About economy of fuel and energy resources in the hot water supply system

P V Rotov¹, A A Sivukhin², D A Zhukov¹, A V Zhukova¹

¹ Ulyanovsk State Technical University, Russia, 432027 Ulyanovsk, Severny Venets str., 32
² UMUE «City Heat_service», Russia, 432001 Ulyanovsk, Karla Markska str., 25

Abstract. The assessment of the power efficiency realized in the current of heat supply system of technology of regulation of loading of the hot water supply system, considering unevenness consumption of hot water is executed. For the purpose of definition the applicability boundary of realized technology comparative analysis of indicators of the effectiveness of its work within the possible range of the parameters of regulations. Developed a software application "The calculation of the total economy of fuel and energy resources in the hot water supply system when you change the parameters of regulations", which allows on the basis of multivariate calculations analyses of their results, to choose the optimum mode of operation heat supply system and to assess the effectiveness of load regulation in the hot water supply system.

In contrast with the heating system which load control can be executed centrally the efficiency of the hot-water supply system (HWS) depends solely on the consumer and is characterized by the groundbreaking daily irregularity. The more open water hydrants, the more heat it is necessary. It is impossible to control this process centrally at the heating source.

The question at issue is that in contrast with the European heat supply systems initially constructed on a footing of the local quantity governing, national heat supply systems were designed and constructed taking into consideration the heat conductor fixed-rate flow under the central ratio governing.

It is possible to improve the efficiency of the HWS system via the automatic water flow control in the circulation line taking into consideration the irregularity of the hot water use conditions. One of such technologies developed in the scientific research laboratory «Heat and power systems and plants» (SRL HPSP) of the Ulyanovsk state technical university has been implemented since 2014 at the central heat supply station (CHSS) of the Ulyanovsk municipal unitary enterprise «City Heat_service».

During non-heating seasons 2014-2016 there was an engineering experiment carried out. As follows from the results of this experiment the data gathering and central heat supply station work mode analysis were carried out with different settings of the temperature regulator installed at the circulation line of the HWS system [1-3]. In Figure 1 you can see a functional metering scheme and process monitoring in HWS system.
Figure 1. Functional automation scheme and metering parameters in the HWS system: 1, 2 – delivery and return conduits of the hot-water supply system; 3 – shut-off valve; 4 – temperature gauge; 5 – shut-off control valve; 6, 7 – electromagnetic flow transducers.

Primary measuring instruments of heat conductor parameters during the experiment were resistance thermometers and electromagnetic flow meters. Water flow control in the circulation line is carried out by the shut-off control valve (temperature regulator) 5 installed at the circulation line. Shut-off control valve is operated by the programmable logic controller using impulses from the temperature gauge 4. During the water draw-off thermal heat losses in the HWS system are compensated by the water discharge that is why it is possible to reduce the water flow rate in the circulation line. If there is no water draw-off, the water flow rate in the circulation line will be maintained depending on the defined temperature difference in delivery and return conduits of the HWS system. Therefore necessary thermal load is provided in the HWS system.

Time-of-day setting of the temperature regulator was carried out based on the preliminary performance analysis of the central heat supply station within 24 hours. In Figure 2 you can see a graph with the water consumption change in the hot-water supply system during 6 days whereof it can be seen that the maximum hot water intake was from 8:00 to 15:00–16:00. Hourly average value of the hot water temperature during this period was 60.3 °C. During the minimum hot water intake the temperature regulator setting was carried out for the temperature difference in the HWS system equaled to 10 °C.

Figure 2. Changing of water consumption for the hot-water supply.
To carry out the experiment two primary work modes of the central heat supply station were determined. In the first mode there was no water temperature regulation in the circulation line at all. In the second mode the temperature regulator settings were changed within 24 hours as planned. From 9\(^{00}\) to 15\(^{00}\) the circulation water temperature was 45\(^{0}\)С. At all other times the circulation water temperature was 50 \(^{0}\)С.

Hourly average values of working conditions of the CHSS in each of two modes during 2014-2016 are presented in Table 1. Heat consumption saving at the CHSS was determined for the second mode in contrast with the first mode when there was no regulation of the circulation water consumption in the HWS system at all.

As follows from the data analysis presented in Table 1 it has been established that the heat energy saving at the CHSS in the mode with the time-of-day regulation of the circulation hot-water consumption against the mode without any regulation is 20% (0.04 Gcal/h). Herewith the hourly average water consumption in the circulation line was reduced by 46.5%.

**Table 1.** Regulation indices at the central heat supply station during 2014-2016.

| Hourly average values                  | First mode | Second mode |
|---------------------------------------|------------|-------------|
|                                       | 2014  | 2015  | 2016  | 2014  | 2015  | 2016  |
| Heat consumption in HWS system (Gcal/h) | 0.212 | 0.22  | 0.17  | 0.18  | 0.19  | 0.15  |
| Water temperature in delivery conduit HWS system (°С) | 64.30 | 59.83 | 65.82 | 61.63 | 59.53 | 61.79 |
| Water temperature in circulation conduit HWS system (°С) | 53.53 | 57.00 | 58.71 | 46.49 | 46.86 | 48.18 |
| Water consumption in delivery conduit HWS system (t/h) | 12.76 | 13.05 | 14.79 | 7.74  | 5.73  | 5.58  |
| Water consumption in circulation conduit HWS system (t/h) | 11.39 | 11.60 | 13.6  | 6.10  | 3.85  | 4.0   |

In Figure 3 you can see the dynamics of the heat conductor flow variation in the HWS system during the regulation period.

![Figure 3](image-url)
In Figure 4, 5 you can see the changing dynamics of the water temperature and heat consumption in the HWS system at scheduled time at different work modes of the CHSS. At presented graphs you can clearly see the temperature reduction of the circulation water, water heat consumption in the HWS during the temperature regulation period of the circulation water. Reduction in the heat consumption results in the respective economy of fuel and power resources. Equality of the water temperature provided for the hot-water supply in different modes shows that the consumption reduction of the heat conductor and heat energy is only due to the optimization of the work mode of the HWS system by means of the water consumption regulation in the circulation line. Whereby the temperature of water in the delivery conduit of the HWS system conforms to statutory requirements.

![Figure 4](image1.png)

**Figure 4.** Temperature of water in the delivery 1 and return 2 conduits of the HWS system during the regulation period.

![Figure 5](image2.png)

**Figure 5.** Dynamics of the heat consumption changing in the hot-water supply system.

To estimate the investment attractiveness there is a feasibility study of the implemented load governing regulation technology in the HWS system. Based on the analysis of work modes of the
we determined the minimum hourly average heat economy 0.04 Gcal/h (Table 1). Estimated operating hours of the hot-water supply system with the regulation of the circulation consumption is 3600 hours per year. Total heat economy at the one CHSS during this period will be 144 Gcal. Taking into consideration that the heat energy tariff is 1500 rub/Gcal the amount will be more than 200 th. rub. Capital expenditures for the installation of the automatic regulation system were 95 th. rub. [3].

As can be seen from the above expenditures for the purchasing of the equipment and as assembling operations are compensated during the half of the work time period of the automatic regulation system (2.5-3 months).

Automation of the heating unit in the district heating supply system can be considered as efficient only when it reduces the consumption of fuel and power resources in all structural elements of the heat supply system.

Calculation of economic efficiency of the hot-water supply system when load governing of the HWS system by VIS (Vladimir Ivanovich Sharapov) developed and tested in the SRL HPSP [4] was carried out using the results of the abovementioned engineering experiment [4]. Values of operating parameters for examined work modes of the HWS system are presented in Table 2.

When calculating it was acknowledged that the HWS system consisting of 8 CHSS with the total calculated thermal load 28.5 Gcal/h is connected to the Thermal power plant (TPP) using the open scheme. Pipe range of the HWS system is 45000 m. Duration of the regulation period is 2640 h. Pipeline is made of a steel pipe do = 159 mm with the wall thickness 6 mm in the foam-polymer-mineral isolation. The cost per ton of the fuel equivalent is Cf = 4.0 th. rub. Aggregate expenditures for the installation of the regulating equipment at all central heat supply stations taking into consideration construction and assembling operations are 0.76 mln rub. [3].

| Mode            | Dext,1 (t/h) | Nep,1 (kW) | Qhws,1 (Gcal/h) | Ne1 (kW) | qtl,1 (W/m) |
|-----------------|--------------|------------|-----------------|-----------|-------------|
| First mode      | 51.79        | 11966.84   | 28.5            | 404.57    | 19.83       |
| Second mode     | 39.38        | 9097.79    | 21.7            | 216.35    | 16.14       |

Cost efficiency indicators both by value and volume are presented in Table 3. Indicators presented in Table 3 with sign «-» characterize excess consumption of fuel, power and natural resources.

| Indicators effectiveness | Economy of fuel and energy resources ΔB (t.f.e) | Saving S (mln rub.) |
|--------------------------|--------------------------------------------------|---------------------|
| Fuel costs associated with the changing of the combined generation electric energy at the TPP | -1893.1 | -7.57 |
| Decrease in fuel consumption due to the reduction of heat consumption HWS system | 3221.04 | 12.88 |
| Fuel economy due to the cost cutting for the electric energy and water transfer | 47.05 | 0.19 |
| Fuel economy due to the reduction of thermal loss | 78.27 | 0.31 |
| Capital costs | - | -0.76 |
| Sum | 1453.26 | 5.05 |

To study applicability limits of the loan regulation on hot-water supply systems let’s calculate the total saving Srot, mln rub. within the possible decrease of the water temperature in the circulation line
of the hot-water supply system $\Delta \tau_2 = \tau_{21} - \tau_{22}$ and possible changing of the water consumption in the HWS system $\Delta G = G_{\text{sw1}} - G_{\text{sw2}}$. Let’s admit $\Delta \tau_2 = 4\div12 ^\circ C$ and $\Delta G = 500\div900 \text{ t/h}$.

We determined analytical dependence for the discovery of key indicators of the energy efficiency when changing of regulation parameters [3].

Fuel costs associated with the changing of the combined generation electric energy at the TPP are determined as

$$\Delta B_{cg} = \left[ (G_{\text{sw1}} - \Delta G)c(\tau_i - (\tau_{21} - \Delta \tau_2)) - G_{\text{sw1}}c(\tau_i - \tau_{21}) \right] (i_2 - i_1) \eta\eta_m (b_{\text{e.c}} - b_{\text{e.h}}) n$$

where $G_{\text{sw1}}$ – consumption of the delivery water in the i regulation mode, t/h; $\tau_i$ – temperature of supplied delivery water, $^\circ C$; $\tau_{21}$ – temperature of return delivery water in the i regulation mode, $^\circ C$; $i_1$, $i_2$ – steam enthalpy of the lower supply-line extraction and condensed steam, kJ/kg; $i_1$ – sharp steam enthalpy, kJ/kg; $\eta_e$, $\eta_m$ – electrical and mechanical efficiency of the turbo generator; $b_{\text{e.c}}$ – specific consumption of the fuel equivalent for the condensed generation of electric energy, kg/(kW*h); $b_{\text{e.h}}$ – specific consumption of the fuel equivalent for the heating generation of electric energy, kg/(kW*h); n - running time of the hot-water supply system in the mode with the process monitoring; c – specific heat of water, kJ/(kg.$^\circ C$).

Decrease in fuel consumption due to the reduction of heat consumption in the HWS system determined when comparing regulatory modes:

$$\Delta B_{hc} = \frac{G_{\text{sw1}}c(\tau_i - \tau_{21}) - (G_{\text{sw1}} - \Delta G)c(\tau_i - (\tau_{21} - \Delta \tau_2))n}{Q\eta_b}$$

where $Q_i$ – lower heat value, kcal; $\eta_b$ – efficiency of the boiler.

Fuel economy due to the cost cutting for the electric energy and water transfer:

$$\Delta B_e = \frac{(G_{\text{sw1}} - (G_{\text{sw1}} - \Delta G))\gamma H(b_{\text{e.c}} - b_{\text{e.h}}) n}{\eta_p}$$

where $\gamma$ – specific gravity of pumped fluid, N/m$^3$; H – pump head, m; $\eta_p$ – efficiency of the pump.

Fuel economy due to the reduction of thermal loss:

$$\Delta B_d = \frac{2\pi(\tau_i - (\tau_{21} - \Delta \tau_2))n l}{\lambda_m \ln \frac{d_i}{d_o} + \lambda_u \ln \frac{d_i}{d_d}} Q_i \eta_b$$

where l – pipe range, m; $\lambda_g$ – steel conductivity coefficient, W/(m$^\circ C$); $\lambda_{in}$ – conductivity coefficient of thermal insulation, W/(m$^\circ C$); $d_{id}$ – inside diameter of tubing, m; $d_o$ – outside diameter of tubing, m.

Calculation data according to equations (1)-(4) are presented in Table 4.

**Table 4.** Total saving of fuel and power resources.

| $\Delta G$ (t/h) | $\Delta \tau_2 = 4^\circ C$ | $\Delta \tau_2 = 6^\circ C$ | $\Delta \tau_2 = 8^\circ C$ | $\Delta \tau_2 = 10^\circ C$ | $\Delta \tau_2 = 12^\circ C$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 500             | 3.81            | 2.33            | 0.85            | -0.62           | -2.10           |
| 600             | 5.62            | 4.30            | 2.98            | 1.66            | 0.34            |
| 697.5           | 7.39            | 6.22            | 5.05            | 3.88            | 2.71            |
| 800             | 9.25            | 8.24            | 7.23            | 6.22            | 5.21            |
| 900             | 11.07           | 10.21           | 9.36            | 8.50            | 7.65            |

When the water temperature in the circulation line of the HWS system is decreased the saving of fuel and power resources is reduced due to the decrease of the combined electric energy generation. If $\Delta G = 600 \text{ t/h}$, the total saving of fuel and power resources $S_{\text{tot}}$ will be reduced by a factor of 16 when the water temperature in the circulation line of the hot-water supply system is decreased by 12 $^\circ C$. 
If the water consumption is reduced almost twofold, the total saving of fuel and power resources will be increased by a factor of more than 2.5. In this way if $\Delta \tau_2=8$ °C and $\Delta G = 900$ t/h, the total saving of fuel and power resources $S_{tot}$ will be more by a factor of 11 than if $\Delta \tau_2=8$ °C and $\Delta G = 500$ t/h.

From the graph in Figure 6 it follows that if the water temperature in the circulation line is decreased by more than 10 °C and the water consumption is reduced by less than 500 t/h, the equipment for the automated regulation will not be compensated.

![Figure 6. Dependence of the total saving on the changing of temperature and the water consumption in the circulation line of the HWS system: 1 – total saving after decreasing of the temperature in the circulation line $\Delta \tau_2 = 4$ °C; 2 – $\Delta \tau_2 = 4$ °C; 3 – $\Delta \tau_2 = 8$ °C; 4 – $\Delta \tau_2 = 10$ °C; 5 – $\Delta \tau_2 = 12$ °C.](image)

To increase the speed and accuracy of calculations and also the opportunity of use of different source data for calculating of efficiency regulation indicators within the possible range of calculation of working parameters of the HWS, we developed the software application «The calculation of the total economy of fuel and energy resources in the HWS system when you change of the parameters of regulations». This application refers to the scope of the heat-power engineering and can be applied for the calculation of total saving of fuel and power resources in the heat supply system when changing consumption regulation parameters in the circulation line of the hot-water supply system to analyze and improve work modes of the heat supply system, to assess the energy-saving potential when implementing parameter regulation technology in the HWS system.

Application is developed using Visual Studio 2015 and the programming language C#. Application provides the fulfillment of the following functions:

- identification of parameters of the HWS system;
- identification of the regulating duration of the HWS system;
- identification of the range for the water temperature decrease in the circulation line of the HWS system and the possible changing of the water consumption in the HWS system;
- identification of parameters of the energy efficiency for the load governing in the HWS system;
- calculation of total saving due to the improvement of the work mode in the heat supply system;
- construction of the dependency graph for total saving from the temperature changing and water consumption in the circulation line of the HWS system.

In Figure 7 a window of the application interface is presented. To perform calculations with new basic data it is necessary to fill-in cells with the characteristic of the heat supply system and press the button «Calculate».

![Figure 7. Window of the application interface «The calculation of the total economy of fuel and energy resources in the HWS system when you change of the parameters of regulations» with the field for entering basic data.](image)

To enter a new range of data within the possible decrease of the water temperature in the circulation line and possible changing of the water consumption in the HWS system it is necessary to press the button «Close» and enter new values in the window of the application interface. In Figure 8 a window of the application with results of the calculation is presented. Results of calculation can be displayed in the form of the table or graph by pressing the relevant buttons «Table» and «Graph» and also save results of calculation in the file Microsoft Office Excel by pressing the button «In excel» (Figure 9).

Number of calculations in the application расчетов is unlimited. This gives an opportunity to compare work modes of the heat supply system under different working conditions of the hot-water supply system. Application gives an opportunity to perform multiple-option calculations and save results of calculations in the file Microsoft Office Excel at the design stage of the hot-water supply system when energy inspection and determination of the implementation practicability of the examined technology of the load governing in the HWS system.
Figure 8. Window with results of the calculation of energy efficiency indicators of load governing in the hot-water supply system.

Figure 9. Window with results of the calculation in the file Microsoft Office Excel.

References

[1] Rotov P V, Sivukhin A A and Rotova M A 2015 O regulirovanii nagruzki goryachego vodosnabzheniya v otkrytkh sistemakh teplosnabzheniya Energosnabzhenie i vodopodgotovka vol 3 (95) pp 32–37

[2] Rotov P V, Sharapov V I and Sivukhin A A 2015 Povyshenie effektivnosti raboty system goryachego vodosnabzheniya sbornik nauchnykh trudov nauchno-issledovatelskoi laboratorii «Teploenergeticheskie sistemy i ustanovki» UIGTU (Ul’yanovsk: UIGTU) vol 11 pp 110–122
[3] Rotov P V and Sivukhin A A 2016 Otsenka effektivnosti tehnologii regulirovaniya nagruzki goryachego vodosnabzheniya *Energosnabzhenie i vodopodgotovka* vol 6 (104) pp 22–28

[4] Sharapov V I, Pazushkin P B, Tura D V and Makarova E V 2003 Raschet energeticheskoi effektivnosti tehnologii podgotovki goriachei vody na TES *uchebnoe posobie* (Ulyanovsk: UlGTU) p 120