Circulation management in hot water supply systems

P V Rotov¹, A A Sivukhin², M A Rotova¹, R A Gafurov¹ and A V Gorshkov³

¹ Ulyanovsk State Technical University, Ulyanovsk, Russia
² Ulyanovsk Municipal Unitary Enterprise "Municipal Heat Service", Ulyanovsk, Russia
³ Ulyanovsk Branch of the T Plus PJSC, Ulyanovsk, Russia

p.rotov@rambler.ru

Abstract. The compliance of the actual heat consumption for heating cold water for public hot water supply service with the approved standard has been analyzed. Using passive engineering experiments, we studied the operating modes of hot water supply systems for several groups of houses, in which different methods for regulating water consumption in hot water supply systems were used. Data were collected using online energy monitoring and commercial metering system. Features of the static and dynamic load regulation of hot water systems have been investigated. The effect of methods for regulating the heat load of hot water supply systems on their actual heat consumption has been analyzed. An assessment has been made of the possibility of bringing the actual operating mode of the hot water systems to the specified value which is the basis for calculating the consumption rate. Ways to improve the efficiency of hot water supply systems have been determined. Conclusions have been drawn concerning the need to revise the standardized indicators of hot water quality and adjust the methodology for calculating the consumption rate in hot water supply systems.

One of the key performance indicators of district heating systems is the return water temperature, which is determined by the accuracy and quality of load regulation in heating, ventilation, and hot water supply systems [1, 2].

The regulation of return water temperature in heating systems and the absence of regulation of circulating water temperature in hot water systems lead to an increased influence of the operating mode of hot water systems on the temperature of network return water [3].

At present, the consumption in hot water supply systems is calculated using the standardized heat consumption for heating cold water, which in the regions of Russia varies from 0.057 to 0.069 Gcal/m³ [4, 5]. Studies have shown that the heat consumption rate for water heating is widespread and significantly underestimated. In re-circulation systems with a hot water temperature between 60 °C and 70 °C, the actual specific heat consumption for hot water supply can exceed 0.1 Gcal/m³, which leads to significant annual financial losses of energy utilities, which, according to experts, can reach 100 million rubles for a city with a population of around 700 000 people.

A number of heat consumption systems in the Ulyanovsk heat supply system were surveyed to determine whether the actual and normative heat consumptions for heating cold water are consistent. The operation of hot water supply systems was compared with the traditional circulation flow limitation using constant-section orifice valves and by the installation of thermostatic valves.
The evolution of the specific heat consumption before and after technical measures in residential buildings connected to one of the central heat exchange stations is shown in Figure 1.

Figure 1. Dynamics of specific heat consumption in the systems of the central heat exchange station of the Locomotivnoe Depo central heat supply station: 1 – ul. Zheleznodorozhnaya 45; 2 – ul. Kirova 50; 3 – ul. Kirova 52.; 4 – estimated heat consumption rate for heating water for hot water supply.

The following results were obtained from the technical measures carried out in the residential buildings:

1. Prior to the above technical measures, the actual consumption in the hot water supply systems was significantly (more than twice) higher than the approved normative consumption of heat energy for heating cold water for hot water supply service. The reason for the discrepancy is the design features of hot water systems due to which the heat energy from the internal hot water supply system is used to heat bathrooms irrespective of the time of day and outside temperature.

2. The specific heat consumption is significantly influenced by the hot water consumption mode. The specific heat consumption in circulation systems decreases to 0.054 Gcal/m\(^3\) during peak hours and rises to 0.140–0.20 Gcal/m\(^3\). In non-circulating hot water supply systems, the influence of the amount of drained coolant on the actual specific heat consumption is not as significant as in circulating systems. During peak and minimum hours, the heating coefficient varies between 0.053 and 0.081 Gcal/m\(^3\). Obviously, a greater effect can be achieved by using dynamic control methods that take into account the irregularities in the operation of hot water systems [6–8]

3. The actual specific heat consumption was brought to the approved normative values of 0.062 Gcal/m\(^3\) without compromising the quality of the end user's hot water supply, only in houses not equipped with towel heaters.

4. The technical measures implemented to limit the circulation flow or maintain the set value of the circulating water temperature do not fully bring the actual specific heat consumption to the normative values without deteriorating the quality parameters. It can be assumed that when lowering the lower limit of the permissible range of hot water temperature control, for example, to 55° C, the efficiency of such technical measures will be higher and will not affect the sanitary reliability of hot water supply systems even without the use of corrective measures.

It has been established that restrictive measures alone cannot ensure that the actual operation of hot water supply systems meets the approved normative values. One way to solve this problem could be to
dynamically adjust the hot water supply load according to the consumption mode. Technically, this is solved by installing control equipment on the circulation line of the hot water supply system. The equipment is adjusted so as to reduce the circulation flow rate during peak demand and compensate for heat loss in the hot water system by draining water. During the hours of minimum water withdrawal, losses in the hot water system are compensated for by increasing the circulating water flow.

In 2019–2020, 46 control units were installed in 28 buildings supplied by the Ulyanovsk heat supply system. The main equipment of the control units included TA-Modulator combined control valves with a TA-Slider 160 electric actuator, OWEN DTS3225-PT1000.B2 surface-mounted water temperature sensors with a Pt1000 sensitive element, and OWEN-PR200 controllers with freely programmable logic.

Initially, the control units were set to maintain the temperature in the return pipeline within -50–52 °C around the clock. Decreasing the temperature by 2–3 °C did not have a tangible effect. Therefore, the control units were partially readjusted according to the actual hot water supply consumption schedule (Table 1). The calculated daily average water temperature in the circulation line was 44 °C. After applying the temperature schedule shown in Table 1, there was a significant change in the operation of hot water systems.

Table 1. Temperature control schedule for temperature control in the circulation line

| Hours | Temperature, °C | Hours | Temperature, °C |
|-------|-----------------|-------|-----------------|
| 00:00 | 48              | 12:00 | 45              |
| 01:00 | 46              | 13:00 | 45              |
| 02:00 | 45              | 14:00 | 45              |
| 03:00 | 44              | 15:00 | 45              |
| 04:00 | 44              | 16:00 | 45              |
| 05:00 | 45              | 17:00 | 45              |
| 06:00 | 48              | 18:00 | 40              |
| 07:00 | 48              | 19:00 | 40              |
| 08:00 | 45              | 20:00 | 40              |
| 09:00 | 40              | 21:00 | 40              |
| 10:00 | 40              | 22:00 | 48              |
| 11:00 | 40              | 23:00 | 48              |

The study showed that the actual average daily water temperature in the circulation pipeline decreased by more than 6 °C. The average daily water consumption in the hot water supply and circulation pipelines decreased by 37% and 48%, respectively, which resulted in a corresponding reduction of heat consumption by the system. The average reduction in heat consumption for water heating was more than 15%.

The average savings per control unit was more than 90 Gcal/year. It can be assumed that the total annual savings for all 46 units will be more than 2.9 million rubles. With a cost of construction and installation work of 3.5 million rubles, the simple payback period will be 1.2 years.

However, simultaneously with the positive economic effect, there was a decrease in the water temperature in the hot water supply system during the hours of minimum consumption, which was due to the reduced circulation flow at these times. Thus, in the periods from 00:00 a.m. to 4:00 a.m. and from 10:00 a.m. to 8:00 p.m., the water temperature in the DHW supply pipeline was below 60°C. This deviation required an additional readjustment of the control units and an increase in the water temperature in the hot water supply pipeline. The average daily water temperature in the circulation line after readjustment was 44 °C.

A change in the temperature of the return network water results in a proportional change in the production of electricity for the heat demand [9, 10]. According to [9], the change in the turbine capacity ΔΝ_{пр}, kW/MW, per 1 MW of the heat load of the turbine can be defined as
\[ \Delta N_{\text{typ}} = 4 \Delta t \cdot \alpha \eta_{\text{em}} \]  

(1)

where \( \Delta t = t_{\text{fin}} - t_{\text{mix}} \) is the difference between the base \( t_{\text{fin}} \) and modified \( t_{\text{mix}} \) return water temperatures, \(^\circ\text{C}\); \( \alpha \) is the thermodynamic coefficient taking into account the relationship between the saturation temperature and the heat drop at the points of adiabatic steam expansion in the turbine, kW/(kg\(\cdot\)^\circ\text{C}); \( \eta_{\text{em}} \) is the electromechanical efficiency of the turbine generator.

Calculations using formula (1) show that at \( \Delta t = 4-6 \)^\circ\text{C}, the electricity generation using heat consumption \( \Delta N_{\text{typ}} \) increases by 13–20 kW per 1 MW of heat load from turbine extraction.

Studies have shown that consumption-based flow control in the circulation line can optimize the operation of the hot water supply system and provide significant technical and economic benefits. However, dynamic load control in the hot water supply system makes it impossible to achieve the design standard for heating and to achieve a significant drop in water temperature after the hot water system. With an average daily water temperature in the circulation pipeline of 44–46\(^\circ\text{C}\), there are already modes that do not provide the standard quality of hot water. It is safe to say that during the transitional hours of the heating period, when the water temperature in the heating systems is significantly lower than 44 \(^\circ\text{C}\), the operating mode of hot water supply systems will negatively affect the energy efficiency of the thermal power plant. A way out of this situation may be to reduce the standard temperature of hot water to 55 \(^\circ\text{C}\) and to expand the range of its regulation [11] or to revise the methodology for establishing a standard value for the consumption of thermal energy for heating water or reject the use of this standard value. This will not deteriorate the sanitary reliability of the systems and will provide an opportunity to realize the hidden energy saving potential in hot water systems.

**Conclusions**

The calculated standardized consumption of thermal energy for heating cold water does not correspond to the actual operating conditions of hot water supply systems. This is due to the need to maintain a higher hot water temperature in the heat supply system to meet the quality standards of end customers and to maintain excessive circulation flow to compensate for the heat losses during periods of minimum water withdrawal.

The well-known and widely used static control methods for limiting the circulation flow by using throttling valves or by installing thermostatic valves do not allow the actual heat consumption to be brought close to the standardized values and can lead to violations of the current hot water quality.

The efficiency of hot water systems can be significantly improved by dynamically adjusting the flow and temperature of the circulating water to account for daily and weekly irregularities in their operation.

In the Ulyanovsk heat supply system, dynamic load regulation of the hot water system was implemented for a number of residential buildings. Despite the proven efficiency, this control method did not provide the design value of the heat consumption standard for hot water supply heating, and a significant reduction in the temperature in the circulation line was impossible due to the regulatory requirements for the quality of hot water at the water draw-off points.

To increase the efficiency of the control methods used, the range of possible regulation hot water temperature should be legally expanded. A short-term decrease in hot water temperature to 50–55\(^\circ\text{C}\) will not affect the sanitary reliability of the hot water supply systems.

In our opinion, the existing method for calculating the consumption in hot water systems does not allow the actual heat consumption to be determined. It is advisable to revise the methodology for standardizing heat consumption for water heating or abandon the normative method of calculation.
References

[1] Rafalskaya T A 2019 Investigation of the possibility of organizing low-temperature heat supply with central quality control Therm Eng 11 102-12.

[2] Xiaofang S, Peng W, Panhong R and Hua Z 2016 The Influence of Central Regulation Methods upon Annual Heat Loss in Heating Network MATEC Web of Confer. 54 06004 DOI: 10.1051/matecconf/20165406004/

[3] Rafalskaya T A and Mansurov R Sh 2017 Assessment of the influence of water temperature in the hot water supply system on the temperature regime of premises Water supp. and sanitary equipm. 4 42-9.

[4] Semenov V G 2018 Standards for Hot Water Heating Heat Supply News 6-7 8-17.

[5] Rotov P V, Sivukhin A A, Gafurov R A and Rotova M A 2020 About standards for hot water heating J. of Phys.: Conference Series 1683 042017.

[6] Rotov P V, Zhukov D A, Zhukova A V and Sivukhin A A 2017 About economy of fuel and resources in the hot water supply system J. of Phys.: Conference Series 891 012160.

[7] Rotov P V and Sivukhin A A 2016 Evaluation of efficiency of hot water supply load control technologies Energy saving and water treatment 6 22-2.

[8] Tumanova T and Cimbale A 2015 The Technical-Economic Analysis of Hot Water Supply Systems for Residential Buildings Advanced HVAC and Natural Gas Technologies 177–83 DOI: 10.7250/rehvaconf.2015.025.

[9] Yakovlev B V 2008 Improving the efficiency of heating and heat supply systems (Moscow: Heat supply news) p 448.

[10] Zamaleev M M, Sharapov V I, Gubin I V and Pavlov V A 2016 Feasibility study of new technologies for snow utilization at CHPP Power engineer.: resear.,equip., technol. 11-12 3–9.

[11] Pieper H, Ommen T S, Markussen W B and Elmegaard B 2017 Optimal Usage of Low Temperature Sources to Supply District Heating by Heat Pumps Proc. of ECOS 2017: 30th International Conference of Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (San Diego: California, USA, 2–6 July 2017) http://orbit.dtu.dk/files/134463914/ECOS_2017_paper_191.pdf.