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ENERGY PERFORMANCE INDICATORS FOR DRINKING WATER PUMPING STATIONS

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Abstract: *In the current context of population growth, urbanization, and climate change, the efficient operation of urban water systems is essential. Pumps represent the main consumers of electrical energy and are extensively utilized in water extraction, treatment, and distribution processes. This paper conducts an analysis of energy efficiency in pumping stations, which constitute critical components of urban water supply infrastructure. Two case studies are developed in which the performance of pumping stations is assessed using performance indicators. The obtained results contribute to the establishment and implementation of new strategies for improving energy efficiency.*

Key words: *water pumping stations, energy indicators, efficiency, water-energy interdependence, urban water system.*

1. Introduction

Accelerated urbanization, climate change, and increasing resource demand have intensified the stress on water and energy supply systems and require integrated strategies focused on enhancing energy efficiency and sustainable resource use [3], [5], [14], [17]. Electrical energy, the most extensively utilized forms of energy, plays a critical role in water supply processes, with urban water systems generating up to 80% of their operational costs from electricity consumption [12]. This interdependence is conceptualized through the Water-Energy Nexus (WEN) paradigm, which highlights the reciprocal influence of water and energy systems and emphasizes the necessity of optimized, data-driven management approaches [8], [11].

Urban Water Systems (UWS) are infrastructures characterized by high energy consumption, accounting for approximately 7 % of the total urban energy consumption [9]. Among UWS components, pumping stations represent the largest energy consumers, being critical in the processes of extraction, treatment, storage, and distribution of drinking water [8, 9], [15]. Optimizing their operation is essential for reducing energy consumption, operational costs, and environmental impact [13], [18].

Energy Indicators (*EI*) represent essential tools for assessing the performance of water systems, enabling the quantification of energy consumption, the identification of energy losses, and guiding decision-making towards sustainability [2], [7], [10]. Their utility is

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further enhanced by the integration of digital technologies, such as IoT and SCADA, which facilitate real-time monitoring [1], [16].

The present study addresses the gap in applied research by analysing two drinking water pumping stations, which are components of distinct urban systems. The comparative analysis conducted on these two case studies enables the evaluation of relevant energy indicators aimed at optimizing energy consumption. A replicable methodology is proposed to enhance the energy efficiency of water supply systems.

2. Objectives

The primary objective of this study is the definition and application of performance indicators for drinking water pumping stations, aiming to assess their energy efficiency, reliability, and operational functionality. By identifying and analysing these parameters, the study seeks to optimize pump operation, reduce energy consumption, and mitigate environmental impacts. Additionally, the proposed indicators will support decision-making processes concerning maintenance, rehabilitation, and integration of advanced technologies to enhance the adaptability of systems to evolving demands.

The analysis focuses on two pumping stations associated with urban water supply systems featuring different configurations: one is equipped with variable-speed drive pumps (SP1), and the other with fixed-speed drives pumps (SP2). This comparative approach facilitates the formulation of relevant indicators for evaluating and optimizing the energy performance of the two pumping station types. The study exclusively addresses drinking water pumping systems, excluding wastewater systems, to provide a specific and directly applicable analysis within the context of drinking water distribution.

3. Material and Methods

The research methodology involves a detailed assessment of the energy performance of pumps within water distribution systems, achieved through the integration of hydraulic and electrical data. This approach combines critical operational parameters, such as flow rates and energy consumption, to deliver an analysis of pump efficiency and overall system performance.

3.1. Performance indicators

The study is grounded in the performance evaluation principles recommended by the International Water Association (IWA), adapted to the specific characteristics of the analysed infrastructures.

To support the analysis, measurements of electrical parameters (voltage, current, frequency, etc.) were conducted during the operation of the equipment.

Experimental determinations were carried out using a portable network analyser (Qualistar CA 8336), which enabled continuous recording of electrical variables under real operating conditions of the pumping stations. Simultaneously, the transported water flow rates were monitored with ultrasonic flowmeter to allow the correlation between electrical energy consumption and the actual volume of water conveyed.

Pumping station performance indicators Table 1

Symbol	**Name and definition**	**Mathematical formula**	**Measurement units**
EI1	Energy intensity – represents the ratio between the total active energy consumed (E_a) and the volume of water delivered (V) during the analysed period (i).	$EI1 = \sum_{i=1}^{n} \frac{E_{a_i}}{V_i}$	kWh/m³
EI2	Standardized energy – refers to the energy consumed (E_a) per cubic meter of pumped water (V), normalized to a reference head (H) of 100 meters.	$EI2 = \frac{E_{a_i}}{V_i \cdot \frac{H}{100}}$	kWh/m³/100 m
EI3	Average active power – denotes the average amount of active power (P_a) used during the analysed time interval.	$EI3 = \frac{\sum_{i=1}^{n} P_{a_i}}{N}$	kW
EI4	Maximum active power – represents the peak value of active power (P_a) consumed within the analysed period.	$EI4 = \max(P_{a_1}, \ldots, P_{a_N})$	kW
EI5	CO_2 emissions – indicate the total amount of CO_2 released as a consequence of energy consumption (E_a), calculated using a standard emission factor (ef).	$EI5 = E_{a_t} \cdot ef$	kgCO_2e/kWh
EI6	Reactive energy intensity – is the ratio between the reactive energy consumed (E_r) and the volume of water delivered (V) during the analysed period (i).	$EI6 = \frac{E_{r_i}}{V_i}$	kVArh/m³
EI7	Standardized reactive energy – refers to the reactive energy consumed (E_r) per cubic meter of pumped water (V), standardized to a head of 100 meters.	$EI7 = \frac{E_{r_i}}{V_i \cdot \frac{H}{100}}$	kVArh/m³/100 m
EI8	Average reactive power – represents the average amount of reactive power (P_r) used during the analysed time interval Δt.	$EI8 = \frac{\sum_{i=1}^{n} P_{r_i}}{N}$	kVAr
EI9	Maximum reactive power – denotes the highest value of reactive power (P_r) consumed during the analysed period.	$EI9 = \max\ (P_{r_1}, \ldots, P_{r_N})$	kVAr
EI10	Energy proportionality index – expresses the percentage ratio between reactive (E_r) and active energy (E_a). It is inversely proportional to the power factor.	$EI10 = \frac{E_{r_i}}{E_{a_i}} \cdot 100$	%
EI11	Pump utilization degree – represents the proportion of the maximum pumping capacity (P_{a_n}) that is effectively used by the system on the day with the highest energy consumption ($E_{a_{max}}$) within the reference period.	$EI11 = \left(\frac{E_{a_{max}}}{P_{a_n} \cdot \Delta t}\right) \cdot 100$	%

Based on this experimental data, a series of energy performance indicators were calculated. These indicators were designed to accurately reflect the operational status of the analysed systems, the level of operational efficiency, and the potential for technological optimization.

Table 1 presents a synthesized overview of the performance indicators used, which serve as the foundation for the detailed analysis that follows.

These indicators provide a comprehensive framework for the analysis and improvement of the energy performance of water pumping and distribution systems. They enable systematic benchmarking and facilitate targeted interventions aimed at enhancing operational efficiency and sustainability.

3.2. Description of pumping stations

In this study, two drinking water pumping stations from Brasov region were analysed, selected to highlight differences in energy performance based on technological architecture and operational regime. Measurements were conducted on-site on October 20, 2024, using specialized equipment for recording both electrical and hydraulic parameters.

The first pumping station, designated as SP1, is intended for water distribution within the urban network and is equipped with five vertical multistage centrifugal pumps of the type CR 64-3-2 A-F-A-E-HQQE produced by Grundfos [6]. The technical specifications are presented in Table 2. Each pump is individually controlled by a frequency converter of the type FC 202 by Danfoss, which allows continuous adjustment of motor speed according to actual flow and pressure demands. The control system operates under a coordinator–subordinate (master-slave) architecture.

Table 2

Characteristics of the pumping units in SP1

Technical Characteristics	**Values**
Pump Characteristics	
Nominal flow (Q_n)	64 m^3/h
Nominal pumping head (H_n)	52.8 m
Drive Motor Characteristics	
Nominal power (P_n)	15 kW
Frequency (f_n)	50 Hz
Nominal voltage (U_n)	Δ 380-415 V / Y 660-690 V
Nominal current (I_n)	Δ 26-28 A / Y 15.6-16.2 A
Nominal rotational speed (n_n)	2930-2950 rpm
Power factor ($\cos\phi_n$)	0.87-0.89

The efficiency–power characteristic graph of the motors installed in the CR64 pump station is presented in Fig. 1. This technical configuration provides a high degree of flexibility.

The second pump system is intended for water transfer between two storage areas located at different altitudes. The pump station, designated as SP2, is equipped with three centrifugal pumps of type 10LR produce by Ingersoll-Dresser, driven by asynchronous motors with constant rotational speed. In Fig. 2 is presented the electrical characteristics for the pumping units and in table 3 the technical characteristics of the pumping units.

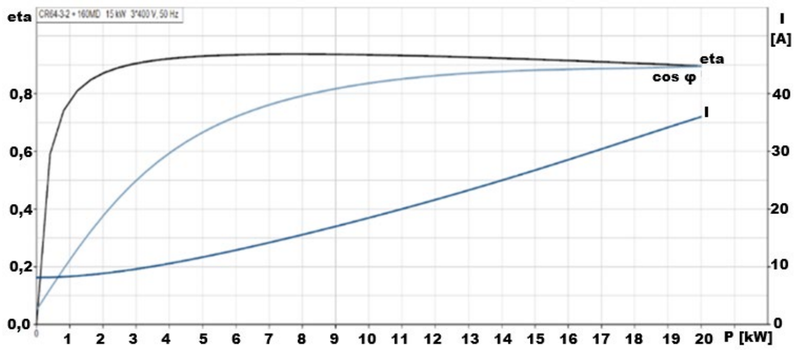

Fig. 1. *Electrical characteristics for the pumping units in station SP1 [6]*

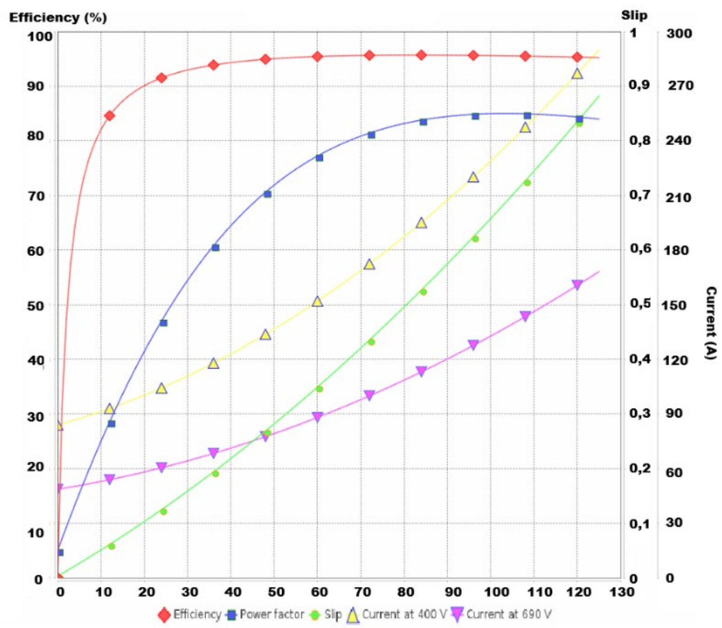

Fig. 2. *Electrical characteristics for the pumping units in station SP2 [4]*

These characteristics provide a comprehensive framework for the analysis and enhancement of the energy performance of water pumping and distribution systems. Combined with the proposed energy indicators, they enable systematic benchmarking and facilitate targeted interventions aimed at improving operational efficiency and sustainability.

Characteristics of the pumping units in SP2 Table 3

Technical Characteristics	**Value**
Pump Characteristics	
Nominal flow (Q_n)	1170 m^3/h
Nominal pumping head (H_n)	38.5 m
Drive Motor Characteristics	
Nominal power (P_n)	150 kW
Frequency (f_n)	50 Hz
Nominal voltage (U_n)	380V / 400V / 415V / 660V / 690V
Nominal current (I_n)	276 A (380 V), 265 A (400V), 258 A (415V), 159 A (660V), 154 A (690V)
Nominal rotational speed (n_n)	1.480 rpm
Nominal power factor ($\cos\phi_n$)	0.86

3.3. Experimental determinations

Figures 3 and 4 present the graphs of the experimental measurement curves obtained at the pump stations SP1 (29 measurement) and SP2 (16 measurement). The measurements were performed at 15-minute intervals.

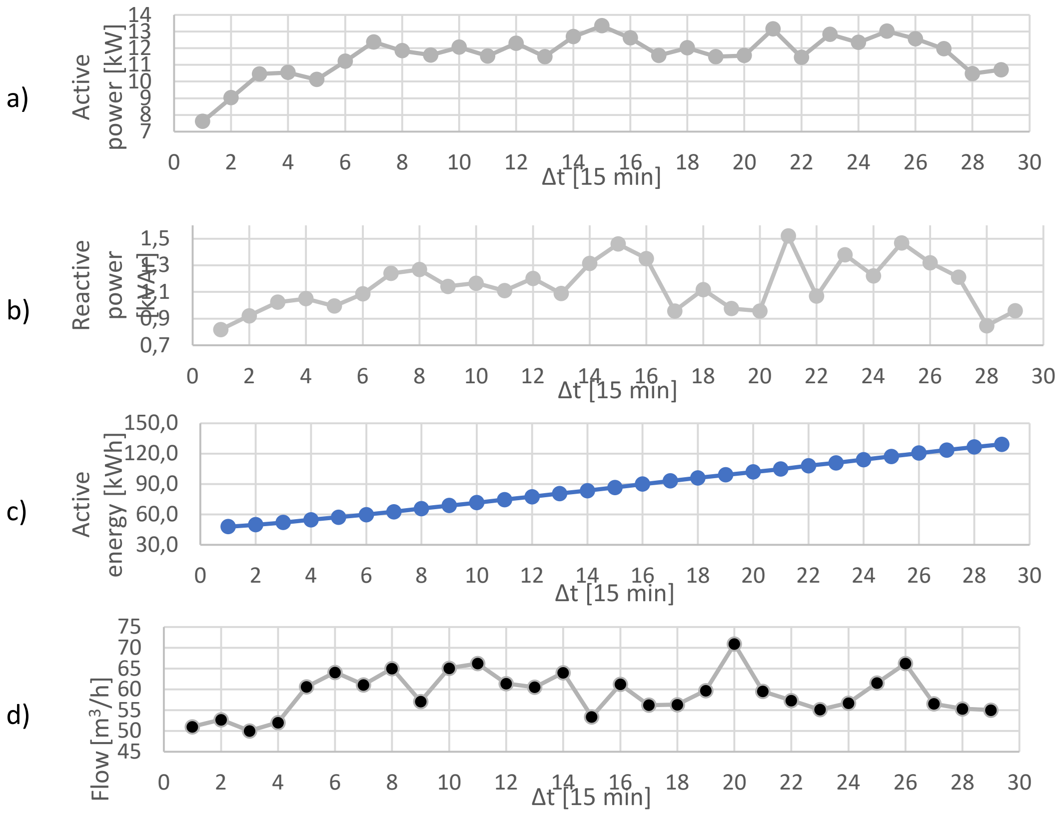

Fig. 3. *Experimental determinations at pump station SP1:*
a) active power; b) reactive power; c) active energy; d) water flow rate

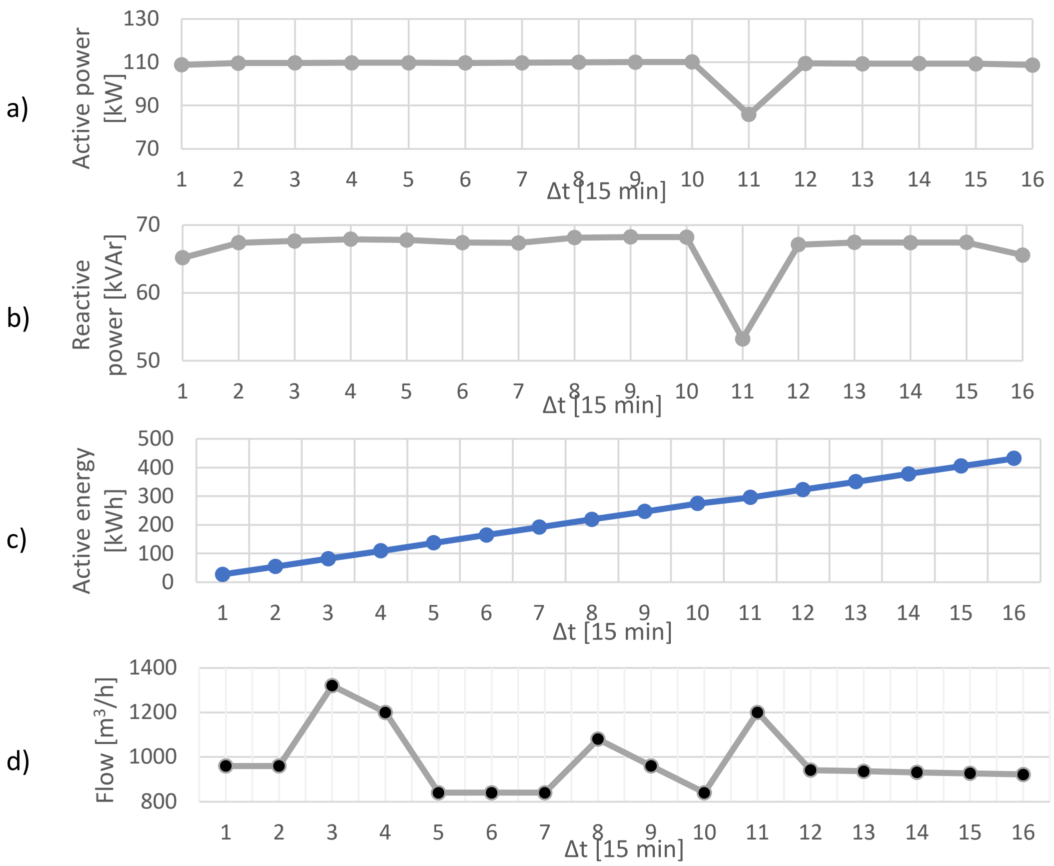

Fig. 4. *Experimental determinations at pump station SP2:*
a) active power; b) reactive power; c) active energy; d) water flow rate

4. Results and Discussions

Using the data obtained from the experimental determinations and the performance indicators defined in Table 1, the performance indicators for the two pump stations were calculated. The results are presented in Table 4.

Interpretation of the data in Table 4 highlights the differences between the two pumping stations, SP1 and SP2, based on the calculated energy performance indicators:

The total active energy consumed relative to the volume of water delivered during the analysed period is higher for SP1 compared to SP2. Appropriate adjustments are necessary at SP1 to improve this indicator.

The energy consumed per cubic meter of pumped water, standardized to a head of 100 meters, is higher at SP1. This is attributed to the operation of pumps with relatively low nominal power, which leads to an increase in this indicator. Load curves significantly influence pump performance. At SP1, the maximum variation of active power is given by the ratio P_{max} / P_{me} = 1.44. At SP2, the corresponding value is P_{max} / P_{me} = 1.01.

Performance indicators for pump stations SP1 and SP2 Table 4

Symbol	Performance indicators	Measurement units	SP1	SP2
EI1	Energy intensity	kWh/m^3	0.1956	0.1308
EI2	Standardized energy intensity	kWh/m^3/100 m	0.3705	0.3396
EI3	Average active power	kW	10.6130	108.0840
EI4	Maximum active power	kW	15.3820	110.1190
EI5	CO_2 emissions	kgCO_2e/kWh	85.0917	139.2006
EI6	Reactive energy intensity	kVArh/m^3	0.0203	0.0804
EI7	Standardized reactive energy	kVArh/m^3/100 m	0.0384	0.2088
EI8	Average reactive power	kVAr	1.1040	66.4560
EI9	Maximum reactive power	kVAr	2.0780	68.2190
EI10	Energy proportionality index	%	0.1036	0.6149
EI11	Pump utilization	%	14.6811	12.0083

The load curve at SP2 is flatter, indicating smaller load variations.

CO_2 emissions are higher at SP2. Pumping stations equipped with higher nominal power installations generate noticeably greater carbon emissions. To account for the volume of conveyed water, the introduction of a new performance indicator is recommended. Performance indicators EI6 and EI7 depend not only on the power and load of the pumps, but also on how the power factor is compensated within the electrical supply system.

The maximum variation of reactive power is Q_{max} / Q_{med} = 1.88 at SP1. At SP2, the corresponding value is Q_{max} / Q_{med} = 1.02. These data can be used to implement more effective control of the power factor at both pumping stations.

The pump utilization factor (*EI11*) is 14.6811 % at SP1 and 12.0083 % at SP2. A reassessment of the operational strategy for the pumps at the analysed stations is necessary to enhance system efficiency.

5. Conclusions

The pump stations SP1 and SP2 exhibit distinct energy behaviours, determined by their differing hydraulic performance, hydraulic loads, and electrical drive configurations. At SP1, the drive system operates with variable speed control, which is expected to enable a more accurate adaptation to consumption demands. However, varying the motor's rotational speed leads to a shift in the pump's operating point, which may deviate from the zone of maximum efficiency. Therefore, a detailed analysis of the control strategy for the operating parameters of the pumping units at SP1 is necessary.

In contrast, pump station SP2 operates with asynchronous motors at constant speed. Provided that the load variation is minimal and the system is properly dimensioned, the pumping units operate stably and close to their optimal efficiency point.

Energy performance indicators play a fundamental role in assessing and comparing these operating regimes. In the context of pump stations, such indicators enable the identification of losses, support technical decision-making, and facilitate consumption optimization. Consequently, they represent key tools for improving the efficiency and sustainability of urban water supply systems.

References

1. Bedassa, D. K., Semu, M. A., et al.: *Quantifying water-energy nexus for urban water systems: A case study*. In: Environmental Science 7 (2020) No. 6, p. 486–504.
2. Ding, T., Liang, L., et al.: *Water-energy nexus and sustainable resource management*. In: Renewable and Sustainable Energy Reviews 118 (2020), p. 109524, DOI: 10.1016/j.rser.2020.109524
3. European Council: https://www.consilium.europa.eu/en/european-council/ (accessed on 14 December 2024).
4. Flowserve: https://www.flowserve.com/en/ (accessed on 14 December 2024).
5. Grey, V., Smith-Miles, K., et al.: *Empirical evidence of climate change and urbanization impacts on warming stream temperatures*. In: Water Research 247 (2023), p. 120703, DOI: 10.1016/j.watres.2023.120703
6. Grundfos: https://www.grundfos.com/ro (accessed on 14 December 2024).
7. Helerea, E., Calin, M. D., et al.: *Water-energy nexus and the energy transition*. In: Environmental Systems Research 9 (2023) No. 4, p. 364–380, DOI: 10.1186/s40068-023-00235-x.
8. Holmatov, B., Lautze, J., et al.: *The nexus across water, energy and food (WEF): Learning from research, building on evidence, strengthening practice*. In: Natural Resources Forum 47 (2023) No. 4, p. 817–841, DOI: 10.1111/1477-8947.12256
9. International Water Association (IWA): https://iwa-network.org/ (accessed on 14 December 2024).
10. Liu, Y., Mauter, M. S.: *Marginal energy intensity of water supply*. In: Energy & Environmental Science 14 (2021) No. 8, p. 4533–4540, DOI: 10.1039/D1EE01234A
11. Macharia, P., Kreuzinger, N., et al.: *Applying the water-energy nexus for water supply—a diagnostic review on energy use for water provision in Africa*. In: Water 12 (2020) No. 9, p. 2560, DOI: 10.3390/w12092560
12. Machete, F., Shakantu, W.: *A review of energy consumption in water supply systems.* In: IEEE Access 8 (2020), p. 213646–213658, DOI: 10.1109/ACCESS.2020.3041395
13. Oh, H., Guk, I., et al.: *Energy saving through modifications of the parallel pump schedule at a pumping station: A case study.* In: Journal of Water Process Engineering 54 (2023), p. 104035, DOI: 10.1016/j.jwpe.2023.104035
14. Pan, B., Tian, H., et al.: I*nvestigating the environmental dynamics of emerging pollutants in response to global climate change: Insights from bibliometrics-based visualization analysis.* In: Science of the Total Environment 957 (2024), p. 177758, DOI: 10.1016/j.scitotenv.2024.177758
15. Sarbu, I.: *Modernization of pump systems in Romania*. In: Procedia Engineering 181 (2017), p. 1090–1097, DOI: 10.1016/j.proeng.2017.02.532
16. Semu, M. A., Geremew, S. G., et al.: *Energy efficiency in water supply and its impact on sustainability*. In: Journal of Urban Systems 8 (2021) No. 2, p. 112–129.

17. Shen, P., Ji, Y., et al.: *Performance of district energy system under changing climate: A case study of Shenzhen*. In: Applied Energy 379 (2025), p. 124986, DOI: 10.1016/j.apenergy.2025.124986
18. Wang, G., Ghoddousi, S., et al.: *Development, validation and application of an energy model for energy efficient operation of parallel pump systems*. In: Journal of Building Engineering 59 (2022), p. 105098, DOI: 10.1016/j.jobe.2022.105098