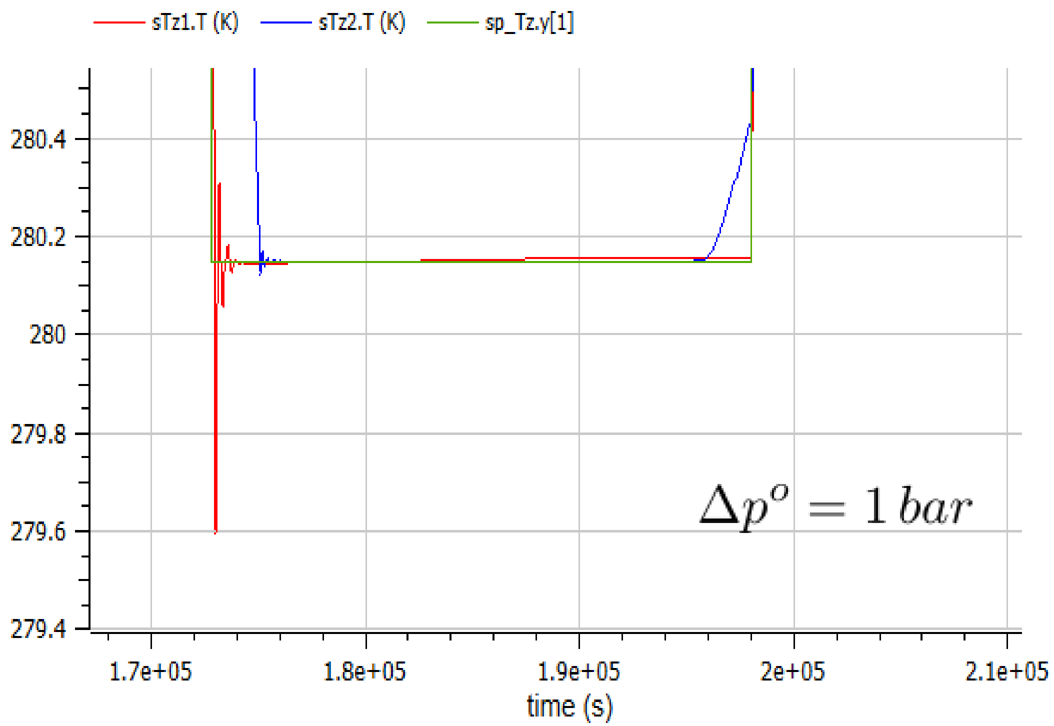
Power consumption with different outlet pressure in day mode

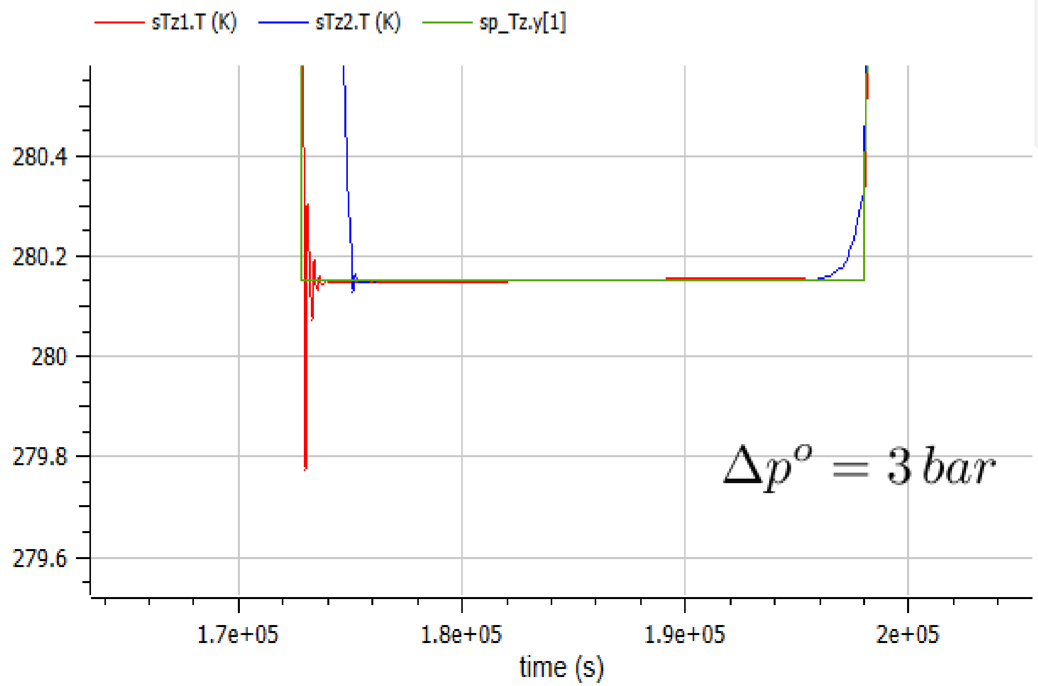




The higher the reference pressure, the more the pump will be used. As the overall consumption remains the same, I can decrease or increase the pressure reference based on the efficiency of the heater and the pump. In this case I change the pressure keeping the temperature at 45°C.

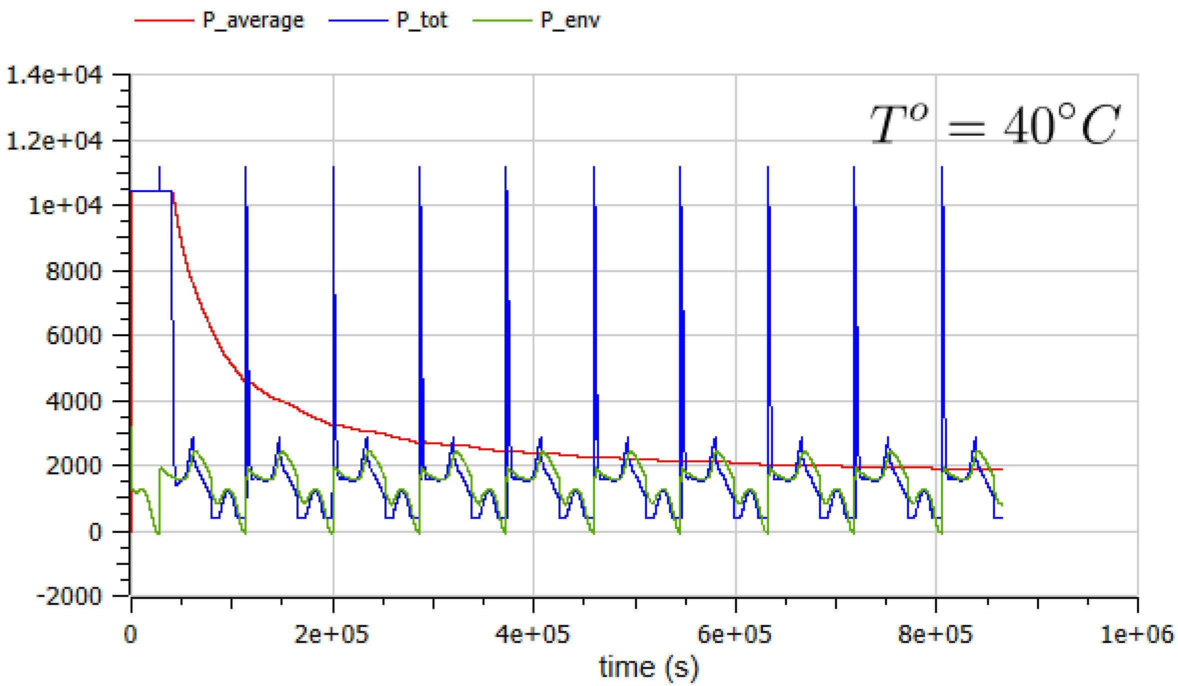
Comparison of different reference values in day mode

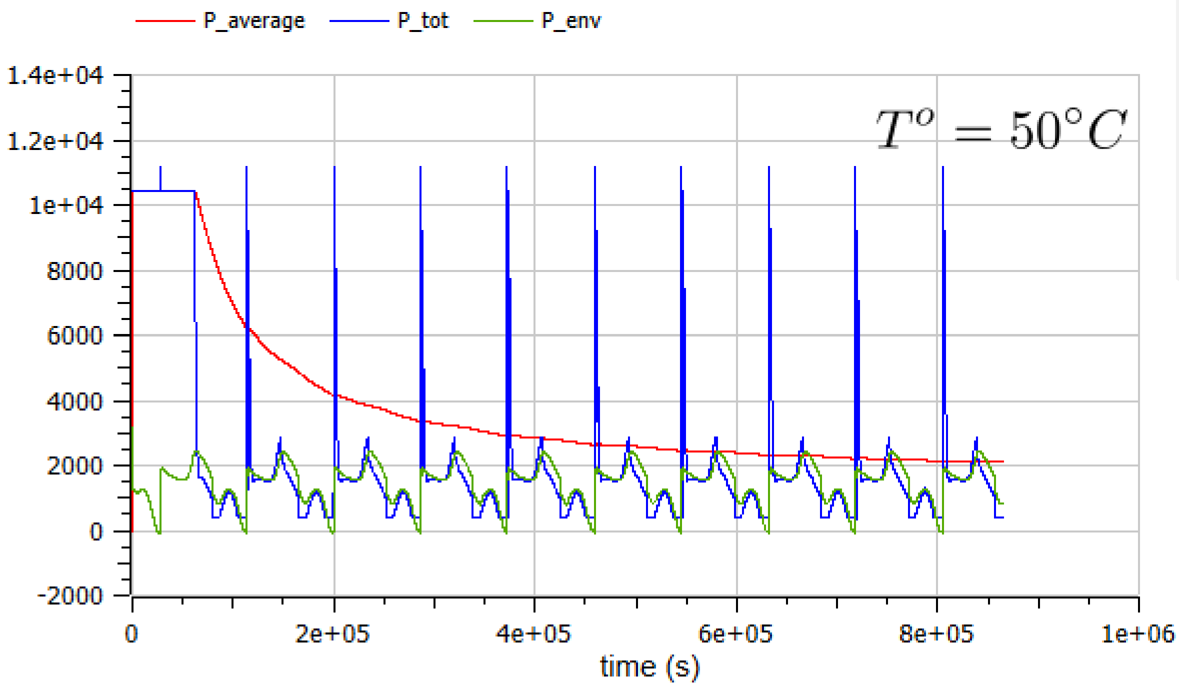




Modifying the pressure and outlet temperature references I don’t change the room temperature dynamics. I only have a small reduction of the amplitude of oscillations in the case I operate at higher pressure. It is not advisable therefore to operate at higher fluid temperatures because I don’t have consistent advantages.

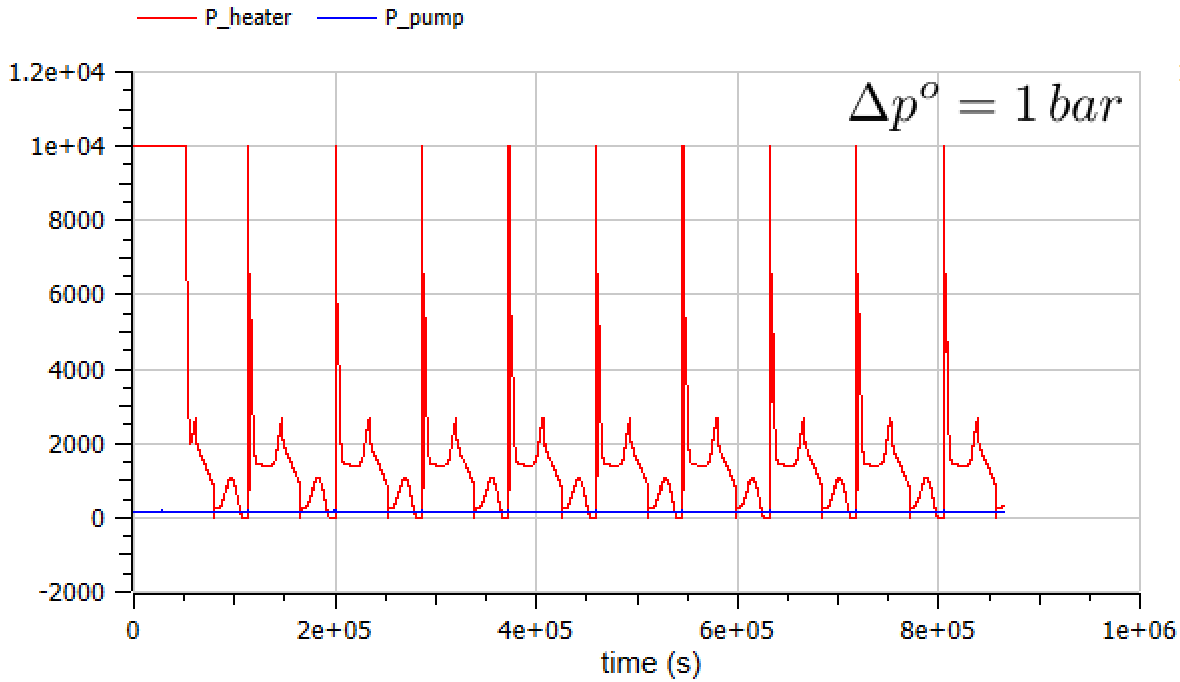
Power consumption with different outlet temperatures in day/night mode

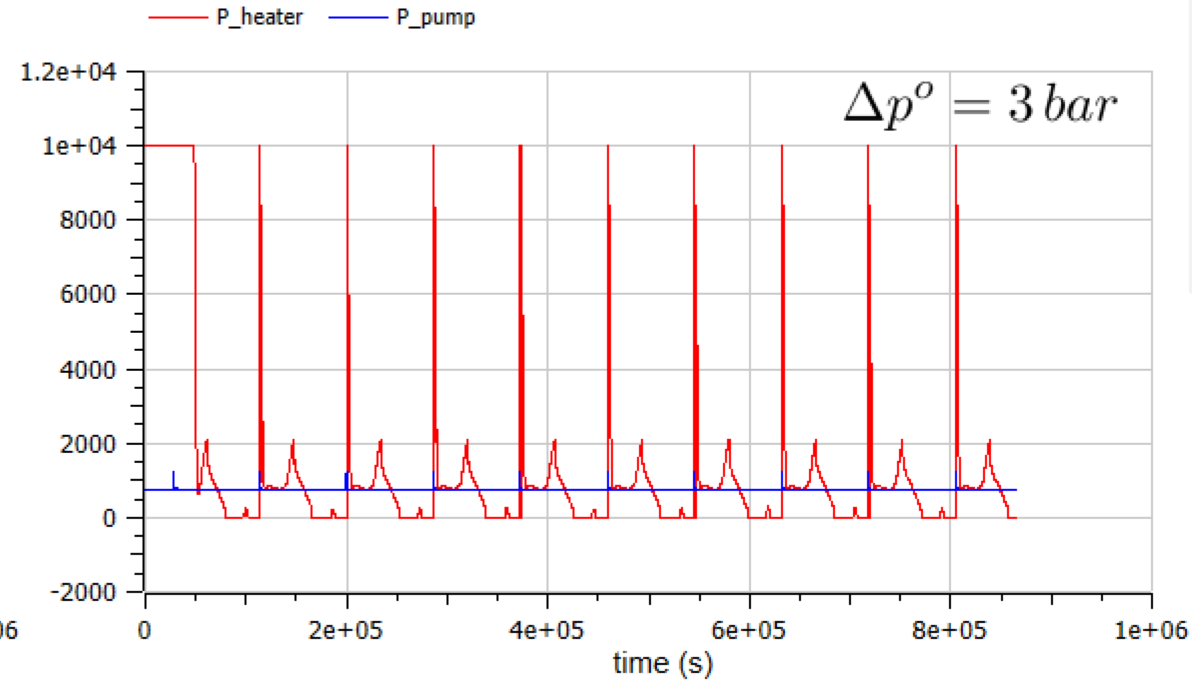




The same behavior can also be observed in the day/night mode. The only difference with the previous case is that the same increment of the fluid temperature produces now a higher average power increase: 12% compared to a 10.7% increase in the day mode.

Power consumption with different outlet pressure in day/night mode





As in the other case, higher pressure references mean more utilization of the pump instead of the heater. As during the night one of our objectives is to minimize the heater usage, we are more inclined to consider the second option.