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Improvement of energy efficiency in industrial water circuits
by online self-assessment, benchmarking and economic decision support

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Contents

1. Executive Published Summary

In this deliverable the key Performance Indicators (KPI's) are specified for each component and industrial water case study circuit. The KPI's correspond to indicators that translate the energy performance of the components by itself and of the overall circuits. From these indicators it will be possible to understand if the component/system is running efficiently in terms of energy. Typical industrial water circuits KPI's may be expressed in kWh/m^3, kWh/t, €/t, €/m^3.

The models presented in task 2.1 including the components of the circuits can at this stage be characterised by the relevant KPI's. This task initiates by defining a set of different parameters that will enable the evaluation platform users to assess the level of Energy-efficient at a macro- and micro-level. Namely, these indices include:

a) specific performance parameters (Micro-level) of each component namely: motor-pump, pump, motor-fan, fan, sand filter, boiler, cooling tower, heat exchanger, barometric condensers and cyclone for separation of suspended solids of the case study water circuits and;
b) an overall KPI (Macro-level) representing the Energy-efficient level of each entire circuit.

The energy consumption of each component is influenced by several parameters as: the volumetric flow rate, pressure drops, efficiencies of the equipments, etc. Overall, these KPI's will allow to evaluate the performance of the typical water circuits and to simulate the impact of the implementation of the available energy efficiency solutions. Moreover, these indicators will be used in the evaluation platform, therefore it has to be assured that they can be integrated into the evaluation platform.

Firstly, the KPI's are specified for each component. Furthermore, the gathering of KPI's of the components of each circuit will allow the specification of the KPI's per circuit. The optimization of this system can be for example: to modify the number of pumps (i.e. substitute one pump with two pumps with lower rated power), or substitute a motor with one with a higher efficiency expecting to achieve a better global efficiency and also to gain the sensitivity of what was the increase/decrease of energy used by this new configuration. Other usual systems include the heat exchangers, condensing, cooling tower, etc. All these identified parameters will be introduced in the physical model in order to define the energy consumption behavior of each component of the typical industrial water circuits. The model is developed in open source software, such as Modelica (modeler) and Open Modelica (solver). Moreover, the result of this task will enable the definition of KPIs in Task 2.2 and the evaluation of the potential improvement of the developed measures (Task 2.4).

2. Defining KPI's

The KPI's will be defined for each separate for each component (section 2.1) and for each circuit (section 2.2).

2.1 Components

This subsection presents the KPI related to each component individually. They are based on the energy that is required for its specific purpose. Brief description is given and corresponding units. A summary is presented in Table 1.

2.1.1 Motor-pump

Each pump is coupled to a motor. For the motor of the pump, the KPI is related with the efficiency of the motor and consequently energy consumption during the running time (kWh).

2.1.2 Pump

The KPI of the pump corresponds to the energy that is required to move a certain volume of water during the operation time and the unit correspond to kWh/m^3.

2.1.3 Motor-fan

Each pump is coupled to a motor. For the fan, the KPI is related with the efficiency of the motor and consequently the energy consumption (kWh) during the operation time.

2.1.4 Fan

The KPI of the fan corresponds to the energy that is required to move a certain volume of air and the unit corresponds to kWh/m^3.

2.1.5 Sand filter/ Scrubber/Cyclone of suspended solids

The KPI of the sand filter corresponds to the energy that is required to move a certain volume of water to pass through the filter and therefore the unit correspo2.1.6nds to kWh/m^3. Another KPI is related to pressure drop associated to the passage of a certain water flow rate through the filter ($(Pa.h)/m^3$).

2.1.6 Boiler

The KPI of the boiler corresponds to the volume of fuel that is required to heat up a certain volume of water, hence the units correspond to $m_{fuel}^3/°C$.

2.1.7 Cooling tower

The KPI for the cooling tower corresponds to the energy consumption of the fan and pump to move required hot water and air inlet flowrates to cool down the water to a certain temperature, the unit corresponds to $kWh/(m_{cooledwater}^3.°C)$.

2.1.8 Heat exchanger

The KPI for the cooling tower corresponds to the energy consumption of the fan and the pump to allow the movement of certain amount of water and air and consequently the heat exchange to cool down a certain volume of water. The unit corresponds to $kW/(m_{cooledwater}^3.°h)$.

2.1.9 Barometric condensers

The KPI for the barometric condensers corresponds to the enthalpy change of a certain volume of water and its units corresponds to kW/ $m_{cooledwater}^3$.˚h.

A summary of the components KPIs is listed in Table 1.

Table 1- Summary of KPI's

Component	**KPI**	**Unit**
Motor-pump	E_{pump}	kWh
	η	Dimensionless
Pump	$\frac{E_{pump}}{V_{water}}$	kWh/m^3
	$\eta = \frac{\dot{m}_{water}\Delta P}{P_{electric}}$	Dimensionless
Motor-fan	E_{fan}	kWh
	η	Dimensionless
Fan	$\frac{E_{fan}}{V_{air}}$	kWh/m3
	$\eta = \frac{\dot{m}_{air}\Delta P}{P_{electric}}$	Dimensionless
Sand filter/ Scrubber/Cyclone of suspended solids	ΔP_{filter}	Pa
	$\frac{\Delta P_{filter}}{(\dot{m}_{water/air})}$	(Pa.h)/m^3
Cooling tower	$\frac{E_{fan} + E_{pump}}{\Delta T_{water} \cdot V_{chilledwater}}$	kWh/$m_{chilled\ water}^3$.°C
	$\eta = \frac{(T_{water,in} - T_{water,out})}{(T_{water,in} - T_{wetbulbair})}$	Dimensionless
Heat exchanger	$\frac{m_{water} cp \Delta T}{V_{chilledwater}}$	kJ/$m_{chilled\ water}^3$ = kW/($m_{chilledwater}^3$.h)
Barometric condensers	$\frac{\Delta h}{V_{chilledwater}}$	kJ/$m_{chilled\ water}^3$= kW/($m_{chilledwater}^3$.h)

Component	KPI	Unit
Furnace/Oven	$\frac{V_{fuel}}{\Delta T_{water}}$	m_{fuel}^3/°C

2.2 Circuits

The case study circuits can be grouped into 6 main representative circuits in different industry sectors as listed in Table 2 and Fig. 1

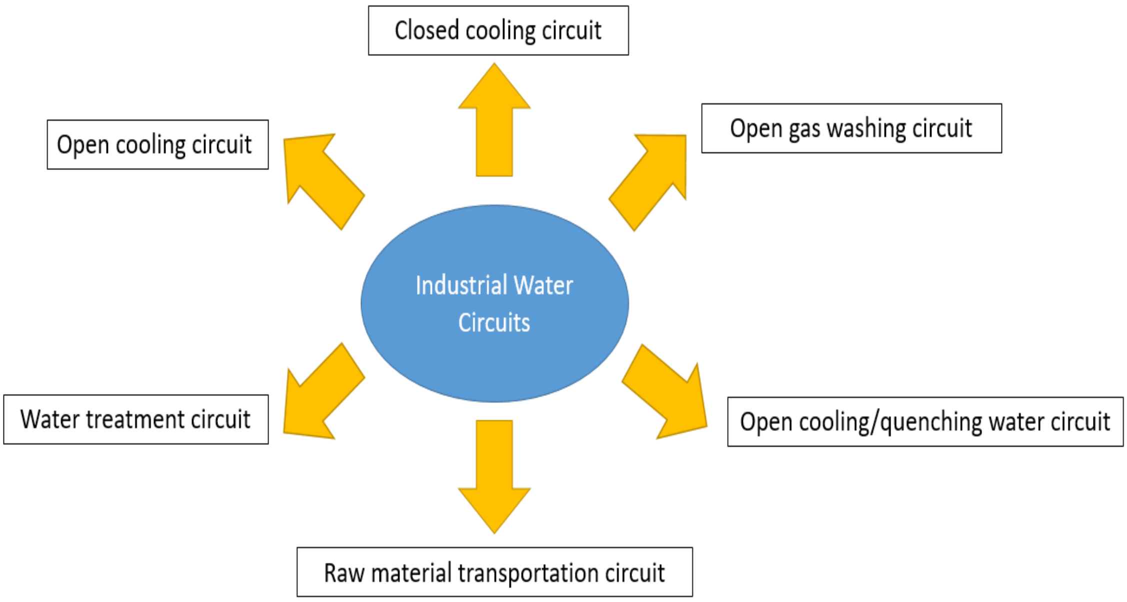

Fig. 1- Types of representative circuits for the industry sector.

Table 2- Types of representative circuits for the industry sector.

Industry Sector	Type of Representative Circuit
Chemical, Food and Beverage, Metal	Open cooling water circuit
Metal	Closed cooling water circuit
Metal	Open gas washing circuit
Metal	Open cooling/quenching water circuit
Paper	Raw material transportation circuit
Food and Beverage	Water treatment circuit

2.2.1 Cooling water circuit

✓ Open circuit

In open circuits the cooling of the water occurs from the heat/mass transfer between the heated water an external/ surrounding cooled fluid, hence open circuits. Commonly they may include cooling towers, barometric condensers and heat exchangers.

Overall, for this circuit the optimization opportunities are mainly related with the water and air flow rates, therefore enabling controls to adjust the fans and pumps to a certain flow to achieve the required temperature and flow of the cold water.

Table 2 presents the components associated to general components of open cooling circuits and consequently the overall circuit KPI.

Table 2 – Cooling water open circuit KPI

Components	**Circuit KPI**
Motor	kWh/ $m_{cooledwater}^3$
Pumps	
Barometric condenser	
Cooling tower	
Heat exchangers	

✓ Closed circuit

Closed circuits corresponds to the cooling of water by a cooled fluid in closed circuits. Such circuits may include pumps, dry cooling units and ventilators to provide the cooling.

Overall, for this circuit the optimization opportunities are mainly related with the water and air flow rates, therefore enabling controls to adjust the fans and pumps to a certain flow to achieve required volume of cooled water.

Table 3 presents the components associated to general components of closed cooling circuits and consequently the overall circuit KPI.

Table 3 – Cooling water closed circuit KPI

Components	**Circuit KPI**
Motor - pump	kWh/ $m_{cooledwater}^3$
Pumps	
Motor – fan	
Fan	
Furnace/Oven	

2.2.2 Water treatment circuit

The main objective of this type of circuits is to provide fresh water to a certain process of the factory. Commonly, part of the water is provided by ground water sources. This circuit may include: pumps and sand filter.
Overall, for this circuit the optimization opportunities are mainly related with the energy that is required by the pump to overcome the pressure drop induced by sand filters and hence volume of filtered water.

Table 4 presents the components associated to general components of water treatment circuits and consequently the overall circuit KPI.

Table 4 – Water treatment circuit KPI

Components	**Circuit KPI**
Motor - pump	kWh/m_{water}^3
Pumps	
Sand filter	

2.2.3 Raw material transportation circuit

This sort of circuits include mainly motor and pumps in order move water mixed with fibres or other raw materials along industrial processes. Table 5 presents the components associated to general components of raw material transportation circuit and consequently the overall circuit KPI.

Table 5 – Raw material transportation circuit KPI

Components	**Circuit KPI**
Motor - pump	kWh/m_{water}^3
Pumps	

2.2.4 Open gas washing circuit

Gas washing circuits refer to gas control process that use water to wash unwanted pollutants/contaminants from a gas stream. Common gas washing circuit include pumps to supply water to a filter, moving on to a scrubber and water is deposited to a sedimentation tank.
Table 6 presents the components associated to general components of open gas washing circuit and the overall circuit KPI.

Table 6- Open gas washing circuit

Components	**Circuit KPI**
Motor - pump	kWh/m_{water}^3
Pumps	

Filter	
Scrubber	

2.2.5 Open cooling/quenching water circuit

Quenching process involves the rapid cooling of a workpiece to obtain certain material properties. Extremely rapid cooling can prevent the formation of all crystal structure, resulting in amorphous metal or "metallic glass". This cooling occurs through with the contact with chilled water. Hence, such circuits include mainly pumps as listed in Table 7.

Table 7 – Open cooling/ quenching water circuit

Components	**Circuit KPI**
Motor-pump	kWh/m_{water}^3
Pump	

3. Conclusions

This deliverable presents the main components that integrate typical water circuits in industrial processes. The key performance indicators have been established individually, for each component. Furthermore, typical water circuits have been grouped into 6 groups: open cooling water circuit, closed cooling water circuit, open gas washing circuit, open cooling/quenching water circuit, raw material transportation circuit and water treatment circuit. For each circuit the associated components have been listed and the KPI of the overall circuit was established. This KPI allow industrial professionals to optimize components in particular or circuits in general by comparing the KPI for different working conditions.