Optimization of design solutions for domestic water supply systems considering the anthropogenic impact on the environment

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Abstract. Based on the results of the analysis of current scientific research in the field of water supply systems of buildings, existing methods for determining the parameters of the applied schemes, as well as design methods, a number of areas have been identified, the study of which would make it possible to determine the optimal scheme of the water supply system at a minimum cost for construction and operation. In addition, optimization must consider the latest requirements on reliability and environmental safety for engineering life support systems of buildings and structures. Creating a clear algorithm based not only on theoretical (calculated) data, but also on the operating experience of existing buildings, equipment, and experimental data will simplify the process of designing new and reconstructing existing systems, provide the end user with water in an appropriate amount, and operate in an uninterrupted mode, without prejudice to the environment and people.

1. Introduction
Urban engineering and technical support systems, including water supply systems, are an integral part of any residential area, a source of drinking water or technical quality necessary for the vital activity security and the normal functioning of industrial or agricultural enterprises.

Urban development is associated with an increase in the construction of buildings for various purposes in retrained urban conditions, including those on the site of previously existing buildings for residential, administrative, public, and industrial purposes. At the same time, the task of increasing the amount of supplied drinking water by means of reconstruction or new construction of external water supply networks requires solving two opposite problems: increasing the capacity of networks and very dense "packing" of existing underground networks. Hence, the optimization of design decisions comes to the fore and the smaller the required diameter of the pipeline section, the easier and cheaper it is to construct it to a new building. More often a new building affecting by the development of building materials, as well as construction technologies, is built not according to standard projects, as it was before, but of an increased number of storeys and (or) a modern architectural form with large spans, different storeys of the building parts, etc. Under these conditions, the system design of domestic building water supply includes both conventional [1] processes: hydraulic calculations, compliance with maximum permissible pressures in the system and the minimum guaranteed water pressure from consumers, the maximum allowable levels of noise and vibration [2] in living rooms and technical floors caused by boosting pump installations, but also issues of energy efficiency, improving the network reliability [3], environmental safety [4] of systems while minimizing costs at the construction stage and operating costs.
Based on the above, we can conclude that optimizing the design of water supply systems at the design phase with an emphasis on reducing the anthropogenic impact on the city's environment (by reducing leaks from the water supply network, reducing the material consumption of the system, increasing its energy efficiency) is an important issue that needs to be solved. To a large extent, the work of researchers known to the authors is devoted not to the complex solution of the entire system, but to its individual elements.

Alexandros Maziots [5] analyzes trends in construction and housing and utility, in the construction sector and the housing and utilities system on the technical and economic requirements for sanitary equipment.

An important issue for both urban water supply networks and domestic water supply systems of buildings is reliability [6, 7], uninterrupted operation [8]. Methods for determining reliability are described in the research of scientists: Galperina E. M. [9], Dillon B., Singh Ch., Ivanchenko G. I., Alekseev M. I. [10] investigated the probabilistic characteristics of the operating time between failures of repaired water supply and drainage facilities.

Tian Y., Li C., and others [11] proposed several models for selecting water supply pipeline systems for the city's external network. M. M. Brodach developed an "Algorithm for evaluating and selecting pipeline systems based on energy efficiency indicators" [12]. However, according to the authors, there is a significant drawback in the presented algorithm - there is no determination of the reliability of elements and the system as a whole, which has a significant impact when selecting the scheme of the domestic water supply system.

The introduction of energy-efficient methods is described in the scientific research conducted by Lavronova L. I., who in her work [13] was engaged in improving the electric drives control systems of a group of pumping units in order to increase the energy effect by using frequency-controlled pump drives. At the same time, considering the provisions set out in the paper [14], the issue of optimizing the schemes of water supply systems for multi-storey buildings by the parameter of specific electricity consumption when zoning by height or depending on the number of storeys remains poorly studied.

While selecting a water supply system scheme, it is important to find energy-efficient equipment and calculate subsequent operating costs. B. K. Mikhsin [15] proposed a method for estimating operating costs and space-planning parameters of industrial and civil residential buildings at different stages of design.

The paper [16] explores the issues of multiple risk assessment, the relationship of water supply, hydropower and the environment in the water resources system. However, the existing methods of designing schemes for water supply systems in most cases do not provide calculations for reliability and environmental safety [17].

Based on the study of the design of water supply systems for non-standard buildings (multi-storey, with an architectural concept), the authors suggest that there are currently no clear methods to determine the optimal scheme of water supply systems that meets high reliability, environmental safety and at the same time has minimal capital and operating costs.

Thus, the task is to create an algorithm that involves all the aforementioned parameters, allowing you to determine the optimal scheme of the water supply system by following parameters: material consumption, energy efficiency, systems reliability, that may entail a joint solution and reduce the consumption of natural resources, electricity generation, mitigate emissions of harmful substances into the atmosphere, so that reducing the anthropogenic impact on the environment in general and the residential area in which the building is being built in particular.

2. The study objective and the methods applied

When the entire chain from sewage facilities to the end user has been analyzed, then it may be interred that the external water supply networks and structures on them, which are a major element of water supply systems in cities and industrial enterprises, as well as a potential source of anthropogenic impact (as a result of emergencies) on the environment, are directly dependent on the domestic water supply systems of buildings. Moreover, external water supply networks (laid underground) in most
cities have already been set, and their drastic change (except for maintenance or sections replacement) is expensive and not always efficient. Therefore, the domestic water supply systems of buildings and multifunctional complexes with the greatest potential for energy efficiency and solving environmental problems were chosen as the objective of research.

For the calculations, based on the analysis of the current construction market, we selected a 26-storey model building, which is one of the most common structures under construction and belongs to the high-rise buildings.

To achieve this goal, seven different variants of schemes of water supply systems were considered, the technical solutions of which are described in the paper [18]:

- series-circuit system;
- schemes with tanks (2- and 3-zones);
- parallel zoning schemes (2- and 3-zones);
- schemes with intermediate technical floors and pumping stations installed on them (2- and 3-zones).

The schemes under consideration provide separate schemes for domestic drinking and fire-fighting water supply, which meets the requirements [19] and ensures the independence and reliability of fire extinguishing systems in buildings.

Involving all special techniques and the same parameters of the required water consumption by consumers, we have conducted hydraulic, technical, economic, reliability calculations, considering the impact on the environment, for each of these schemes.

Hydraulic calculation of water flow and the coefficient of its hourly irregular consumption, pressure losses in pipelines were conducted according to the generally accepted method [1].

The study determines the parameters, that may be optimized in domestic water supply systems to achieve the previously set goal. These parameters include:

- material characteristics: (pipelines, fittings, etc.)
- the amount of electricity consumption by pumping equipment;
- reliability indicators (failure rate, probability of failure-free operation)

One of the priority areas of research (the least studied at the moment, according to the authors) was to determine the reliability indicators (including the probability of failure-free operation, readiness coefficient, etc.) of both individual elements and the water supply system of the building as a whole.

The reliability calculation for each of the water supply schemes was carried out as follows:

1. we considered the schematic diagram of the water supply system, studied its functioning and the relationship between the individual elements of the system structurally designed as a whole;
2. complex systems consisting of several zones were divided into subsystems, which, in their turn, were divided into nodes (blocks);
3. we determined possible variants of system elements failure, providing regular operation and steady flow of failures;
4. we worked out a circuit diagram for calculating the probability of failure-free operation of each system;
5. a table of reliability calculation results was compiled for each of the systems;
6. the resulting values of the probability of failure-free operation of the blocks and the system as a whole were calculated using formulas and methods of probability theory.

Some restrictions are applied while determining reliability. In particular, considering sudden failures (that is, a sequence of failures that follow one another at random times), the system assumed a
simple mechanism that means that the flow of failures simultaneously satisfies the conditions of stationarity and the absence of aftereffect and ordinariness.

For each of the considered schemes, we made calculations in the course of research [19] using three involved methods:

1. Methods described in GOST 27.002-2015. "Reliability in technology. Basic concepts, terms and definitions".
2. Methods presented in GOST R 27.011-2019. "Reliability in technology. Probabilistic risk analysis of technical systems. Estimation of the intensity of the final event for a given initial state".
3. "Procedure for determining the reliability of water supply and drainage facilities", proposed by E. M. Galperin [9].

To correctly use the data obtained by the calculation method, as well as the possibility of their further application for real capital construction projects, it was decided to analyze the experience of operating water supply systems, as well as conduct a number of experiments.

Based on experience, while testing lock valves in the laboratory of hydraulics at the Department of Water Supply and Drainage Systems, the technical characteristics of the valves stated in the equipment passports and certificates were checked.

Tests of lock valves were conducted on the testing unit for pipelines pressure testing (figure 1) and using a hand press (figure 2).

**Figure 1.** Testing unit for pipelines pressure testing.  
**Figure 2.** Hand press.

The sequence of the experiment was as follows:

- the test sample of the lock valve was connected by means of a screwed end to the pipeline section after the booster pump or after the hand press;
- after the lock valve in the first series of experiments, a 150 mm long pipeline section and a plug were installed, in the second series of experiments, we installed a pipeline line with various fittings, turns, bends, several branches and valves on them;
- the screwed ends were sealed using a tape made of fluoroplastic sealing material;
- lock valves were installed in the "open" position;
- on the pipeline supplying water from the city water supply system, we open the lock valve, then lock valve is filled with water under pressure of urban network (about 2 kp/cm²);
- after that, the booster pump unit was switched on (the pressure was regulated by the opening degree of the lock valve on the pressure pipeline);
the valve was under various pressures for several hours, the readings were noted.

As a result of the experiment, the lock valves were checked for the integrity and pressurization of the body and the rod gland seals. After experiments on the testing unit for pipelines pressure testing, the samples were tested on a hand press.

The progress of an experiment is similar to testing on the testing unit for pipelines pressure testing. After setting up the test sample of the lock valve to the connection junction of the hand press, the valve was tested to a press pressure. Water was taken from the tank, using a handle on the principle of a pump, a pressure was created in the pipeline and the valves connected to it. The samples were tested under various pressures (from 4 kp/cm² to 15 kp/cm²).

After testing for body integrity and leakage, an additional part of the experiment was carried out - all samples had pressure testing, after more than 130 cycles of "opening and closing" of the valve.

3. Identification of environmental factors
The building's water supply system has certain stages throughout its service life, which are called Life Cycle Costs (LCC). At each period of the system's existence, each of the stages has a certain impact on the environment, as follows:

1. Design - affects the amount of materials used, and as a result, the extraction of minerals used on the production of metal elements (valves, elements of pumping equipment, pipeline fittings, etc.), hydrocarbons for the production of pipeline plastic. The quantity (consumption) of materials depends on the accepted scheme of the water supply system.

2. Construction (erecting works) - affects the amount of construction materials waste (for example, plastic pipe cut-offs), which later need to be disposed of. Carrying out competent erecting works also reduces the construction materials waste.

3. Operation - has an impact due to the amount of electricity consumed, mainly by pumping equipment. The amount of electricity consumed in modern megacities determines the need for natural resources (including non-renewable natural energy sources - hydrocarbons) used in the generation of electric energy. Sources of electricity such as thermal power plants (TPP), while burning various types of fuel used, in their turn pollute the atmosphere with emissions. The operation of systems that are experiencing the failures of elements and (or) equipment, may entail emergency situations of a local character.

4. Disposal of pipelines, equipment and materials - affects the environmental safety of cities, as a result of man-caused impact on ecosystems during the disposal of waste elements of the building engineering support system (solid domestic waste disposal sites).

Each of the listed parameters is in a certain way indirectly or directly a source of impact on the ecological system.

4. The results of calculations, research and experiments
To select a possible scheme for the building's water supply system, the algorithm described in [20] was made, which is the basis for the final version of the scheme based on the given initial data.

As a result of the algorithm implementation, several possible variants of schemes (41 variants in total) of the water supply system are determined. Further the optimization parameters given in [18, 20] should be applied to them. The implementation of all these measures is necessary to determine the optimal scheme of the building's water supply system and as a whole can improve the environmental safety of engineering systems.

For each of the parameters (material consumption, reliability, energy consumption), a system of equations was compiled, which was further combined into a single integral equation of the reliability and economic index.
The calculated numerical values of the coefficients included in the equation were adjusted by considering the material used (for example, plastic or metal), as well as involving experimental data. The results of testing the valves allowed us to compare the declared characteristics of manufacturers and actual data on operation in the laboratory. It is necessary to determine the operating time, the number of "open-close" cycles, and the maximum pressure that the valve can withstand.

A number of tested valve samples did not confirm the claimed characteristics (figure 3, figure 4). The number of failures, as well as identified defects in the valve can include:

- insufficient quality of the valve-stem packing, incurring leakage;
- deformation of the integrity of the body (during pressure testing);
- deformation of the ball mechanism and the cock body when fully closed (after 130 cycles of "opening-closing").

When substituting the initial data (including: number of storeys, degree of improvement, number of consumers) into the equation [18], we obtained the coordinates of the points, according to which the planes were built in a three-dimensional coordinate system [20].

The constructed planes that define the scope of a particular scheme were combined with reference to a single coordinate center. The result is areas that belong to all schemes and areas that go beyond the general scheme, indicating that they belong to a particular scheme.

5. Conclusions

Having studied the current situation in the field of external and domestic water supply systems, the main research areas were identified, and parameters (material characteristics, reliability, energy efficiency) were highlighted.

A number of calculations were performed for the seven different schemes of water supply systems of model building, as well as another 70 permutations of the original data (different building designs – gallery, sectional, corridor-type; the degree of improvement, number of storeys, etc.). Numerical values of the latter allowed us to form coefficients that are typical for certain schemes of water supply systems.

To verify the theoretical (calculated) and practical (operational) data, a number of experiments with valves were performed.

An algorithm for determining the possible application, depending on the initial data of the scheme of the water supply system was composed.

To determine the optimal scheme for the selected parameters, a single integral equation of the reliability and economic index was formulated.

Finding the optimal scheme of the water supply system using the proposed algorithm and equation will reduce the number of irrational design decisions, increase the reliability and environmental safety of the water supply system of a building or structure, while minimizing capital and operating costs.
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