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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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1 Executive Publishable Summary

This deliverable presents an overview of the typical measures to improve the efficiency of water circuits and approach to their prioritisation. In general, the improvement of energy efficiency in water circuits can be reached by:

- Reduction of water consumption in the production process,
- Dynamic adjustment of the circuit operation to the production process,
- Reduction of pressure demand and pressure losses in water circuits and
- Improvement of energy efficiency of pumps and cooling towers.

Improvement measures can be evaluated and prioritised according to the following technical, economic and environmental objectives:

- Improvement of production process reliability (avoidance of downtime; maintaining of required flow, pressure and temperature),
- Cost reduction,
- Energy saving and reduction of CO_2 impact.

The main evaluation aspect for the companies considering improving energy efficiency is cost reduction. In order to prioritise improvement measures on basis of cost reduction several indicators were chosen:

- Energy savings in %,
- Specific investment costs per kW power saved in €/kW,
- Pay-back time in years,
- Absolute savings per year in €/y and
- Investment costs.

These indicators and their order reflect the industrial prioritisation praxis and the methodological approach of the WaterWatt project. Expected energy savings in % provides the primary basis for comparison. This indicator is transferable to other circuits but does not give an idea of economic efficiency of the measures. The indicator specific investment costs enables first rough economic comparison of various improvement measures. This indicator does not depend on the local energy prices and thus possess high transferability potential. Thus it can be used on the E^3 Platform as a general indication of energy efficiency measures. The payback time indicator is highly specific but also the most used prioritisation indicator in industry. If several measures have comparable payback times the indicators of the absolute savings per year and the required investment costs can help to choose the most relevant and affordable one.

Selected measures for the case studies had payback times of 0.2 to 3.6 years and energy saving potential of 5 to 42 % or up to 95,000 €/y. It proves the existing improvement potential and motivates to have a closer look at energy efficiency of industrial water circuits.

The applicability of improvement measures to comparable circuits mostly depends on the achievable savings and electricity costs. In countries with high electricity costs payback times tend to be lower and the proposed measures are more likely to be implemented. As the proposed prioritisation methodology is based on costs and payback times, it can be applied in any industrial plant independent of the company origin and local boundary conditions.

2 Measures to improve energy efficiency of industrial water circuits

A typical industrial water circuit (IWC) contains pumps, a water treatment facility and sometimes a cooling tower (**Figure 1**). The water is partly discharged to prevent accumulation of salts. Fresh water is added to replenish the losses. The main energy consumers are pumps and cooling tower fans. The energy demand of pumps depends on the pressure losses in the pipes and circuit units as well as on the required pressure in the production process, water treatment and cooling towers. The energy demand of the fans depend on the heat load as well as on the outdoor temperature.

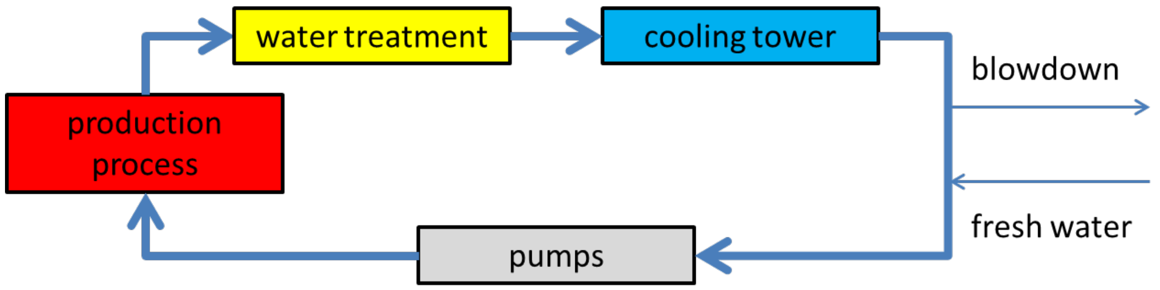

Figure 1: Example of an industrial water circuit

The improvement measures for energy efficiency in IWCs can be directed to the reduction of pressure losses in single units as well as to the improvement of energy efficiency of pumps and fans. Furthermore, the optimisation of the production process itself can lead to the reduction of water demand and thus reduced energy consumption. On the following pages a non-exhaustive overview of most wide-spread measures is performed.

2.1 Reduction of water consumption in the production process

Optimisation of the production process towards the reduction of water consumption and/or required water pressure will contribute to the reduction of energy demand in water circuits. This can be reached by the following measures:

- Introduction of alternative production processes with lower water demand,
- Introduction of alternative cooling processes,
- Waste heat reuse instead of waste heat transfer into the cooling water.

Waste heat can usually be reused for pre-heating of process liquids, for drying or for district heating in case the production equipment can be cooled at 65 °C by means of a closed circuit. Alternatively, a heat pump can be applied to reach required temperature level.

2.2 Dynamic adjustment of the circuit operation to the production process

In some production processes water demand fluctuates significantly over the day. To provide energy efficient operation in such cases several approaches can be considered:

- Installation of several pumps that can be operated independently covering the most common water demand cases,
- Installation of variable speed drives (VSD) for pump motors and pressure and/or temperature sensors to provide automatic flow adjustment to the process needs,
- Installation of a high-level tank to compensate the fluctuations of water and pressure demand.

For the fluctuating heat load in a cooling circuit or fluctuating energy demand for cooling due to the seasonal changes of the outdoor temperature, following measures can be applied:

- Separation of the cooling tower from the main circuit and its demand oriented operation,
- Installation of VSD for the cooling tower fans and their automation by means of temperature sensors.

2.3 Reduction of pressure demand and pressure losses

Due to corrosion and scaling processes the inner diameters of the pipes decrease and their inner surface roughness increase with time causing excessive pressure loss. Furthermore, with changes in the production process its piping network should be adjusted to the new flows in order to stay energy efficient. The reduction of pressure losses can be reached by the following measures:

- Pipe cleaning,
- Change piping to larger ones to provide laminar flow conditions if technically applicable,
- Isolating of redundant pipe runs and reducing of number of pipe bends.

The reduction of pressure demand in a circuit with several consumers and various pressure demands can be reached using a small booster pump to supply loads with high pressure drop and small flow. Furthermore, the reduction of pressure demand can be reached by the exchange/ adjustment of the circuit units:

- Choice of nozzles with low pressure drop in cooling towers and production process,
- Choice of heat exchangers with low pressure drop,
- Choice of water treatment equipment with lower pressure drop.

For example filters are one of the typical treatment units. There are various filter systems for suspended solids separation. The most widespread filters are sand filters. Some of them are operated at a pressure of 2 bar and some at atmospheric pressure, which has direct impact on energy consumption. Thus the initial choice of filters has the highest impact on energy efficiency. Once installed, regular maintenance and effective cleaning of the filling can prevent increase in energy consumption. Choice of larger filter grain sizes and optimal flocculant doses, if technically possible, can also contribute to the reduction of the pressure drop.

2.4 Improvement of energy efficiency of pumps and cooling towers

The main electrical energy consumers in the most relevant circuits are pumps and cooling tower fans. The improvement of their efficiency is crucial for the energy savings in water circuits. Furthermore, improvement of heat transfer in the cooling tower contributes to the reduction of energy demand.

2.4.1 Pumps

Pumps are the main energy consumers in most circuits and thus possess the highest optimisation potential. Each pump shows its highest efficiency for a limited number of flows and corresponding pressures. Outside of this optimum its energy efficiency decreases. Thus, in circuits with variable water demand, pumps are not always operated in their optimal efficiency range. Furthermore, even in circuits with fixed water demand of the production process, adjustment of water demand may change causing inefficient pump operation. In order to improve pumping efficiency in existing circuits following approaches can be considered:

- Exchange of pumps and/or motors to more efficient ones,
- Exchange of the pump impeller or its adjustment to current water and pressure demand,
- Implementation of variable speed drives to dynamically adjust pump rotation frequency to the optimal efficiency point,
- Adjustment of the number of pumps and their switching points,

During operation time efficiency of pumps will decrease due to aging. In order to maintain high efficiency, the following measures are required:

- Regular maintenance of bearings to minimise friction losses,
- Regular exchange of gaskets to reduce water losses,
- Inline-monitoring of vibrations and energy consumption to rapidly react to irregularities and prevent energy losses/ pump damage.

2.4.2 Cooling towers

Most industrial cooling towers found in the relevant industrial circuits are evaporative cooling towers equipped with electric fans. There exist also dry cooling units and hybrid cooling units but they require 75 % and 50 % more electric energy accordingly. Flow-through cooling requires only the energy for pumping, but it is not applicable for the most plants due to the water scarcity and water discharge quality requirements.

The cooling tower efficiency depends on the required operating pressure, droplet size induced, specific surface that can be provided for the water flow and the air flow per fan efficiency. Thus for the optimisation of energy efficiency of a cooling tower, the following measures can be considered:

- Exchange of influent nozzles to the ones with lower operating pressure,
- Exchange of fans/ motors to more efficient ones,
- Implementation of variable speed drives to dynamically adjust air flow,

- Demand oriented operation of fans on the basis of the water temperature,
- Installation fills into the cooling tower to increase heat exchange surface,
- Regular cleaning of heat exchange surfaces.

3 Evaluation and prioritisation of the improvement measures

3.1 Methodology

In general, improvement measures can be evaluated and prioritised according to the following technical, economic and environmental objectives:

- Improvement of production process reliability (avoidance of downtime; maintaining of required flow, pressure and temperature),
- Cost reduction,
- Energy saving and reduction of CO_2 impact.

In interviews which have been conducted in the frame of the WaterWatt project it became obvious that the improvement of the reliability of a certain production process is a strategic decision; a motivation to deal with industrial water circuit which does not necessarily correlate with improvement of energy efficiency. The energy savings and reduction of CO_2-impact are less important in industrial water circuits, because of its small share in comparison to the production process. The main evaluation aspect for the companies considering improving energy efficiency is cost reduction.

In order to prioritise improvement measures on basis of cost reduction several indicators were chosen:

- Energy savings in %,
- Specific investment costs per kW power saved in €/kW,
- Pay-back time in years,
- Absolute savings per year in €/y and
- Investment costs.

These indicators and their order reflect the industrial prioritisation praxis and the methodological approach of the WaterWatt project. Expected energy savings in % provides the primary basis for comparison. This indicator is transferable to other circuits but does not give an idea of economic efficiency of the measures. The indicator specific investment costs enables first rough economic comparison of various improvement measures. This indicator does not depend on the local energy prices and thus possess high transferability potential. Thus it can be used on the E^3 Platform as a general indication of energy efficiency measures. The payback time indicator is highly specific but also the most used prioritisation indicator in industry. If several measures have comparable payback times the indicators of the absolute savings per year and the required investment costs can help to choose the most relevant and affordable one. Frequently there are limited budgets for improvement of energy efficiency which makes absolute investment costs an important prioritisation indicator.

For the application on the E^3 Platform these indicators will be calculated for selected improvement measures for certain circuits and presented in a table format. The user can choose their required prioritisation indicator and the program will arrange the measures accordingly. The ways to the indicator calculations with the help of E^3 Platform are shown below, taking payback time as an example.

For the European industry economic measures are considered as efficient if the investment payback times are below 2-3 years. Payback time indicator *i* depends on the equipment price, equipment installation costs, difference in maintenance costs for old and new equipment and induced energy savings:

$$i = \frac{\text{(investment costs + installation costs)}}{\text{(annual energy savings + maintenance savings)}} \quad (1)$$

In the frame of this project the following steps for the evaluation of energy efficiency improvement measures are considered:

- Rough estimation of payback time and
- Calculation of payback time.

3.1.1 Rough estimation of payback time

Using E^3 Platform the estimation of payback time can be performed as follows:

1. Estimation of energy saving potential in % filling out short questionnaire or comparing own specific consumption to the benchmark,
2. Estimation of annual saving in own circuit on the basis of the saving potential and annual energy costs,
3. Choice of relevant improvement measures with highest energy saving potential using automatic recommendations, case studies and energy efficiency database,
4. Estimation of investment costs using energy efficiency database + 20% for the installation,
5. Estimation of payback time by dividing the investments by the annual savings.

3.1.2 Calculation of payback time

The crucial aspect for the calculation of payback time for various improvement measures is the realistic calculation of savings. On the E^3 Platform the calculation of savings can be performed with the help of a mathematical model of the circuit. The user can choose an existing model from the database and adjust it to their own circuit or can build a completely new model. By modifying the circuit model and its units with the solutions from the energy efficiency database or case studies the user can estimate energy savings in percentage. Introducing the energy price the user can calculate expected annual savings. Investment costs can be estimated using the energy efficiency database or by asking an according technology provider for a quotation. The payback time is calculated using **equation 1** above.

3.2 Case studies

3.2.1 Description and prioritisation of improvement measures for each case study

After the characterisation of the circuits in the frame of the case studies (Table 1), measurement of energy demand was performed. In the next step the applicability of the improvement measures (see chapter 2) was evaluated for the case study circuits. The measures were evaluated according to the methodology in chapter 3.1. As there were very few improvement measures for each circuit, no prioritisation was needed. An exemplary prioritisation is performed in chapter 3.2.2. The improvement measures for each case study (CS) are described below.

Table 1: Overview of the investigated circuits in the frame of the case studies

Industry	Case study	Origin	Representative circuits	Flow [m³/h]	Installed power [kW]	CS No
Metal	Stainless wire processing	DE	Open cooling circuit (rolling mill) with sand filtration	2400	1220	**1**
			Closed cooling circuit (inductive furnace)	63	37	**2**
	Carbon steel production	UK	Closed cooling circuit (blast furnace)	5700	901	**3**
	Carbon steel production	DE	Open gas washing circuit (basic oxygen furnace)	3200	800	**4**
	Carbon steel production	NO	Open cooling/quenching of rebar rods and wire coils	780	315	**5**
	Manganese production	NO	Closed cooling circuit (furnace)	350	171	**6**
			Open gas washing circuit	250	111	**7**
Chemical	Pharmaceuticals	DE	Open cooling circuit	3600	1254	**8**
Paper	Paper factory	PT	Fiber transportation circuit	2400	240	**9**
Food and beverage	Sugar factory	PT	Water treatment (filtration)	145	135	**10**
			Open cooling circuit	1600	627	**11**

* CS No – Case Study Number

CS 1: Open cooling circuit of a hot rolling mill

As the circuit has been completely refurbished in 2016, very few improvement possibilities are still open. The circuit model shows that energy efficiency could be slightly improved by the optimisation of the switch points of the pumps equipped with variable speed drives. Furthermore, introduction of fills into the cooling towers will improve its efficiency and reduce energy consumption. The economic evaluation (Table 2) shows that both measures are feasible and their implementation can contribute to savings and improvement of energy efficiency. The validation possibility for the simulation results is being discussed with the plant operator.

The proposed measures as well as the circuit automation and maintenance practice are transferable to other circuits with variable water demand. The savings and payback times may vary depending on the local energy costs.

Table 2: Economic evaluation of improvement measures for case study 1

Measure	Investment and installation costs		Energy savings		Operating costs savings		Pay back time	Comment
	[€]	[€/kW]	[€/y]	[%]	[€/y]	[%]	[y]	
Introduction of fills into cooling tower	45000	1560	19000	6	0	0	2.4	Considerable energy savings (> 3 %) and economically efficient (I < 3 y)
Optimisation of the pump switch points	800	224	1700	1	0	0	0.5	Minor energy savings but without any investment costs

CS2: Closed cooling circuit of an inductive furnace

Due to the constant operation conditions no improvement possibilities is seen for this studied circuit. Exchange of the pumps for more efficient one can provide 2 % improvement of the energy efficiency (Table 3). Due to very low absolute savings expected (ca. 160 €/y per pump) and high payback time this exchange will be performed only in case the pump breaks.

Table 3: Economic evaluation of improvement measures for case study 2

Measure	Investment and installation costs		Energy savings		Operating costs savings		Pay back time	Comment
	[€]	[€/kW]	[€/y]	[%]	[€/y]	[%]	[y]	
Pump exchange	2800	3784	320	2	0	0	8.8	not economically efficient (I > 3 y)

CS3: Closed cooling circuit of a blast furnace

The conditions in the blast furnace are not always constant. Thus, automatic flow adjustment of the circuit by means of variable speed drives or additional pumps could lead to improvement of energy efficiency. At the current conditions it is not realistic due to the high safety requirements.

CS4: Open gas washing circuit of a basic oxygen furnace

Due to the current automation algorithm the pumps are running under optimal conditions. One of the pumps showed higher vibrations than normal. It has to be maintained to prevent damage and energy losses. No further improvement measures were identified.

CS5: Open cooling circuit for rebar rods and wire coils

Since the pumps in use already have installed frequency converters, the main improvement measure related to energy use is to install new, more efficient pumps. Table 4 shows an economic evaluation of the improvement measure and indicates that the payback time would be a bit higher than usually acceptable in the industry.

Table 4: Economic evaluation of improvement measures in case study 5

Measure	Investment and installation costs		Energy savings		Operating costs savings		Pay back time	Comment
	[€]	[€/kW]	[€/y]	[%]	[€/y]	[%]	[y]	
Installation of new pumps	90000	1685	25000	20	0	0	3.6	Longer payback time than usually accepted in the industry, but shorter than the pump lifetime. High absolute savings.

CS6: Closed cooling circuit at Manganese plant

The water circuits are newly built, and no energy efficiency improvement measures could be found.

CS7: Open gas washing circuit at Manganese plant

These water circuits are newly built, and no energy efficiency measures could be found.

CS8: Open cooling circuit of a pharmaceutical company

Due to the recent circuit refurbishment and improvement of energy efficiency (exchange of pumps and installation of frequency converters) no further measures could be identified.

CS9: Raw material transportation

The circuit has not been refurbished in the last years. The circuit model showed that energy efficiency could be slightly improved by refurbishment of all old pumps. The economic evaluation (Table 5) shows that this measure is feasible and its implementation can contribute to savings and improvement of energy efficiency.

The proposed measures as well as the circuit automation and maintenance practice are transferable to other circuits with variable water demand. The savings and payback times may vary depending on the local energy costs.

Table 5: Economic evaluation of selected improvement measures in case study 9

Measure	Investment and installation costs		Energy savings		Operating costs savings		Pay back time	Comment
	[€]	[€/kW]	[€/y]	[%]	[€/y]	[%]	[y]	
Refurbishment of all 6 old pumps	960	40	5705	5	0	0	0.16	Considerable energy savings (> 3%) and economically efficient (I < 3 y)

CS10: Water Treatment Circuit

The circuit model showed that energy efficiency could be slightly improved by:

- Pump of ground water to operate during a longer period of time with a lower flow thus achieving the same water volume
- The refurbishment of old pumps requires changing rolling bearing, sealing rings, and applying an internal ceramic coating. This refurbishment will improve the pump energy efficiency by 5 %.

The economic evaluation (Table 6) shows that both measures are feasible and their implementation can contribute to savings and improvement of energy efficiency.

Table 6: Economic evaluation of <u>selected</u> improvement measures for case study 10

Measure	Investment and installation costs		Energy savings		Operating costs savings		Pay back time	Comment
	[€]	[€/kW]	[€/y]	[%]	[€/y]	[%]	[y]	
Adapt variable speed device – ground water pump (single pump)	414	192	518	42	0	0	0.8	Considerable energy savi-ngs (> 3 %) and econo-mically efficient (I < 3 y). Low absolute savings
Refurbish-ment of old pumps (all pumps)	640	217	708	5	0	0	0.9	Considerable energy sav-ings (> 3 %) and econo-mically efficient (I < 3 y). Low absolute savings

CS 11: Open cooling circuit of a barometric condenser

The circuit model showed that energy efficiency could be slightly improved by:

- The refurbishment of old pumps requires changing rolling bearing, sealing rings, and applying an internal ceramic coating.
- Adjustment of variable speed device of the cooling tower fan.

The economic evaluation (Table 7) shows that both measures are feasible and their implementation can contribute to savings and improvement of energy efficiency. The validation possibility for the simulation results is being discussed with the plant operator.

Table 7: Economic evaluation of selected improvement measures for case study 11

Measure	Investment and installation costs		Energy savings		Operating costs savings		Pay back time	Comment
	[€]	[€/kW]	[€/y]	[%]	[€/y]	[%]	[y]	
Refurbishment of all pumps	1920	69	15967	15	0	0	0.12	Considerable energy savings (> 3 %) and economically efficient (I < 3 y). High absolute savings
Adjustment of the existent variable speed device of the fan in the	0	0	170	1	0	0	0	Low energy savings (< 3 %) and economically efficient (I < 3 y). Low absolute savings

cooling tower								

3.2.2 Exemplary prioritisation of improvement measures

In the case studies just one or two circuits per plant were studied. As for the same circuit maximal two improvement measures have been identified and they can be implemented simultaneously, there is no need for prioritisation. Usually the responsible manager has to choose between several improvement measures in various circuits or production processes. To simulate this, selected improvement measures from various case studies are put together as if they were belonging to the same plant/ decision area of a manager.

The description of measures is provided in Table 8 and calculated prioritisation indicators in Table 9. Depending on the objective, the first prioritisation could for example occur according to the lowest specific investment costs (No. 2 and No. 4). These improvement measures also have the shortest payback times. In the next step absolute savings could be considered and No. 2 would get the highest priority.

Table 8: Description of selected improvement measures for case studies

No	Case study	Improvement measure description
1	Open cooling circuit at a hot rolling mill	In order to improve cooling tower efficiency, fills can be introduced. They increase heat exchange surface and thus reduce operation time of cooling tower pumps and fans.
2	Open cooling circuit at a hot rolling mill	Optimisation of the pump switch points and rotation frequencies in order to reach maximal efficiency of the pump group
3	Water treatment circuit	Pump of ground water to operate during a longer period of time with a lower flow thus achieving the same water volume.
4	Water treatment circuit	The refurbishment of old pumps requires changing rolling bearing, sealing rings, and applying an internal ceramic coating. This refurbishment will improve the pump energy efficiency by 5 %.
5	Open cooling circuit at a carbon steel production plant	In order to reduce the energy consumption, new pumps with higher efficiency can be installed.

Table 9: Prioritisation indicators for selected improvement measures from case studies

No	Measure	Investment and installation costs		Energy savings		Operating costs savings		Payback time	Comment
		[€]	[€/kW]*	[€/y]	[%]	[€/y]	[%]	[years]	
1	Introduction of fills into cooling tower	45000	938	19000	6	0	0	2.4	Considerable energy savings (>3%) and economically efficient (i < 3 y)
2	Optimisation of the pump switch points	800	224	1700	1	0	0	0.5	Minor energy savings but without any investment costs
3	Adapt variable speed device – ground water pump	414	192	518	42	0	0	0.8	Considerable energy savings (>3%) and economically efficient (i < 3 y). Low absolute savings
4	Refurbish-ment of old pumps	160	217	710	5	0	0	0.2	Considerable energy savings (>3%) and economically efficient (i < 3 y). Low absolute savings
5	Installation of new pumps	90000	1685	25000	20	0	0	3.6	Longer payback time than usually accepted in the industry, but shorter than the pump lifetime. High absolute savings

**) – Specific investment costs per saved kW power*

3.2.3 Conclusion on the prioritisation of improvement measures in case studies

Selected measures for the case studies had payback times of 0.2 to 3.6 years and energy saving potential of 5 to 42 % or up to 95000 €/y. It proves the existing improvement potential and motivates to have a closer look at energy efficiency of industrial water circuits.

The measures identified in the case studies were mostly addressing the following aspects of the circuit optimisation:

- Dynamic adjustment of the circuit operation to the production process,
- Reduction of pressure demand and pressure losses in water circuits and
- Improvement of energy efficiency of pumps and cooling towers.

No possibility was seen for the following:

- Introduction of alternative production processes with lower water demand,
- Introduction of alternative cooling processes,
- Waste heat reuse instead of waste heat transfer into the cooling water.

Nevertheless, these latter options should be considered before the circuit optimisation especially by a general refurbishing of the production or planning of new production lines.

4 Applicability of improvement measures and prioritisation methodology

The case studies have shown that in the most circuits economic improvement of energy efficiency is possible. The measures mostly addressed the improvement of the circuit units and dynamic adjustment of the circuit operation to the production process.

The transferability of improvement measures to comparable circuits depends on the achievable savings and electricity costs. In countries with high electricity costs payback times tend to be lower and the proposed measures are more likely to be implemented. As the proposed prioritisation methodology is based on costs and payback times, it can be applied in any industrial plant independent of the company origin and local boundary conditions. Further prioritisation parameters as energy savings allow to evaluate the environmental impact of the measures and to choose them accordingly.

For the improvement of the own circuit the following steps are proposed:

1. Documentation of the current state of the circuit and its energy demand,
2. Choice of suitable improvement measures from chapter 2,
3. Calculation of expected savings and prioritisation parameters as in chapter 3.1,
4. Prioritisation of the measures as in chapter 3.2.2,
5. Compilation of the priority list,
6. Implementation of the measures according to the priority list.