Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24029

154 (2019) 132–140
June

Energy assessment and savings for the sewage treatment plant using EUAT and Tool-kit in Korea

Juwon Jang[a], Seokhun Park[b], Jongseok Park[b], Hoseop Kim[b], Jaemoon Kim[c], Hosik Lee[a,*]

[a]*Department of Railroad Infra System Engineering, Korea National University of Transportation, 157, Chelodobangmulgwan-ro, Uiwang-si, Gyeonggi-do, Republic of Korea; email: hlee@ut.ac.kr (H. Lee)*
[b]*Korea Environment Corporation, 42, Hwangyeong-ro, Seo-gu, Incheon, Republic of Korea*
[c]*Department of Transportation System Engineering, Korea National University of Transportation, 157, Chelodobangmulgwan-ro, Uiwang-si, Gyeonggi-do, Republic of Korea*

Received 31 July 2018; Accepted 25 February 2019

ABSTRACT

As an energy consumption facility, the sewage treatment plants in Korea account for 0.5% of the total annual electricity consumption of the country, but the energy self-sufficiency rate is only 0.8%; therefore measures to reduce energy consumption are needed. The main purpose of this study was to analyze the energy consumption status and over-consumption process by applying the US Environmental Protection Agency's Energy Use Assessment Tool (EUAT) and Korea Environment Corporation's (KECO) Tool-kit, which were sewage treatment plant energy diagnosis programs, simultaneously to the sewage treatment plant. Based on the results of the analysis, a plan to reduce energy consumption was examined. Both the EUAT and Tool-kit can grasp the energy flow by process and analyze the efficiency of the equipment. As a result of the energy diagnosis for A- sewage treatment plant, three types of energy reduction methods, replacing lightning, replacing low-efficiency devices, and changing the operation, were derived. The expected effect of applying the energy-savings method to A-sewage treatment plant was that the amount of power used would decrease by 38,000 kWh per year. The savings was of more than 10% of the total energy use.

Keywords: Energy diagnosis and assessment; Energy reduction and saving; EUAT; Sewage treatment plant; Tool-kit

1. Introduction

The sewage treatment plants in Korea account for 0.5% of the total annual electricity consumption of the country as an energy consumption facility, but the energy self-sufficiency rate is only 0.8%; therefore measures to reduce energy consumption are needed [1]. The Korean sewage treatment plant policy has been promoted with the aim of introducing new sewage treatment technology, advanced treatment, and attaining a stable quality of treated water; however, it does not the aim for efficient use of energy.

As a result, it is currently being evaluated as a representative of energy-consuming facility among public facilities. To cope with energy shortage and climate change, it is necessary to reduce the energy consumed in water treatment and make sewage facilities self-reliant through the use of new and renewable energy and other methods. Most importantly, it is necessary to take various steps, and aggressive measures to maximize energy efficiency while maintaining sewage treatment efficiency [2]. The Korean Ministry of Environment has established the "Basic Plan for Energy self-sufficiency 2010." This plan has set targets for energy self-reliance rate of 18% (years 2010–2015, introduction of energy saving and production business) in the first stage, 30% (years 2016–2020, energy conservation and gradual expansion of production business) in the second stage, and 50% (years 2021–2030, energy saving and production project completion) in the

* Corresponding author.

third stage for public sewage treatment plants with abundant energy potential [1].

In the case of the U.S.A, based on the revised 2005 Energy Policy Act, we began implementing energy policies to reduce greenhouse gas emissions, used new and renewable energy, and save energy and increase efficiency [3]. For reference, around year 2000 the energy used in water treatment plants and sewage treatment plants in the U.S. accounted for 3–4% of total U.S. electricity consumption [4]. Also, In Europe, the power consumption of sewage treatment plants accounted for 1–4% [5]. In other countries, studies on energy and water treatment for water resources and sustainable development were policy issues [6–12].

In Korea, energy diagnosis is carried out by the energy use rationalization method, but there is no specialized energy diagnosis program for the general sewage treatment plant. Therefore, it has been difficult to compare the process and power consumption among sewage treatment plants by producing different analysis data for each subject of diagnosis [13]. Consequently, in this study, the Energy Use Assessment Tool (EUAT) of the United States Environmental Protection Agency (US EPA), which has been widely used as an energy diagnostic program in the U.S. since 2007, and the Tool-kit developed by the Korea Environment Corporation (KECO) were used to perform energy diagnosis for the sewage treatment plant. The main purpose of this study was to analyze the EUAT and Tool-kit simultaneously in a sewage treatment plant to diagnose energy consumption and analyze the status of energy consumption and the over-consumption process. Based on the results, a possible operation method to reduce the energy used was examined. In addition, the features of each EUAT and Tool-kit were examined and their application characteristics in the sewage treatment plant were analyzed.

2. Materials and methods

The EUAT used in this study consists of five tabs: the program introduction tab, sewage treatment plant general information input tab, building information input tab including lighting equipment, sewage treatment plant information input tab, and analysis result tab. In addition, the configurations are able to check data conveniently through the movement between tabs. This program has the advantage of knowing the energy over-consumption device because it can calculate and examine the annual usage power of each machine [13].

Unlike EUAT, the Tool-kit developed by KECO can be applied even though there is no history of previous operation time. In addition, it is possible to calculate the load factor through actual power measurements and to measure the energy loss of the rotating equipment and efficiency of the pump; thus, accurate energy diagnosis is possible. In addition, the I-smart (confirmation of suitability of electric power receiving facility capacity, comparison of electric charges, etc.) can offer a power cost optimization method to diagnose the power cost, and at the peak time, it can take measures such as adjusting the operation rate of the equipment and blocking the load.

Both the EUAT and Tool-kit can determine the flow of energy usage in each process. The EUAT has the advantage of being able to make accurate diagnoses of the lighting, air conditioning, and heating facilities in the process and administration office. The Tool-kit has the advantage of being capable of diagnosing the load and efficiency calculation of the equipment through actual measurement of the electric power, thus providing information pertinent to replacement or improvement of equipment.

Data reviewed from A-sewage treatment plant and obtained data from the treatment status (inflow and outflow). To examine the current consumption of electricity at A-sewage treatment plant, the I-smart of the Korea Electric Power Corporation (KEPCO) was used to determine the electricity rate and the amount of electricity. Among the field data, especially focused on the design books and examined the list of electric lamp facilities and the list of electric equipment not used in the process, such as air conditioning equipment, electric heaters, and exhaust fans. In addition, the collected data using the Supervisory Control and Data Acquisition–Onsaemiro (SCADA) system, which was a field operation program, and reanalyzed the data to apply it to the program. In this study, power, current, voltage, total harmonic distortion (THD), etc., were measured using electric power measuring equipment (Power Analyzer, model CW500). The contents of the actual power were input to the Tool-kit to diagnose the state of the equipment. The electric power measurement work was characterized as only that measured during operation of the facilities. Fig. 1 shows the derivation process of energy reduction measures.

3. Results and discussion

3.1. STP energy diagnosis

3.1.1. Sewage treatment plant status

The data collected from A-sewage treatment plant were applied to the EUAT and the Tool-kit program to analyze the current energy consumption status of each process. Based on this analysis, energy reduction measures were derived and reapplied to the EUAT program to examine the energy reduction effect. In (Table 1) the energy consumption electrical equipment status of A-sewage treatment plant is explained.

A-sewage treatment plant is a small to medium-size sewage treatment plant with a capacity of 800 m^3/d, and the sewage exclusion method is a separate sewer system. The plant is operated by the Pumyang sequencing batch reactor (PSBR) method, which is a modified continuous sequencing batch reactor method. A flotation system is utilized for the treatment of total phosphorus, and dehydration for sludge reduction is operated by applying a multi-disk type dehydrator. When sewage is introduced into A-sewage treatment plant, the contaminants and sludge eliminators remove sewage contaminants. Next, the material is transferred to the flow equalization basin, and the generated contaminants are collected in a storage container and removed. The sewage transferred to the reaction tanks enters the two reaction tanks alternately. Anaerobic and aerobic processes are operated repeatedly in one reaction tank. In the remaining reaction tank, a sedimentation process is conducted, and the generated sludge is pumped into a sludge holding tank. At the same time, the reactor-treated water is transferred to the treated-water tank, and this process is performed repeatedly according to a predetermined time

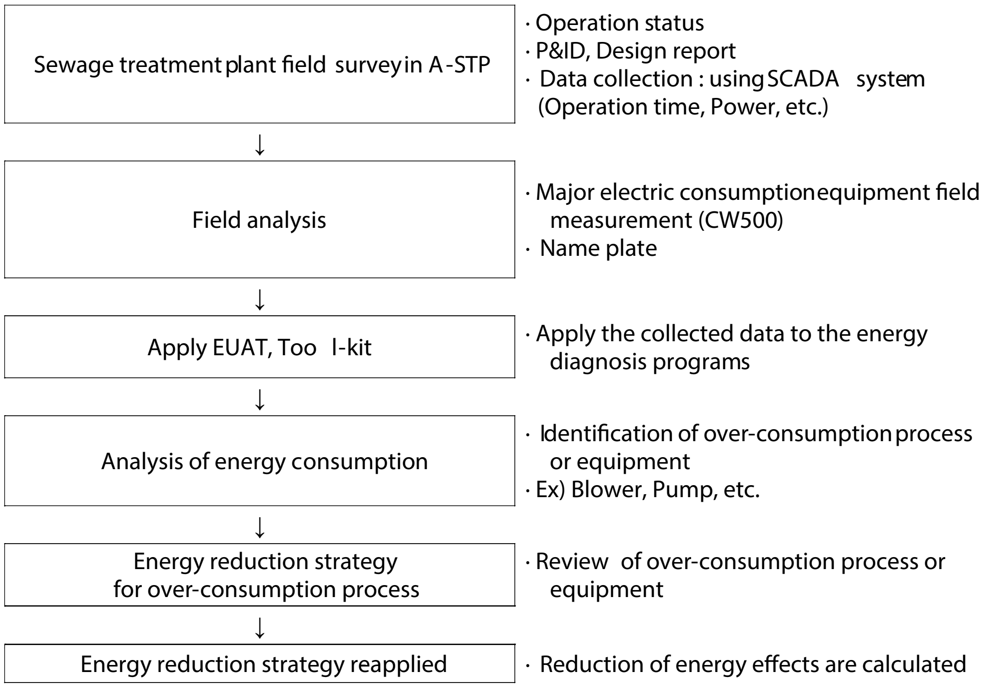

Fig. 1. Process of an energy reduction plan.

Table 1
A-sewage treatment plant energy consumption electrical equipment status

	Equipment name	Main equipment power
Flow equalization basin	Inflow valve, grit removal, storage container, flow equalization basin mixer, inflow pump, hoist	Flow equalization basin mixer, 3.7 kW inflow pump, 7.5 kW
Secondary treatment	Reactor inflow valve, mixer, diffuser, blower, rising curtain wall, outflow valve, sludge draw valve, sludge transfer pump, excess sludge pump, sludge transfer valve, sewage pump	Mixer, 2.2 kW Blower, 15 kW Sludge transfer pump, 2.2 kW
Filtration	Filter supply pump, automatic filter, disinfection equipment, automatic water supply system	Filter supply pump, 3.7 kW Automatic water supply system, 3.7 kW
Sludge handling	Sludge holding tank diffuser, Sludge holding tank blower	Sludge holding tank blower, 2.2 kW
Odor control	Deodorization fan, deodorizer	Deodorization fan, 3.7 kW Deodorizer, 4.5 kW

sequence. The effluent from the reactor passes through a treatment tank and is transported to an automatic filter.

After disinfection and discharge through the filter, some effluent water is reused as cleaning water and backwashing water. The sludge generated in the water treatment process is concentrated and dehydrated by using a polymer and iron salts. The generated sludge is stored in a cake hopper for a certain amount of time and then removed [14].

3.1.2. Energy diagnosis of A-sewage treatment plant using EUAT

EUAT is a ranked energy consumption process (rankings from 1 to 5). The highest power consumption in A-sewage treatment plant is found in the secondary treatment, and this accounted for 37% of the total process. Considering that 30% of the power is used only in the mixer and blower during the secondary treatment process, there is a possibility of saving energy through operation of the biological reactor or improvement of the facility.

In domestic sewage treatment plants, the aeration tank blower, which consumes the most power at a sewage treatment plant, consumes 40.1% of the electricity in the secondary treatment process; in the U.S., this proportion is 56%. Therefore, it has been reported that the greatest power-saving effect can be obtained through improvement of facilities and operation methods [13]. Other studies [15–21] also report that the aeration of biological reactors constitutes 40%–60% of the total sewage treatment plant energy consumption. [22–27] have studied the optimization of operation such as aeration, pump, and mixer control to reduce energy consumption.

As a result of the survey on the use condition of luminaries from the site visit of A-sewage treatment plant, the numbers of the luminaries are 25 ea in the first basement and 61 ea on the first floor. The power consumed by the luminaries is 35,040 kWh per year, which accounts for 9% of the total power consumption. Figs. 2 and 3 show the application of EUAT.

In addition, high-efficiency and low-efficiency equipment can be identified by checking the power consumption ratio and the motor efficiency standard of the equipment installed in the sewage treatment plant. To save energy, it is possible to consider a driving method that substitute's low-efficiency equipment with high-efficiency equipment. In the case of high-efficiency appliances, energy saving can be achieved by adjusting the air flow rate. In A-sewage treatment plant, considered devices that would be effective upon replacement with consideration of operation time and efficiency. As a result, the contaminants and grit removal system, deodorization fan, and rising curtain wall are components that should be replaced.

3.1.3. Energy diagnosis of A-sewage treatment plant using Tool-kit

The results of the diagnosis made by the Tool-kit showed that 48% of the energy was consumed in the secondary treatment process, mainly by the blower, which was close to the EUAT diagnosis result showed in Table 2. In the filtration system, 21% was consumed due to the operation of the filter supply pump. The ratio difference between the EUAT and Tool-kit results because of the power consumption of the lightning or the administrative office electricity consumption were not included in the Tool-kit results. The reason for this, only the amount of electricity used in the process considered as a ratio.

In the case of A-sewage treatment plant, the energy diagnosis through power analysis using Tool-kit showed

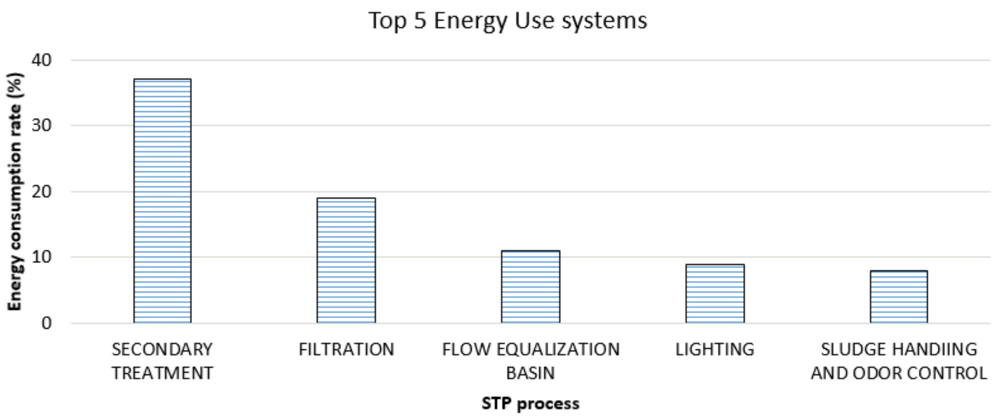

Fig. 2. A-sewage treatment plant power consumption by process.

Major Process/Top Energy Use Systems	Motor Efficiency (%)	Efficiency Rating	Electric Energy Use (%)	Electric Energy Use (kWh)	Electric Energy Cost ($)
Secondary Treatment					
Blower - A	91.5	High	10.42%	40,316	$3,357.93
Blower - D	91.5	High	10.72%	41,452	$3,452.59
Drive - outflow valve A	75	Low	0.01%	33	$2.73
Drive - outflow valve B	75	Low	0.01%	29	$2.38
Drive - rising curtain wall A	74.5	Low	1.94%	7,522	$626.54
Drive - rising curtain wall B	74.5	Low	1.99%	7,701	$641.41
Drive - sludge draw valve A	72	Low	0.02%	94	$7.87
Drive - sludge draw valve B	72	Low	0.02%	91	$7.61
Other kW Load - mixer A	N/A	N/A	2.86%	11,052	$920.49
Other kW Load - mixer B	N/A	N/A	2.82%	10,915	$909.09
Other kW Load - mixer C	N/A	N/A	2.91%	11,277	$939.23
Other kW Load - mixer D	N/A	N/A	2.91%	11,277	$939.23
Pump - excess sludge pump A	79	Low	0.07%	290	$24.14
Pump - excess sludge pump B	79	Low	0.00%	0	$0.02
Pump - sewage pump A	75	Low	0.00%	10	$0.86
Pump - sewage pump B	75	Low	0.00%	0	$0.01
Pump - sludge transfer pump	83	Low	0.15%	574	$47.83
Pump - sludge transfer pump	83	Low	0.00%	0	$0.03

Fig. 3. Example of A-sewage treatment plant electrical equipment efficiency EUAT diagnosis result.

Table 2
A-sewage treatment plant ratio of power consumption by process

		Flow equalization basin	Secondary treatment	Filtration	Sludge handling	Odor control	Total	Remarks
Ratio(%)	Tool-kit	16	48	21	8	7	100	Power of luminaire and administrative office is input separately
	EUAT	11	37	19	4	5	76	Power of luminaire, administrative office, and unidentified power: 24%

that the 7.5 kW inflow pump was at risk of overdriving, with a load ratio of 160% showed in (Fig. 4). In the case of this sewage treatment plant, facilities other than the inflow pump have a good energy loss standard and facility efficiency according to the unbalance rate. In addition, the power charges optimization diagnosis, determined that it uses a proper charge system.

3.2. STP energy savings plan

3.2.1. Energy reduction by utilizing LED lights

A-sewage treatment plant uses conventional fluorescent lamps, and the energy-saving effect of replacing these with high-efficiency lighting fixtures such as LED lighting, which was recommended by the Korea Energy Agency, was considered. According to Korea Energy Agency data, replacing existing lighting with LED luminaries should result in an energy-saving effect of more than 50% compared to the energy consumption of the current luminaries. The existing fluorescent instruments were the exposed type, and dust or other fine debris frequently becomes attached; thus the lifespan of the lighting was short and short-circuit accidents may occur. Therefore, installing a dustproof-type fluorescent lighting apparatus has been proposed [28].

As a result of the energy diagnosis of A-sewage treatment plant, the power ratio of the luminaries used in the treatment plant was estimated about 10%. In the case of sewage treatment plants in the U.S., about 10% of the electricity was reported as being consumed in offices and by air conditioning [29]. This indicates that energy consumption trends in the U.S.A. are similar to those of sewage treatment plants in Korea. In the case of the Salineville sewage treatment plant in the U.S.A., the power was reduced by 587 kWh by replacing existing lighting with high-efficiency light bulbs, and 708 kWh was saved by attaching an automatic detection sensor to the bulbs. It was also reported that the LED lamp replacement saved 491 kWh of power [30].

Thus, the amount of energy saving obtained by replacing the luminaires of A-sewage treatment plant with LED luminaires was calculated. For A-sewage treatment plant, about 100 lamps, including metal halide lamps, incandescent lamps, three-wavelength lamps, and fluorescent lamps, were available to be replaced with LED lighting. Table 3 shows

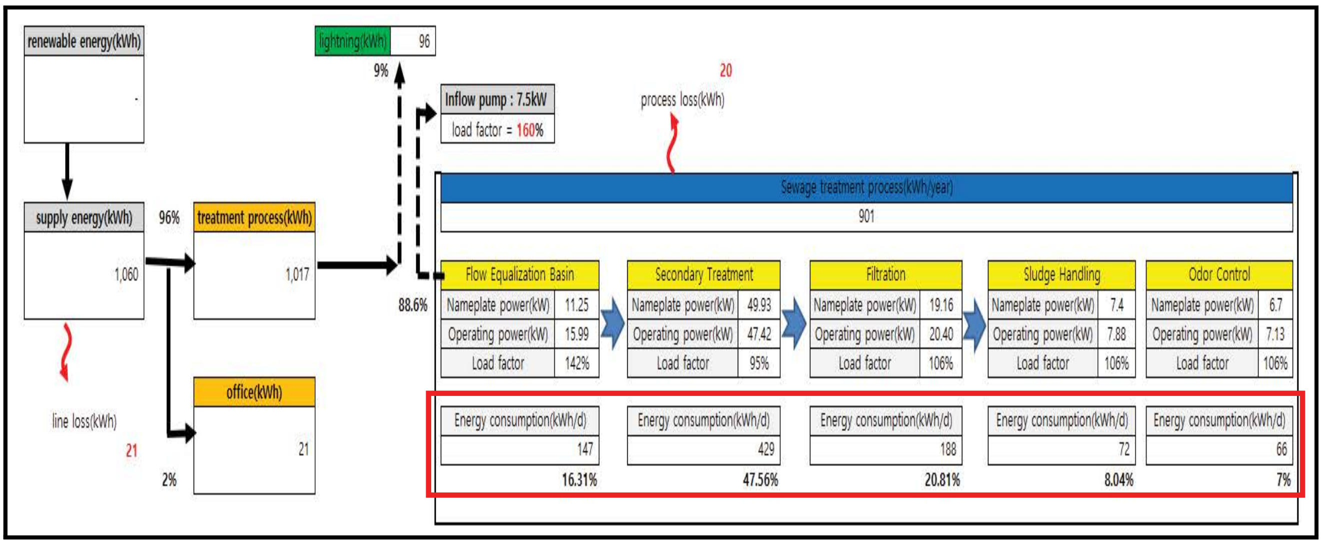

Fig. 4. Tool-kit energy flow map for A-sewage treatment plant.

Table 3
Energy savings obtained by replacing the lamps of A-sewage treatment plant

Energy conservation measure	Expected action	Energy saving possibility
Replacement of lighting	Metal halide lamps, incandescent lamps, three-wavelength lamps, fluorescent lamps, etc. Replacing about 100 lights	22,548 kWh/year (6%)

that the energy savings change was 22,548 kWh/year, the energy saving rate was 6% of the total, and the cost payback period was approximately 1 year.

3.2.2. Energy reduction through equipment efficiency review

In this study, the data of facilities surveyed at A-sewage treatment plant were entered. The low-, medium-, and high-efficiency instruments obtained from the EUAT results were considered with replacement of the low-efficiency devices with high-efficiency devices, according to EPA standards, and the energy savings were calculated. The US EPA provides efficiency standards for electrical equipment. High-efficiency equipment was classified as equipment having an efficiency of 90% or more, medium-efficiency equipment has values of 85–90%, and low-efficiency equipment was that with values of 85% or less. Replacement of low-efficiency equipment was recommended for energy reduction [31]. The equipment with low operation time and small power was excluded because its inclusion was ineffective and there was less power saving than cost.

In the case of the Salineville sewage treatment plant in the U.S., it was reported that replacing a regular motor with a premium motor saved 1.2% of the original power and that replacing a 50-hp pump with a 15-hp pump saved 55% of the energy originally used [30].

For A-sewage treatment plant, energy savings obtained by replacing the three facilities of concomitant and grit removal, deodorization fan, and rising curtain wall, which were diagnosed as low-efficiency equipment, with highly efficient equipment were calculated according to EPA standards. Table 4 shows that the energy savings amount is 7,345 kWh/year, which is 2% of the total energy.

3.2.3. Energy reduction through operational change

The results of the review of the operation status of A-sewage treatment plant, show that the surplus sludge concentration is less than 4,000 mg/L and it is operated with a relatively low level compared to MLSS. This is presumed to be a problem of sludge settling characteristics or excessive sludge drawing, and an inadequate capacity of the sludge draw pump is a problem. The quantity of sludge draw flow is high, and the excess sludge concentration is low, which may adversely affect the operation of mass fraction management (solid retention time (SRT) control, ratio food-to-microorganism ratio (F/M) management, etc.). Therefore, it is necessary to replace the sludge draw pump or improve the wasting method. In addition, because the operation of the SRT is unstable, it affects the stability of the biological treatment process; thus, stable operation is required. Also considered ways to reduce SRT, etc., because it exceeded the BOD, SS, and T-P designed water quality standards even though the operational quantity of flow and water quality are lower than design standards.

The energy consumption of the Psyttalia WWTP in Athens, Greece, was 55% of the total in the aeration tank and 10% in the sludge treatment, and a reduction effect was examined through various scenarios (using GPS-X). The largest energy reduction effect among the scenarios was reported to be an 11.2% energy savings by applying changes of DO concentration and SRT [32].

The operation sequence of the bioreactor process of A-sewage treatment plant was fill, anaerobic, aerobic, settle, transfer, draw, respectively, and the process was operated with four cycles of 360 min per cycle is shown in (Table 5). A-sewage treatment plant examined the effect of energy reduction by computer simulations (using a computer simulation program developed by UNU, a Korean modelling company, based on activated sludge model ASM2d) according to SRT control to solve the sludge drawing problem and unstable SRT management problem. Adjustment of SRT can be done without problems in summer, but when the temperature falls, the T-N value increases, and it was difficult to operate by lowering SRT. Therefore, the first computer simulation was designed to be similar to the water quality of the winter season, and the second computer simulation changed the operation setting (anaerobic time increased by 20 min and aerobic time decreased by 20 min showed in (Table 6)) within a range that does not affect nitrification. In addition, the amount of excess sludge was adjusted from 12 to 18 m^3/d, and computer simulations conducted.

As a result of the computer simulation, there was improvement of the water quality parameters of BOD (4.5%),

Table 4
Energy savings at A-sewage treatment plant obtained by replacing low-efficiency facilities with high-efficiency facilities

Energy conservation measure	Expected action			Energy saving possibility
	Low-efficiency equipment	Efficiency (%)	Power (kW)	
Low-efficiency equipment replace with high-efficiency equipment	Grit removal	82.5→95	0.75	7,345 kWh/year (2%)
	Deodorization fan	75→95	2.2	
	Rising curtain wall	74.5→95	1.5	

Table 5
Energy savings resulting from changing the operation of A-sewage treatment plant

Energy conservation measure	Expected actions	Energy saving possibility
Blower and aeration mixer control according to the changes in operational condition (changes in the bioreactor operation cycle)	Change of aerobic condition time by SRT control (20-min decrease in aerobic time / 1 cycle: 4 cycles per day)	8,025 kWh/year (2–3%)

Table 6
A-sewage treatment plant bioreactor operation cycle (unit: min)

Process	Anaerobic	Aerobic	Settle	Transfer	Draw	Total
Existing operation	70	135	95	40	20	360
Changed operation	90	115	95	40	20	360

COD (0.6%), SS (8.4%), T-N (1.1%), and T-P (12.2%) [14]. The bioreactor operation cycle was changed to an anaerobic operation time of 20 min per cycle of aerobic time (4 cycles per day). The effect of the energy reduction due to the reduction of expiration time was examined.

In the aerobic condition, the energy reduction effect occurred as the operating times of the blower and aeration mixer were decreased.

3.2.4. Application result for the energy-saving plan

A-sewage treatment plant was reviewed according to the three energy-improvement measures of replacement of luminaries, replacement of low-efficiency equipment, and adjustment of equipment operation time due to changes in aerobic condition time. The effect of the re-application of the reviewed improvements to the EUAT follows.

It was determined that the amount of power consumed by the existing luminaries was 9.06%. When the existing luminaries were replaced with LED luminaries, the amount of power was decreased remarkably to 3.23%. In addition, we examined the energy reduction effect of high-efficiency equipment replacement for some of the equipment of A-sewage treatment plant that was confirmed to have low efficiency. As a result, there was a slight difference in each appliance, but these differences produced a reduction of about 2% of the total energy consumption.

In the case of blowers and aeration mixers, which consume relatively large amounts of power, the effect of reducing the aerobic time conditions resulted in reductions of about 2–3% compared to the energy consumption of the sewage treatment plant. As a result of the application of each energy saving plan for power saving of A-sewage treatment plant, it was determined that the amount of power reduced annually was about 38,000 kWh from the total power showed in (Fig. 5).

3.2.5. EUAT and tool-kit comparison analysis

The EUAT and Tool-kit are represented by charts of power usage by each process. In addition, it is possible to

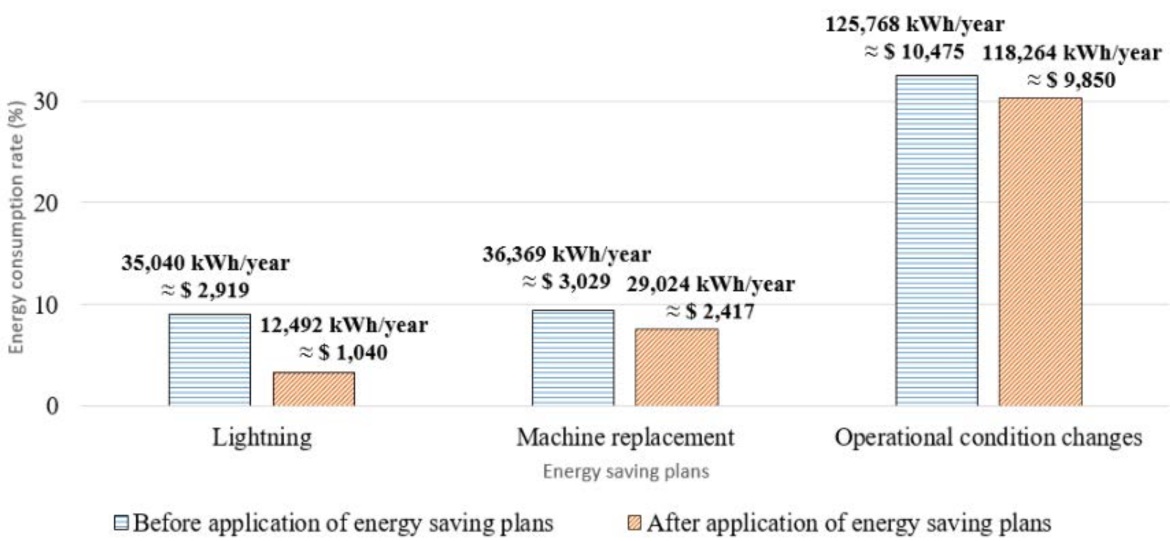

Fig. 5. Comparison of energy use status before and after applying the energy saving plan of A-sewage treatment plant.

calculate the power consumption by each facility so that the flow of energy consumption can be understood. Therefore, there is a similarity that can be compared with other methods of process or the same method of process. Because EUAT uses all the machine data from the sewage treatment plant and previous operation time history data, easier and more accurate self-diagnosis is possible by constructing more data. In addition, there is an advantage, as shown by Figs. 1 and 3, of enabling identification of low-, medium-, and high-efficiency devices based on the data.

Tool-kit can diagnose without these data because it inputs the actual measured power based on the power analyzer. In the case of Tool-kit, accurate diagnoses, such as load factor calculation, can be performed with the actual data measured by the power analyzer. However, it takes a lot of time to perform the measurement using the power analyzer, which is a disadvantage. According to the facility evaluation standard established by the Tool-kit, it has a great advantage of being able to identify the problem analysis (load unbalance factor of voltage and current, optimum operation according to operating load ratio, actual efficiency of pump, etc.) and points of improvement for the rotating equipment and the pump, which are the main electricity consumption equipment. Therefore, it can be a basis for correct diagnosis, replacement, or repair in terms of improvement of facilities.

In the case of Korea's sewage treatment plants, it is not easy to grasp the amount of electricity used in only the sewage treatment process because the electricity consumption is charged through one measuring instrument. In other cases, such as the Strass sewage treatment plant in Austria, it is possible to identify the power of each process through process measurements (power meter usage) and operate efficiently in terms of energy [33]. Therefore, if a power meter is installed in each major process in plants in Korea, it would be easy to identify some unnecessary energy uses, problems, and improvements.

In the energy diagnosis results of EUAT and Tool-kit for A-sewage treatment plant, the ratios of power used by the process are almost similar. In the EUAT, it is possible to understand the power consumption of the luminaries, the administrative office, and the low-efficiency equipment. In addition, the Tool-kit can determine the load factor of the equipment, the efficiency of the pump, and the appropriateness of the power cost by analyzing the power through the power analyzer.

4. Conclusions and recommendations

In this study, a study was made to improve the energy use in the sewage treatment plant. Before proposing energy saving measures, two energy diagnosis programs were used to make an accurate diagnosis of energy use. The results of the energy diagnosis and the improvements were as follows:

- As a result of using the EUAT for the A-sewage treatment plant, the highest power consumption in A-sewage treatment plant is found in the secondary treatment, and this accounted for 37% of the total process. Considering that 30% of the power is used only in the mixer and blower during the secondary treatment process, there is a possibility of saving energy through operation of the biological reactor or improvement of the facility.
- The energy diagnosis for A-sewage treatment plant, three types of energy reduction methods, replacing lightning, replacing low-efficiency devices, and changing the operation, are derived. The expected effect of applying the energy-savings method to A-sewage treatment plant is that the amount of power used would decrease by 38,000 kWh/year. This is a savings of more than 10% of the total energy use.
- In the energy diagnosis results of EUAT and Tool-kit for A-sewage treatment plant, the ratios of power used by the process are almost similar. In the EUAT, it is possible to understand the power consumption of the luminaries, the administrative office, and the low-efficiency equipment. In addition, the Tool-kit is able to determine the load factor of the equipment, the efficiency of the pump, and the appropriateness of the power cost by analyzing the power through the power analyzer.

References

[1] MOE, Basic plan of energy self-sufficiency, Report of Ministry of Environment, 2010.

[2] K-ECO, Study on Development of technology diagnosis technique through analysis of energy consumption pattern of sewage treatment facility, Report of Korea Environment Corporation, 2015.

[3] KEI, A Study on the Improvement of Energy Management for Wastewater Utilities, Report of Korea Environment Institute, 2011.

[4] EPRI, Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment – the next half century, Report of Electric Power Research Institute, 2002.

[5] S. Longo, B. Mirko d`Antoni, M. Bongards, A. Chaparro, A. Cronrath, F. Fatone, J.M. Lema, M. Mauricio-lglesias, A. Soares, A. Hospido, Monitoring and diagnosis of energy consumption in wastewater treatment plants. A state of the art and proposals for improvement, Appl. Energy, 179 (2016) 1251–1268.

[6] S.S. Ashlynn, C.H. David, E.W. Michael, Energy recovery from wastewater treatment plants in the United States: a case study of the energy-water nexus, Sustainability, 2 (2010) 945–962.

[7] C. Matos, S. Pereira, E. Amorim, I. Bentes, A. Briga-Sá, Wastewater and greywater reuse on irrigation in centralized and decentralized systems—an integrated approach on water quality, energy consumption and CO_2 emissions, Sci. Total Environ., 493 (2014) 463–471.

[8] P. Foladori, M. Vaccari, F. Vitali, Energy audit in small wastewater treatment plants: methodology, energy consumption indicators, and lessons learned, Water Sci. Technol., 72 (2015) 1007–1015.

[9] O.W. Awe, R. Liu, Y. Zhao, Analysis of energy consumption and saving in wastewater treatment plant: case study from Ireland, J. Water Sustain., 6 (2016) 63–76.

[10] Mo Chalabi, CH2M Beca, Artificial intelligence in the water industry: myth or reality? Online, Available at: https://www.waternz.org.nz/Article?Action=View&Article_id=1377 (accessed 11 December 2018)

[11] B.S. Renan, S.M. Marina, P.R. Regiane, F.G. Ricardo, Comparative analysis of the energy consumption of different wastewater treatment plants, Int. J. Architect. Arts Applic., 3 (2017) 79–86.

[12] Y. Gu, Y. Li, X. Li, P. Luo, H. Wang, Z.P. Robinson, X. Wang, J. Wu, F. Li, The feasibility and challenges of energy self-sufficient wastewater treatment plants, Appl. Energy, 204 (2017) 1463–1475.

[13] K.S. Song, Energy auditing for a wastewater treatment plant: case study for a S-treatment plant, Master`s thesis, University of Chung-Ang, Republic of Korea, 2015.

[14] K-ECO, Study on Improvement of Operation Management of Integrated Management Sewage Facilities, Report of Korea Environment Corporation, 2017.
[15] GWRC, Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies - Global Report, Report of Global Water Research Coalition, 2010.
[16] A.K. Sharma, T. Guildal, H.R. Thomsen, B.N. Jacobsen, Energy savings by reduced mixing in aeration tanks: results from a full-scale investigation and long-term implementation at Avedoere wastewater treatment plant, Water Sci. Technol., 64 (2011) 1080–1095.
[17] R. Gori, L.M. Jiang, R. Sobhani, D. Rosso, Effects of soluble and particulate substrate on the carbon and energy footprint of wastewater treatment processes, Water Res., 45 (2011) 5858–5872.
[18] D. Panepinto, S. Fiore, M. Zappone, G. Genon, L. Meucci, Evaluation of the energy efficiency of a large wastewater treatment plant in Italy, Appl. Energy, 161 (2016) 404–411.
[19] P. Póvoa, A. Oehmen, P. Inocêncio, J.S. Matos, A. Frazão, Modelling energy costs for different operational strategies of a large water resource recovery facility, Water Sci. Technol., 75 (2017) 2139–2148.
[20] S. Sid, A. Volant, G. Lesage, M. Heran, Cost minimization in a full-scale conventional wastewater treatment plant: associated costs of biological energy consumption versus sludge production, Water Sci. Technol., 76 (2017) 2473–2481.
[21] N.A. Ramli, Md. F.A. Hamid, Analysis of energy efficiency and energy consumption costs: a case study for regional wastewater treatment plant in Malaysia, J. Water Reuse Desal., 07 (2017) 103–110.
[22] O. Nowak, S. Keil, C. Fimml, Examples of energy self-sufficient municipal nutrient removal plants, Water Sci. Technol., 64 (2011) 1–6.
[23] L. Åmand, G. Olsson, B. Carlsson, Aeration control – a review, Water Sci. Technol., 67 (2013) 2374–2398.
[24] M.H. Kim, S.H. Ji, Jung H. Jang, A study on energy saving effect from automatic control of air flowrate and estimation of optimal DO concentration in oxic reactor of wastewater treatment plant, J. Energy Eng., 23 (2014) 49–56.
[25] A. Zadorojniy, S. Wasserkrug, S. Zeltyn, V. Lipets, IBM cognitive technology helps aqualia to reduce costs and save resources in wastewater treatment, Informs, 47 (2017) 411–424.
[26] J.J. Zhu, P.R. Anderson, Exploring aeration-associated energy savings at a conventional water reclamation plant, Water Sci. Technol., 76 (2017) 2222–2231.
[27] K. Füreder, K. Svardal, W. Frey, H. Kroiss, J. Krampe, Energy consumption of agitators in activated sludge tanks – actual state and optimization potential, Water Sci. Technol., 77 (2018) 800–808.
[28] KEA, Lighting System Technical Information Collection - Replacement with High Efficiency Lighting Equipment, Korea Energy Agency, 2017.
[29] P.E. Ely Greenberg, CEM, Energy Audits for Water and Wastewater Treatment Plants and Pump Stations, Online, Available at: https://www.cedengineering.com/search?wmq=%20M02-04 (accessed 19 July 2018)
[30] Ohio RACP, Salineville Wastewater Treatment Facility - Energy Audit, Level II, Report of Ohio Rural Community Assistance Program, 2009.
[31] EPA, EPA's Energy Use Assessment Tool User's Guide Version 2.0. United States Environmental Protection Agency, 2012.
[32] D. Mamais, C. Noutsopoulos, A. Dimopoulou, A. Stasinakis, T.D. Lekkas, Wastewater treatment process impact on energy savings and greenhouse gas emissions, Water Sci. Technol., 71 (2015) 303–308.
[33] AIZ, Strass WWTP, Achental-Inntal-Zillertal, 2015.