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Guidelines for performance evaluation of treatment technologies for water reuse systems —

Part 8: **Evaluation of treatment systems based on life cycle cost**

Lignes directrices pour l'évaluation des performances des techniques de traitement des systèmes de réutilisation de l'eau —

Partie 8: Évaluation des systèmes de traitement fondée sur le coût global

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 3, *Risk and performance evaluation of water reuse systems*.

A list of all parts in the ISO 20468 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to more specifically define a methodology for evaluating the economic performance of treatment systems, which is covered in ISO 20468-1:2018, Clause 7. The background to this document is the need to promote water reuse projects with cost-effective treatment systems in communities and industrial facilities in order to achieve sustainable water supply. A variety of stakeholders, including managers of water reuse projects and owners of water infrastructure and facilities, can select appropriate treatment systems through comprehensive performance evaluations using this document and the ISO 20468 series.

The concept of the economic performance evaluation methodology has already been established based on life-cycle cost (LCC), comprising capital, operation and maintenance (O&M), and disposal costs in IEC 60300-3-3. The economic performance evaluation methodologies of the petroleum and natural gas industries and building and constructed assets are defined in ISO 15663 and ISO 15686-5, respectively, based on the general standard of IEC 60300-3-3. The importance of the economic evaluation, based on LCC considering the environmental impact, is also described in guidelines for selecting high-quality water infrastructure and facilities.[14] With reference to these existing standards, this document provides a customized evaluation methodology for treatment systems in water reuse projects based on LCC, taking environmental impact into consideration. In this document there are no restrictions on applicable treatment systems, such as biological, physical or membrane separation.

Guidelines for performance evaluation of treatment technologies for water reuse systems —

Part 8:
Evaluation of treatment systems based on life cycle cost

1 Scope

This document provides life-cycle cost (LCC) methodology for treatment systems for water reuse for initial planning as well as later performance evaluation. LCC analysis provides valid information to determine whether the objectives have actually been accomplished and how operations are improved and optimized. Environmental impact is also taken into account in the LCC evaluation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
capital cost
money used to purchase, install and commission a capital asset

3.1.2
disposal cost
money used to demolish and rehabilitate a capital asset at the end of its life

3.1.3
operation and maintenance cost
cost incurred in running and managing the facility, labour, material and other related costs incurred to retain a building or its part in a state in which it can perform its required functions

3.1.4
life-cycle cost
total cost incurred during the life cycle

[SOURCE: IEC 60300-3-3:2017, 3.1.13]

3.1.5
life-cycle costing
process of evaluating the difference between the life-cycle costs of two or more alternative options

[SOURCE: ISO 15663:2021, 3.1.27, modified — Note to entry removed.]

3.2 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply:

C	LCC, LCY/year
C_a	LCC of alternative system, LCY/year
C_b	LCC of baseline system, LCY/year
C_d	disposal cost, LCY/year
C_i	capital cost, LCY/year
C_o	operation and maintenance cost, LCY/year
$C_{o(w)}$	cost for water input or water output in O&M, LCY/year
ΔC	cost reduction in water use, LCY/year
η_h	heat output recovery ratio
η_w	water recovery ratio
LCC	life-cycle cost
LCY	local currency
O&M	operation and maintenance
Q_{outa}	heat output in alternative system, J/year
Q_{outb}	heat output in baseline system, J/year
u	unit cost, LCY/m^3
w	water consumed, m^3/year
W_{ina}	water input in alternative system, m^3/year
W_{inb}	water input in baseline system, m^3/year
W_{outa}	water output in alternative system, m^3/year
W_{outb}	water output in baseline system, m^3/year

4 Concept of economic evaluation

4.1 General

The concept of life-cycle costing is applied to evaluate the economic performance of treatment systems in a water reuse project. An economic evaluation procedure using the total cost of the treatment system throughout a project's life can be applied to estimate the cost difference between each alternative system to select an appropriate water reclamation technology, while satisfying the project's requirements.

This document describes the economic evaluation methodology for treatment systems based on the following concepts according to existing standards:

— The LCC of an alternative treatment system with water reclamation process (in both cases of new installation and renewal or modification) is compared with that of a baseline system.[3],[15]

— The economic evaluation procedure includes definitions of the boundary of a treatment system, cost elements, calculation and evaluation.

The following characteristics should be especially considered:

— The boundary of an economic evaluation can include an entire treatment system consisting of water supply process and wastewater treatment process, as well as water reclamation process, when a reduction in the total amount of required water is expected by the reclamation process.[16]

— Heat recovery and recovery of valuable materials can be included in the evaluation.

— Environmental impacts can also be included in the evaluation, along with an economic evaluation.

4.2 Timing of the evaluation

A water reuse project requires a careful evaluation of goals, including an assessment of technology feasibility and relative costs to achieve the objectives. The evaluation can be conducted at the planning stage, O&M stage and disposal stage. The assumed data at the planning stage can be replaced with actual and more accurate data at the other stages. This can provide stakeholders with a greater opportunity of understanding the project status.

4.3 Consideration of water quality

Generally, the construction cost and the operation cost of a water reclamation facility differ greatly depending on the water quality of the wastewater supplied and the reclaimed water quality required. When a water reclamation facility is adopted, it is important to evaluate and select appropriate technologies to satisfy the requirements of water quality and quantity that are specified by users (see ISO 20468-1:2018, Clause 6).

5 Economic evaluation procedure

5.1 Boundary definition

For the economic evaluation of treatment systems, it is necessary to accurately define the boundary in accordance with the characteristics of an individual water reuse project. In particular, relevant facilities that will be affected by the project should be included in the boundary. For example, if heat recovered by the water reclamation process is utilized for a heating system, the facilities for heat recovery, such as a heat pump, should be within the boundary. In general, heat pump and heat exchanger equipment are widely applied for the heat recovery facilities in municipal sewage plants. Direct reuse of hot water is often applied in industrial facilities.

In the definition of the boundary, it is important to properly define the alternative system and the baseline system. For example, if the alternative system is defined with the installation of a new water reclamation process, the baseline system does not need the reclamation process. The boundary can be defined for each of several systems with different water reclamation technologies as candidates and compared with a baseline system.

An example of the boundary of an alternative system and a baseline system in a water reuse project utilizing treated municipal wastewater is shown in Figure 1. Treated water with its quality improved by a reclamation process in the alternative system can be used for building and landscapes. Heat recovered by the facility with the water reclamation process can be used for air conditioning systems and other purposes. As a result, an alternative system can achieve cost reduction for water and energy supplies compared with the baseline system. An example of facilities and items in the defined boundary in a case study on a water reuse project using treated municipal wastewater is shown in Annex A.

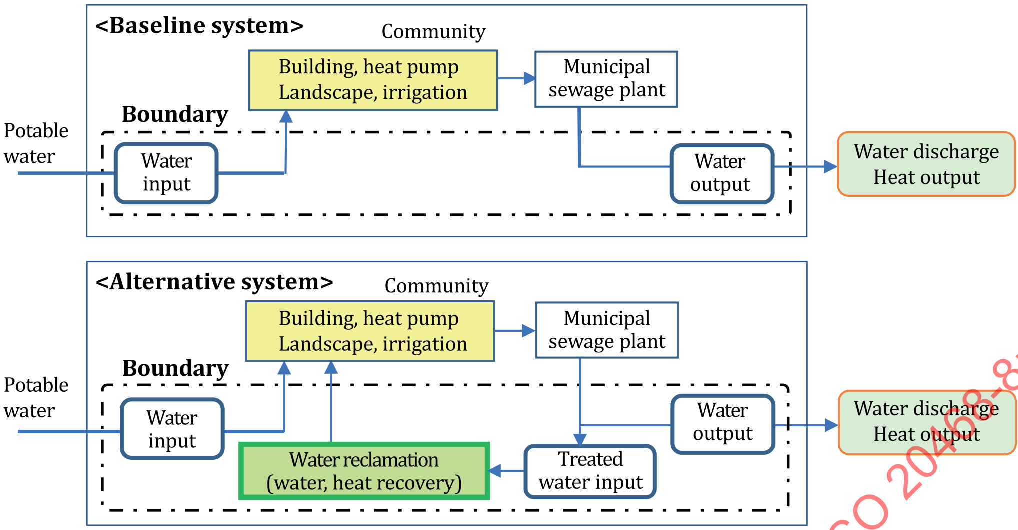


Figure 1 — Example of boundary of treatment system in a municipal water reuse project

Another example of the boundary of an alternative system with a water reclamation process and that of a baseline system are shown in Figure 2. The boundary in the baseline system consists of the water supply process, including water treatment and wastewater treatment processes. In addition, the boundary in the alternative system includes the water reclamation process. The water reclamation process improves treated water quality to meet the needs of domestic use and heat supply facilities, thus enabling heat recovery and recovery of valuable materials, along with water recovery. Consequently, the benefits of cost-effectiveness are estimated from the reduction in the amount of the water supply and water treatment in the alternative system. An example of facilities and items in the defined boundary in a case study of a water reuse project using industrial wastewater is shown in Annex B.

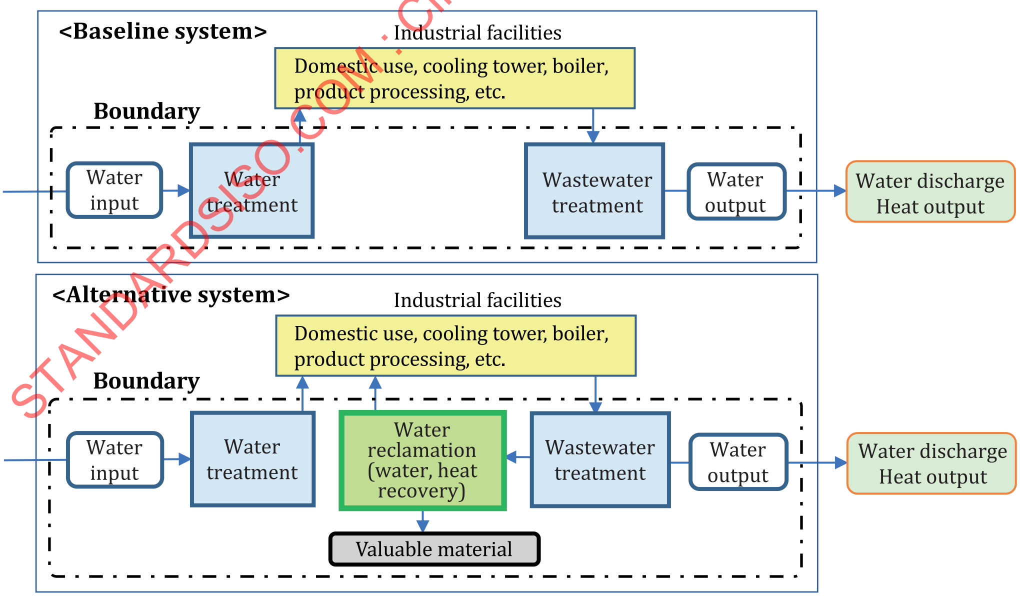


Figure 2 — Example of boundary of treatment system in an industrial water reuse project

Figure 1 and Figure 2 show examples of the boundary of a baseline system and an alternative system with a newly installed water reclamation process. The process can be a renewed or modified one when the baseline system includes an existing reclamation process. The boundary of the treatment system can also include related processes in different communities and industrial facilities, when water and heat are exchanged between them, while transportation costs should be considered in the evaluation.

5.2 Cost elements definition

It is important to accurately define cost elements in the water reuse project, which will have a large impact on the economic evaluation. To avoid missing important elements, it is recommended that the cost elements are defined using systematic procedures. Generally, cost elements are set up under the categories of capital cost (C_i), O&M cost (C_o) and disposal cost (C_d), as shown in Table 1, based on existing standards. The cost elements need to be set in consideration at least of the levels of detailed items required to determine differences between each alternative system or the difference from the baseline, and the cost-related data to be collected.

Indirect damage cost in C_o is composed of warranty expenses, including damage compensation due to a stoppage of facility operation caused by failure and detriment costs, such as damage to credit or reputation. Indirect damage cost should be considered for the convenience of warranty and exemption from legal liability. This is a kind of uncertainty cost that is affected significantly by objects and purposes, therefore it is defined as a recommendation.

Table 1 — Example of cost elements

Cost category	Cost elements
Capital cost, C_i	Design and development cost
	Manufacturing cost
	Transportation, installation and commissioning cost
O&M cost, C_o	Operation cost — energy: electricity, fuel — consumable materials — workforce — chemicals — sludge disposal cost — monitoring cost
	Maintenance cost — periodic inspection — replacement mechanical parts
	Indirect damage cost (recommendation) — warranty cost — liability cost — cost for providing an alternative service
Disposal cost, C_d	Retirement cost
	Disposal and recycling cost

5.3 Calculation

The LCC of each facility or item in the boundary defined in 5.1 can be calculated with Formula (1).

$$C = C_i + C_o + C_d \quad (1)$$

where

C is LCC (LCY/year);

C_i is capital cost (LCY/year);

C_o is O&M cost (LCY/year);

C_d is disposal cost (LCY/year).

In calculating C_i and C_o using the collected data, the economic evaluation period should be defined clearly because the data change significantly depending on the operation period of related facilities. C_i should be annualized based on the construction schedule and C_o should be calculated annually. The different life cycles of each facility should also be taken into account as well as the life cycle of the total treatment system. Financial parameters, such as discount rate, can be applied with reference to IEC 60300-3-3 and other standards relating to LCC, depending on project purposes. The disposal cost can be omitted if it is small compared with other costs or legitimate reasons are given. LCCs calculated for all facilities and items are summed up to obtain the total LCC for one of the alternative systems, and the same procedure is iterated to obtain the total LCCs for other alternative systems and the baseline system.

Cost for water input and water output involved in C_o can usually be calculated with Formula (2), considering the cost variation by region or country.

$$C_{o(w)} = u \times w \tag{2}$$

where

$C_{o(w)}$ is the cost for water input or water output in O&M (LCY/year);

u is the unit cost (LCY/ m^3);

w is water consumed (m^3/year).

Costs of heat recovery and recovery of valuable materials in the water reclamation process can also be calculated as LCC with negative values, namely incomes or revenues, as follows:

— The cost of heat recovery can be obtained as the cost conservation value of the amount of reused heat energy and is deducted from the cost of the heat recovery facility.

— The cost of recovering valuable materials can be obtained as income from selling and is deducted from the cost of the valuable material recovery facility.

5.4 Evaluation

The difference between the LCC calculated for each alternative system and that for the baseline system can be obtained with Formula (3) to evaluate and compare the economic performance of each alternative system clearly.

$$\Delta C = C_b - C_a \tag{3}$$

where

ΔC is the cost reduction in water use (LCY/year);

C_a is the LCC of the alternative system (LCY/year);

C_b is the LCC of the baseline system (LCY/year).

From the LCC values obtained, it is also possible to calculate the unit cost of recovered water for evaluating the economic performance of the treatment system. The evaluation of the results of LCC calculation can include sensitivity analysis to obtain additional information about the factors which have significant influence.

6 Evaluation of environmental benefits

6.1 General

The environmental benefits of applying the treatment system with a water reclamation process, which are not practically evaluated in the calculation of O&M cost, such as the cost of water input or output and heat recovery, should be evaluated along with the economic evaluation based on LCC.

The environmental benefits can be evaluated by using factors specific to water reuse, such as water recovery ratio and heat output recovery ratio (see 6.2).

Other general factors can also be selected and used based on the benefits related to reducing GHG emissions, consumptions of resources and pollutants discharged into the water environment.

The environmental benefits can further be converted to monetary value, where appropriate, and included in the LCC evaluation by relevant reasonable methodologies referring to related guidelines as necessary (see Annex C).

6.2 Water recovery ratio and heat output recovery ratio

The water recovery ratio is defined by Formula (4), using the amount of water input to the system, or by Formula (5), using the amount of water output from the system, as shown in Figure 1 and Figure 2.

$$\eta_{\mathrm{w}} = \frac{W_{\mathrm{inb}} - W_{\mathrm{ina}}}{W_{\mathrm{inb}}} \tag{4}$$

where

η_{w} is water recovery ratio;

W_{ina} is water input in the alternative system (m^3/year);

W_{inb} is water input in the baseline system (m^3/year).

$$\eta_{\mathrm{w}} = \frac{W_{\mathrm{outb}} - W_{\mathrm{outa}}}{W_{\mathrm{outb}}} \tag{5}$$

where

W_{outa} is water output in the alternative system (m^3/year);

W_{outb} is water output in the baseline system (m^3/year).

The heat output recovery ratio is defined by Formula (6), using the amount of heat output in a similar way to the water recovery ratio.

$$\eta_{\mathrm{h}} = \frac{Q_{\mathrm{outb}} - Q_{\mathrm{outa}}}{Q_{\mathrm{outb}}} \tag{6}$$

where

η_{h} is heat output recovery ratio;

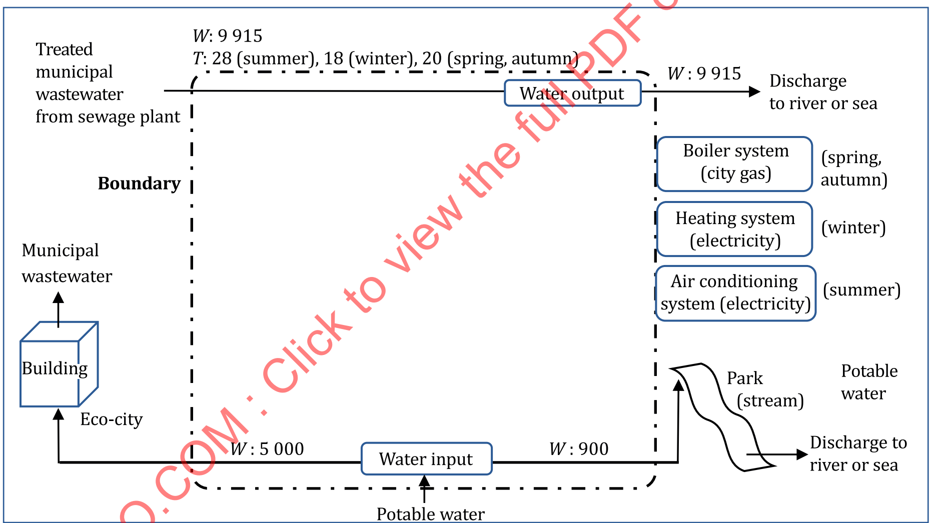
Q_{outa} is heat output in the alternative system (J/year);

Q_{outb} is heat output in the baseline system (J/year).

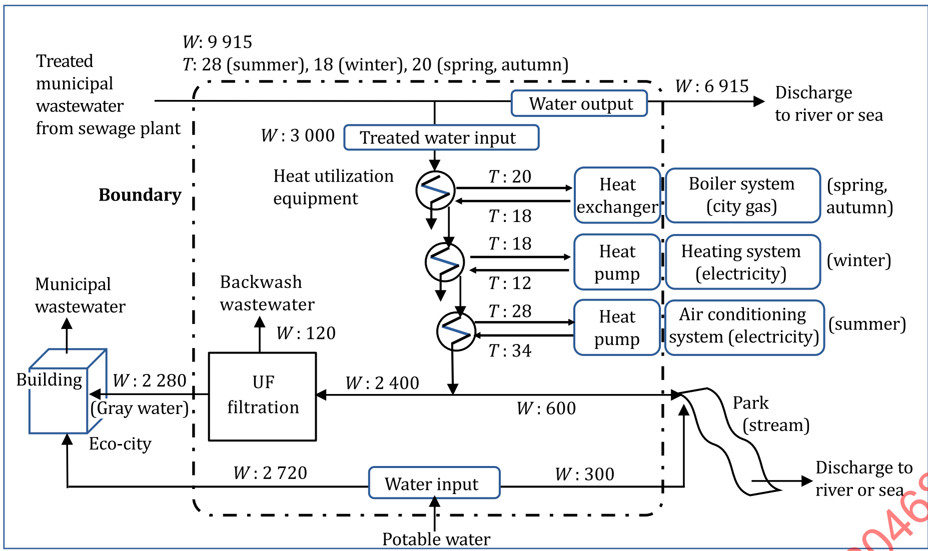
Annex A
(informative)

Example of evaluation of treatment systems for municipal water reuse

Figure A.1 shows the boundary of the cost analysis in the baseline system and in the alternative system with a new water reclamation process introduced for treated municipal wastewater utilization. In the alternative system, heat utilization equipment and ultrafiltration (UF) equipment are added as the water reclamation process. Some of the treated municipal wastewater from a sewage plant, 9 915 m^3/d, is used for reclaimed water of 3 000 m^3/d and heat energy (28 °C in summer, 18 °C in winter and 20 °C in spring and autumn). First, the heat energy is utilized for air conditioning in summer, heating in winter and hot water boilers in spring and autumn. Then the treated water is distributed to an eco-city and a park. 2 400 m^3/d of the treated water is filtrated and disinfected in UF membrane equipment and utilized for a grey water system in the eco-city. The remaining 600 m^3/d is used after disinfection as make-up water for a small stream in the park.



a) Baseline system



b) Alternative system

Key

W water flow rate (m^3/h)

T temperature (°C)

Figure A.1 — Boundary of cost analysis in treatment systems for municipal water reuse

Table A.1 — Example of calculation of cost reduction in water use, Δ*C* (US$/year)

Facilities and items		Cost elements	Baseline system	Alternative system	(Equipment)
Municipal sewage plant	Municipal sewage plant	Capital cost O&M cost Disposal cost	No difference		(General municipal sewage water)
	Treated sewage water output	Cost of treated sewage water output	180 949	126 199	
Hot water boiler system	Heat exchanger facility	Capital cost O&M cost Disposal cost	0	9 427	(Heat exchanger)
	Heat recovery	Total recovered cost		−334 574	

NOTE 1

Operation period: hot water boiler (spring and autumn): 0,5 year/year; heating (winter): 0,25 year/year; air conditioning (summer): 0,25 year/year.

Coefficient of performance: heating (air to water): 4 to 5; air conditioning (air to water): 3 to 4.

Unit cost of treated sewage water output: 0,05 US$/$m^3$ (payment to local government).

Unit cost of city gas: 2,4 US$/$m^3$ (normal).

Unit cost of potable water: 1,3 US$/$m^3$.

Unit cost of electricity: 0,14 US$/kWh.

Annual operation days: 365 days.

Total life span: 30 years.

NOTE 2 Details of the calculation methods of capital cost, O&M cost and disposal cost have been omitted.

NOTE 3 Facilities and items related to heat recovery can be omitted when they are not used.

Table A.1 *(continued)*

Facilities and items		Cost elements	Baseline system	Alternative system	(Equipment)
Heating system	Heat pump facility	Capital cost O&M cost Disposal cost	0	68 343	(Heat pump)
	Heat recovery	Total recovered cost		−13 369	
Air conditioning system	Heat pump facility	Capital cost O&M cost Disposal cost	0	68 343	(Heat pump)
	Heat recovery	Total recovered cost		−22 282	
UF system	UF facility	Capital cost O&M cost Disposal cost	0	937 273	(UF membrane)
	Recovered water	Total recovered cost		0	
Eco-city system	Pipeline and pump (UF to eco-city)	Capital cost O&M cost Disposal cost	0	283 327	(Pipeline and pumps)
	Recovered water	Consumed potable water cost	2 372 500	1 290 640	
Park	Pipeline and pump (heat utilization equipment to park)	Capital cost O&M cost Disposal cost	0	99 367	(Pipeline and pumps)
	Recovered water	Consumed potable water cost	427 050	142 350	
Total: ΔC (US$/year)			C_b	C_a	$C_b - C_a$
			2 980 499	2 655 044	325 455

NOTE 1

Operation period: hot water boiler (spring and autumn): 0,5 year/year; heating (winter): 0,25 year/year; air conditioning (summer): 0,25 year/year.

Coefficient of performance: heating (air to water): 4 to 5; air conditioning (air to water): 3 to 4.

Unit cost of treated sewage water output: 0,05 US$/$m^3$ (payment to local government).

Unit cost of city gas: 2,4 US$/$m^3$ (normal).

Unit cost of potable water: 1,3 US$/$m^3$.

Unit cost of electricity: 0,14 US$/kWh.

Annual operation days: 365 days.

Total life span: 30 years.

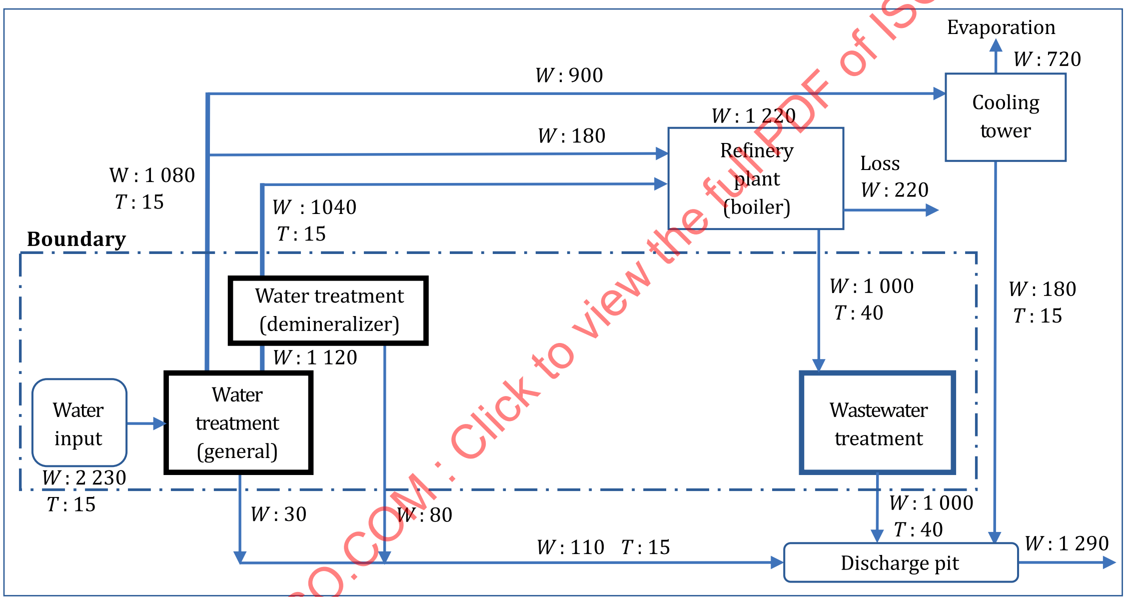
NOTE 2 Details of the calculation methods of capital cost, O&M cost and disposal cost have been omitted.

NOTE 3 Facilities and items related to heat recovery can be omitted when they are not used.

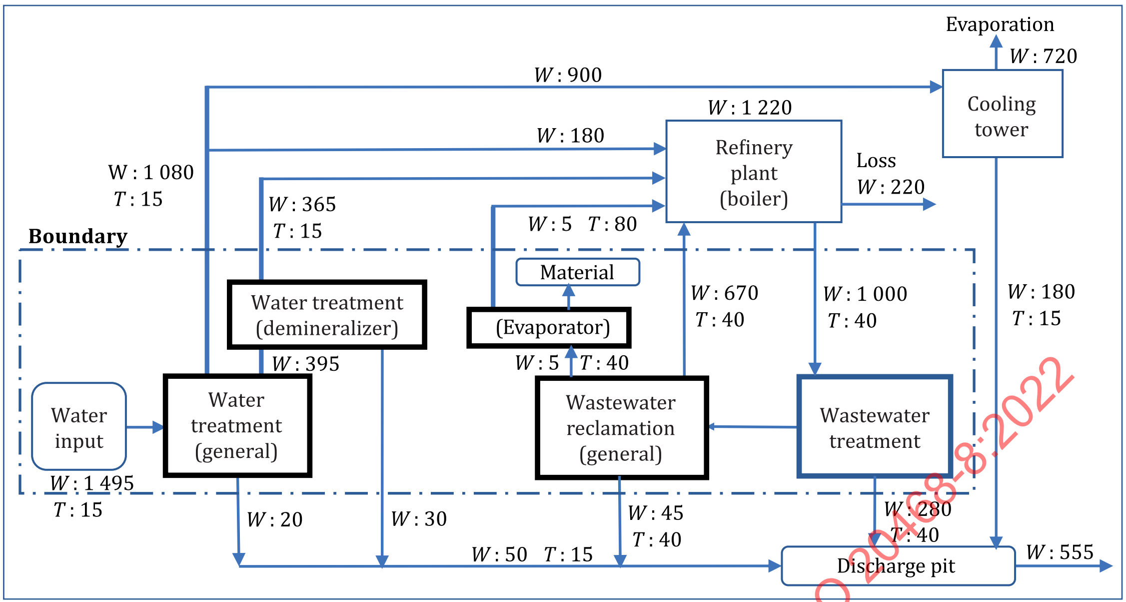
Annex B
(informative)

Example of evaluation of treatment systems for industrial water reuse

Figure B.1 shows the boundary of the cost analysis in the baseline system and in the alternative system with a new water reclamation process introduced for industrial facilities. In the alternative system, general equipment and an evaporator are added as the water reclamation process. Part of the effluent from the wastewater treatment process is reclaimed by the general equipment and is used for a boiler as reclaimed water of 670 m^3/h and 40 °C. In addition, wastewater at 5 m^3/h and 40 °C containing a high concentration (2 000 mg/l) of phosphoric acid is treated by the evaporator; phosphoric acid is recovered as a valuable material. Reclaimed water at 5 m^3/h and 80 °C after recovering the valuable material is used as the supply water for the boiler.



a) Baseline system



b) Alternative system

Key

W water flow rate (m^3/h)

T temperature (°C)

Figure B.1 — Boundary of cost analysis in treatment systems for industrial water reuse

Table B.1 shows the effect of recovering water, heat and valuable material by introducing the water reclamation process in the alternative system compared with the baseline system. Water recovery ratio (η_w) and heat output recovery ratio (η_h) are calculated with Formula (5) and (6), respectively.

Table B.1 — Recovery and recovery ratios of water, heat and valuable materials

Item		Baseline system	Alternative system	Recovery ratio
Water input (m^3/h)		2,230	1 495	–
Water output (m^3/h)	15 °C	290	230	–
	40 °C	1 000	325	–
	Total	1 290	555	η_w : 57 %
Heat output (40 °C) (MJ/year)		837 000 000	272 000 000	η_h : 67,5 %
Recovered heat (40 °C) (MJ/year)		0	565 000 000	–
Valuable material (phosphoric acid) recovered by evaporator (kg/year)		0	80	–
NOTE 1 Inlet wastewater quantity to evaporator: 5 (m^3/h).				
NOTE 2 Phosphate concentration of input wastewater: 2 000 (g/m^3).				
NOTE 3 Annual operation hours: 8 000 (h/year).				

The LCC reduction in water use, ΔC, is calculated with Formula (3) and is shown in Table B.2.