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Verlagen van energiegebruik in residentiële sanitair warm water systemen:

Afweging tussen energie-efficiëntie en *Legionella* infectierisico

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Research group Building Physics
Department of Architecture & Urban Planning
Ghent University, Belgium

October 20 2016
Antwerp

Minnesota Legionnaires' Disease Outbreak Sickens 23

October 9, 2016

Memphis hotel shut down after outbreak of Legionnaires' Disease confirmed

September 22, 2016

Legionella DNA markers in tap water in Flint, Michigan

August 15, 2016

LEGIONNAIRE'S DISEASE OUTBREAK IN MINNESOTA CLAIMS FIRST VICTIM

September 22, 2016

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July 14, 2016

New cases of Legionnaires disease confirmed in Harlem

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- Why is DHW energy use so high?
- What is *Legionella*?
- How to lower DHW energy use?
- Conclusions

Table of contents

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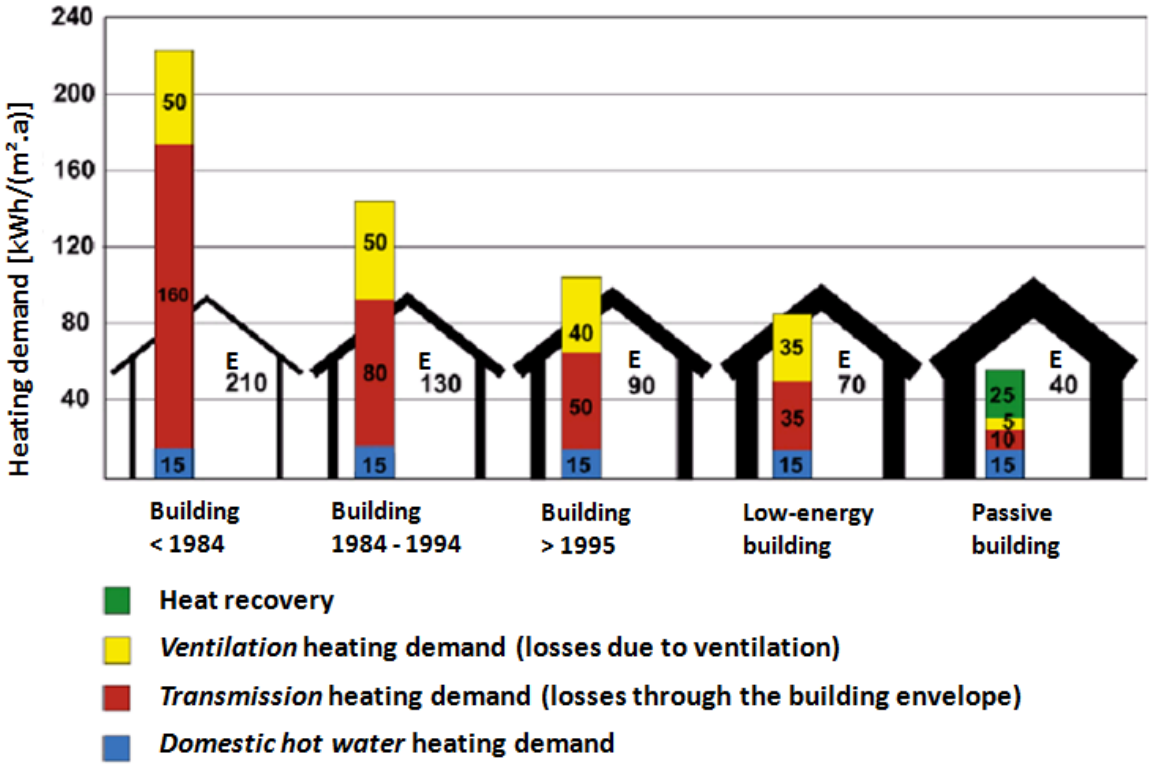
Why is DHW energy use so high?

- State of the art
- Objectives
- Practical implications

Chapter 1

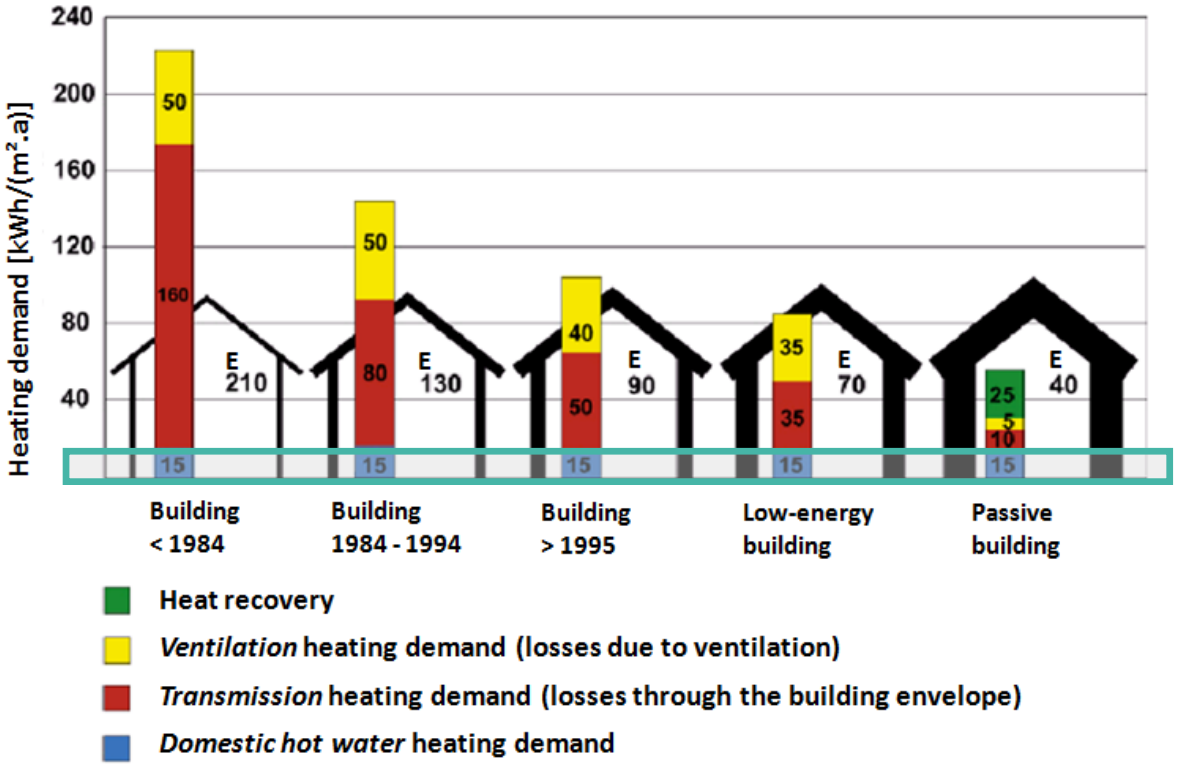
State of the art

- Improving insulation levels and air tightness of building envelopes
- Production of DHW dominates total energy demand
  - 800kWh/occupant/year
  - 15kWh/m²/year



State of the art

- Improving insulation levels and air tightness of building envelopes
- Production of DHW dominates total energy demand
  - 800kWh/occupant/year
  - 15kWh/m²/year
- Energy performance requirements 2020: total energy demand for heating, cooling and DHW production reduced to 1/3 (2006)

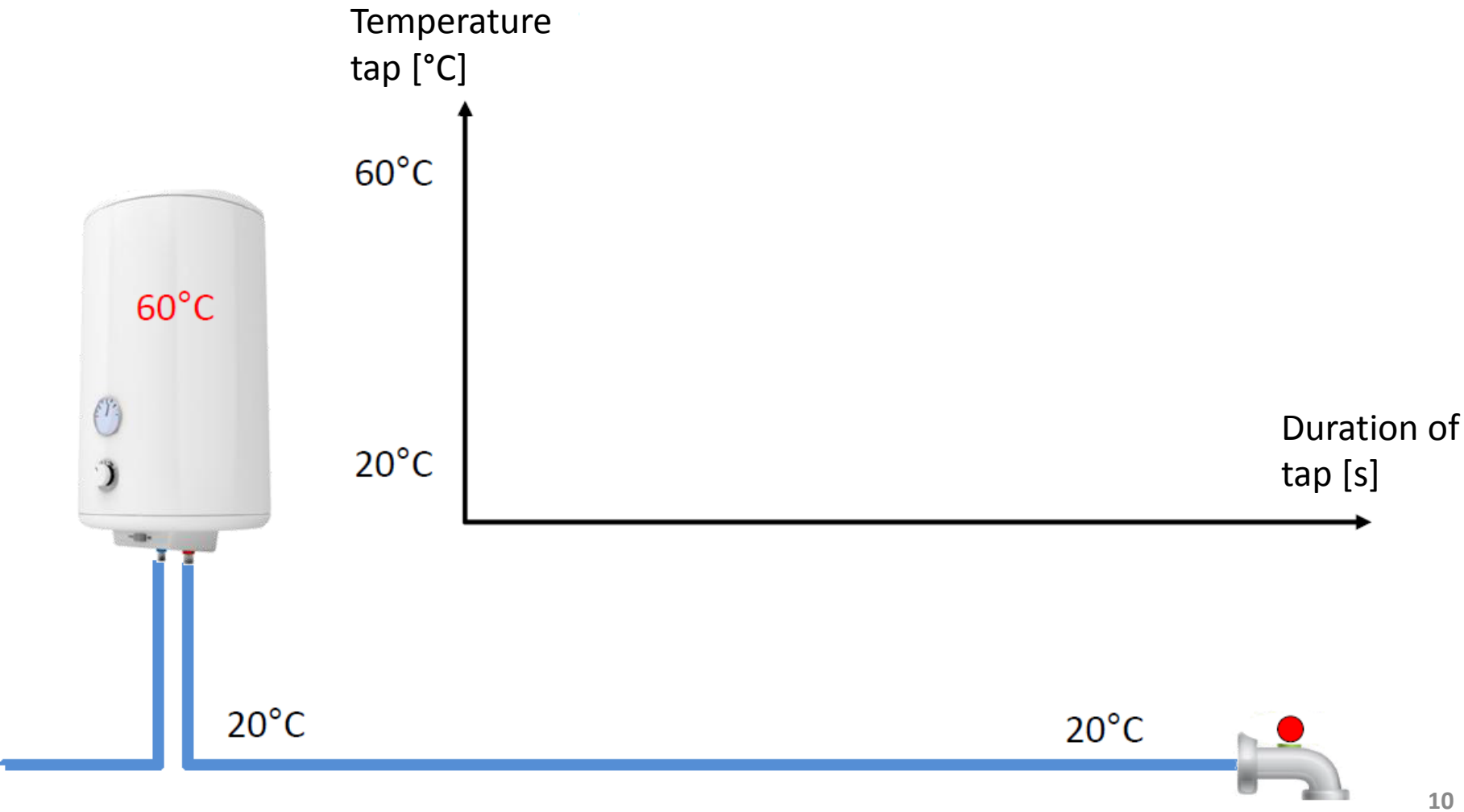


- DHW
  - Stored + distributed: > 60°C
  - DHW applications: 30 - 40°C
- Negative effect of temperature difference:
  - Efficiency of DHW production units
  - Heat loss

DHW production and distribution	
Production and distribution	> 60°C

DHW application	NBN 345	ISSO
Washing hands	35°C	40°C
Shower / Bad	40°C	37°C

- Heat loss of distribution system



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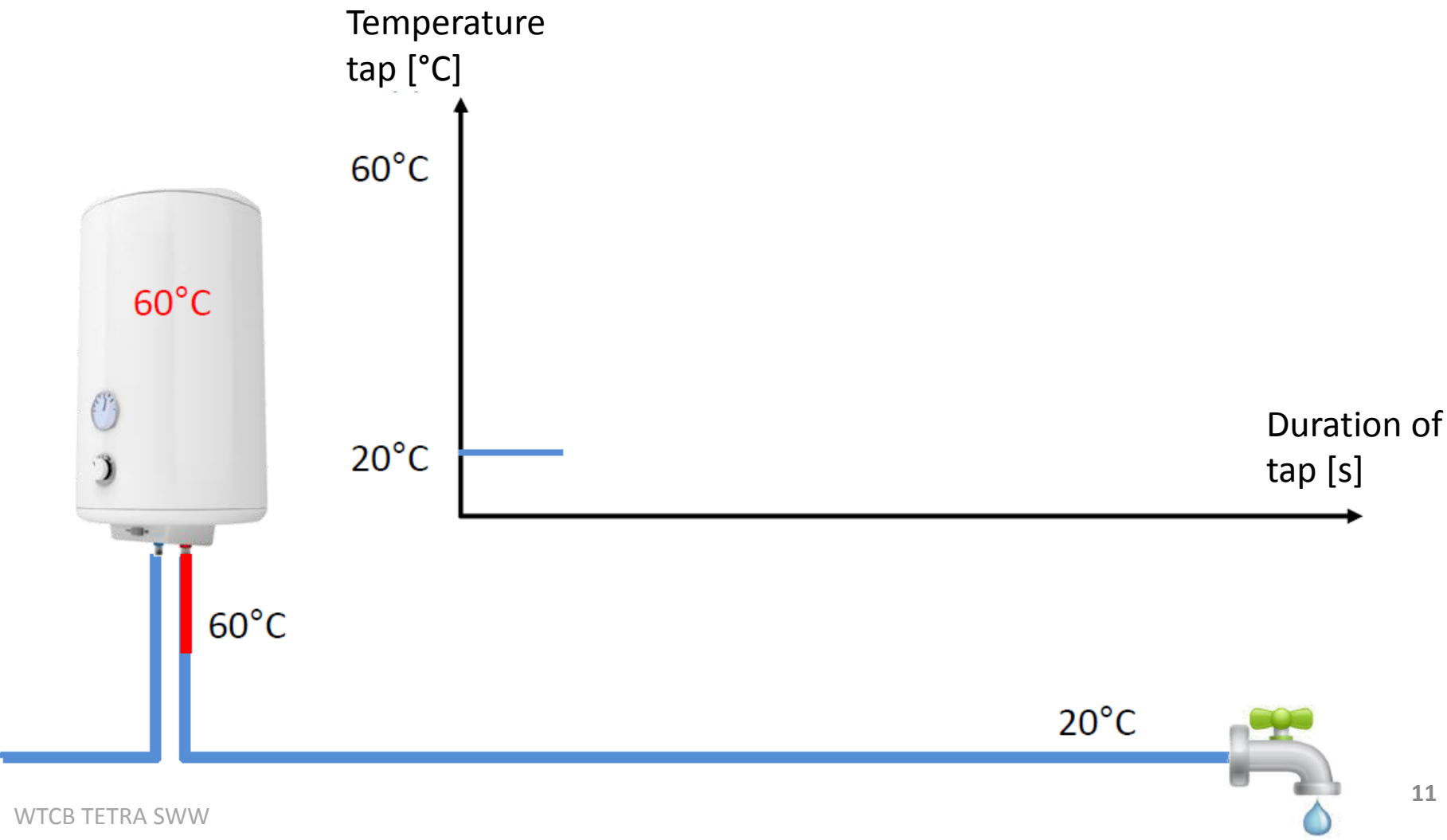

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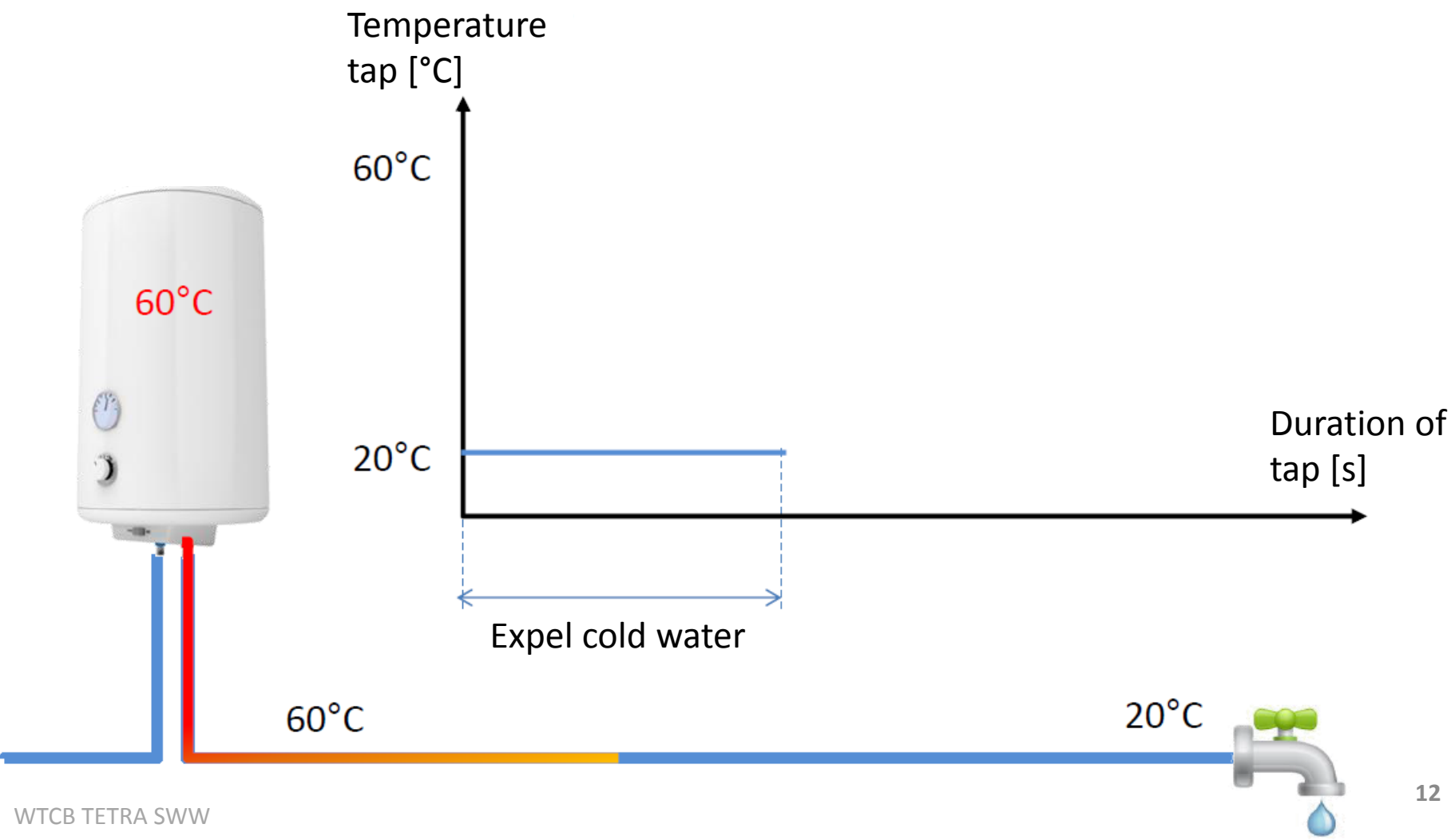

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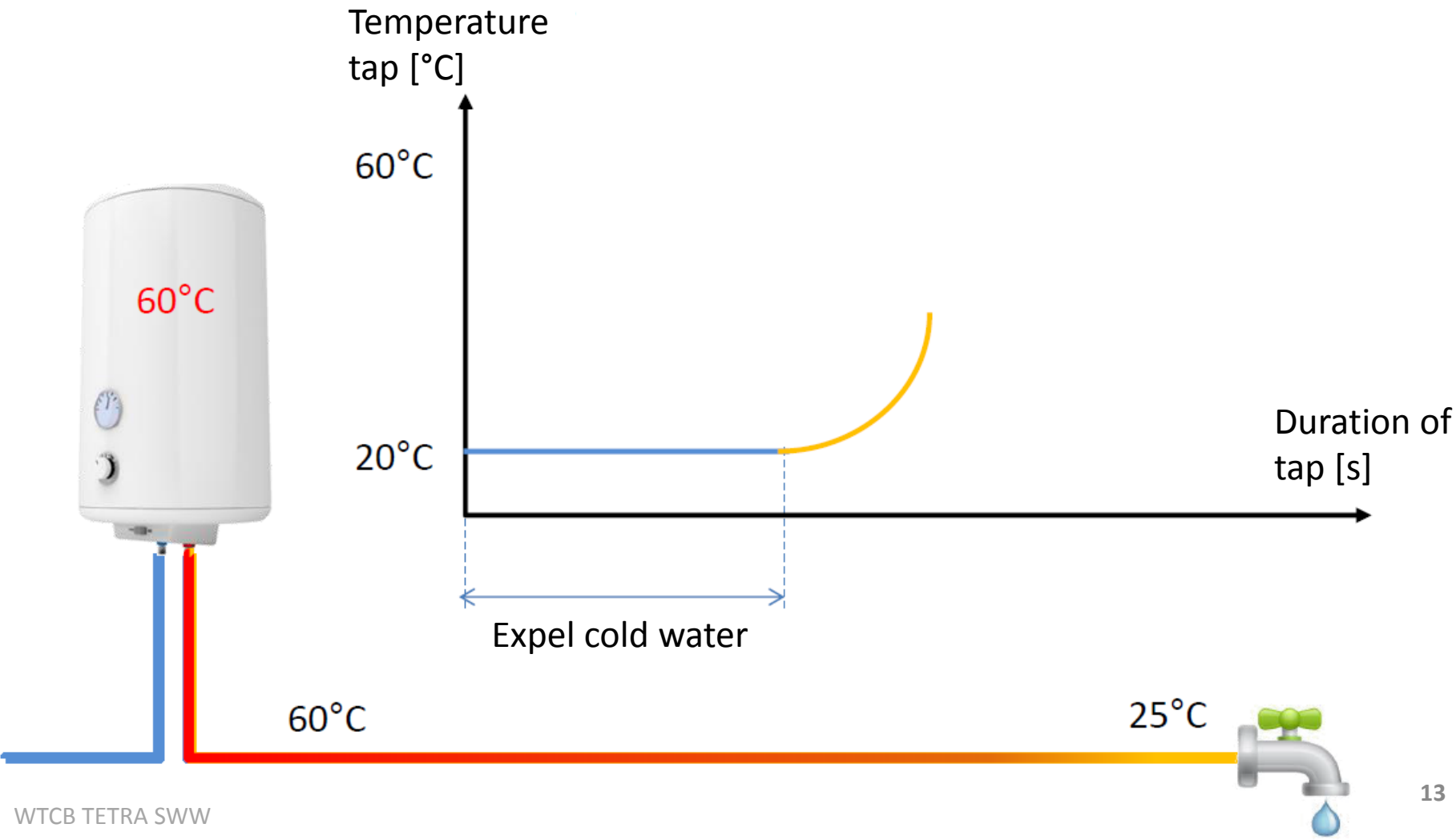

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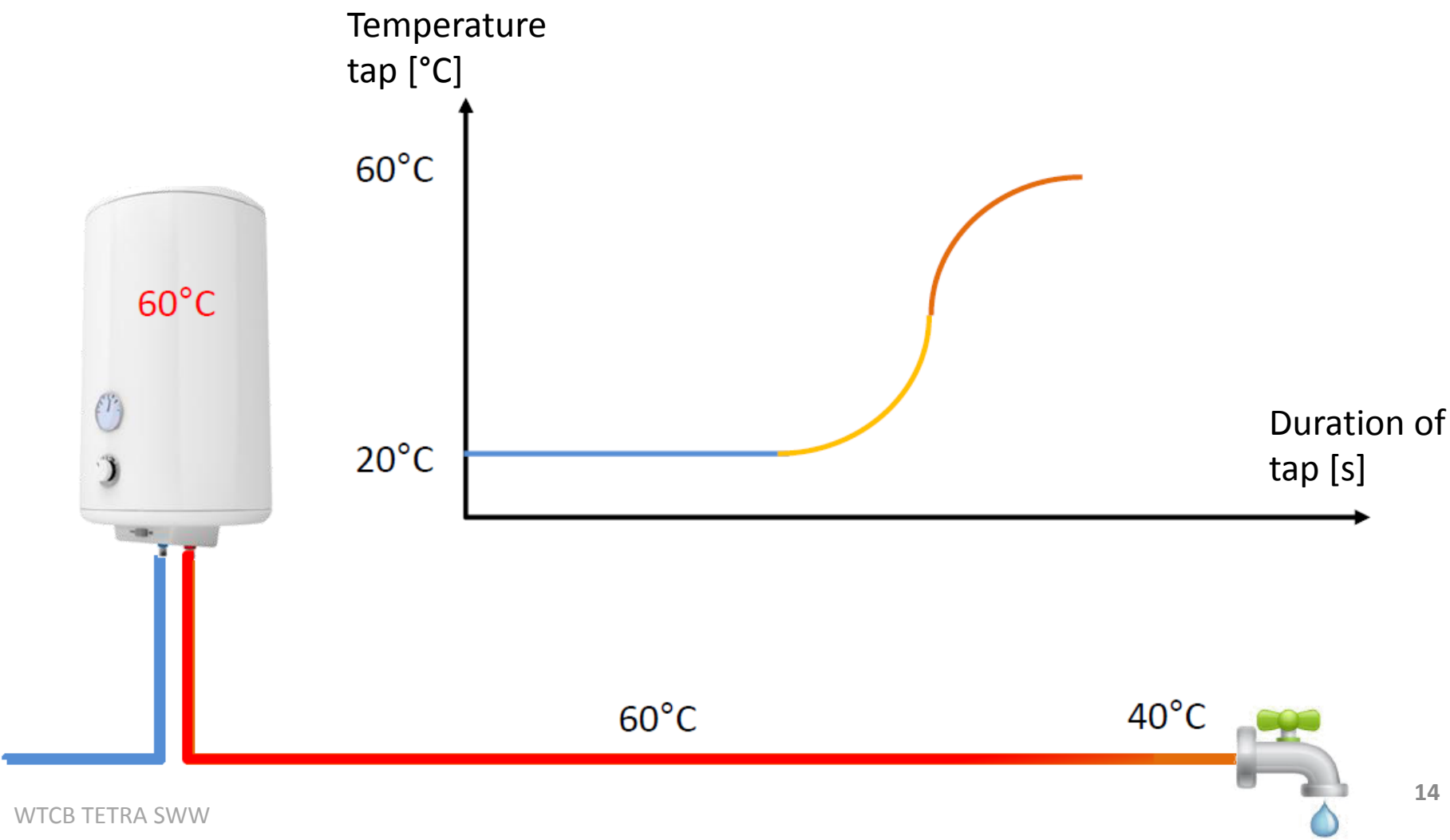

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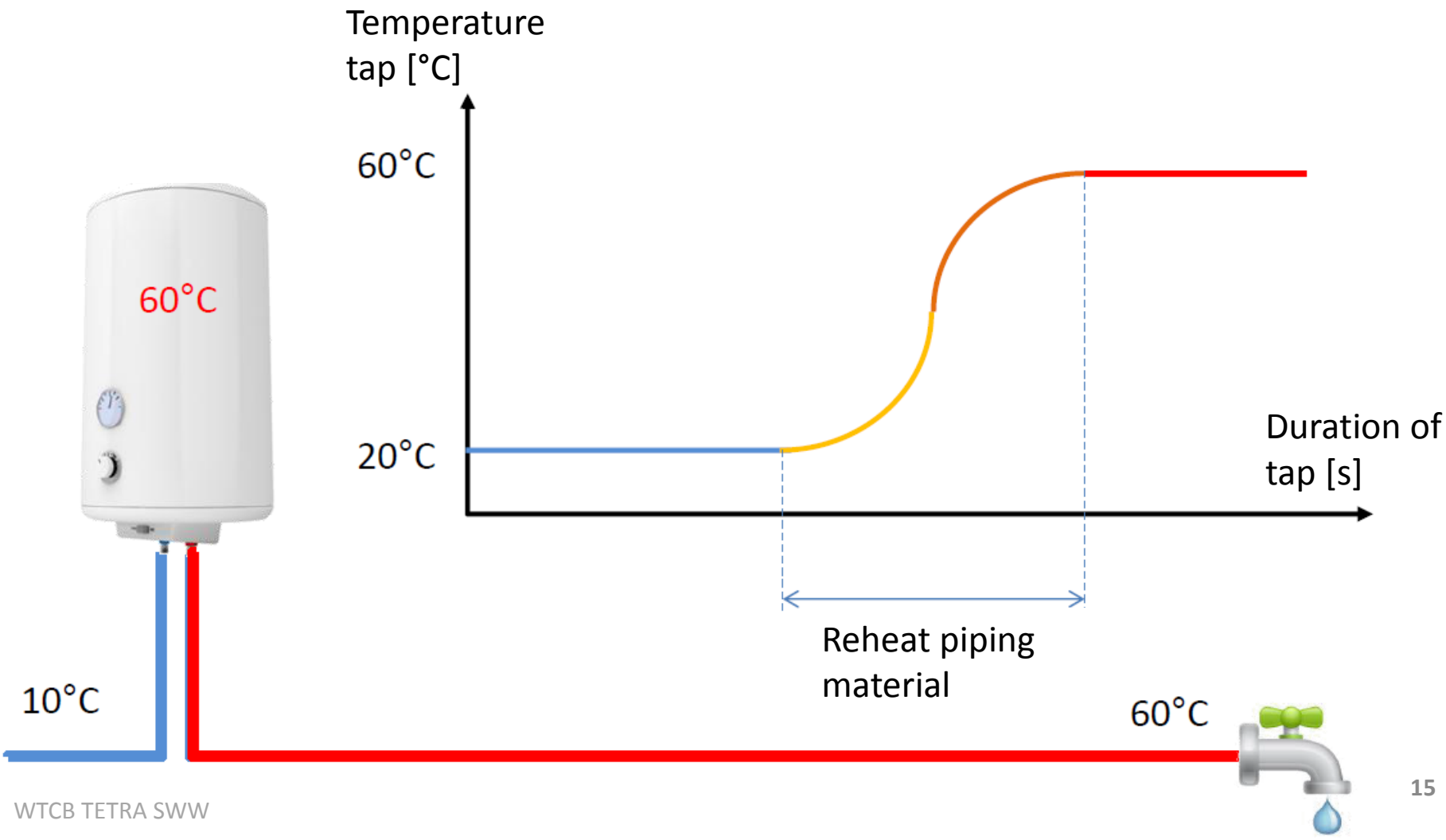


State of the art

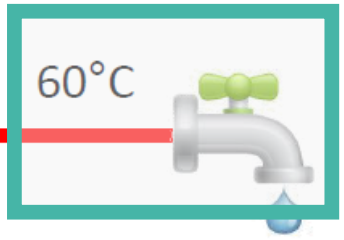
60°C

10°C

https://www.tegeldepot.nl/nieuws/Thermostaatkraan-biedt-veel-voordeel/

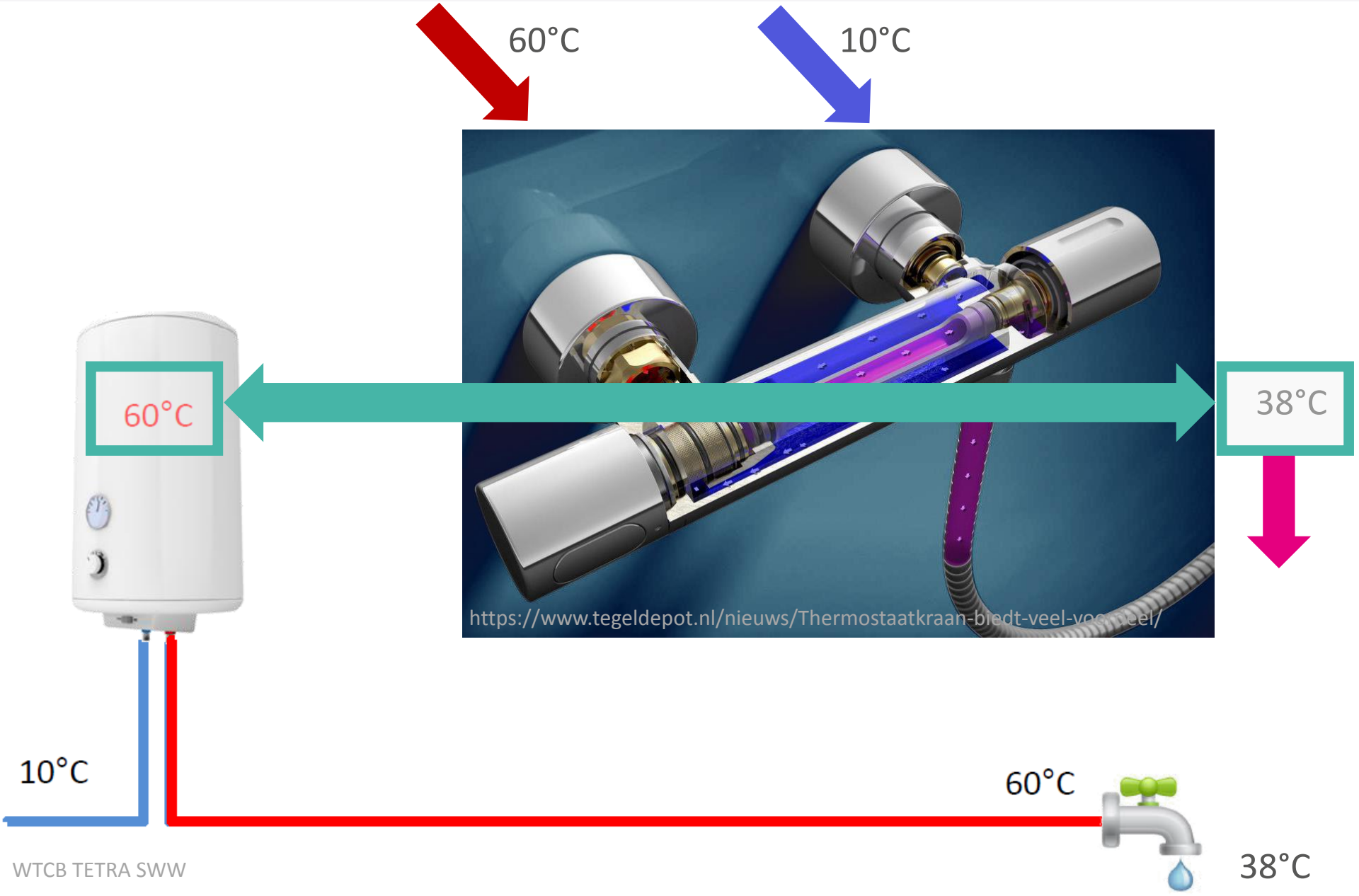
38°C

10°C



38°C

State of the art



- ***Legionella pneumophila***
  = bacteria
  - Acute respiratory disease
    (Pontiac Fever)
  - Severe pneumonia
    (Legionnaires disease)

- **>60°C**: growth temperature limit

DHW production and distribution	
Production and distribution	> 60°C

DHW application	NBN 345	ISSO
Washing hands	35°C	40°C
Shower / Bad	40°C	37°C

Key parameters from literature review

Water between 20°C and 45°C

Pasteurization

Amoebae

Stagnation

A. Castellani

Shock disinfection

Creation of aerosols

Acanthamoeba

Aerosols reach alveoli

Free chlorine

Acid environment

UV radiation

Condition of victim

Biocides

Biofilm

Copper

Nutrients

Copper-silver ionization

Zn

Fe

Objectives

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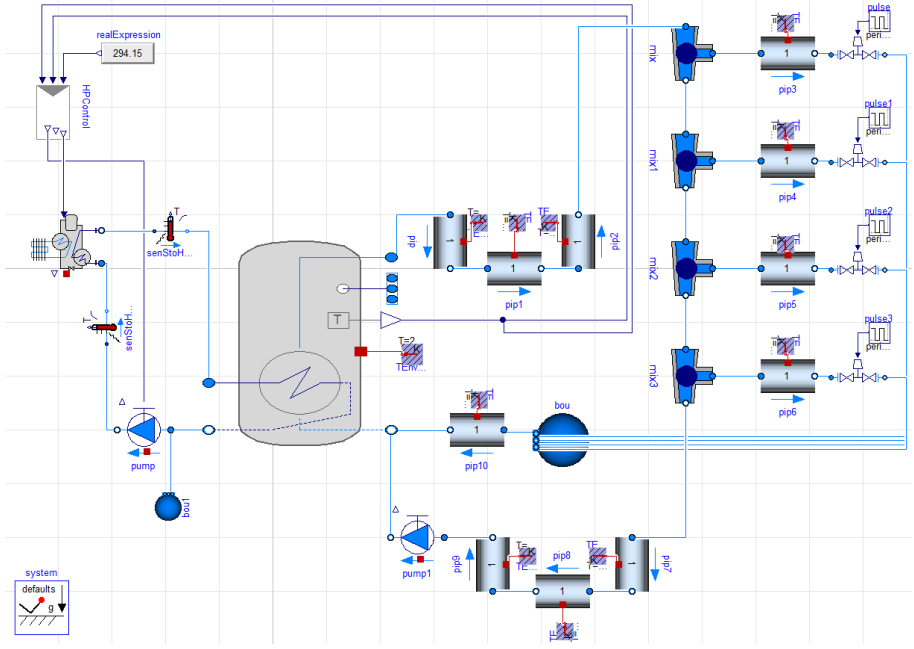
Key parameters from literature review

Compile a simulation model …

… that allows to investigate the **infection risk** *for Legionella pneumophila* in the design phase of a DHW system

… to test the **effectiveness of disinfection techniques** on an infected system



Practical implications

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Key parameters from literature review

↓

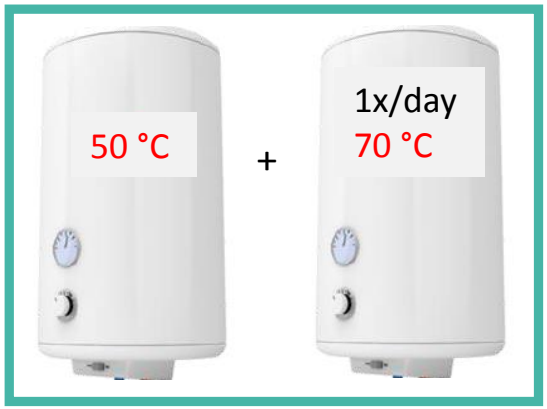
Compile a simulation model ...

↓

HVAC designers ...

... will be able to assess the **infection risk** associated with their design

... reduce the energy demand for DHW production by **optimizing temperature regimes**,...



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What is *Legionella*?

- Background
- Profitable conditions
- Infection process
- Water treatment techniques

Chapter 2

Background

- <1974 Outbreak Hospital in Washington
  - **81** patients became ill, **14** died
- 1974 Oddfellows Convention in the Hotel in Philadelphia
  - **20** attendees became sick, **2** died
- 1976 Outbreak Philadelphia
  - American Legion's Convention at a hotel in Philadelphia
  - **221** American Legion Members were struck, **34** died

Profitable conditions for *Legionella pneumophila* growth

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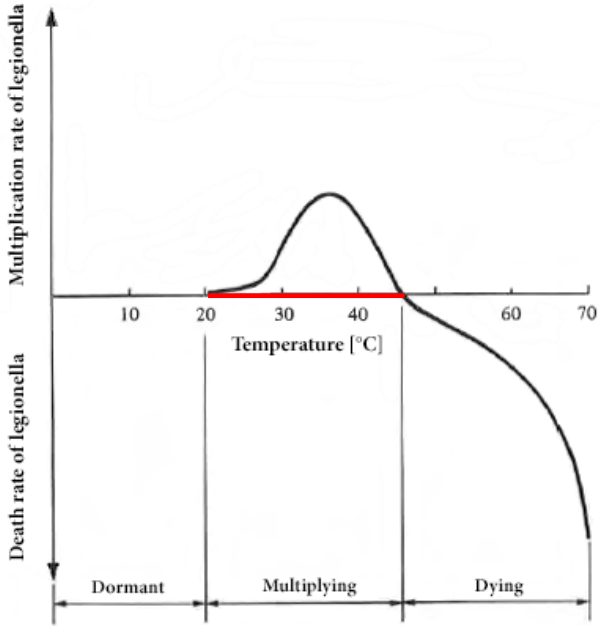
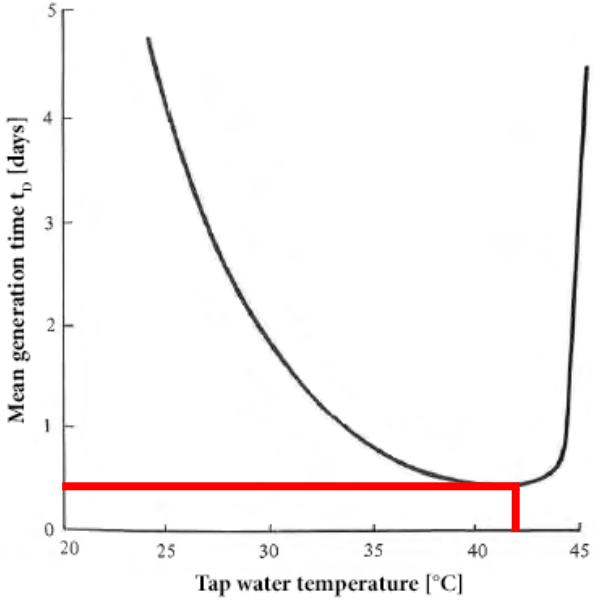
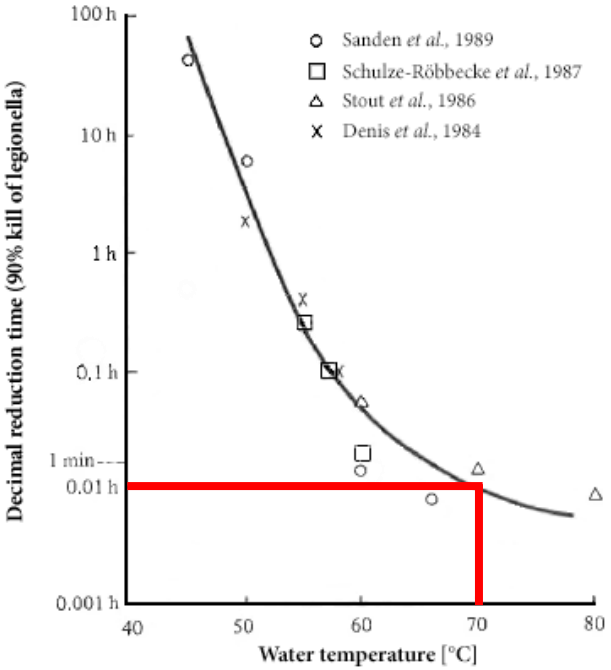
- *Legionella pneumophila* species appear **in most water supplies**
  - Low natural concentrations can be increased in hot water systems where the **temperature is optimal** for their growth







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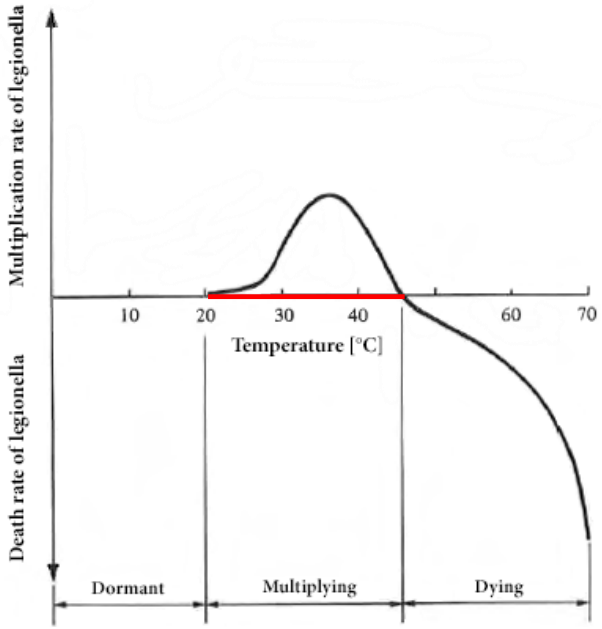

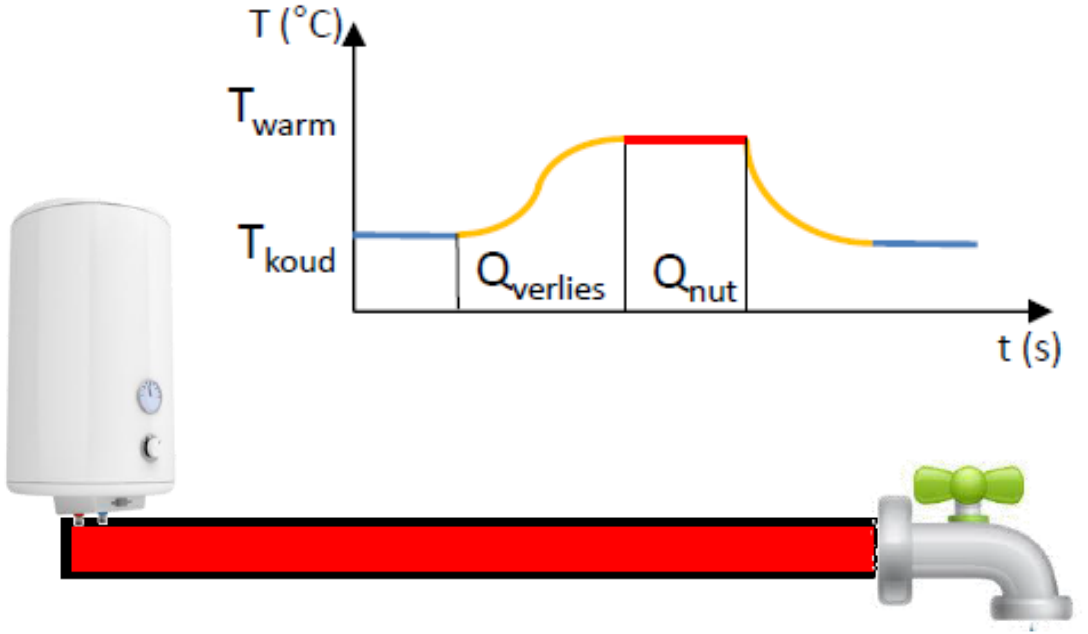

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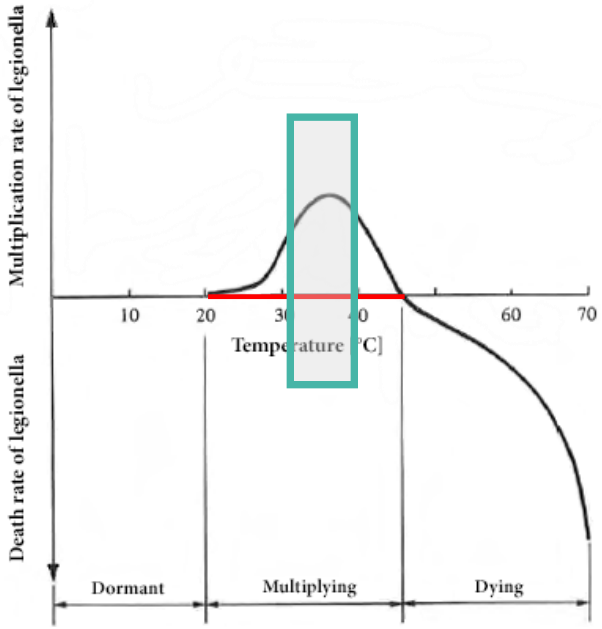
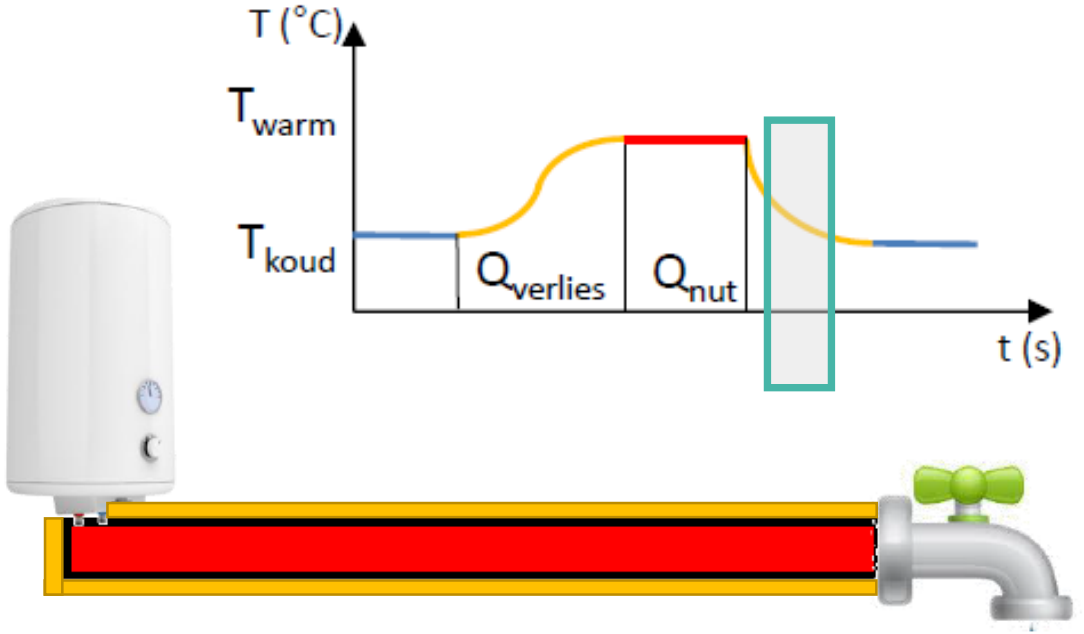




Profitable conditions for *Legionella pneumophila* growth

- **Stagnant** sections of piping

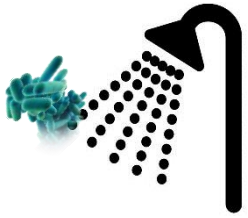
- **Presence of bacteria** is essential for the survival of *Legionella pneumophila* in water systems (HPC mean between 5 and 6 logs cfu/100mL)

- Presence of metals
  - **Fe, Zn favour** *Legionella pneumophila* growth (Fe > 0.095)
  - **Cu inhibits** *Legionella pneumophila* growth

Infection process

- 4 critical steps

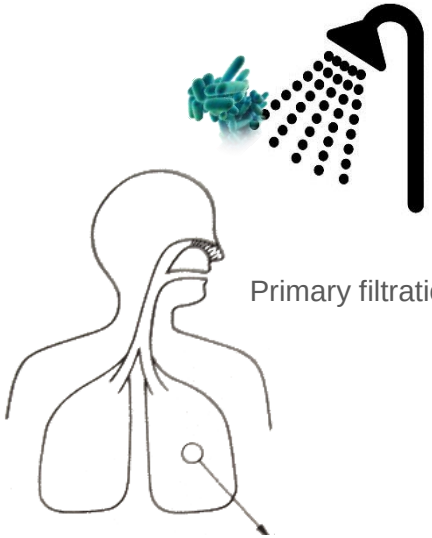
1. Profitable conditions to multiply > dangerous concentration



Infection process

- 4 critical steps

1. Profitable conditions to multiply > dangerous concentration
2. Inhaling aerosols which contain *Legionella pneumophila*



Primary filtration in nose

Infection process

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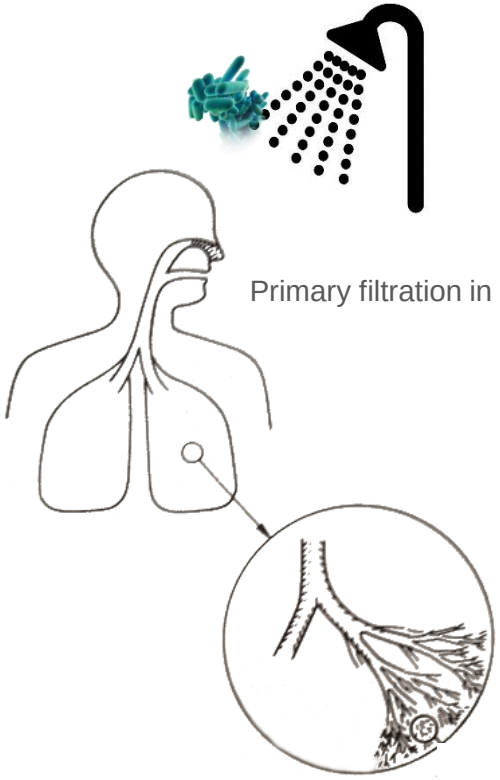
4 critical steps

1. Profitable conditions to multiply > dangerous concentration
2. Inhaling aerosols which contain *Legionella pneumophila*
3. Contaminated aerosols reach the lungs > alveoli > bloodstream



Primary filtration in nose

Bronchi: main airways lined with mucus-generating cells and fine ciliary hairs which beat upwards to eject mucus

Infection process

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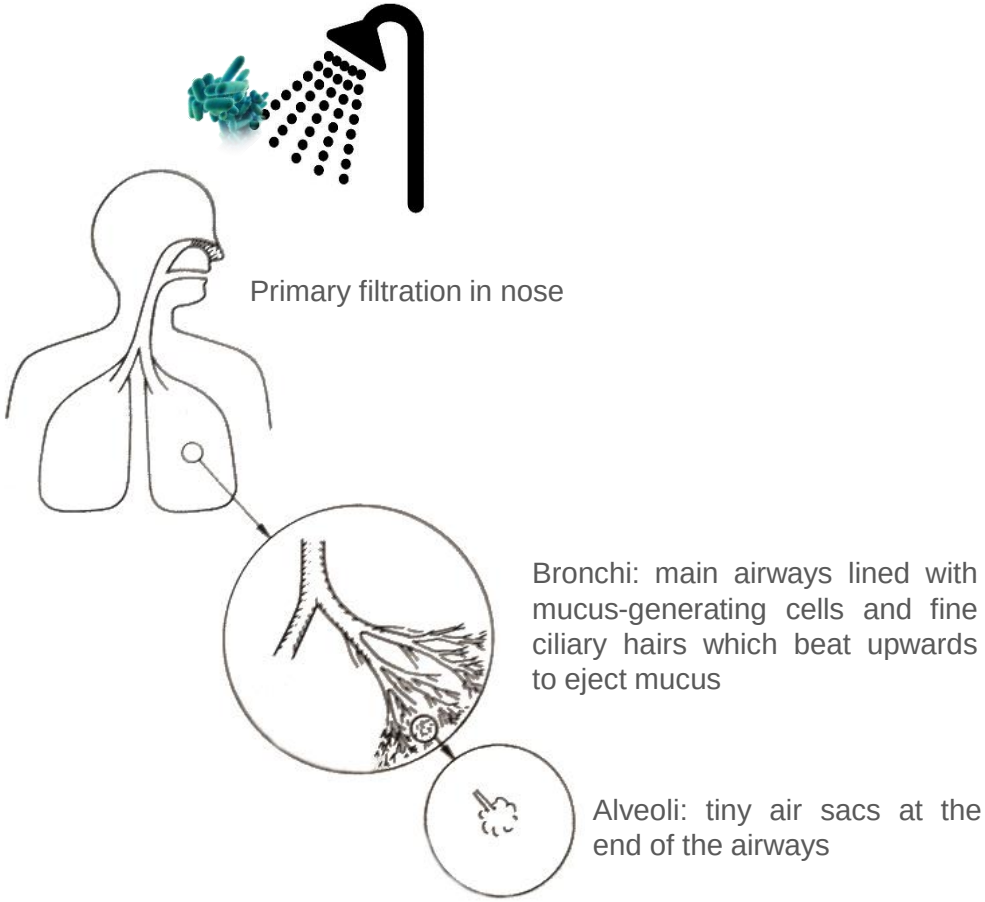
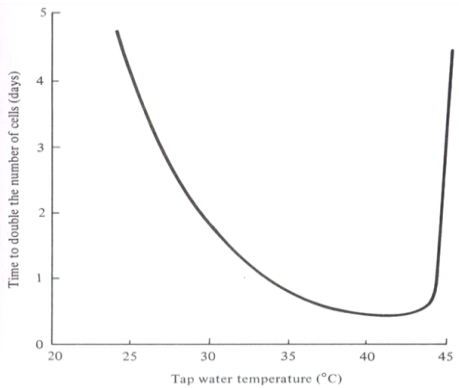
4 critical steps

1. Profitable conditions to multiply > dangerous concentration
2. Inhaling aerosols which contain *Legionella pneumophila*
3. Contaminated aerosols reach the lungs > alveoli > bloodstream
4. Condition of the victim



Water treatment techniques

- Primary disinfectant: **Thermal treatment**
  - Water temperature **> 60°C** when leaving heating unit (WHO)
  - Water temperature **> 50°C** when reaching the tap (WHO)



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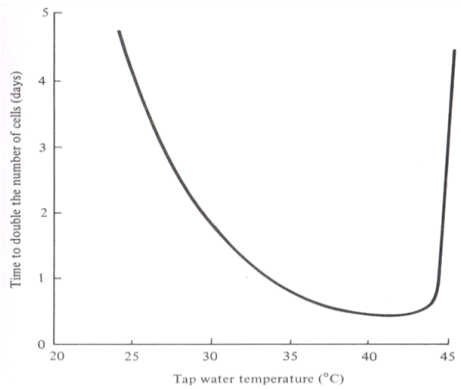
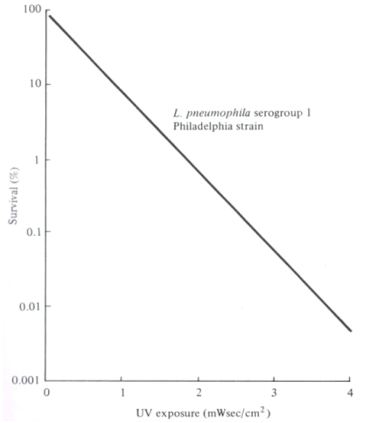


- Secondary disinfectant: **Ultraviolet radiation**
  - High maintenance of the system
  - **Filter** is required ahead of the UV unit



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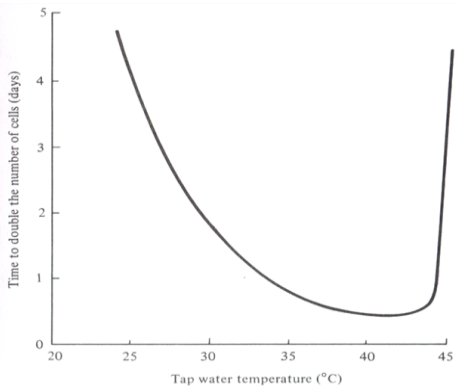

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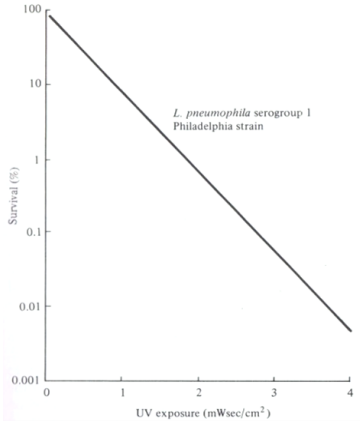
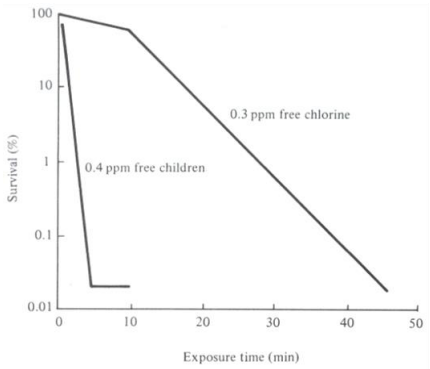


- **Free chlorine**
  - Low concentration (0.2-0.5mg/l) > secondary disinfectant
  - Hyper chlorination (higher concentrations) > installation disinfection treatment
  - 4-6ppm > 90% kill *L. pneum.* species <=> drinking water < 0,75ppm
  - **Can damage plumbing components**



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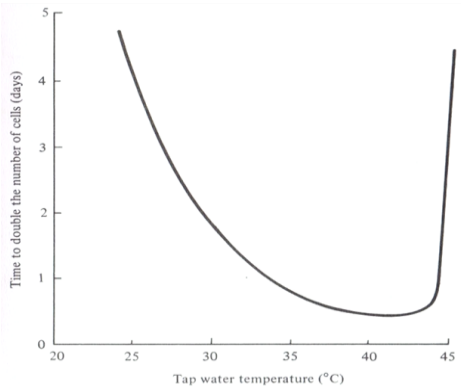

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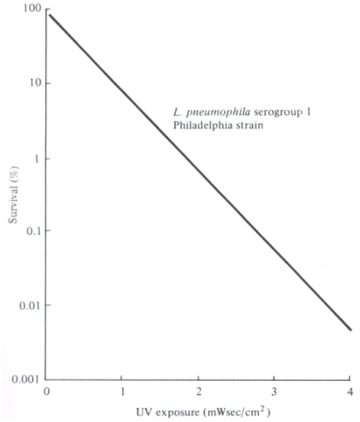

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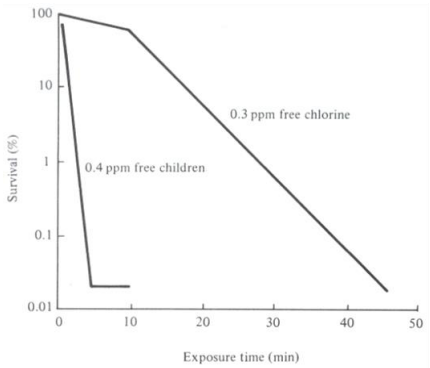
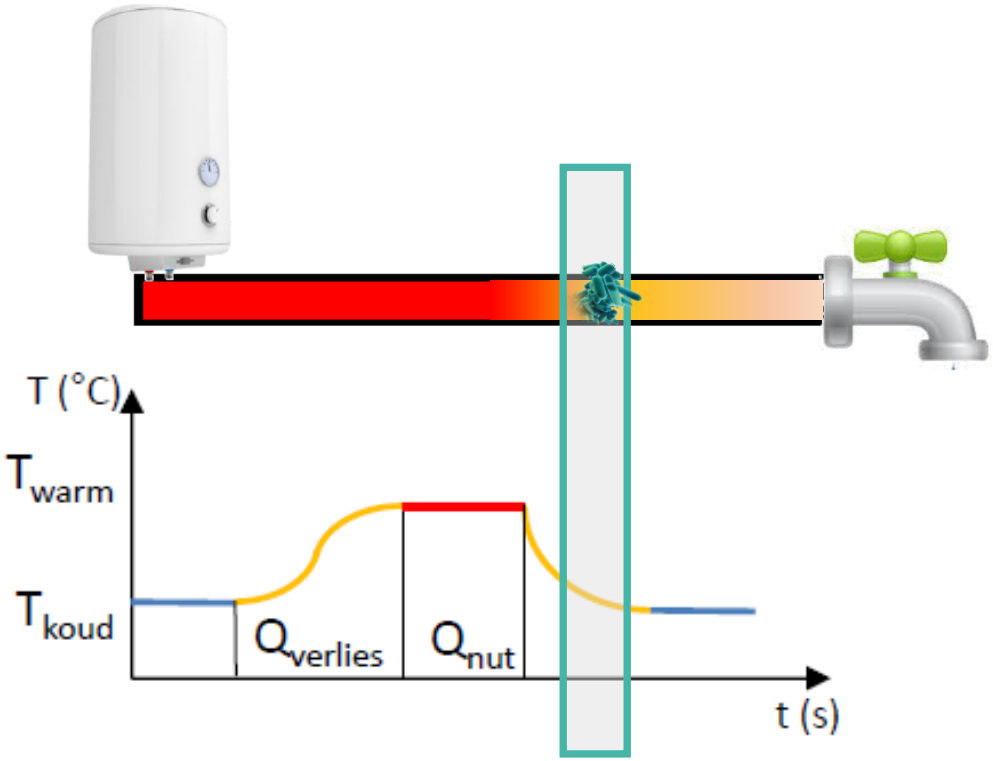


- **Copper-silver ionization**
  - Injection of **small quantities of copper and silver** in water

Water treatment techniques

- Not only in water, also surface-associated in **biofilm**
- Microbial cells that are attached to the surface in a **matrix**
- Protective layer for the bacteria which allows them to **grow and multiply in the biofilm**
- Bacteria in biofilm become **more resistant** to environmental stress



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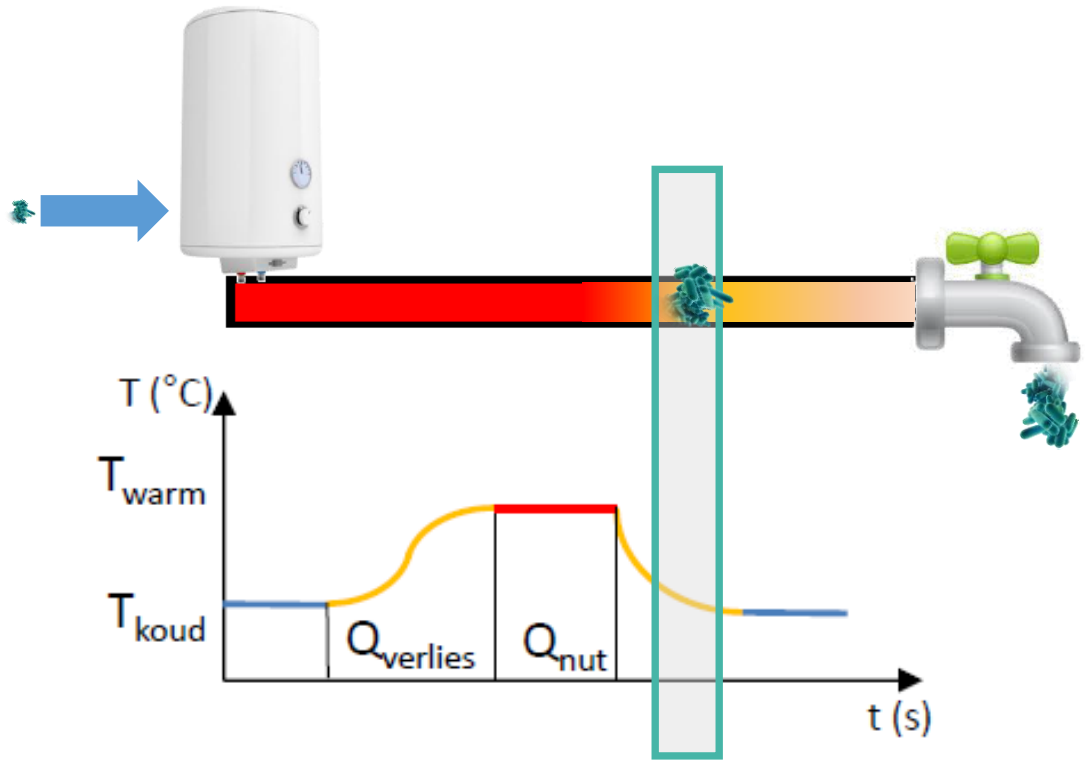

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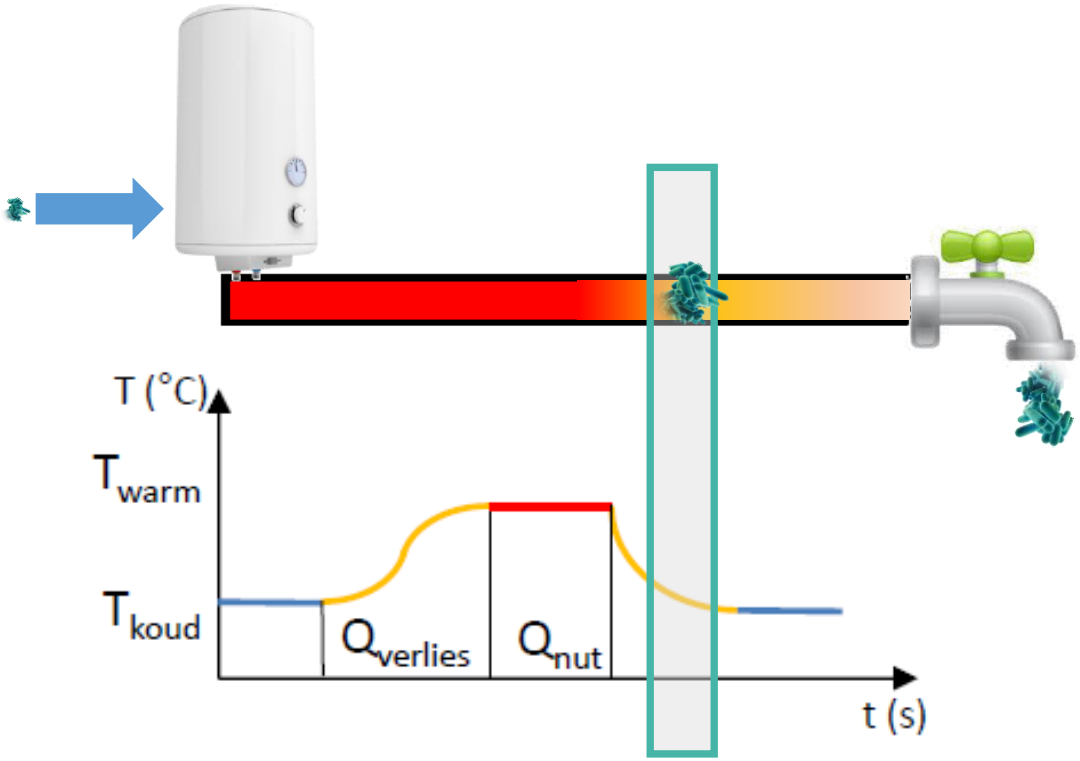
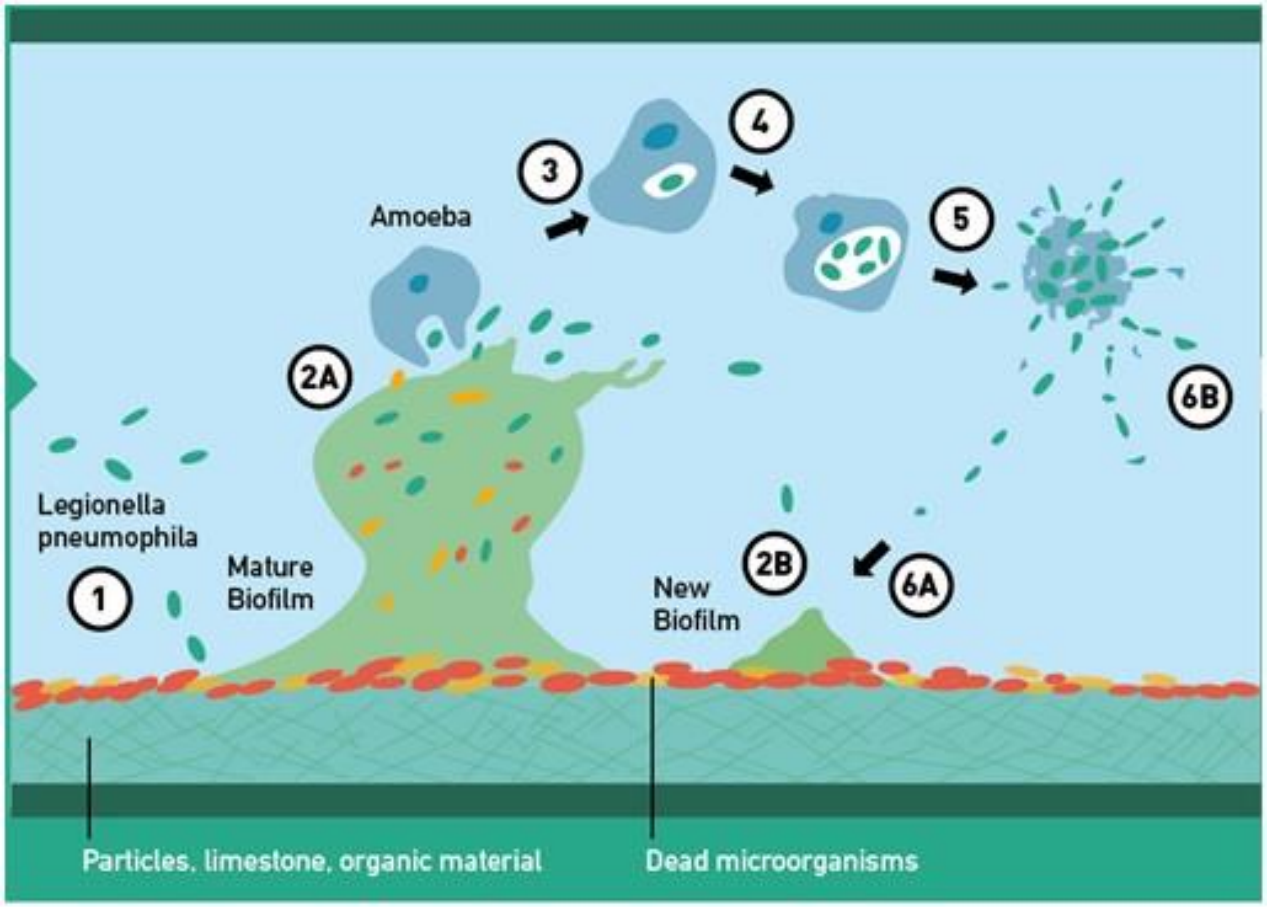


Water treatment techniques

- Survive as in intracellular parasite of free-living **amoebae**
- Use the amoeba host nutritional sources to **replicate intracellularly**



http://www.adept-dental-water.com/articles/legionella-pneumophila-%E2%80%93-lifestyle--virulence-and-presence-in-dental-unit-waterlines.aspx

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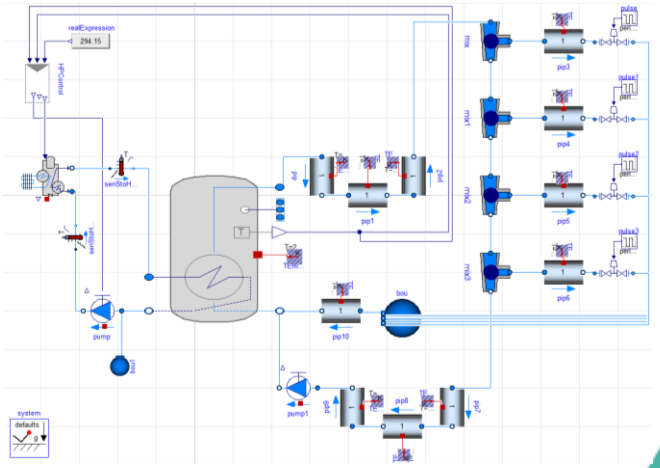
How to lower DHW energy use?

- Methodology
- Simulation model
- Test rig
- Case study buildings

Chapter 3

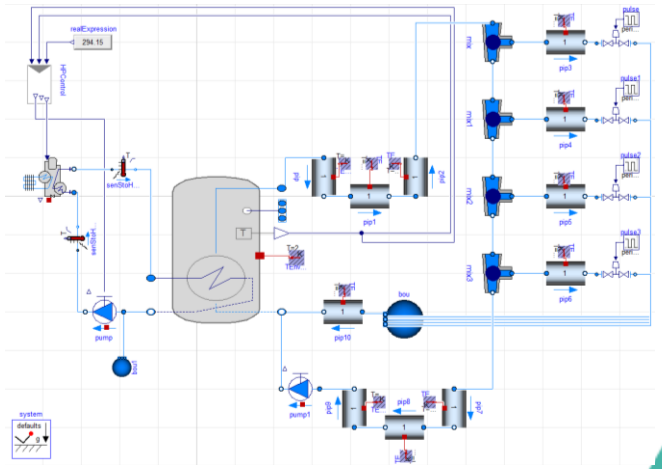
Methodology

Methodology



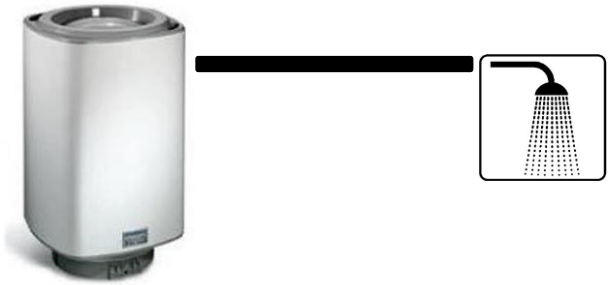
Simulation model

Methodology

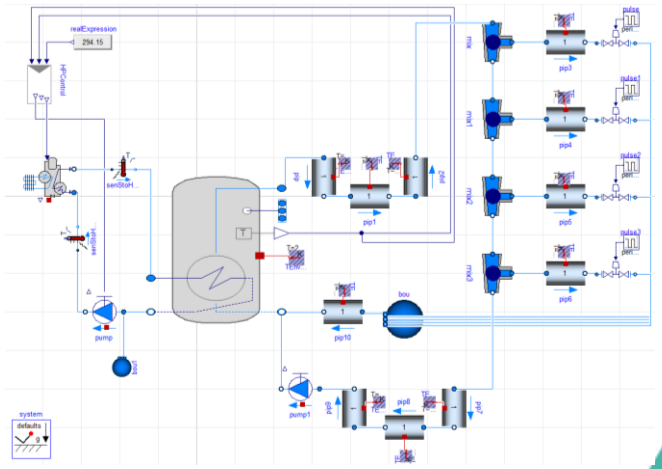


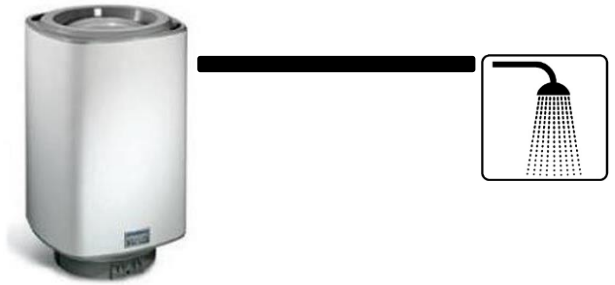
Simulation model

Test rig



Methodology



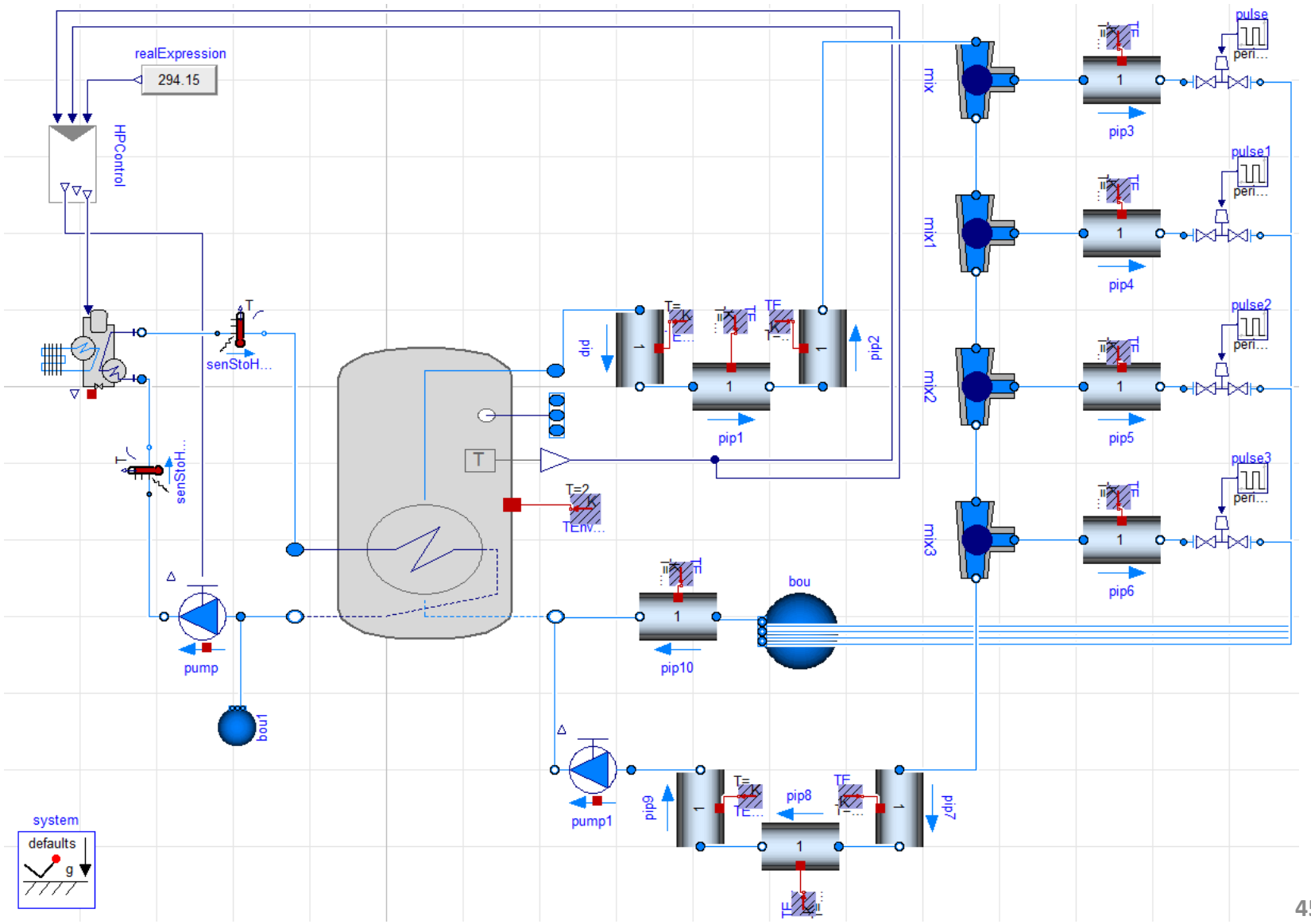


Simulation model

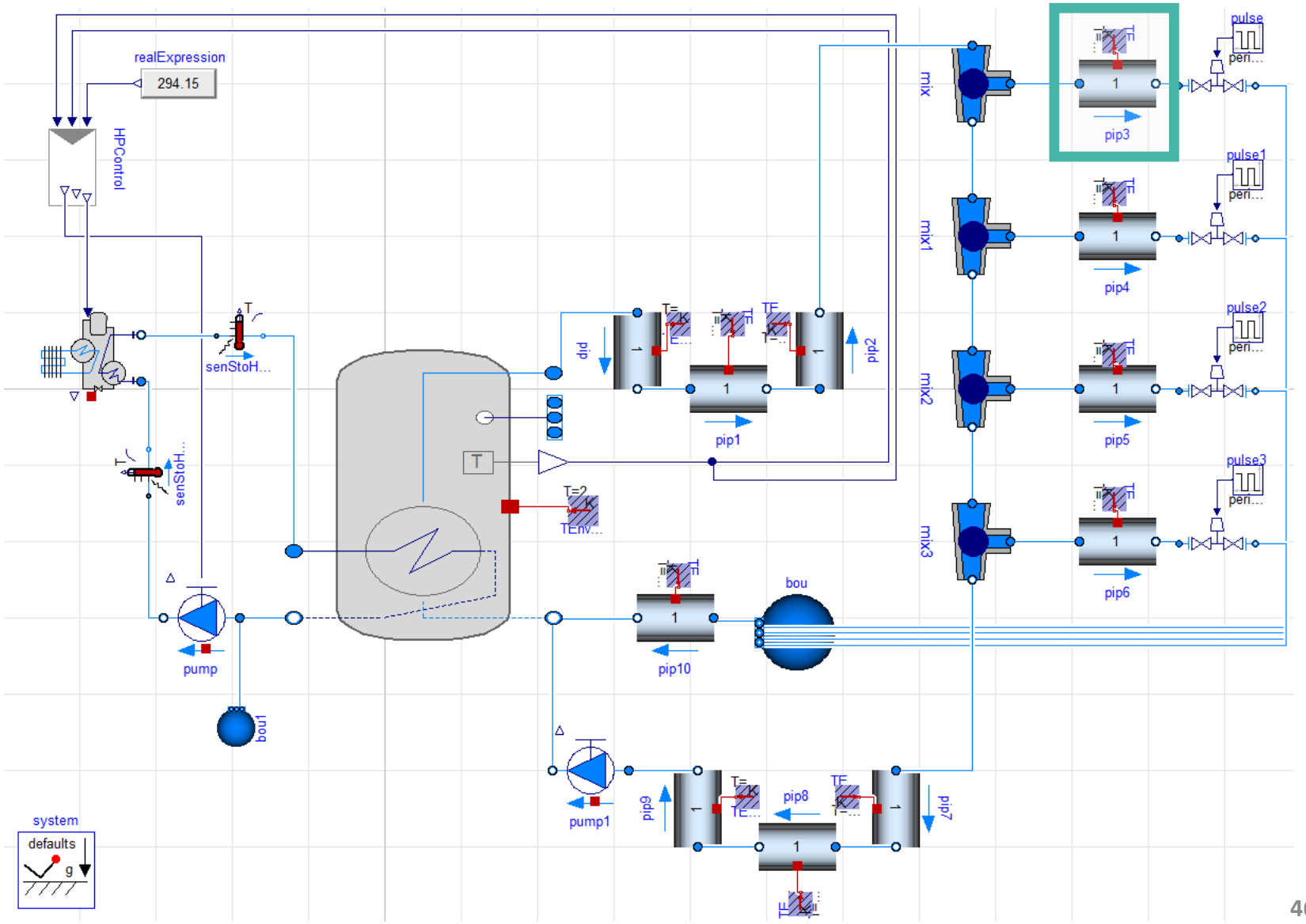
Test rig

Case studies

Simulation model

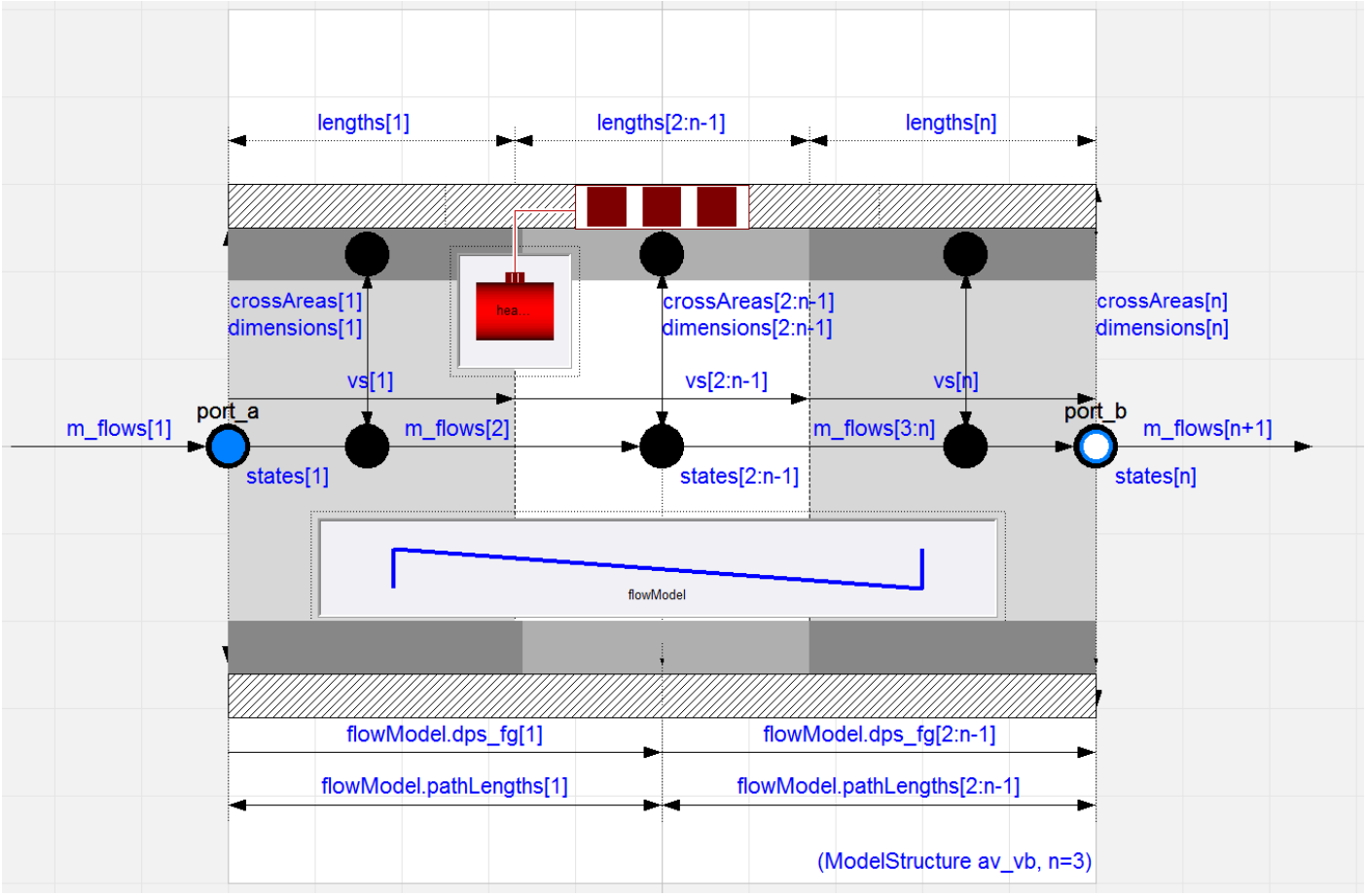


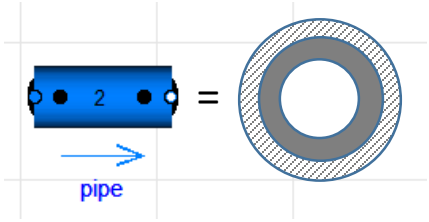
Simulation model



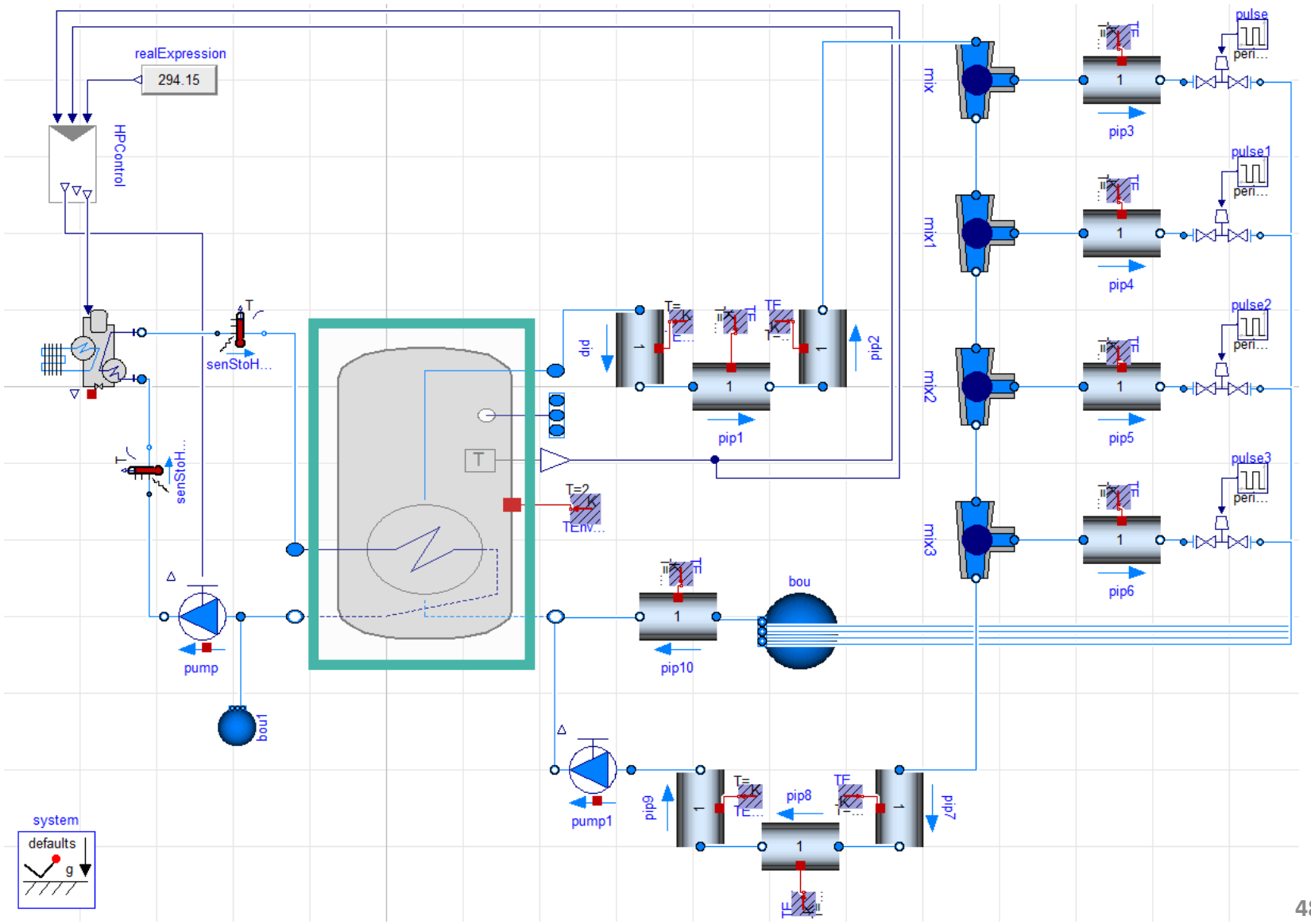
Simulation model

- Adaptation of dynamic pipe model with *Legionella* in water and *Legionella* in biofilm model





Simulation model



Simulation model

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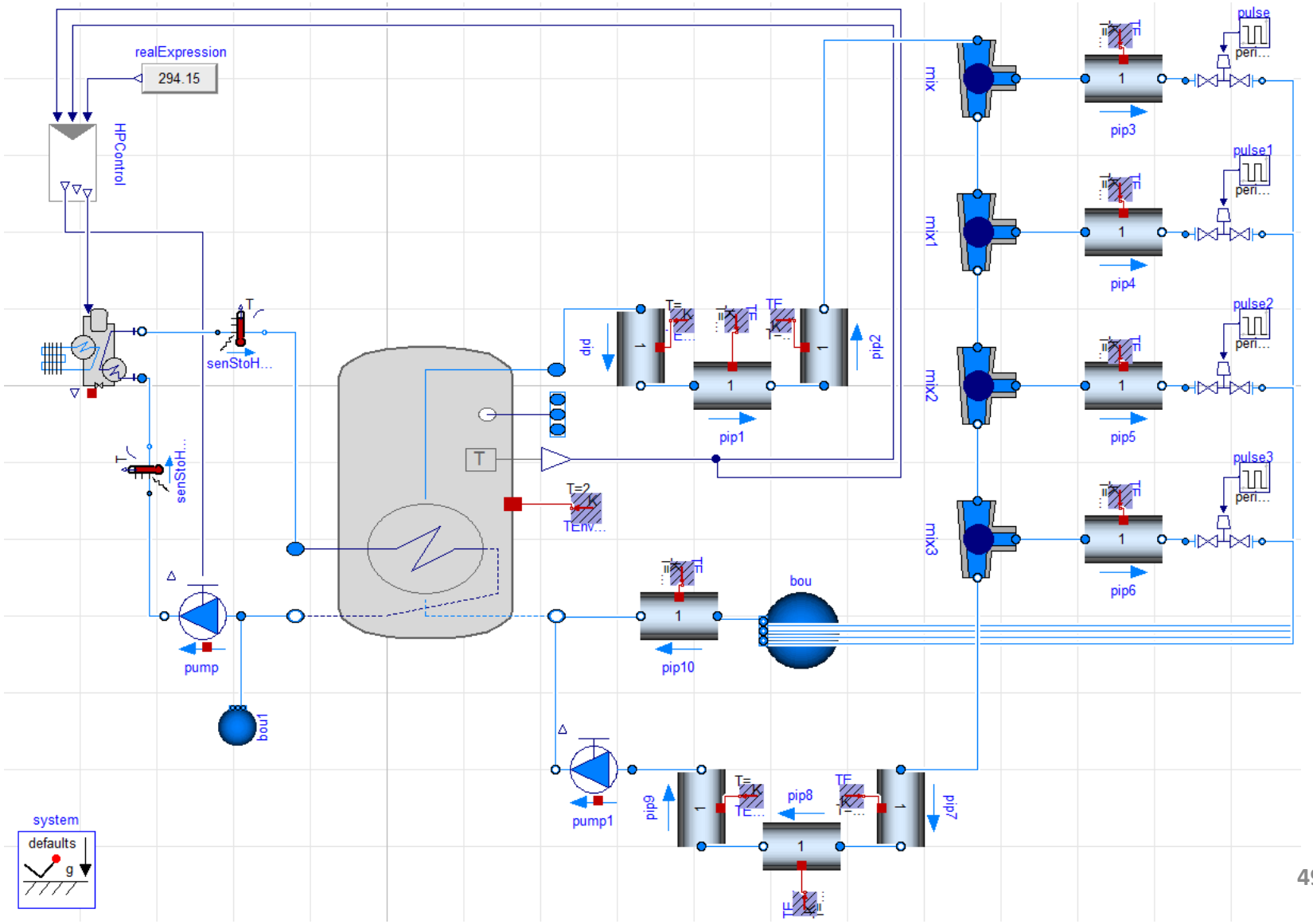
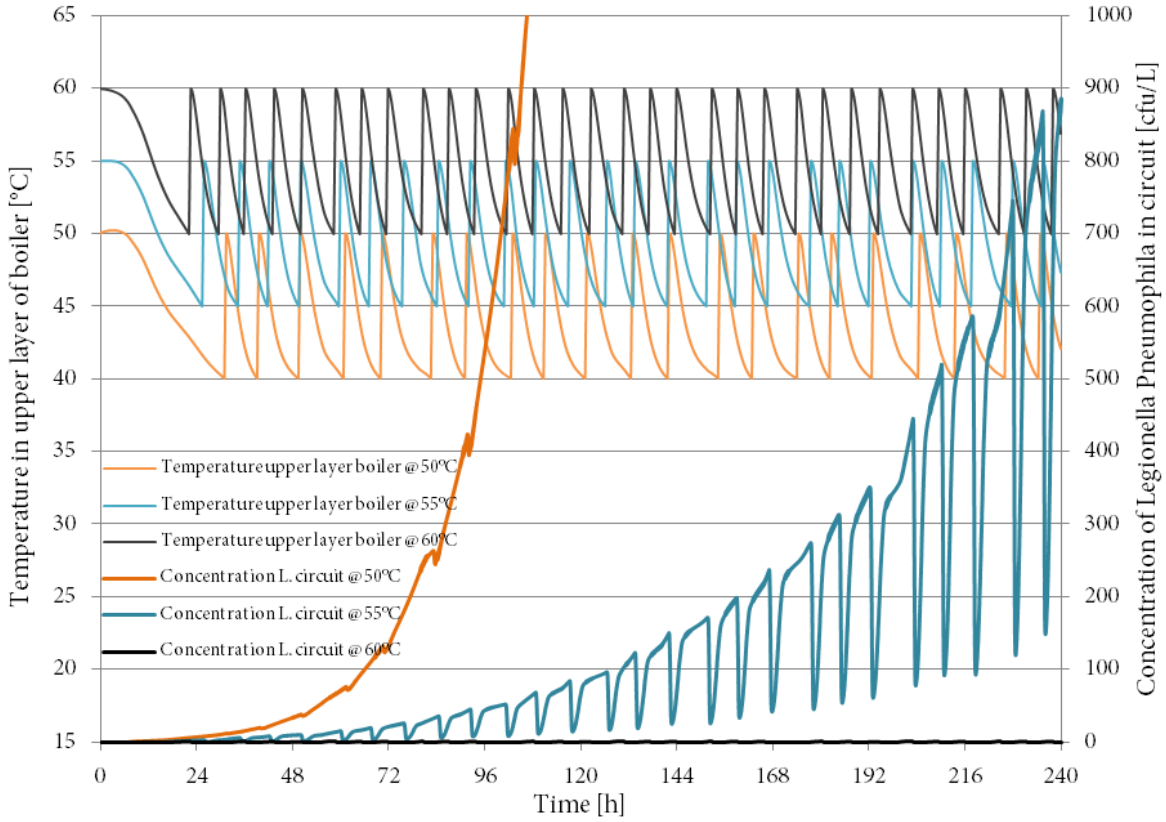
- Dynamic model of circulation system of case apartment building



Simulation model

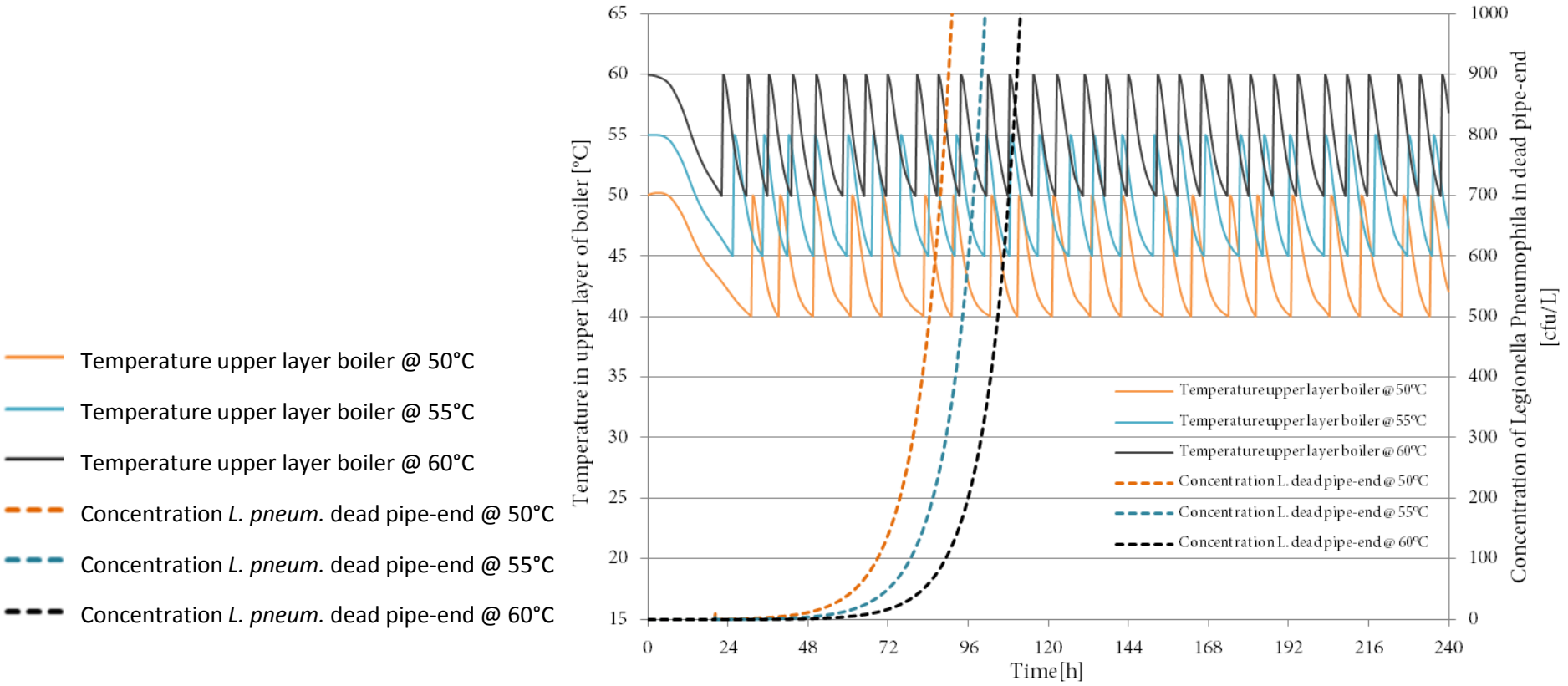
- Influence of the boiler temperature on the concentration of *Legionella pneumophila* in the circuit of case apartment building (10 days)

Temperature upper layer boiler @ 50°C
Temperature upper layer boiler @ 55°C
Temperature upper layer boiler @ 60°C
Concentration *L. pneum.* in circuit @ 50°C
Concentration *L. pneum.* in circuit @ 55°C
Concentration *L. pneum.* in circuit @ 60°C

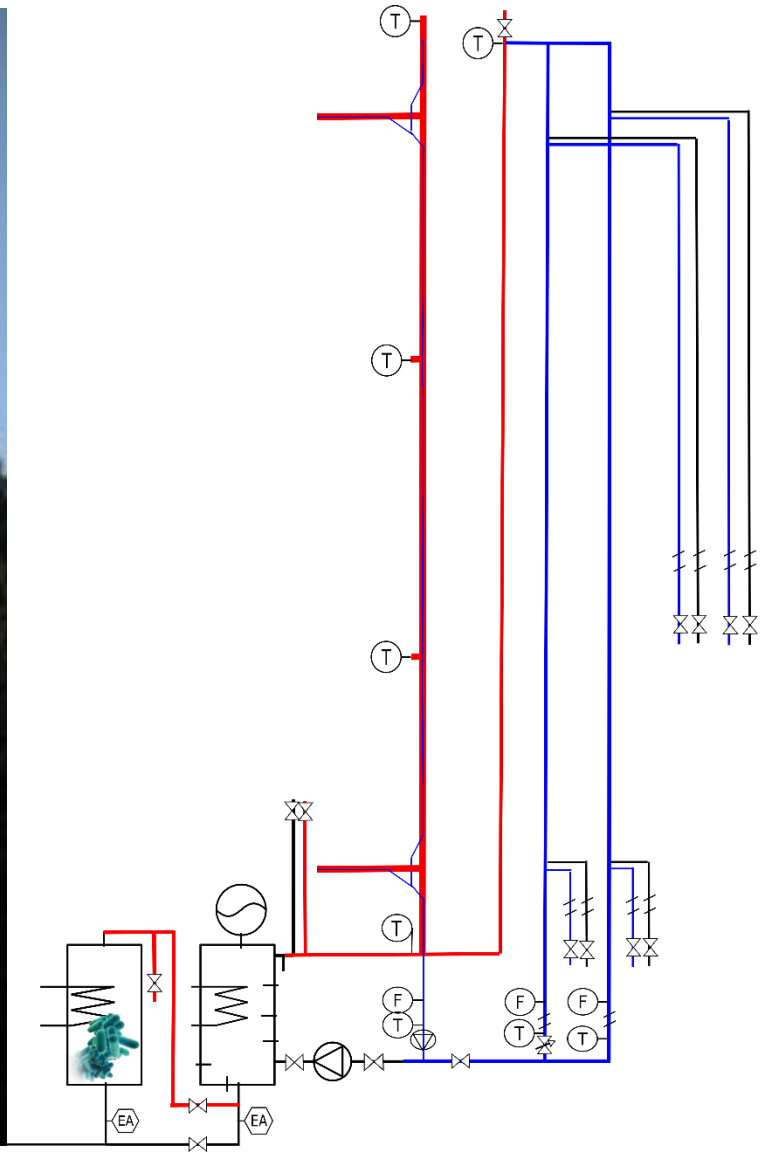


Simulation model

- Influence of the boiler temperature on the concentration of *Legionella pneumophila* in a dead pipe-end of case apartment building (10 days)



Test rig (Instal2020 - WTCB)



Proefopstelling in het kader van onderzoeksproject Instal2020 in de sanitaire toren van het labo watertechnieken van WTCB (Limelette)

Case study buildings

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- **Different systems** for DHW production and distribution
- **Monitoring** of temperature profiles, flow conditions and DHW use on several locations
- Validation of temperature, flow condition and *Legionella* **growth parameters** in model

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PASSIVE AND BEYOND

Conclusions

- Conclusions
- Future research
- Acknowledgement
- References

Chapter 4

Conclusions

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› Requirement: *Legionella* < 1000 cfu/L (circulation system)

VARIATIES	Continu hoge temperatuur	Verhogen pompdebiet	Schokdesinfectie elke 12 dagen
Temperatuur-regime	61-64 °C	50-52 °C	49-51 °C 70 °C (> 3 min)
Pompdebiet	2.500 kg/h	10.000 kg/h	2.500 kg/h
Energiegebruik warmtewisselaar [kWh/jaar]	233.270	168.906	152.524
Energiegebruik pomp [kWh/jaar]	2.365	3.767	2.365
Totaal primair energiegebruik [kWh/jaar]	238.000	176.440	157.254

-26 %

- 34 %

Conclusions

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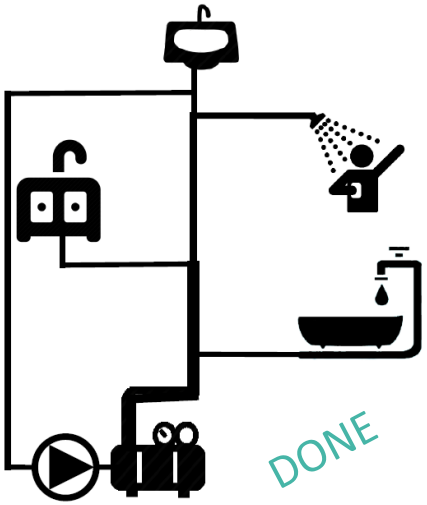
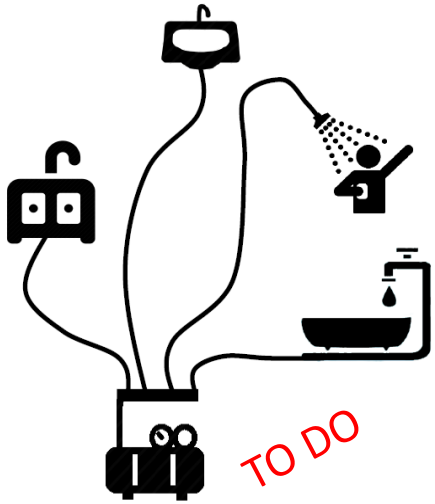
- Little **production temperature** difference can have a large influence on the decontamination level
- Be aware of **dead pipe-ends**
- 50 °C + shock disinfection every 12 days at 70 °C for 3 min = **-34 % energy use**

Future research

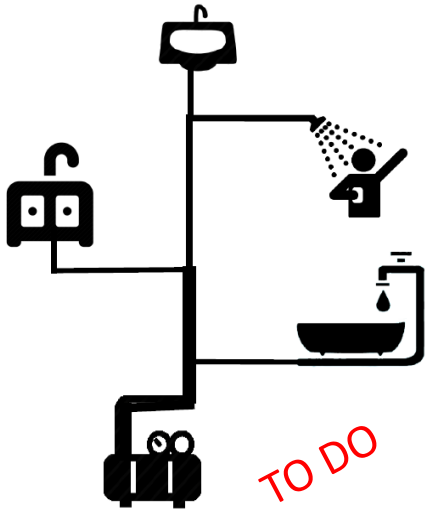
- Assessing the *Legionella* infection risk of different **DHW system configurations**



circulatieleiding



waaier-structuur



boom-structuur

- For each configuration:
  - **Optimization study** that looks for the trade-off between infection risk and energy efficiency
  - **New design guidelines** will be proposed

Minnesota Legionnaires' Disease Outbreak Sickens 23

October 9, 2016

Memphis hotel shut down after outbreak of Legionnaires' Disease confirmed

September 22, 2016

Legionella DNA markers in tap water in Flint, Michigan

August 15, 2016

LEGIONNAIRE'S DISEASE OUTBREAK IN MINNESOTA CLAIMS FIRST VICTIM

September 22, 2016

LEGIONNAIRES DISEASE STRIKES IN COOK COUNTY JAIL

July 14, 2016

New cases of Legionnaires disease confirmed in Harlem

September 1, 2016

Legionella DNA markers in tap water in Flint, Michigan

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More information?

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