Using computer models to save energy: An early warning model for tunnel pasteurizer energy consumption

Falko Jens Wagner

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Technical University of Denmark

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Agenda

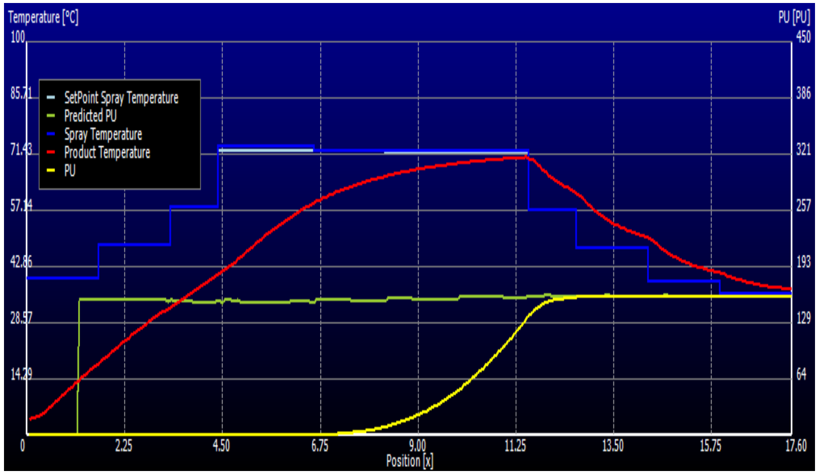
- How does a pasteuriser work?
- The PU Control system
- Possible faults

- Introducing the Virtual Pasteuriser
- Diagnosing possible faults
- Real-life example

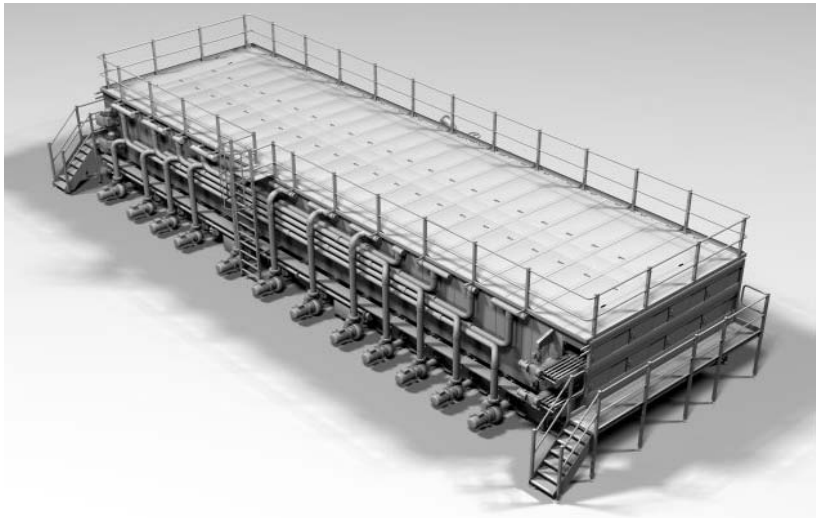
- Conclusion and Outlook

Krones SHIELD Pasteuriser

- Pasteurisation is heating and cooling of products
  - Inlet temperature 3-5°C
  - Typical pasteurisation temperature 62°C
  - Killing Point 60°C
  - Discharge temperature 25-30°C
  - Heating and cooling in steps (zones)

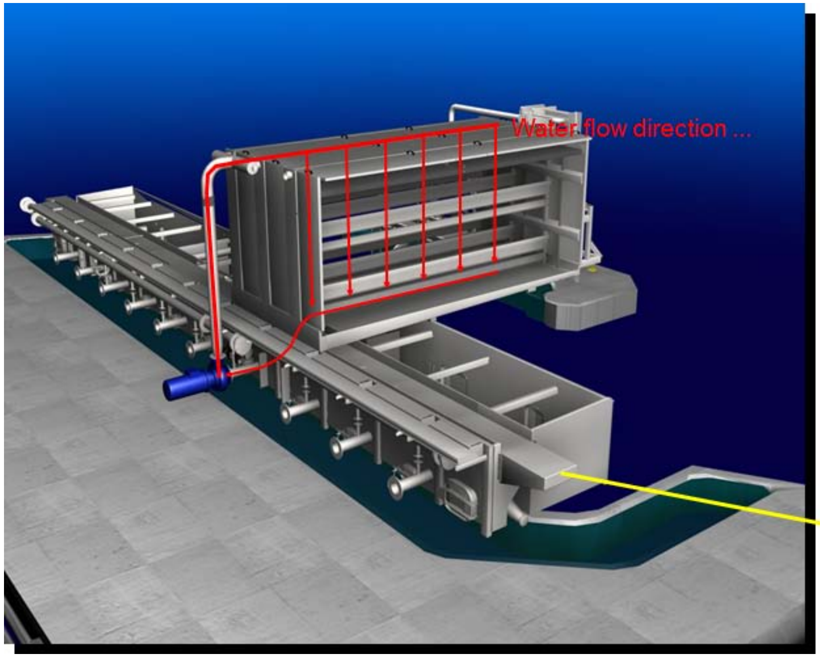


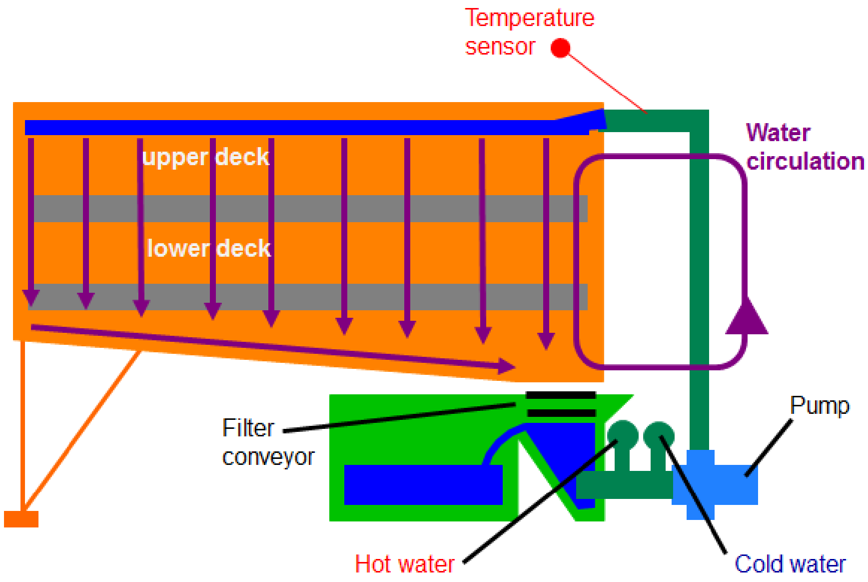
- Tunnel Pasteuriser
  - Pasteurises filled cans or bottles
  - Typically beer and softdrinks
  - Heat transfer by spraying products with water in individual zones



Water circulation and temperature corrections

- Water is pumped from the bottom chanel to the spray system
- The spray water flows across the products on 1, 2 or 3 decks, and via a catch-plate the water is fed back to the bottom chanel
- Temperature change is achieved by adding hot or cold water before the pump





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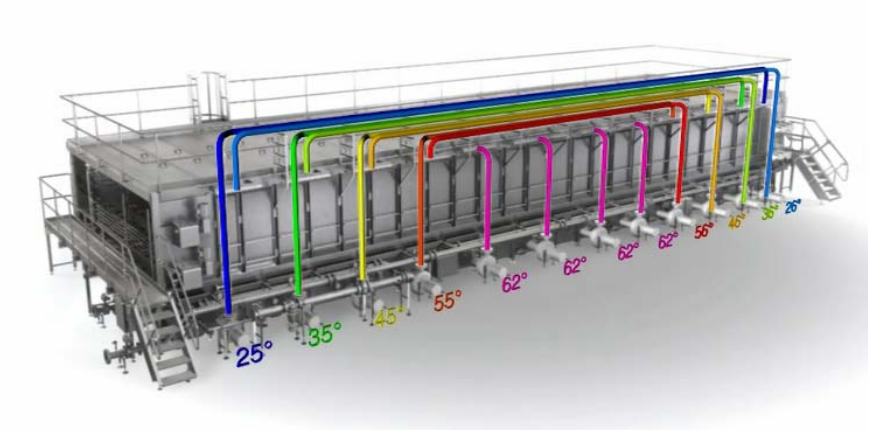
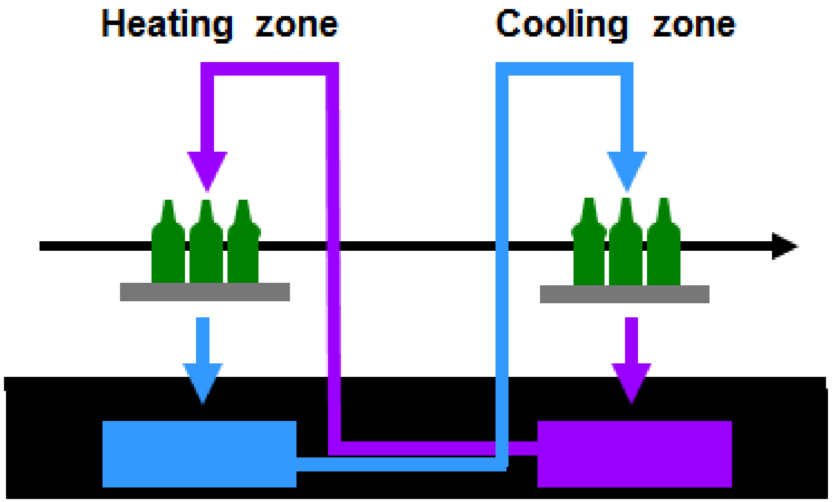
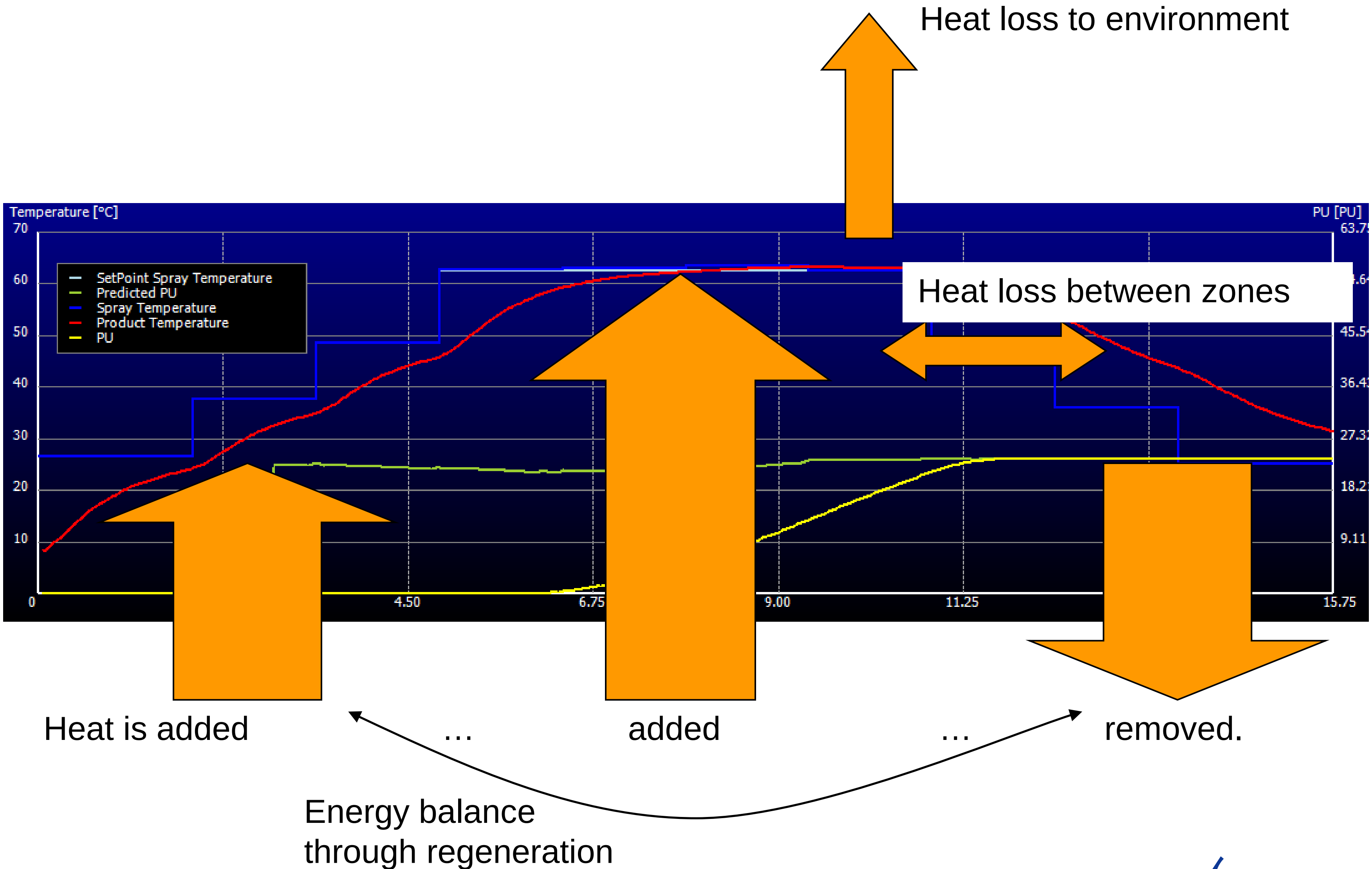
Tunnel pasteuriser energy regeneration

- Energy is reused by cross-pumping water between heating and cooling zones
- Temperature set points are calculated so temperature change of spray water is equal in heating and cooling zones
- During normal operation, energy is only added to the hot zones



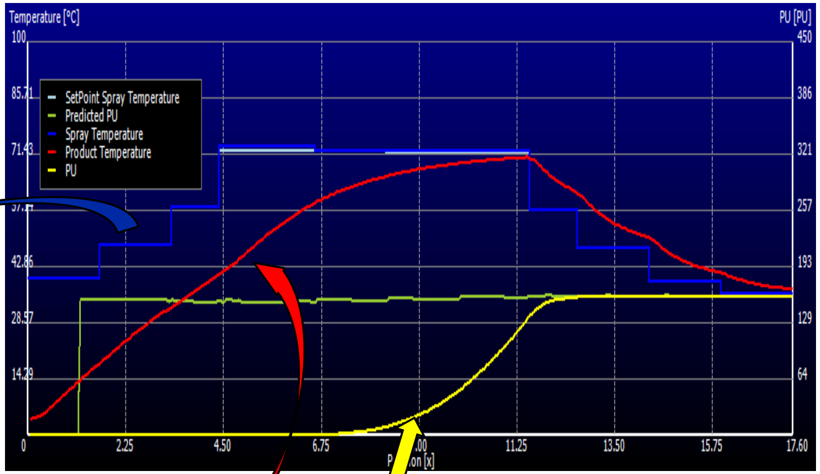


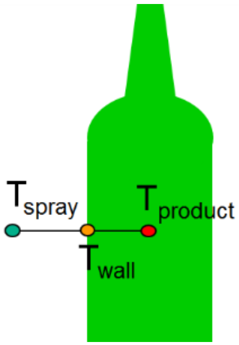
Energy flow in tunnel pasteurisation process



Temperature model and Pasteurisation Units (PU)

- Product temperature (inside can/bottle) is obtained through heat transfer equations
  - Heat transfer coefficients are based on measurements in a controlled environment





$$\frac{dT_{product}}{dt} = Func(T_{wall}, T_{product})$$

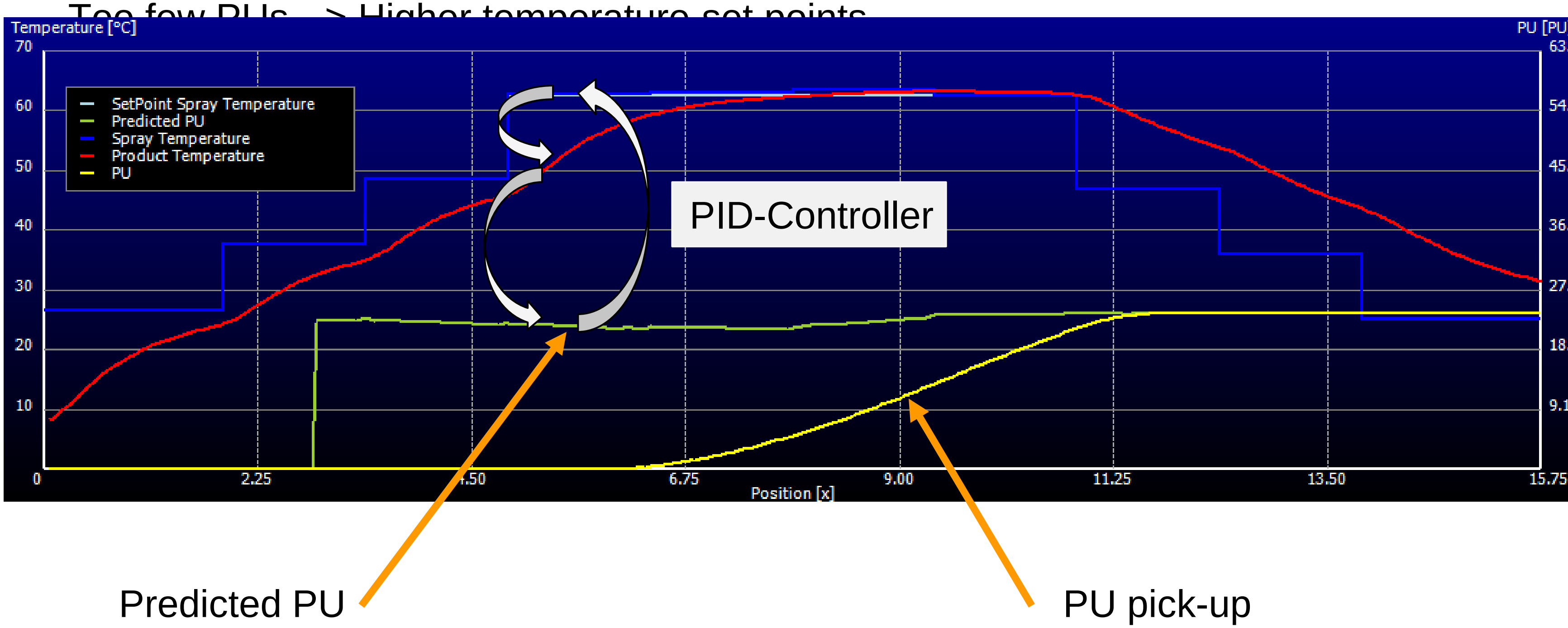
$$\frac{dT_{wall}}{dt} = Func(T_{spray}, T_{wall}, T_{product})$$

$$\frac{dPU}{dt} = 10^{\left(\frac{T_{product} - X}{Z}\right)} / 60$$

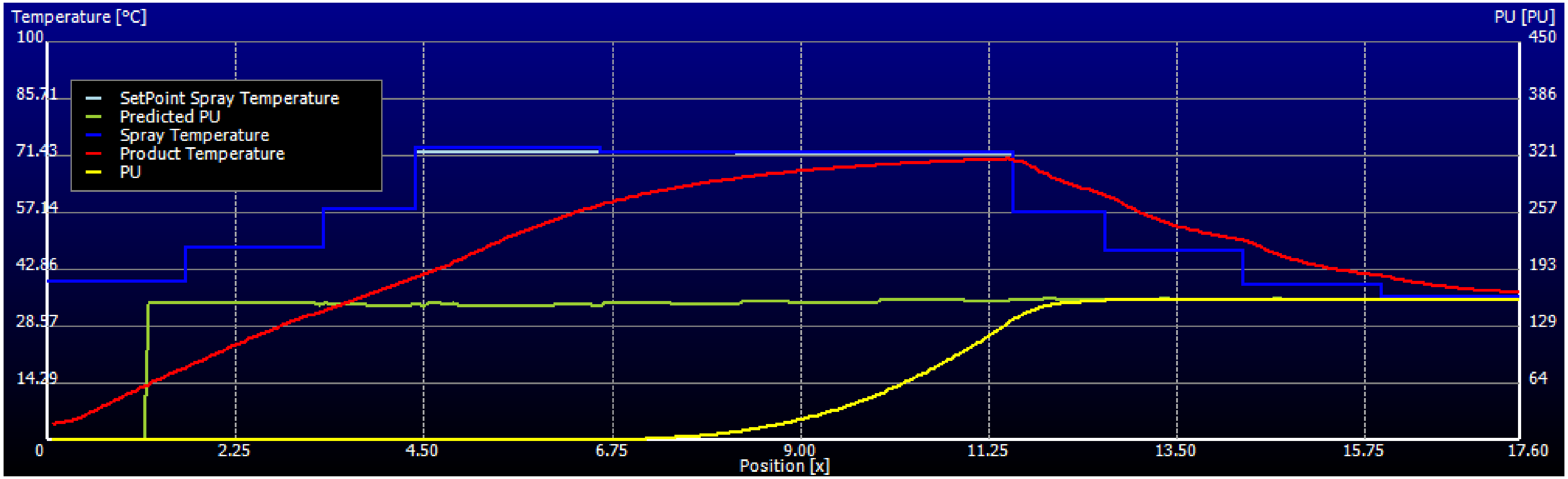
- Empirical formula accepted as standard
  - 1 PU = 1 minute @ 60°C
  - Based on product (content) temperature
  - Exponential formula (Z = 6.94, X = 60°C)

The PU Control

- Optimization: Achieve minimum PUs, reduce maximum as much as possible
  - By heating (with steam) and cooling (with freshwater) **=> Here is where the money goes!**
- Temperature model is used to predict achieved PUs
- Prediction is used to control temperature set points in pasteurisation zones
  - Too many PUs -> Lower temperature set points
  - Too few PUs -> Higher temperature set points



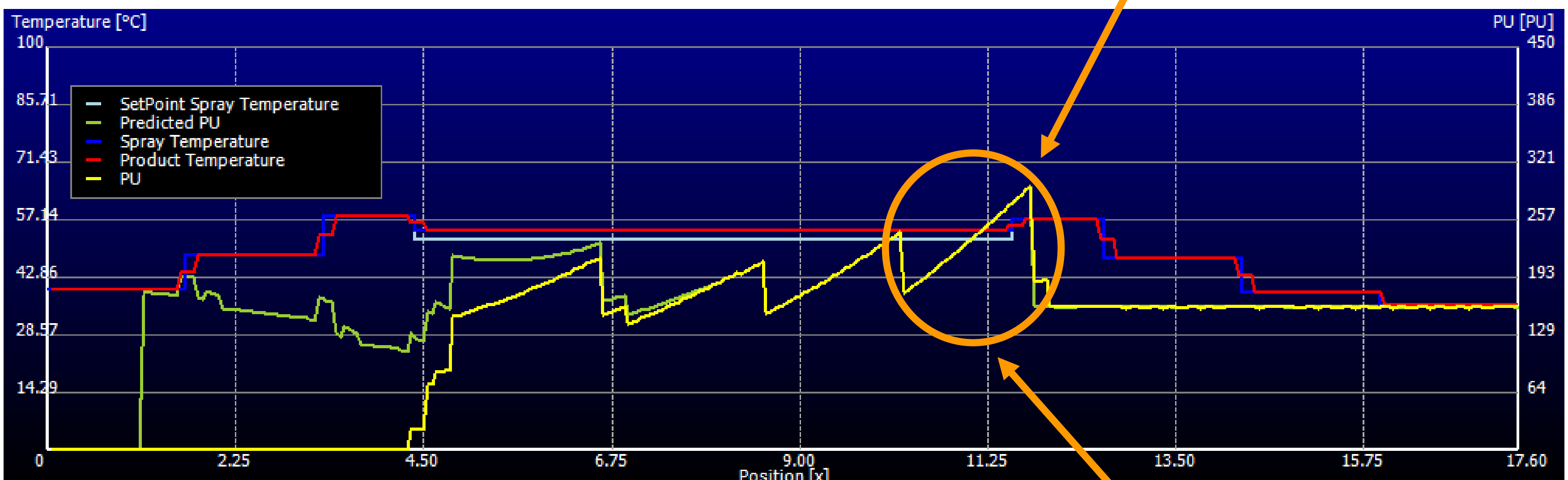
PU Control - Steady State Operation



PU Control – Interrupted production (Stop)

- To ensure, that the critical (worst) product in each pasteurisation zone achieves a minimum of PUs, some products will reach a higher degree of pasteurisation.

Highest PU in same zone as worst product



Critical (worst) product in zone has to achieve the desired PUs

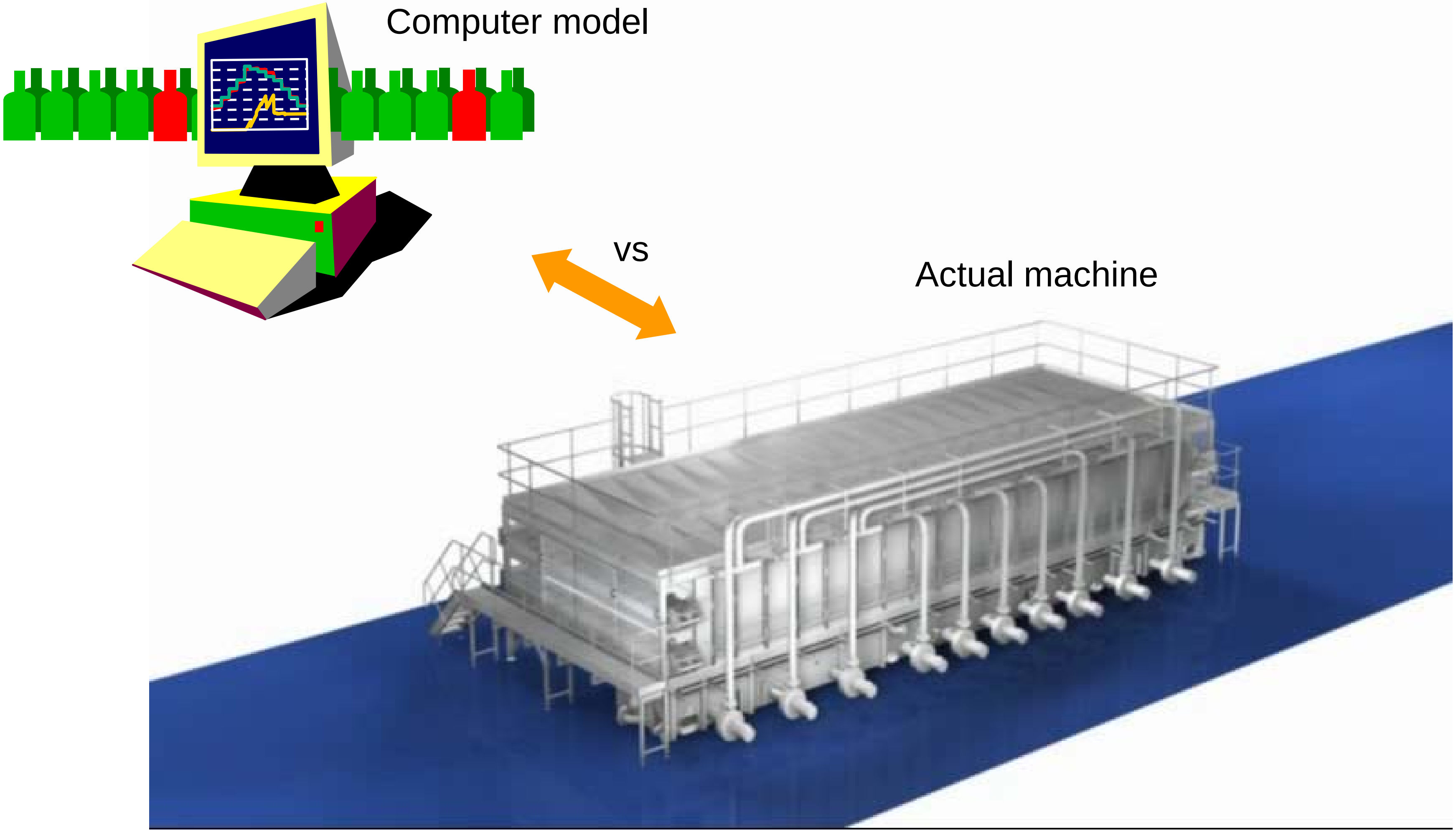
Possible Machine Faults

- Leaking valves
- Water mixing due to incorect water level in buffer tanks (open system, water level measured by pressure sensors)
- Wear on pump impellers giving incorrect flow, causing water imbalance and thus overflow
- Wrong assembly of pumps and orifices after maintenance
- Faulty temperature sensors
- Structural integrity of buffers (rust, corrosion)

The Challenge

- The PU Control optimizes the pasturisation process with the only concern being the PUs
- To optimize the PUs, enormous amounts of energy and water can be used
  - Especially, when the machine is not working as it should due to faults.
- The challenge is to raise awareness and give the operator a possibility to detect, whether a machine uses more energy and water than it should
  - By analysing the pasteurisation process and determining the theoretical (optimal) amount of energy used.

What is a Virtual Pasteurizer?



Purpose

- To monitor the behavior of a running pasteurizer
  - Early warning model
- To obtain better process knowledge
- To serve as a development tool for improvements

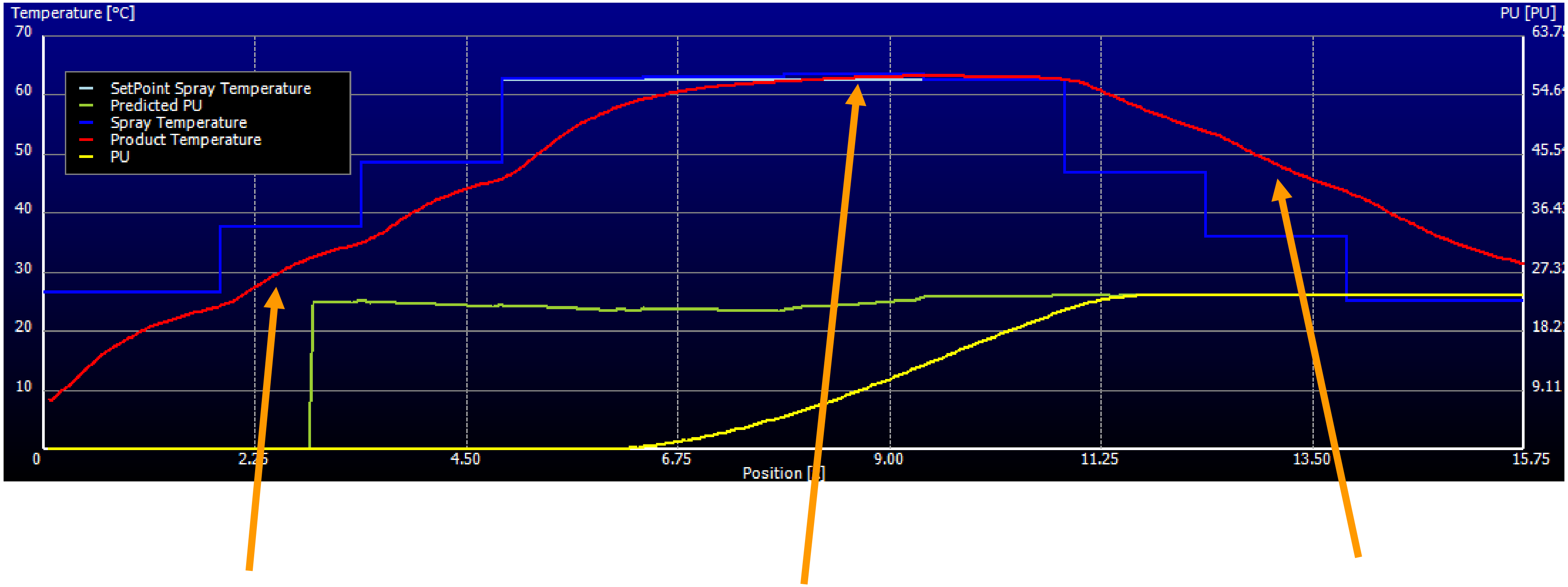
What does it do?

- Calculates the theoretical utility consumption of
  - Water
  - Steam
- Compares the actual consumption with the theoretical values
  - Actual consumption
    - How much energy is the machine actually using?
    - Based on flow and temperature measurements
  - Theoretical consumption
    - Based on temperature model
- Analyses the difference, displays warning messages and gives the operator a hint to where the problem could be.

Theoretical consumption – product energy

$$Q_P = m_P C_P (T_{content} - T_{content\_OLD})$$

$$Q_{P,TOT} = \sum_{MaxAUZ} Q_P n$$



Products are heated … pasteurized … cooled.

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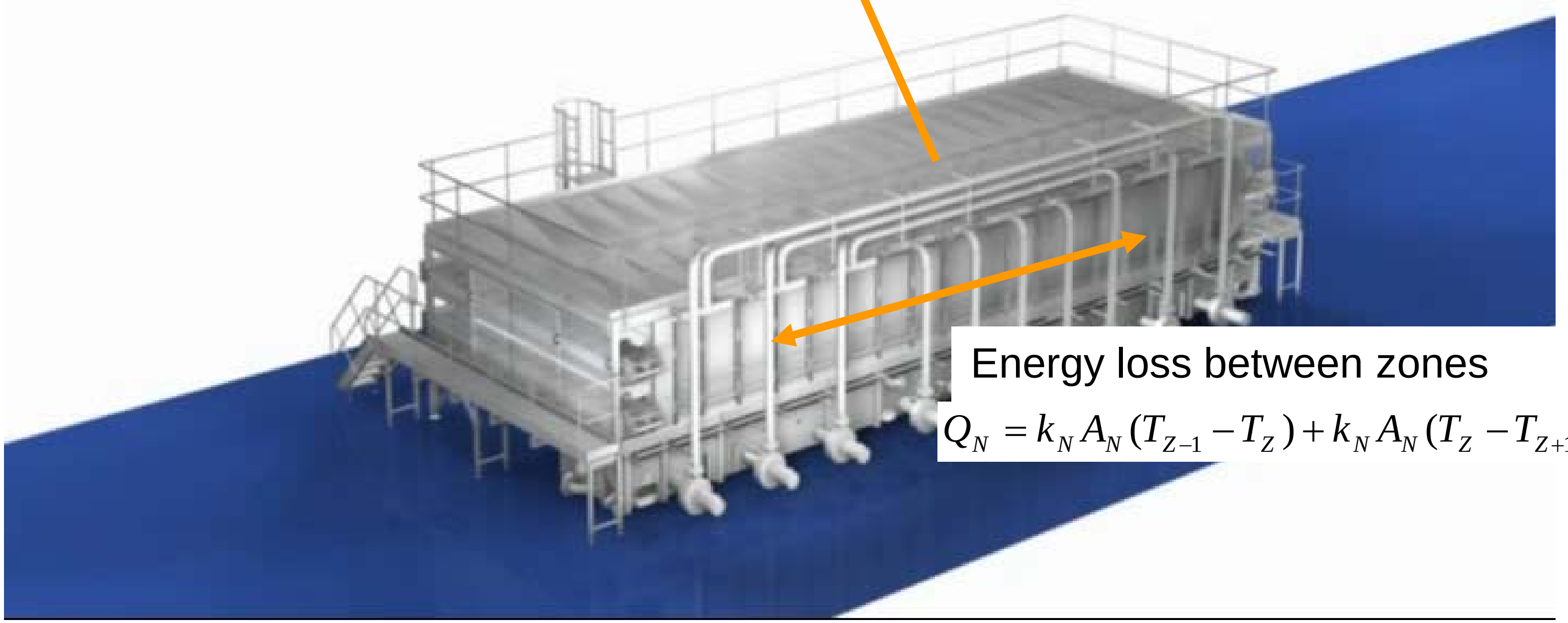
Theoretical consumption – energy losses

Energy loss to environment

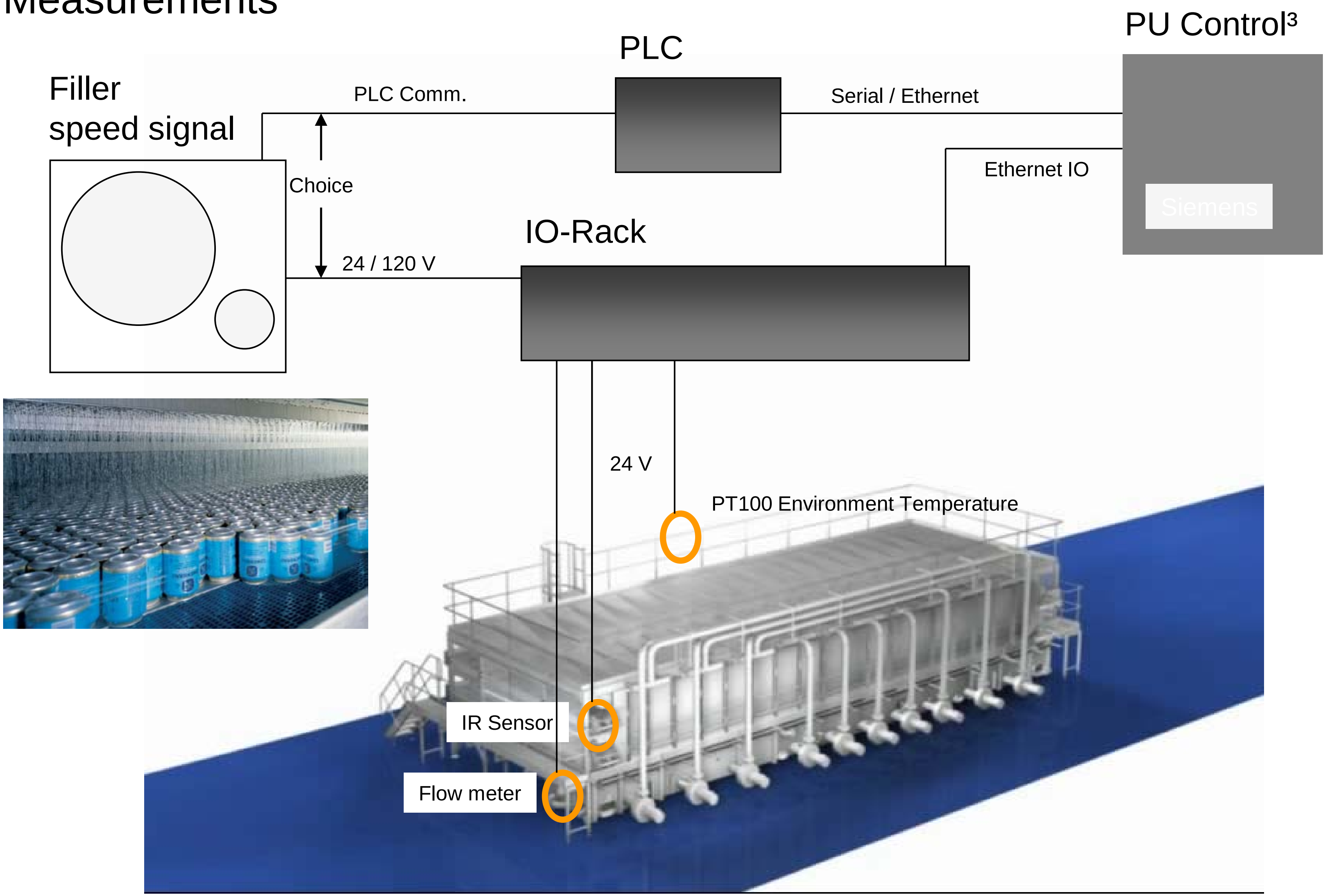
$$Q_L = kA_Z(T_Z - T_{env})$$



Energy loss between zones

$$Q_N = k_N A_N (T_{Z-1} - T_Z) + k_N A_N (T_Z - T_{Z+1})$$

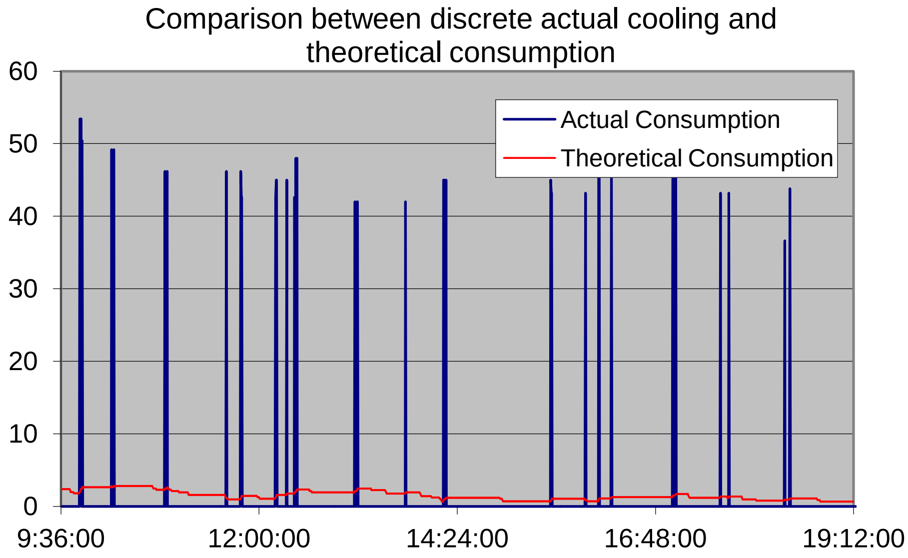
Measurements

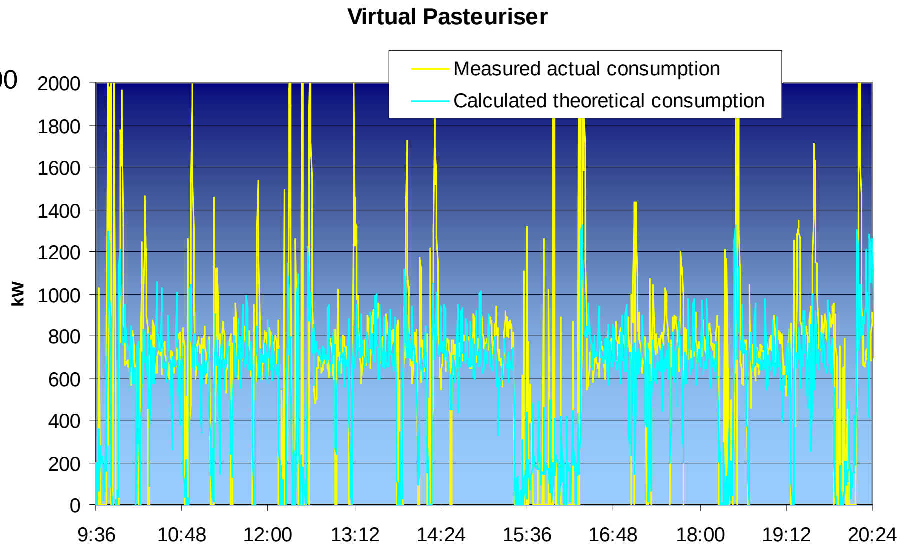


System compares

Process / theoretical		Machine / actual
Heat going into products	⟷	Heating valves opening and flow
Heat taken out of products	⟷	Cooling valves opening and flow
Heat loss to environment	⟷	Zone vs. environment temperature
Water mixing between zones	⟷	Difference between zone temperatures

Measurement data – fluctuations in utility consumption





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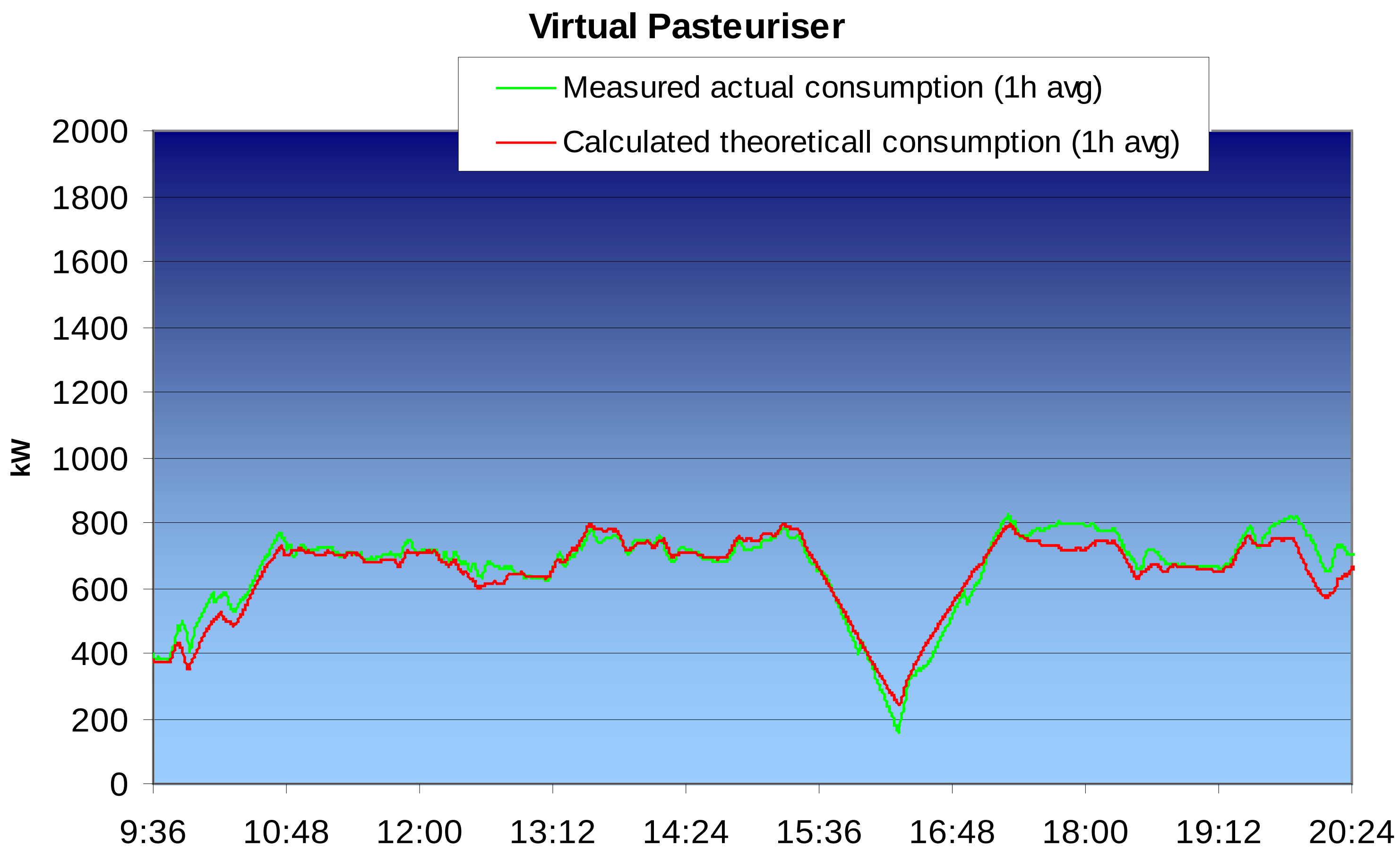
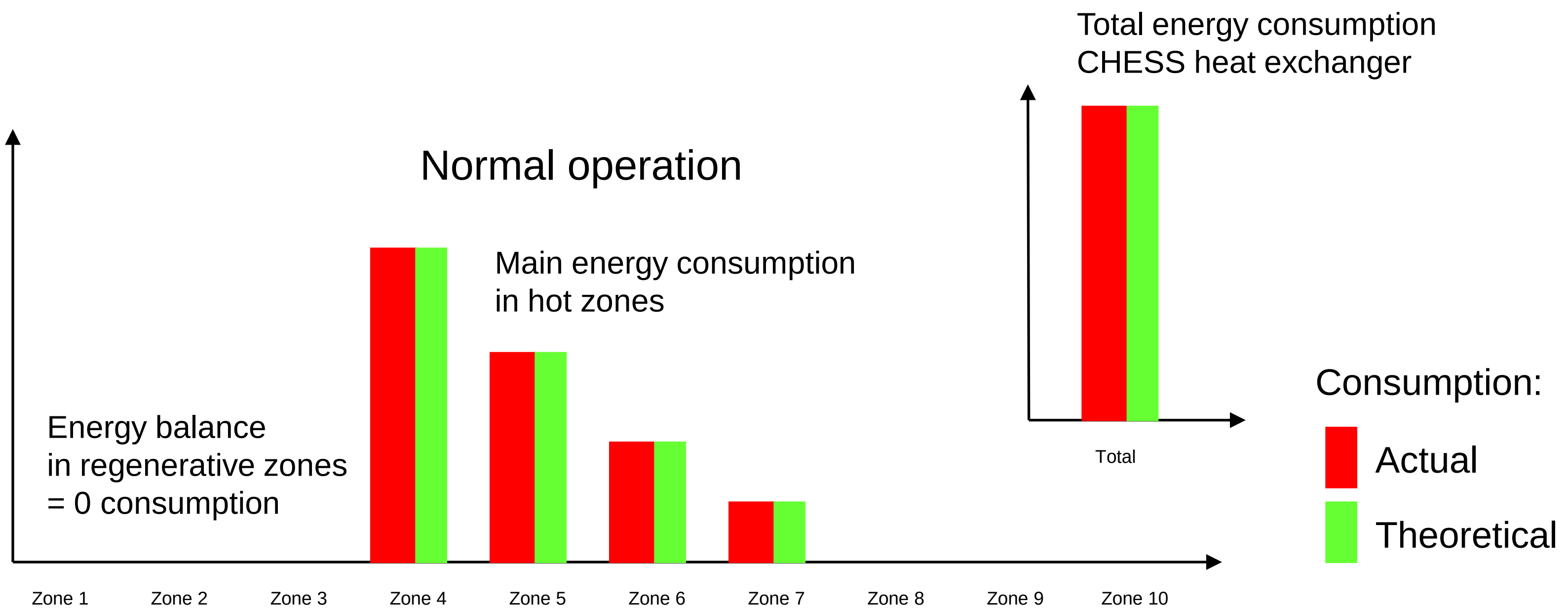
Measurement data – 1 hour moving average



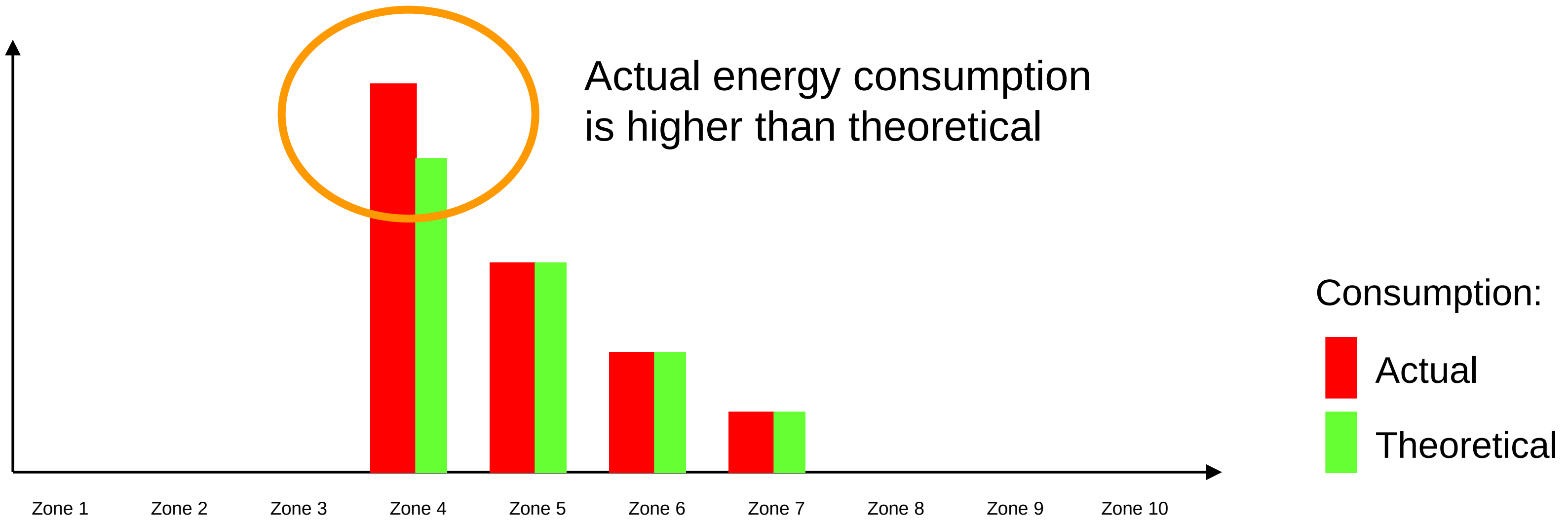
Detailed description of possible faults detected by VP

- Leaking valves
- Water mixing
- Integrity of buffer tanks



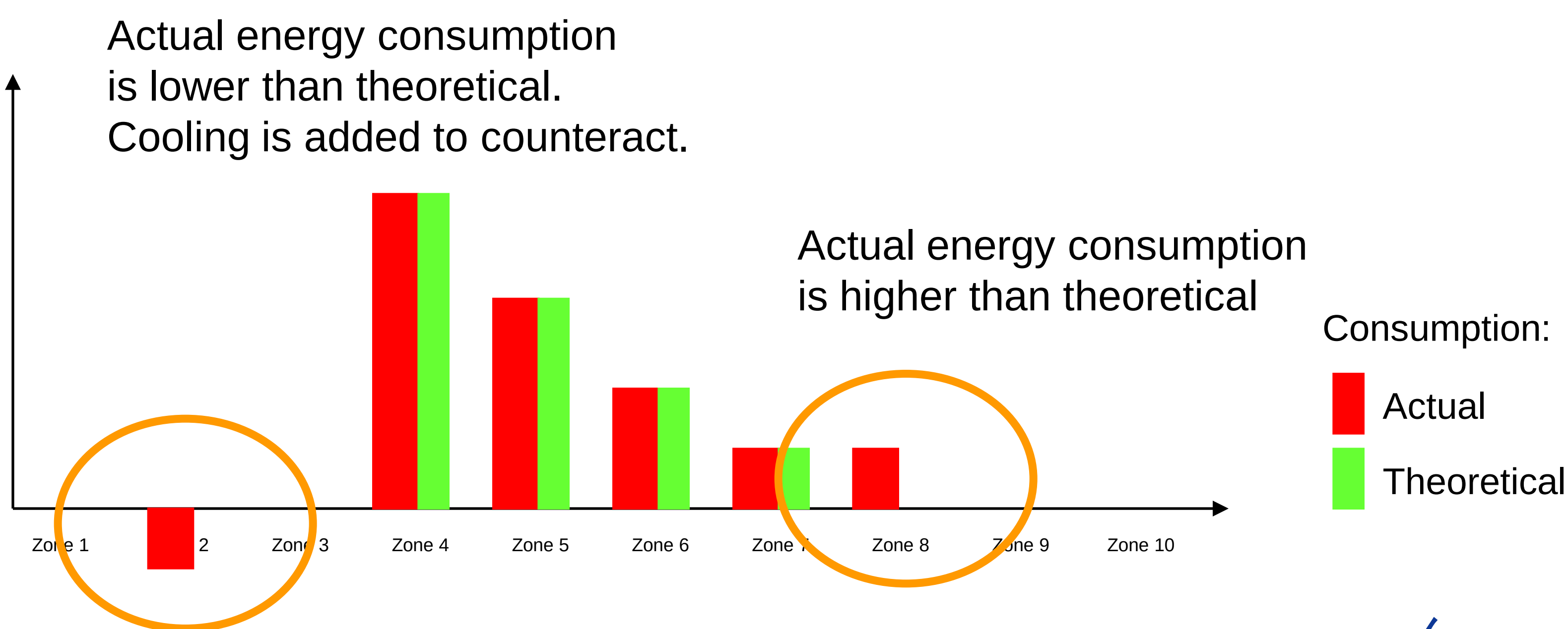
Leaking cooling valve – pasteurization zones

- A leaking cooling valve is not detected by the standard control system.
- It results in an unwanted cooling water flow into the zone, which is counteracted by an additional heating water flow to keep zone temperature set point.



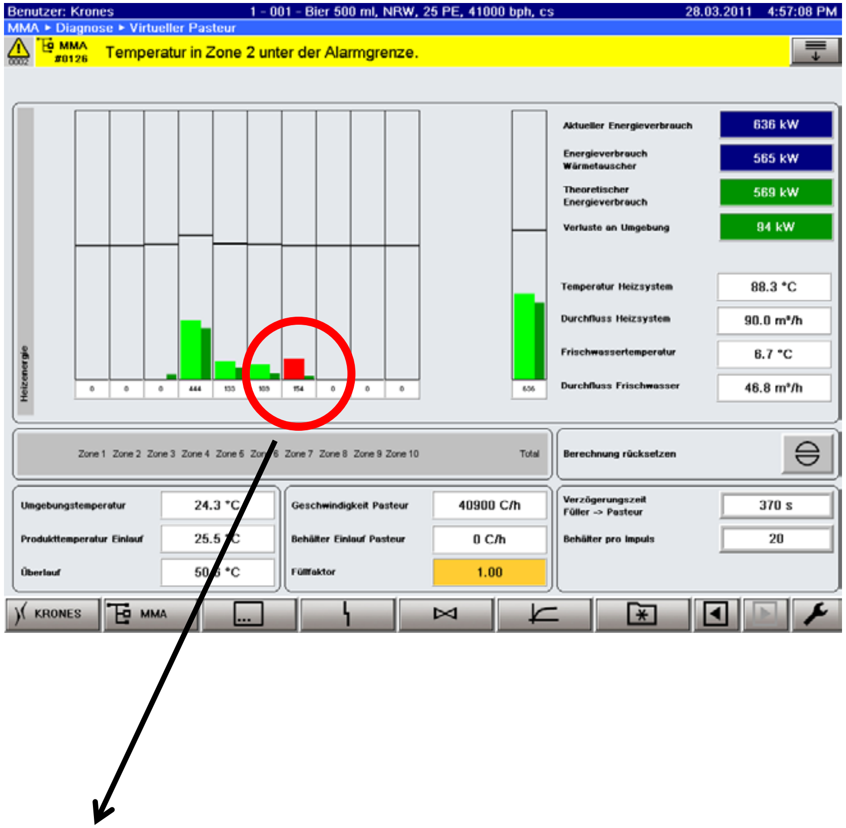
Water mixing between zones – regenerative zones

- Water mixing between zones is not detected by the standard control system.
- It results in unwanted hot and cold water additions to the zones involved to keep the zones at their respective set points.
- This combination predicts possible water mixing between to adjacent zones.



Example from running plant

- 1 Screen
  - Theoretical and actual values
- Each bar compares actual and theoretical consumptions
  - Alarm is displayed if deviation is larger than allowed
- Additional information
  - Current fill factor
  - Current infeed temperature
  - Time between filler and pasteuriser



Notice how last hot zone is using more energy than it should? .....

This gives rise to the operator to look and investigate in this Particular zone ......

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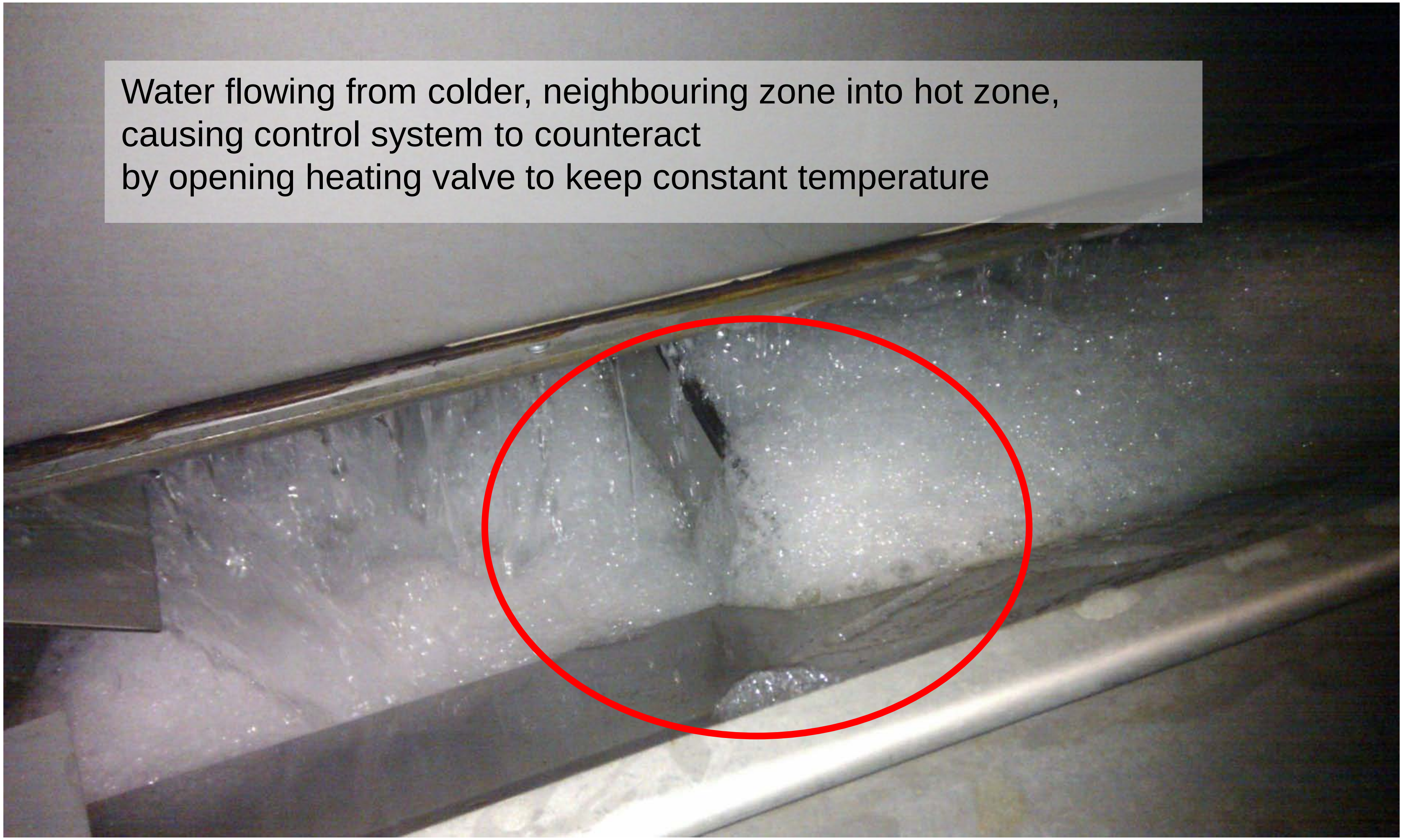
... and here is the reason!



Conclusion

- By using the Virtual Pasteuriser it is possible to detect faults on the equipment immediately.
  - Matter of hours
- Without, the increased energy and water consumptions was possibly detected after a long observation period
  - Typically months
- Savings are eminent and the system is currently being extended to other utilities
  - Electricity
  - Compressed Air

- Side-effect and additional benefit
  - Analysis with the Virtual Pasteuriser has shown a time-lag between the actual energy consumption and the theoretical consumptions due to transport delays in the system.
  - Work is going on to use this knowledge to make a faster PU-Control system.