Greywater and Heat
– double recycling for sustainability

Ecological assessment of AQUALOOP System

Fraunhofer-Institut für System- und Innovationsforschung (Fraunhofer ISI), Karlsruhe
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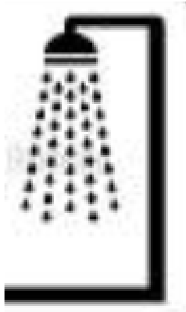
Introduction



- Every time you take a shower valuable water and heat are poured down the drain
- The solution: smart and integrated recycling of **water** and **heat**
- **Water Resource**: Greywater is an ideal resource for water recycling
  - low organic and pollutants loads compared to waste water
  - substitution of drinking water for e.g. toilet flushing, garden, washing machine

- **Energy Resource**: Greywater is an ideal resource for heat recyling and for substitution of fossil energy carriers
  - high temperatures in all seasons
  - 1 m³ greywater, cooled by 10°C substitutes 1 m³ of natural gas (~10 kWh)

Motivation

Water

- With AQUALOOP, less drinking water is required, as water for e.g. toilet flushing, garden etc. is produced in the building from greywater (2nd use, downcycling)
- Less pressure on valuable drinking water resources: even so Germany is a relatively water rich country, our high quality groundwater resources are under pressure due to pollution and overuse, requiring continuously deeper pumping
- Less Water needs to be pumped and treated in the Water Infrastructures

Energy

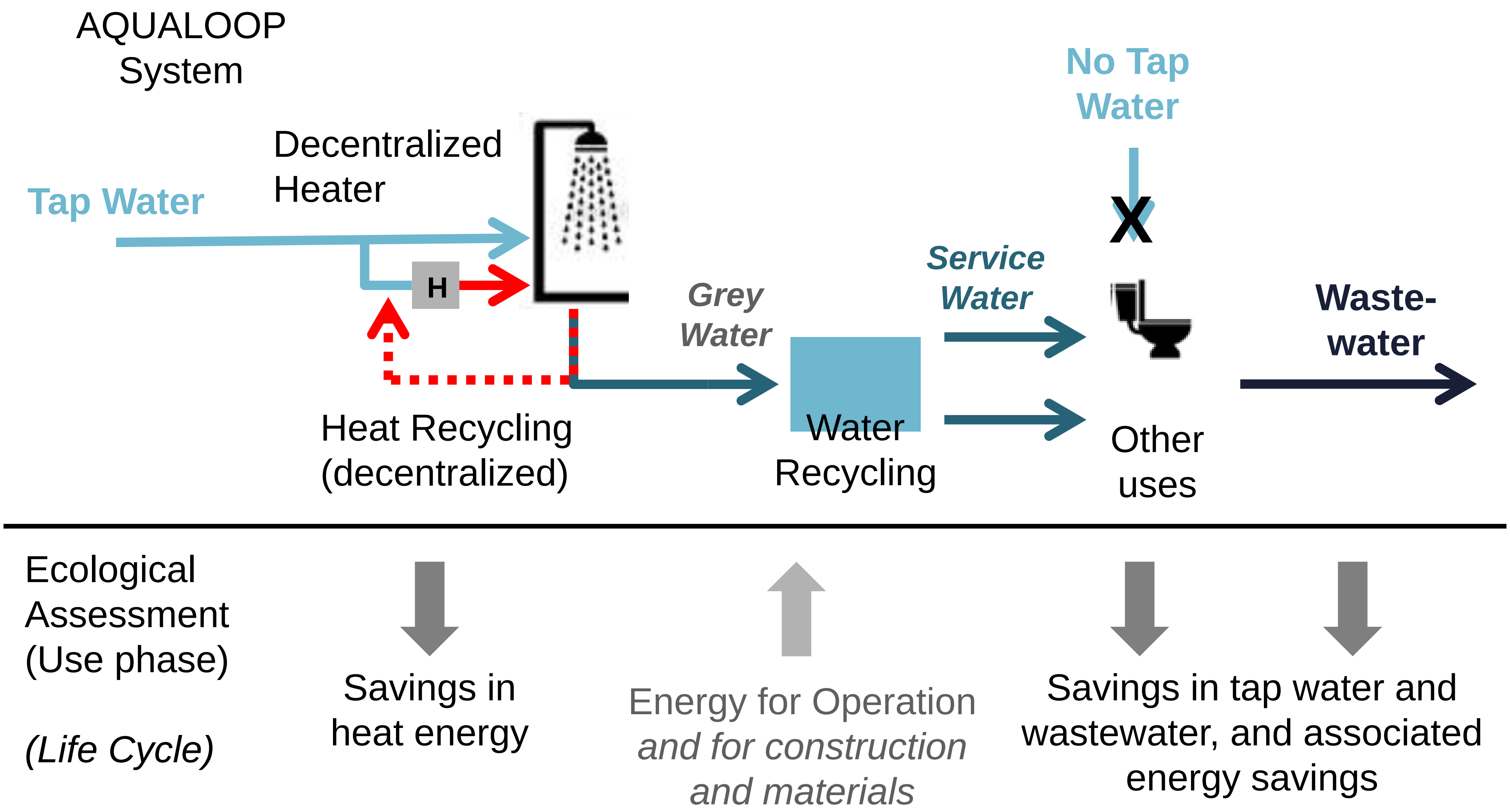
- Less thermal energy for water heating required, as heat from the greywater is transferred safely* to the cold water before heater: Reused energy is renewable energy plus savings in electricity as less water needs to be pumped and treated in the Water Infrastructures, (but additional electricity to run the AQUALOOP System), less CO_2 emissions

Ecosystems

- Less wastewater with lower thermal load reaches the river with benefits for water resources and ecosystems

*double walled transmission to ensure no physical contact between outgoing and incoming water, only heat is transferred

How does it work?



Sustainability of AQUALOOP

How much water and energy do you save with AQUALOOP?

- To assess the ecological sustainability, we perform the
  - Water balance
  - Energy balance
  - CO_2 balance

  of AQUALOOP during the use phase

- We also assess the full life cycle including
  - Production of materials, including piping and membrane cleaning
  - Manufacturing of components
  - Material recycling

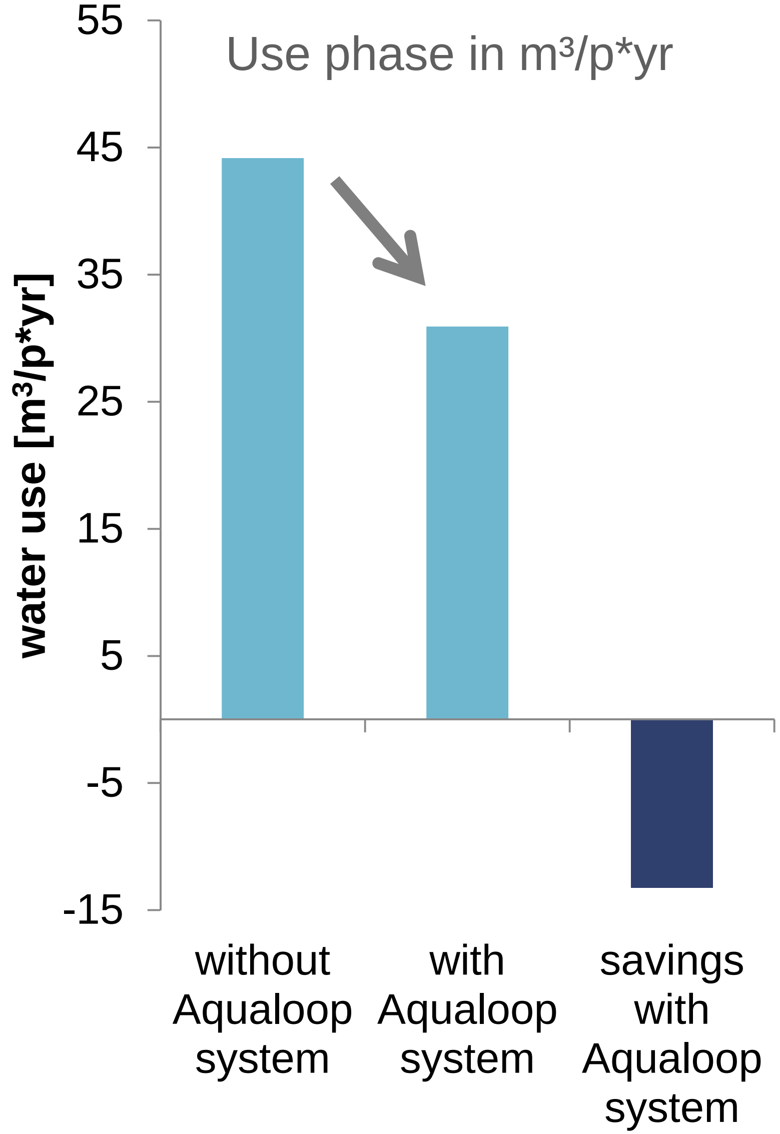
- We analyse the AQUALOOP System in different settings
  - One family home to high rise building with 100 people, sports facility and hotel

Water balance

- Considerable savings in **water** use and consequently in wastewater generation

- **12-18 m³** per person and year or **30%** of water use
- **240- 360 m³** per person during 20 years of lifetime

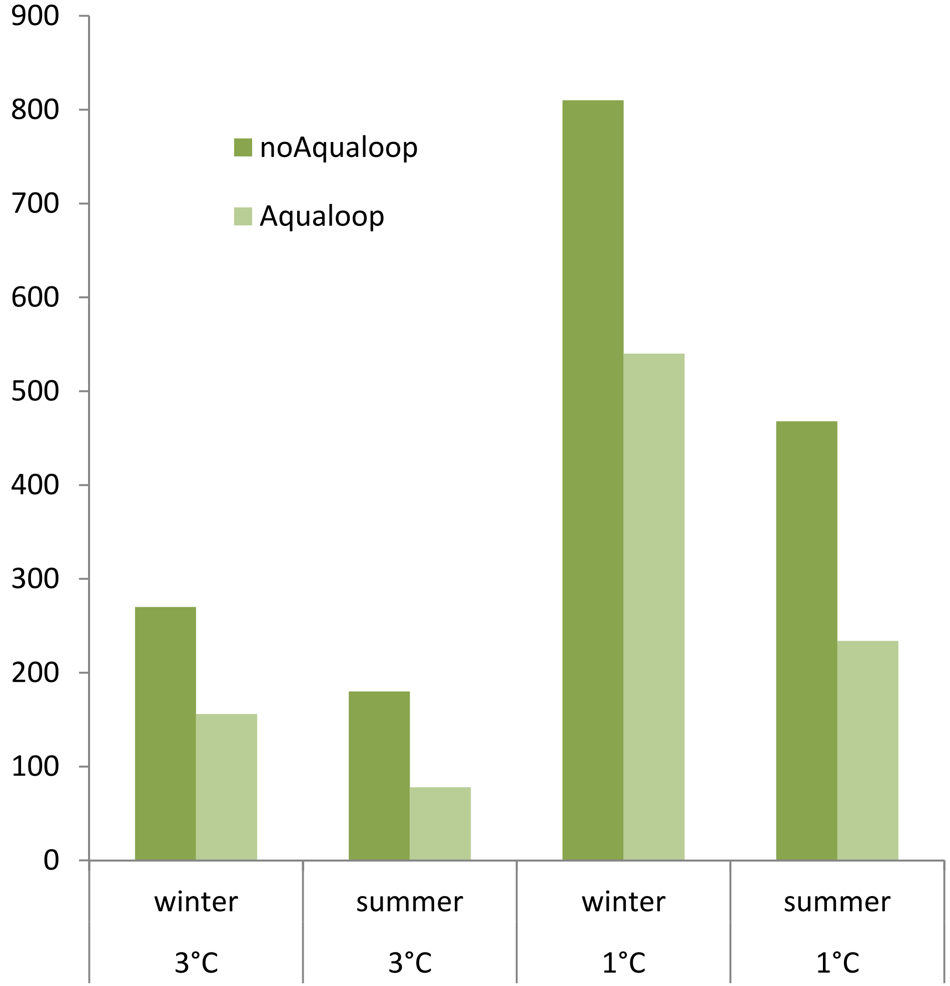
- Less Water needs to be pumped and treated in the Water Infrastructures
- Besides the savings in water and wastewater, there are associated **energy** savings in the water infrastructures



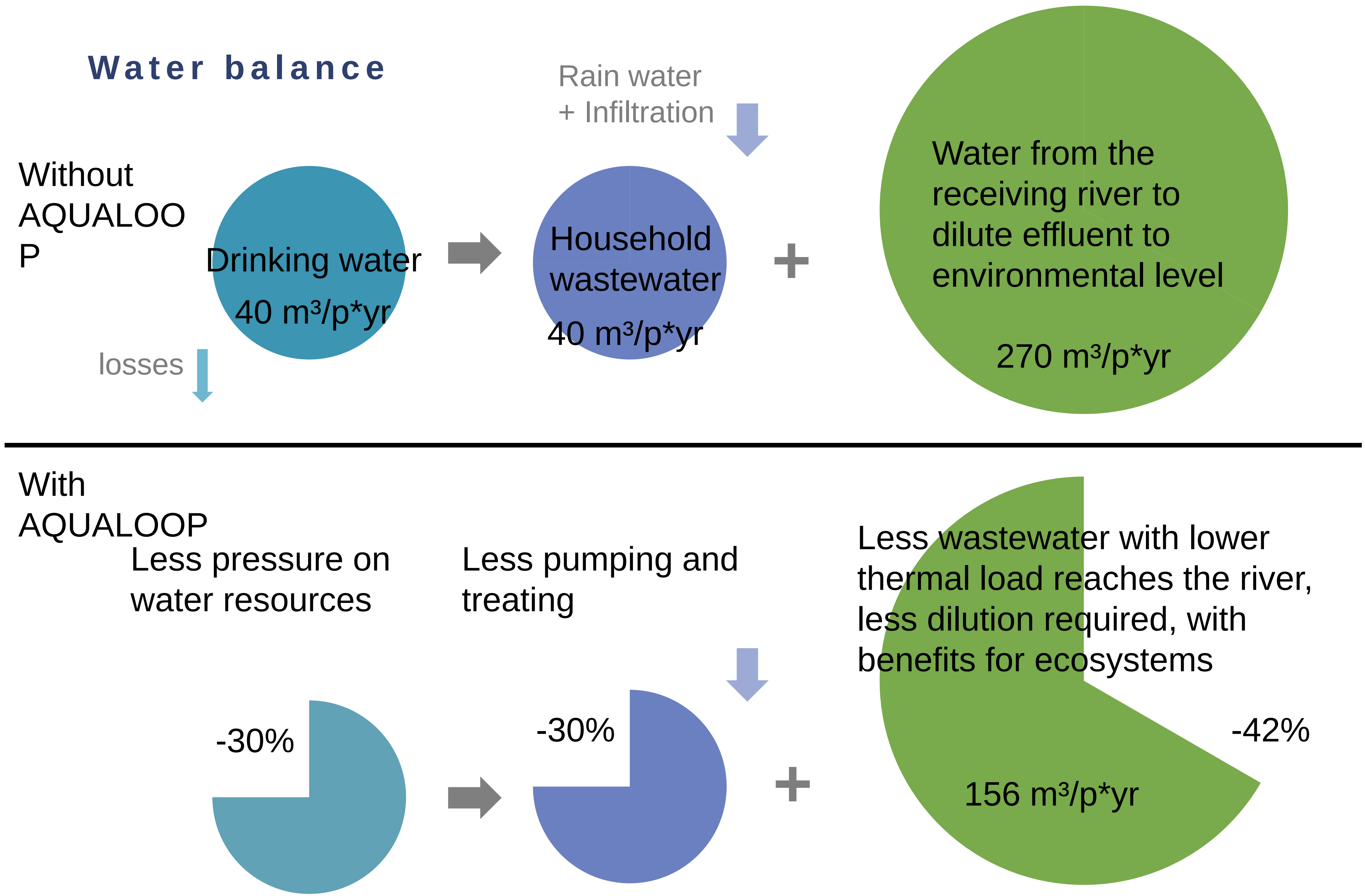
Water balance

- Additional effects are savings in **water from the receiving river**
- As less wastewater with lower thermal load reaches the river, less dilution is required, with benefits for ecosystems
- Amount depends on the maximum allowable temperature increase in the river (3°C standard value, 1°C for sensitive rivers)
- Saves **100-250 m³** per person and year or **40-50%** **2000- 5000 m³** per person during 20 years of lifetime

Use phase in m³/p*yr



Water balance



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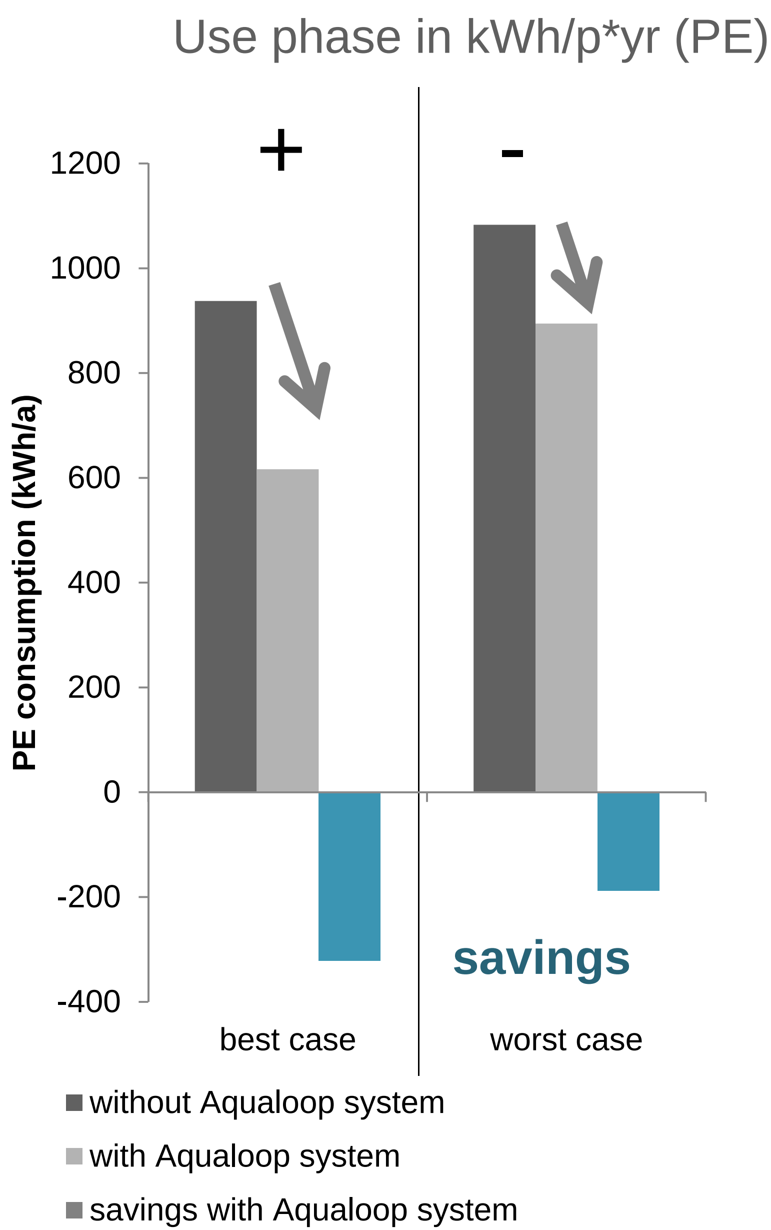
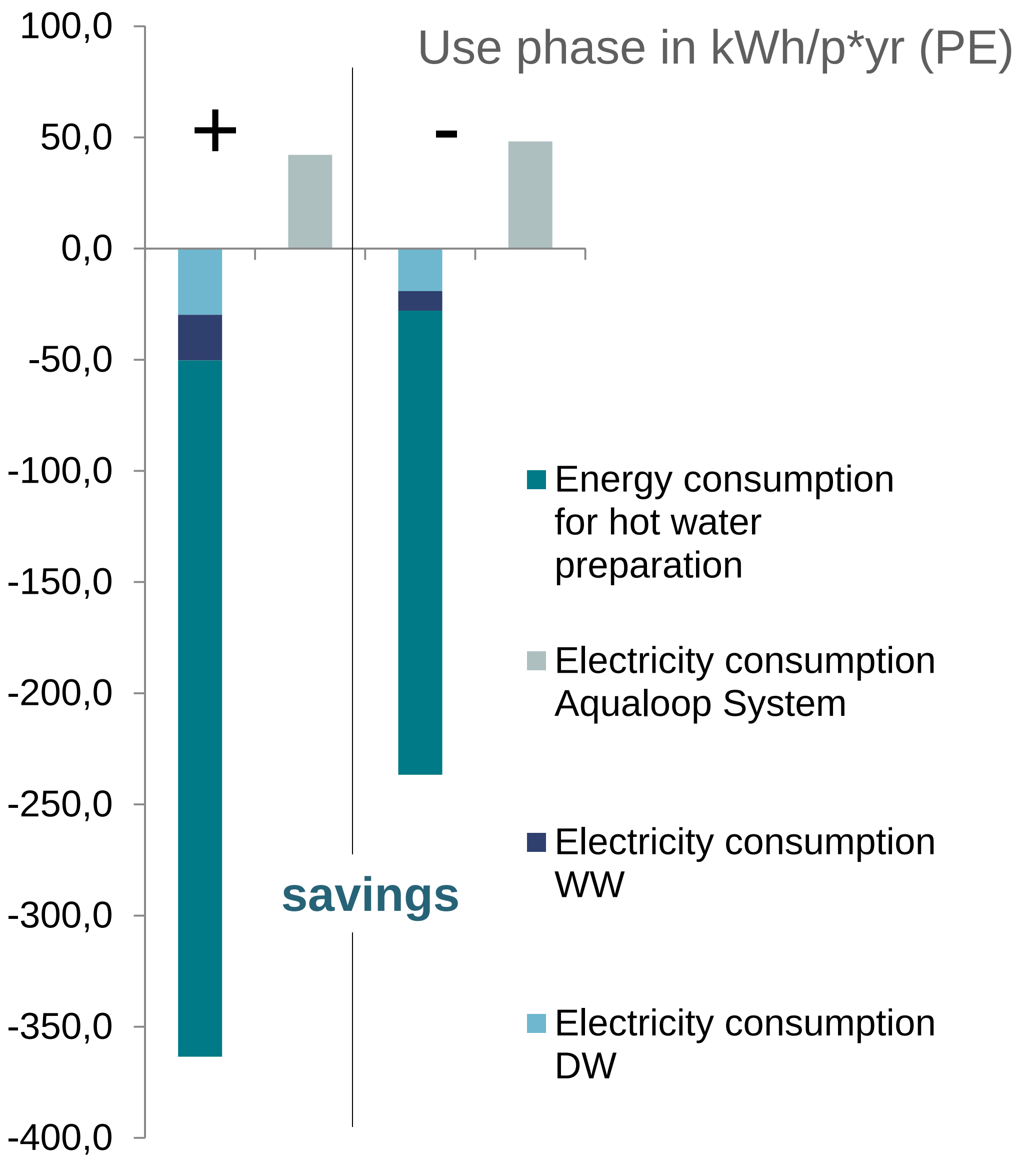
Energy balance

- **Energy** savings per person and year with AQUALOOP (expressed as primary energy PE)
- **190 - 320 kWh** PE per person and year
- **3800- 6400 kWh** per person during 20 years of lifetime
- Optimistic (best case +) and pessimistic scenario (worst case -)



Energy balance

- **Energy** savings per person and year with AQUALOOP
- Optimistic (best case +) and pessimistic scenario (worst case -)
- Considerable savings in energy use:
  - largest contribution from savings in **hot water preparation** equaling energy from 29 – 20 m³ natural gas per person and year
  - followed by savings in water and wastewater
- Additional energy use for operation of AQUALOOP

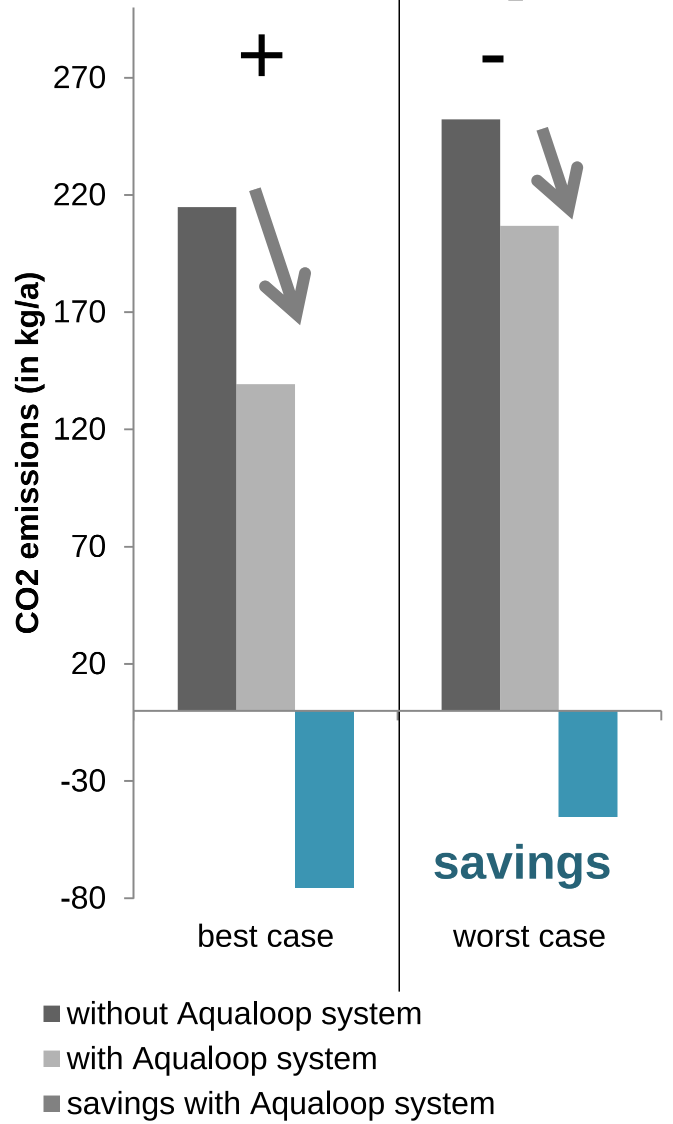


CO_2 balance

- **Energy** savings lead to reduction of emission of **CO_2 and other greenhouse gases** (expressed as kg CO_2 equivalents)
- **45 – 76 kg** per person and year
- **900- 1520 kg** per person during 20 years of lifetime

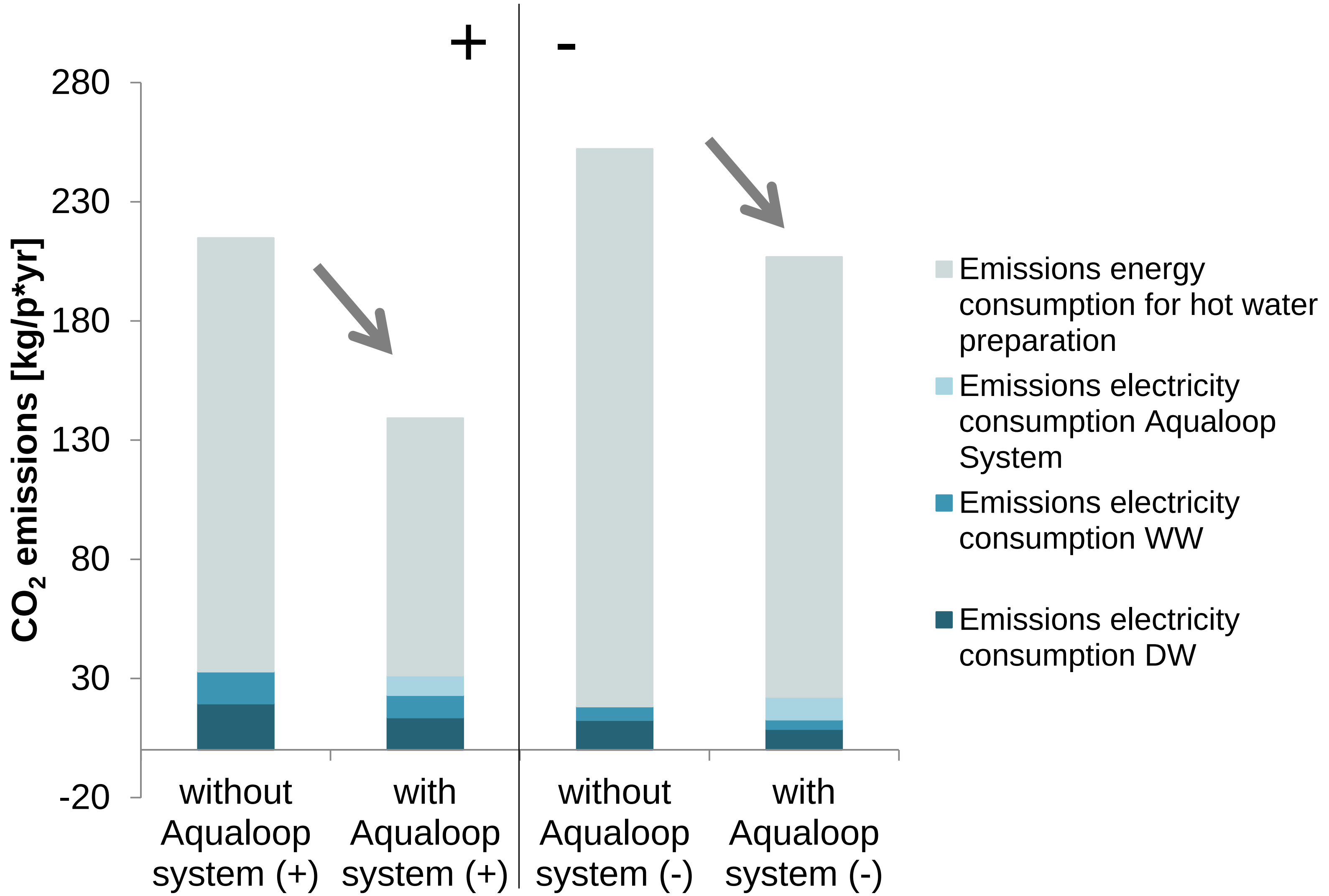
- Optimistic (best case +) and pessimistic scenario (worst case -)

Use phase in kg CO_2-equ. /p*yr



CO_2 balance

Use phase in kg CO_2-equ. /p*yr



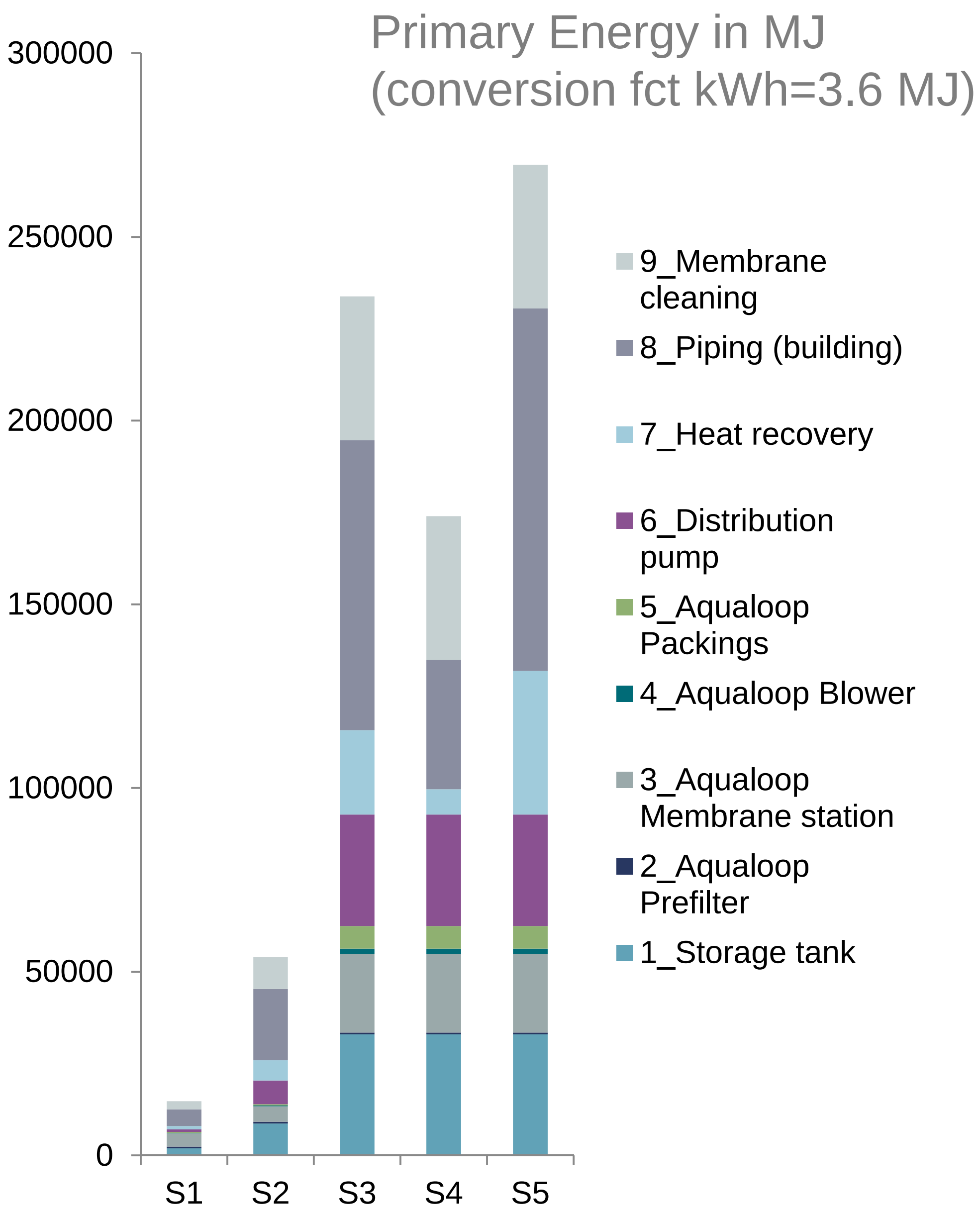
AQUALOOP in different Settings

- To assess the ecological sustainability, we analyse the AQUALOOP System in different settings
- For these Scenarios S1-S5, we assess the full life cycle including: Production of materials, Manufacturing of components and Material recycling

Name	Description	Number of users
S1	One-family home	4
S2	Multi-family home with 6 flats	24
S3	Multi-storey building with 40 flats	100
S4	Sports centre: showers and toilets used by multiple clients	100
S5	Hotel with single and double rooms	100

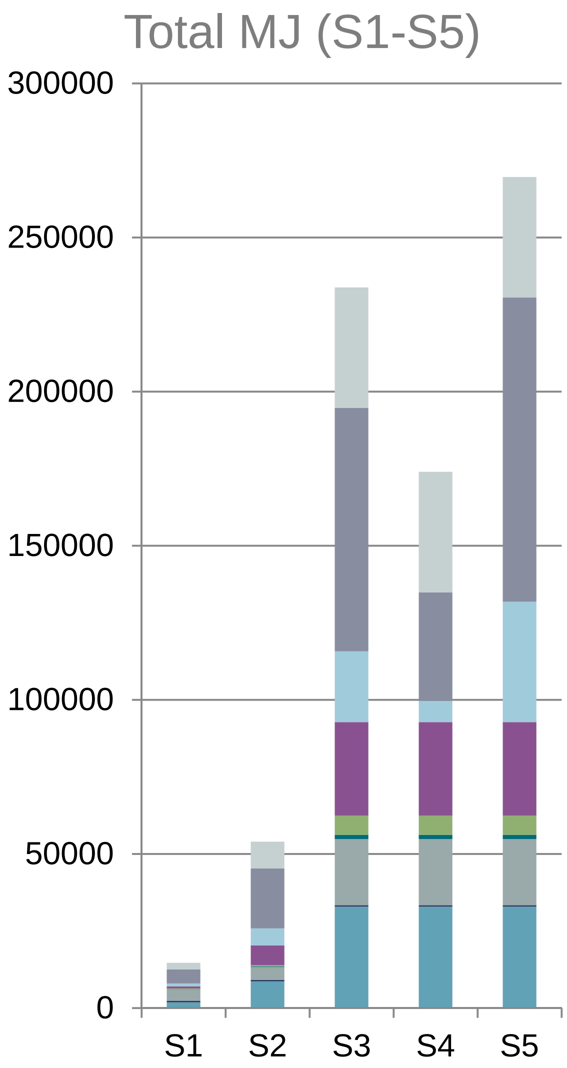
Materials Phase

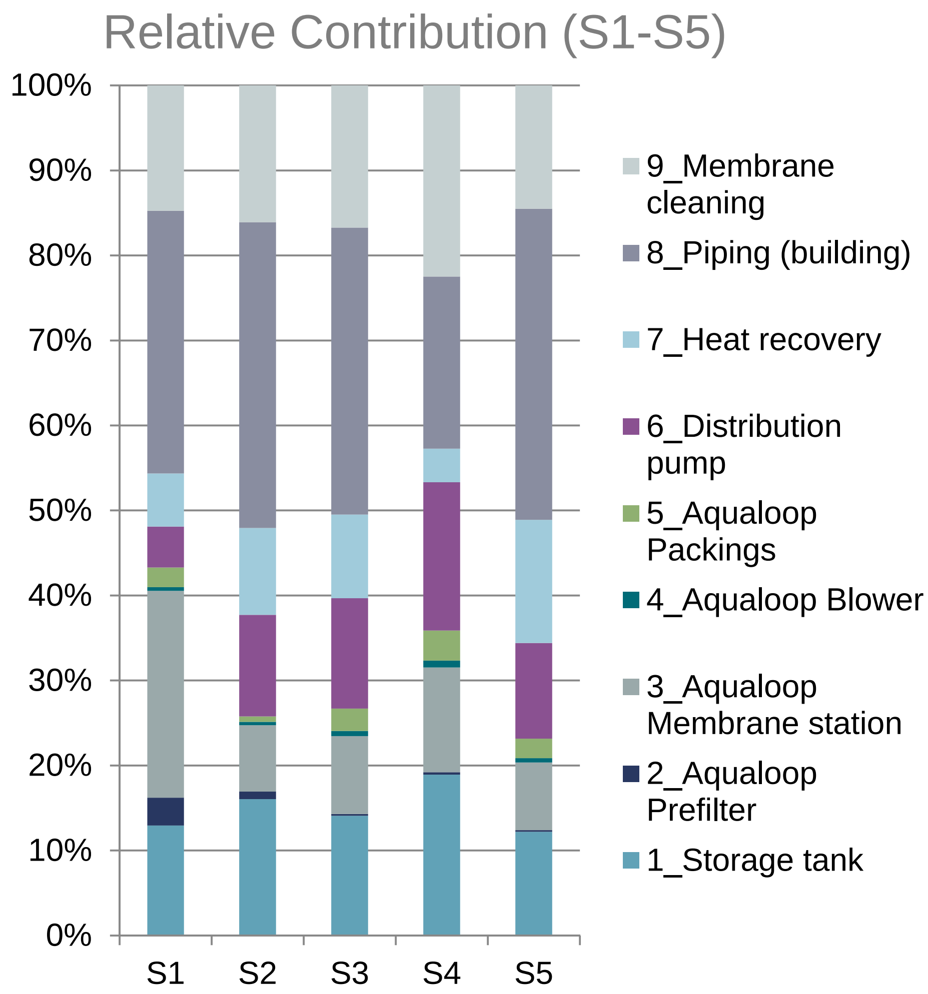
	Description
S1	One-family home
S2	Multi-family home with 6 flats
S3	Multi-storey building with 40 flats
S4	Sports centre: showers and toilets used by multiple clients
S5	Hotel with single and double rooms



Materials Phase

Primary Energy in MJ (conversion fct kWh=3.6 MJ)





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Materials Phase

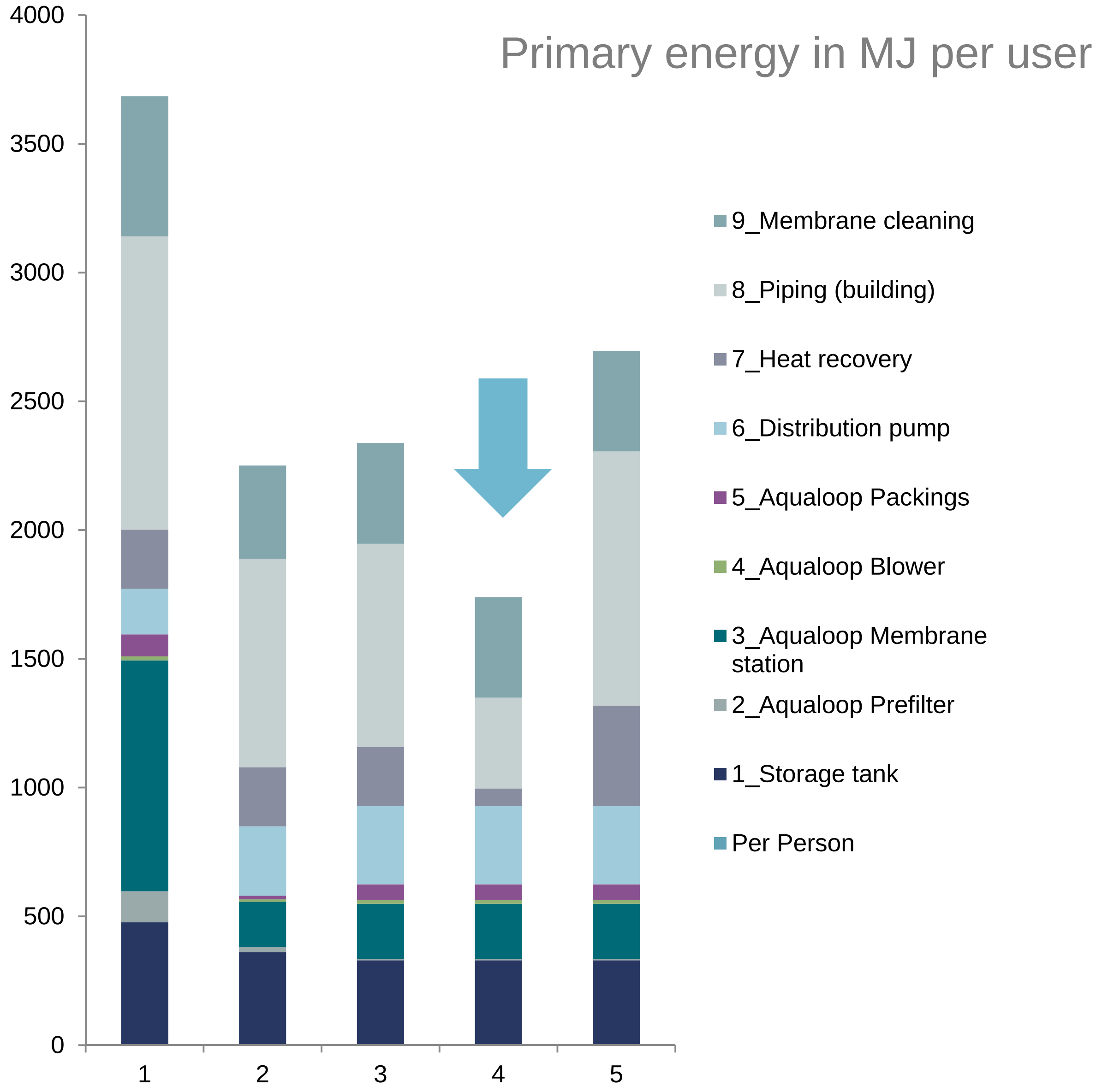
Large impact on material phase

- Piping and heat exchanger*
- Membrane cleaning
- Pump, storage tank
- Membrane station (10 yrs lifetime)

- *Piping and heat exchanger have lifetimes of 50-100 yrs → this study 20 yrs
- Scenario with adapted life time for piping and heat exchanger (Material phase *0.5)

Materials Phase

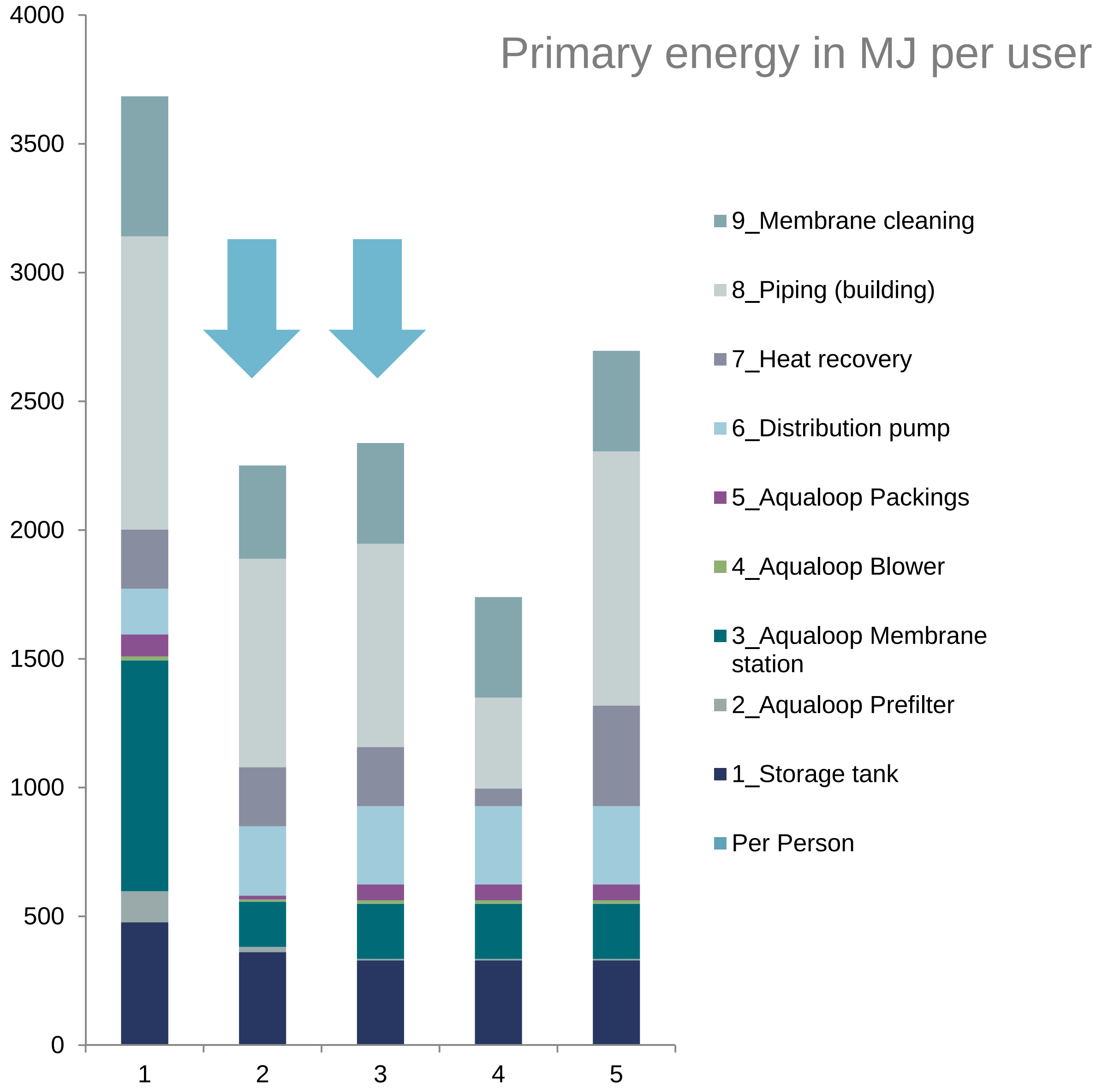
- Material Phase per user
- From a life cycle perspective, the most efficient scenario is the Sports centre (S4). As showers and toilets are used by multiple clients, the piping length is relatively short and a low number of heat exchangers is required



Materials Phase

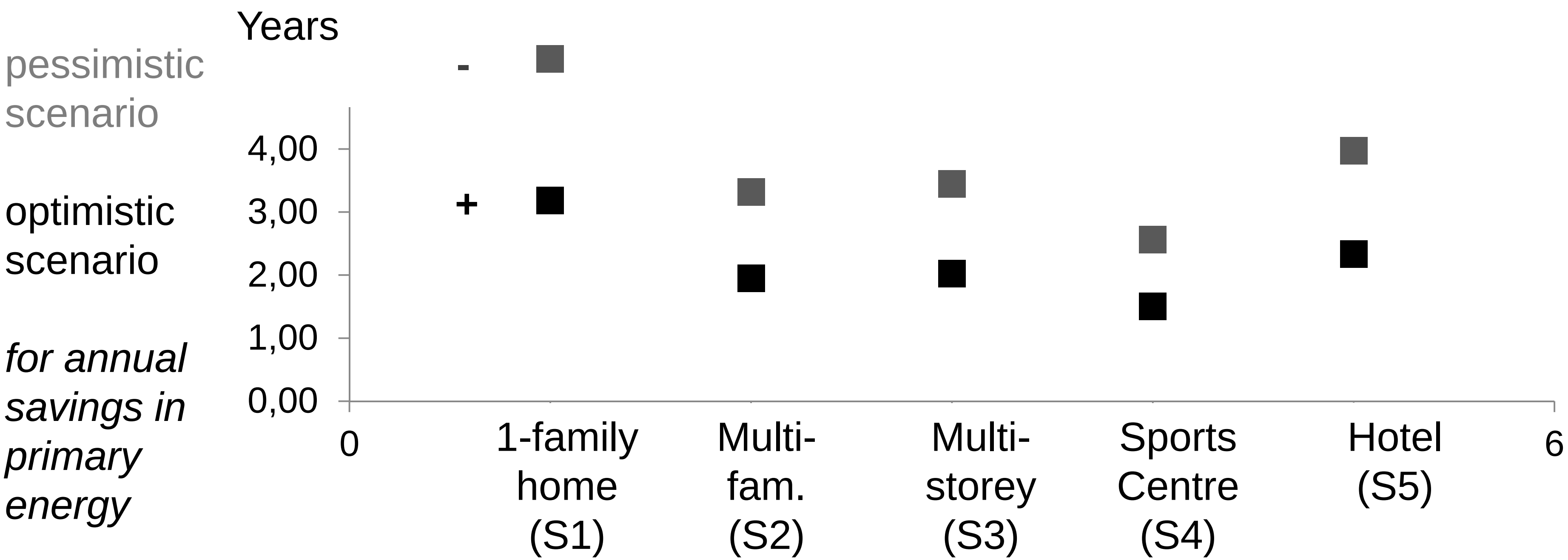
- Material Phase per user

- Also, S3 and S2 perform very well, there are scaling effects for the larger settings (24 users +) compared to the one family home (S1)
- Scenario S5 hotel shows a longer the piping length and a larger number of heat exchangers, due to single rooms and free capacities



Energy Amortisation Time

- Material phase energy consumption divided by annual savings in primary energy gives the **Energy Amortisation Time** in years
- It varies between the settings: between 3-5 years for a one family house and between 1-4 years for the larger settings (without recycling)

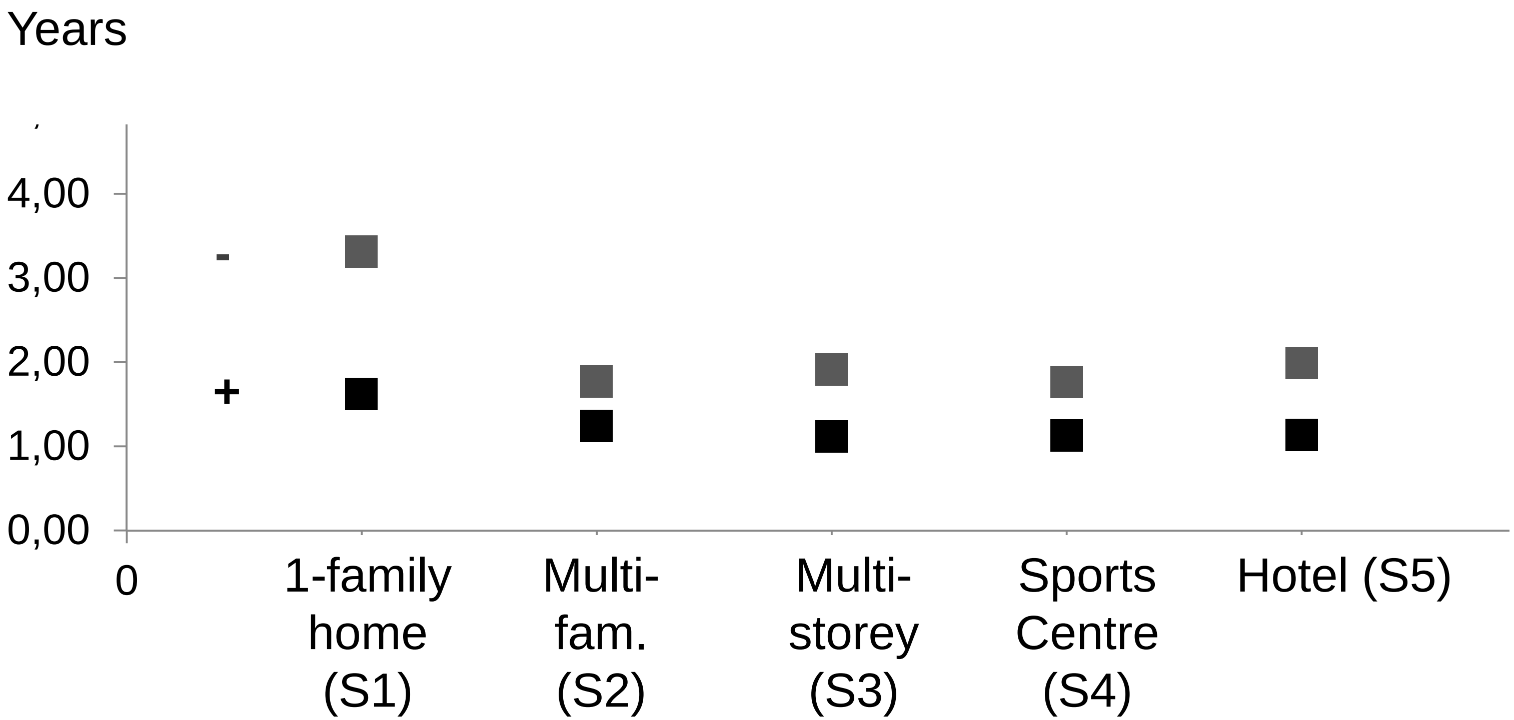


Energy Amortisation Time

- Taking into account the recycling bonus (energy output from recycling of metals and plastics) and adapted life time of pipes and heat exchangers (before 20 years, here 40 years), **Energy Amortisation Time** is lowered to
- **2 - 3.5 years** for a one family house and **1-2 years** for the larger settings

pessimistic scenario and lower recycling bonus (50% energy recovery)

optimistic scenario and higher recycling bonus (70%)



Conclusion

Water perspective:

- Considerable savings in **water use** in households means less pressure on water resources
- In addition, there are large **water savings in the environment**, as less wastewater with lower thermal load reaches the river, thus requiring less dilution in the receiving rivers, with benefits for water resources and ecosystems

Energy perspective:

- Analysis shows considerable **energy savings** during the life cycle, due to **heat recycling** and **energy savings in the water infrastructures**, which balance out the additional energy requirements for operation of AQUALOOP
- **Energy amortisation time** shows that the concept is energetically favourable, also when the energy demand for production of raw materials and manufacturing is included. It is shorter for larger applications (24 users +) and resource efficient piping

ANNEX

Ecological assessment of AQUALOOP System

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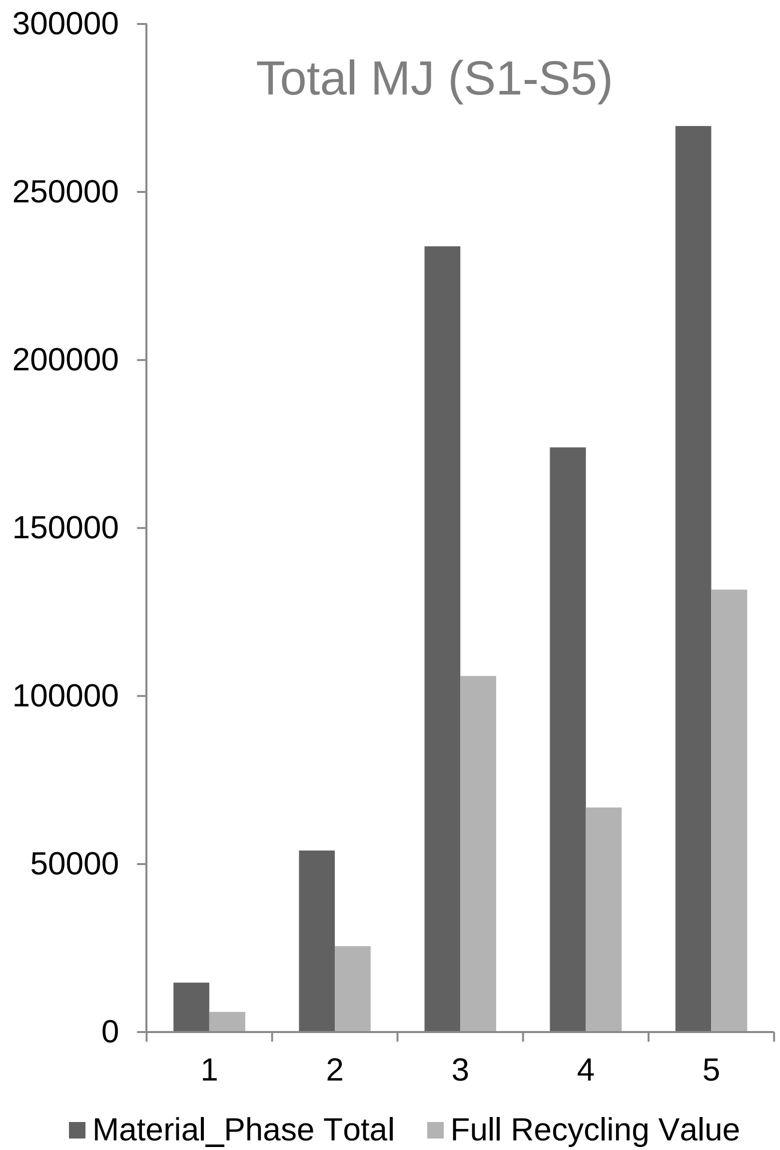
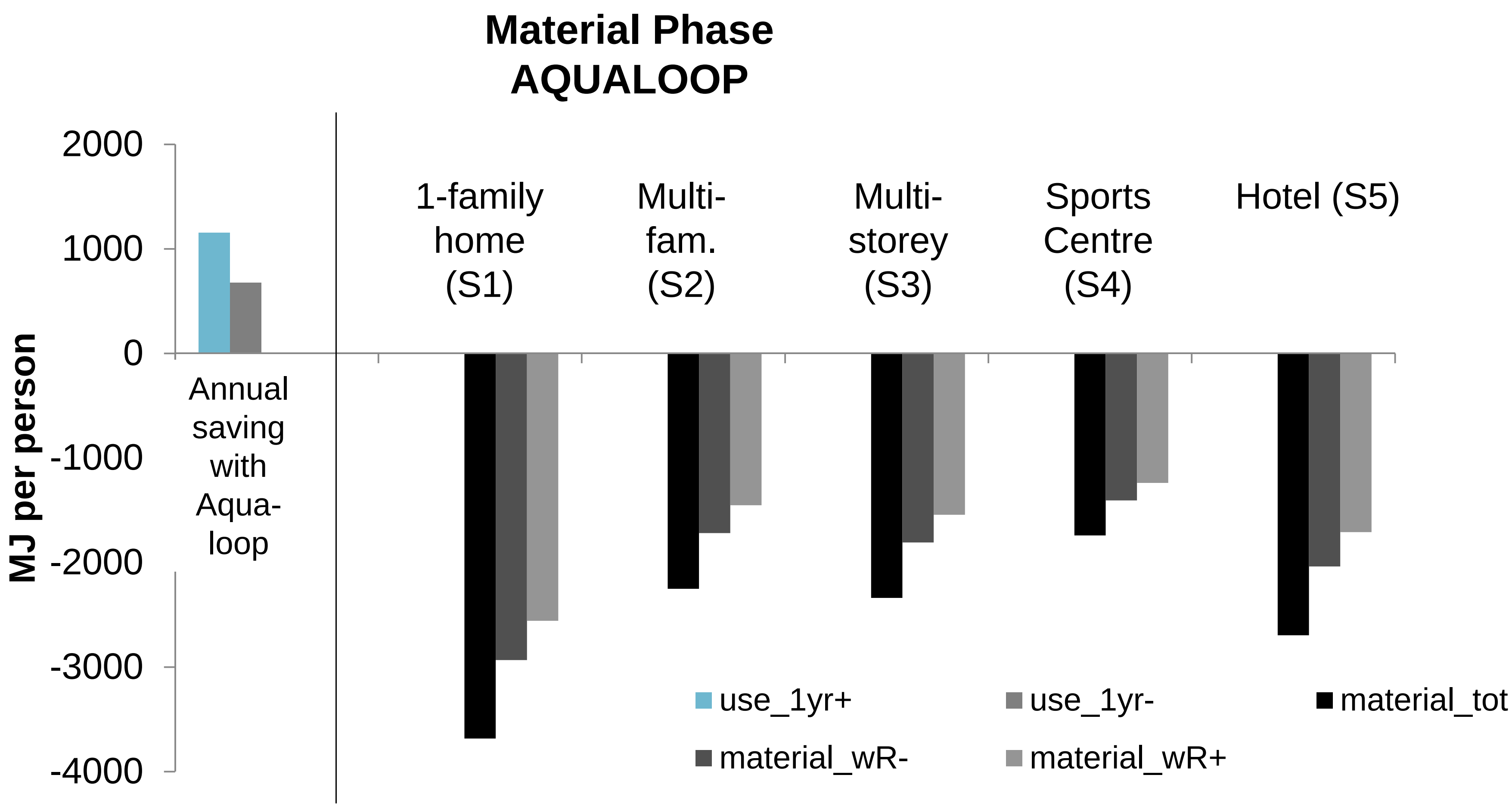
Recycling Phase

- 40-50% of the energy used in the material phase of AQUALOOP are assigned to the „grey energy“ of recyclable materials esp. metals and plastics
- Figure shows the full recycling energy value (energy saved when using the secondary material)
- As recycling also requires energy, we assume two recycling scenarios with a recycling bonus of 50% and 75% of the full recycling value recovered

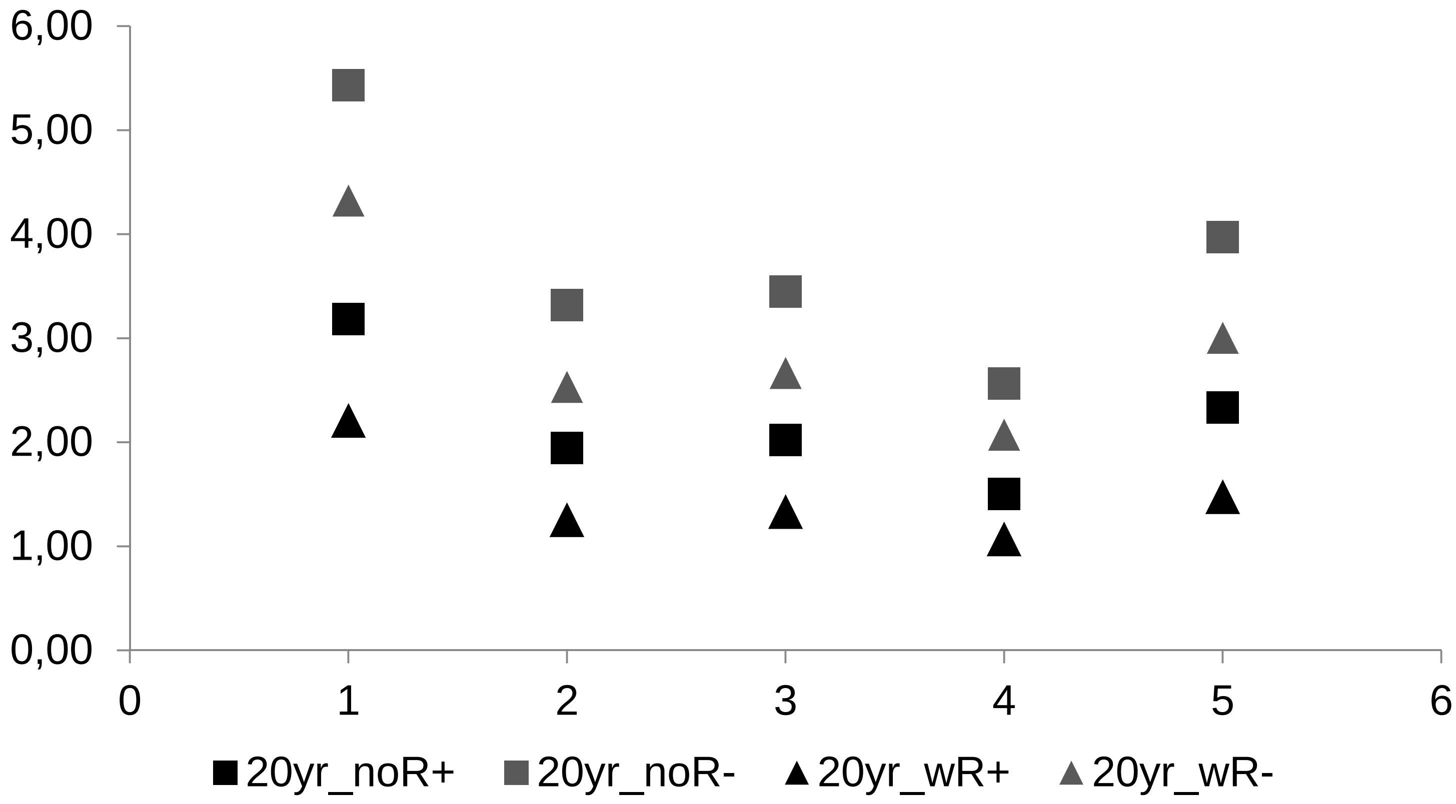


Recycling Phase



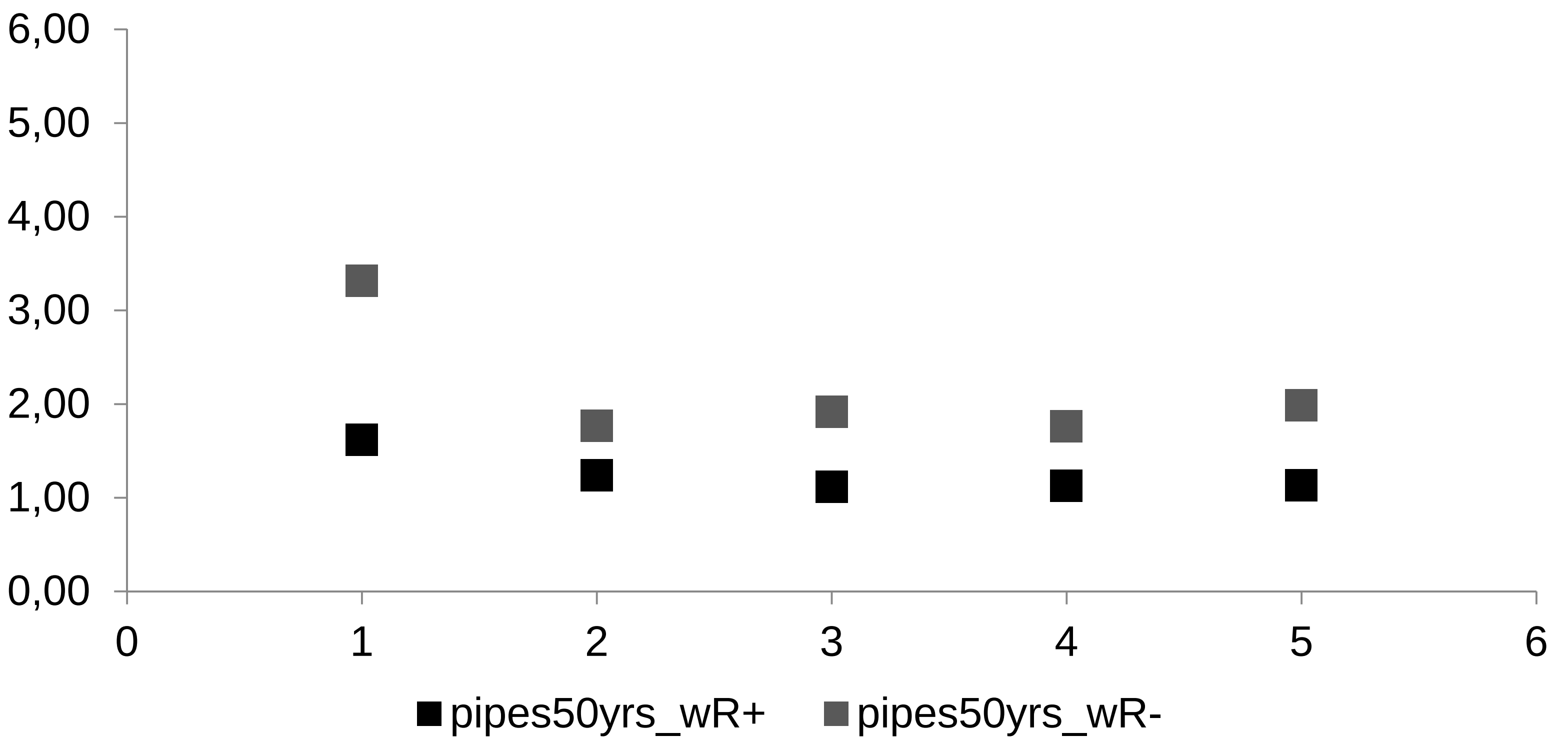
Energy Amortisation Time

- With recycling bonus, Energy Amortisation Time is reduced to 2-4 years for a one family house and 1-2.5 years for the larger settings



Energy Amortisation Time

- With adapted life time of pipes and heat exchangers and recycling bonus, Energy Amortisation Time is reduced to 2-3.5 years for a one family house and 1-2 years for the larger settings



Savings in the Water Infrastructures

- With AQUALOOP, less Water needs to be pumped and treated in the Water Infrastructures

- On the drinking water side
- In Germany, drinking water is mostly sourced from groundwater (70 %), but also from surface water e.g. along the river Rhine where many large cities are located
- For groundwater most energy is required for the extraction (pumping to surface), treatment requirements are low due to excellent quality [0.3 kWh/m^3, depending on depth]
- For surface water most energy is required for the treatment, as the water quality is much lower than for groundwater while pumping requirements are low [0.6 kWh/m^3 depending on quality]
- For the distribution from the water works to the costumer averages 0.3 kWh/m^3 (depending on net characteristics and topography)

Savings in the Water Infrastructures

- With AQUALOOP, less Water needs to be pumped and treated in the Water Infrastructures

- On the waste water side
- Transport of waste water to the treatment plant: Energy demand for wastewater transport is highly variable, as it depends on topography, characteristics of sewer system and amount of rainwater and extraneous water infiltrating the sewers.
- 0.06 kWh/m^3 as average value for Germany, up to 0.2 kWh/m^3 in locations with difficult topographies
- Treatment of waste water: Energy demand for wastewater treatment is highly variable, as it depends on characteristics of the WWTP. Large plants are usually more efficient [0.7 – 1.3 kWh/m^3 household wastewater] . Approx. 50% (large plants) to 80% (small plants) are volume dependant (pumping and aeration), the rest is for sludge handling and other purposes

Savings in the Water Infrastructures

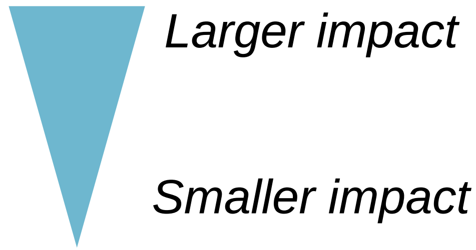
- To include the variation in the water sector, we use 2 scenarios
- Optimistic (best case +) and pessimistic scenario (worst case -)

	-	+	Unit
Losses	6	10	%
Energy consumption DW	0,6	0,9	kWh/m³
Energy consumption WW	0,3	0,7	kWh/m³

Performance of AQUALOOP

- For the performance of AQUALOOP, we also use two scenarios
- Optimistic (best case +) and pessimistic scenario (worst case -)

- Most important parameters are
  - Efficiency of heat recovery
  - Energy consumption for greywater treatment
  - Energy consumption for distribution



	-	+	Unit
Filter loss	10	5	%
Energy consumption (per m^3 treated greywater)	1,1	1,1	kWh/m^3
Energy consumption for distribution (kWh/m^3)	0,5	0,3	kWh/m^3
Heat recovery	10	15	kWh/m^3

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