Energy consumption of water supply system's utilities in building

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Abstract. Authors have continued the study of the energy consumption in the building by various engineering systems in this work. The energy consumption of new engineering system, which was previously not taken into account in the total energy consumption of the building, is investigated. There is discusses the consumption of both electric and thermal energy by the building's cold water supply system. The share of the cold water supply system in the specific thermal and electrical characteristics of the general water supply system (hot and cold parts of the water supply) of the building has been determined. Also, there is a special attention to the passive consumption of thermal energy by the cold water supply system, which was not previously carried out due to its small share in the total heat consumption of the building in this article. In this case, the "active heat energy" is used by the hot water supply system, which, despite the cold, must be forcibly heated in a special installation. Also, there is in this technique, takes into account seasonal fluctuations in the temperature of cold water by dividing the consumption of thermal energy into winter and summer periods of the year. It is also possible to do the full analyse the work of the frequency regulators widely used for the building's water supply system, but it should also be taken into account that the regulators have additional energy costs which is depending on various operating modes (standby mode, regulation mode, etc.) . In this paper, authors consider only in systems where is only booster pumps, mechanical flow meters, and non-automated valves are installed. The objects in which this study was conducted are: a residential building and a low-capacity pumping station (up to 2000 m³ / h).

1. Introduction
This work is a continuation of the methodology which was proposed by V.M. Chaplin, and later improved by V.I. Prokhorov, "Calculation of the specific thermal and electrical characteristics of the building" [1,2]. If the engineer knows the design consumption of thermal and electric energy by the building engineering systems it will affects to the determination of the requested capacity from external urban energy systems, and will help to determine further ways to select new energy-saving technologies. As an example, it could be the electric energy which was generated by the solar module [3] and used by a booster (circulation) pump of the water supply system.

2. Thermal part of energy consumption's calculation
The water supply system is unique because it is not taken into account at the design calculations of the
Building's thermal characteristics. There are a lot of problems in some bathrooms of the building which consist of a decrease in air temperature. This problem is special for civil buildings, where it has been used a natural forced ventilation. A part of heat losses by heating the water in cold water supply system in bathrooms, there is the uprising of air temperature after taking a shower because of the infiltration heat loss [4]. Other characteristics, such as climate, the connection scheme of various heat-consuming systems, etc., affects to the building's thermal regime [5,6].

The methodology for calculating the part of the cold water supply system (CWSS) in the specific thermal characteristic of the building is similar to the calculation the part of the hot water supply system (HWSS) in the specific thermal characteristic of the building [1,2]. The part of the CWSS in the summary specific thermal characteristic of the building for the winter season is determined by the equation (1) and for the summer period by the equation (2):

\[ q_{cwss}^{d.w.} = \frac{Q_{cwss}^{w}}{(t_{room}^{w} - t_{c.w.}^{w})} \times V_e \]  

(1)

\[ q_{cwss}^{d.s.} = \frac{Q_{cwss}^{s}}{(t_{room}^{s} - t_{c.w.}^{s})} \times V_e \]  

(2)

\( Q_{cwss}^{w} \) - unaccounted heat, in the building's thermal balance, for heating water in the cold-water supply system in the winter period, W;

\( Q_{cwss}^{s} \) - unaccounted heat, in the building's thermal balance, for heating water in the cold-water supply system in the summer period, W;

\( t_{room}^{w} \) - designed room temperature in winter season, °C;

\( t_{room}^{s} \) - designed room temperature in summer season, °C;

\( t_{c.w.}^{w} \) - designed cold water temperature in winter season, °C;

\( t_{c.w.}^{s} \) - designed cold water temperature in summer season, °C;

\( V_e \) - external volume of the building, m³.

Unaccounted heat for heating water in a cold-water supply system can be based on the standard equation for heating the substance (equation 3) or on the basis of pipelines number and the equation for the heat transfer for 1 hour (equation 4). It should be noticed that the pressure network of cold water supply will be carried out with a full tube.

\[ Q_{cwss}^{d} = c_w \times G_w \times \frac{(t_{room}^{i} - t_{c.w.}^{i})}{3600} \]  

(3)

\( t_{room}^{i} \) - designed room temperature in winter or summer season, °C;

\( t_{c.w.}^{i} \) - designed cold water temperature in winter or summer season, °C;

\( G_w \) - design water flow of the building's cold water system, l/day;

\( c_w \) - thermal capacity of water, J/kgK;

\[ Q_{cwss}^{d} = K \times F_p \times (t_{room}^{i} - t_{c.w.}^{i}) \]  

(4)

\( K \) - heat transfer coefficient, W/m²·°C;

\( F_p \) - pipeline area of cold water supply system, m².

Equation (4) is the derivation of the stationary thermal regime of the Fourier and Newton-Richman equations. These two equations describe a complex method of heat transfer (convection, thermal conductivity, the radiant heat transfer method is usually neglected). A heat transfer coefficient is used in complex heat transfer. It consists of various coefficients of thermal resistance which are describing various methods of heat transfer. The most difficult in the description is the thermal coefficient, which describes the convective part of heat transfer. In the description of this process it has been used
differential equations of: energy (equation 5), continuity (equation 6), motion (equation 7), which are combined into a general theory of similarity [7].

\[
\frac{\partial T}{\partial \tau} + \omega_x \frac{\partial T}{\partial x} + \omega_y \frac{\partial T}{\partial y} + \omega_z \frac{\partial T}{\partial z} = \lambda \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)
\]  

(5)

\(w_\lambda (\partial T / \partial \tau)\) - full temperature change;
\(\partial T / \partial \tau\) - local temperature change;
\(\lambda\) - thermal conductivity coefficient, W / m K;
\(c\) - thermal capacity coefficient, J / kg K.

\[
\begin{align*}
X & : - \frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2} \right) = v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_y}{\partial y} + v_z \frac{\partial v_z}{\partial z} \\
Y & : - \frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2} \right) = v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_y}{\partial y} + v_z \frac{\partial v_z}{\partial z} \\
Z & : - \frac{1}{\rho} \frac{\partial p}{\partial z} + \nu \left( \frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2} \right) = v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_y}{\partial y} + v_z \frac{\partial v_z}{\partial z}
\end{align*}
\]  

(6)

\(\partial p / \partial x\) - pressure change in the X-axis;
\(\partial v_x / \partial x\) - change of the projection of speed on the X axis along the X axis;
\(\rho\) - substance density, kg/m³;
\(X, Y, Z\) - projections of mass force acceleration;
\(v_x, v_y, v_z\) - velocity of the projection on the axis X, Y, Z;
\(\nu\) - kinematic viscosity of a substance, m²/s.

\[
\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0
\]  

(7)

\(v_x, v_y, v_z\) - velocity of the projection on the axis X, Y, Z;

The annual specific consumption (asc) of thermal energy in a building for cold water supply system in the winter season is determined by equation (8), and for the summer period by equation (9):

\[
q_{cwss,w} = \frac{n}{24} \times (t_{room}^w - t_{c.w.}^w) \times Z_{w.p.} \times q_{cwss}^{d.w.}
\]  

(8)

\[
q_{cwss,s} = \frac{n}{24} \times (t_{room}^s - t_{c.w.}^s) \times Z_{w.p.} \times q_{cwss}^{d.s.}
\]  

(9)

t_{room}^w - designed room temperature in winter season, °C;
t_{room}^s - designed room temperature in summer season, °C;
t_{c.w.}^w - designed cold water temperature in winter season, °C;
t_{c.w.}^s - designed cold water temperature in summer season, °C;
q_{cwss}^{d.w.} - specific thermal characteristics of the building for cold water supply system in winter designed mode, W/m²°C;
q_{cwss}^{d.s.} - specific thermal characteristics of the building for cold water supply system in summer designed mode, W/m²°C;
Z_{w.p.} - the number of days in the winter season, days;
Z_{w.p.} - the number of days in the summer season, days;
n - the used period number in a day of cold water supply system, hours.

The total annual specific consumption of thermal energy for cold water supply system was determined by the equation (10):

\[ q_{asc \text{ (summary)}} = q_{asc \text{ w}} + q_{asc \text{ s}} \]  

(10)

\( q_{asc \text{ w}} \) - the annual specific consumption of thermal energy in a building for cold water supply system in the winter season which include the number of working period by a day and the heating period days, W h / m\(^3\) year;

\( q_{asc \text{ s}} \) - the annual specific consumption of thermal energy in a building for cold water supply system in the summer season which include the number of working period by a day and the warm period days, W h / m\(^3\) year.

3. Electric part of energy consumption's calculation

The annual specific consumption of building's electric energy for CWSS in the winter season is determined by the equation (11), and for the summer period by the equation (12):

\[ N_{asc \text{ w} (E)} = 24 \times Z_{h,p} \times \frac{N_{cwss \text{ w}}}{V_e} \times \frac{n}{24} \]  

(11)

\[ N_{asc \text{ s} (E)} = 24 \times Z_{w,p} \times \frac{N_{cwss \text{ s}}}{V_e} \times \frac{n}{24} \]  

(12)

\( N_{cwss \text{ w}} \) - average total power of pump engines and other power consuming devices used in the cold water supply system for the winter period, W;

\( N_{cwss \text{ s}} \) - average total power of pump engines and other power consuming devices used in the cold water supply system for the summer period, W;

n - the used period number in a day of cold water supply system, hours.

The annual specific consumption of electric energy for cold water supply is determined by the equation (13):

\[ N_{asc \text{ w} (E)} = N_{asc \text{ w} (E)}^\text{cwss \text{ w}} + N_{asc \text{ s} (E)}^\text{cwss \text{ s}} \]  

(13)

\( N_{asc \text{ w} (E)}^\text{cwss \text{ w}} \) - the annual specific consumption of thermal energy in a building for cold water supply system in the winter season which include the number of working period by a day and the winter period days, W h / m\(^3\) year;

\( N_{asc \text{ s} (E)}^\text{cwss \text{ s}} \) - the annual specific consumption of thermal energy in a building for cold water supply system in the summer season which include the number of working period by a day and the summer period days, W h / m\(^3\) year;

n - the used period number in a day of cold water supply system, hours.

The average total pump power can be calculated by the equation (14):

\[ N_{cwss \text{ p}}^d = \frac{k \times L_p \times \Delta p_p}{3600 \times \eta_p} \]  

(14)

k - power reserve factor;

\( L_p \) - pump feed, m\(^3\)/h;

\( \Delta p_p \) - pump pressure, Pa;

\( \eta_p \) - pump efficiently.
There are some works of C. Stravinski and S. Usikova [8, 9] which could be used to determine the electrical energy consumption of these devices.

4. Results of application
The application of using this method is wastewater pumping station. There is a typical building of a sewage pumping station with a productivity of 400 - 2000 m$^3$/h which is located in the Moscow region as an example for the application of this technique. The volume of the building is 2319.3 m$^3$, cold water supply system consumption for civil part of the station is 5.8 m$^3$/h and for technological needs is 7.7 m$^3$/h. Air temperature in the bathrooms and showers is the same for both winter and summer seasons - $+23^\circ$ C. The water temperature of the cold water supply system for the winter period is $+5^\circ$ C, and for the summer period is $+15^\circ$ C. The pressure loss in the CWSS network is 15 meters. The efficiency of the pump motor is 70%, the safety factor is 1.5. The number of winter days per year is 205. The heating capacity of the hot water supply system is 18.56 kW. The heat capacity of water is varies quite widely depending on its temperature. According to M.P. Vukalovich experimental data for a temperature of 5 $^\circ$ C it is 4.202 KJ / kg K, and for a temperature 15 $^\circ$ C it is 4.187 KJ / kg K. An additional amount of heat which is required to maintain the standard temperature in the rooms at the winter season will be 284 W and 126 W at the summer part. The minimum power of the pump for CWSS should be 1200 W. The annual specific consumption of electric energy for warm period of the year will be 4532.4 W h / m$^3$ year because of the pump which works 24 hours a day. The annual specific heat energy consumption for the cold water supply system will be 811.1 W h / m$^3$ year. The water temperature in the hot water supply system is $+55^\circ$ C. The minimum power of the pump for HWSS should be 2625 W. The annual specific consumption of electric energy for cold period of the year will be 9914.6 W h / m$^3$ year because of the pump which works 24 hours a day. The annual specific heat energy consumption for the hot water supply system will be 59,480 W h / m$^3$ year.

\[\text{Figure 1. Contribution of cold and hot water supply system to the total thermal characteristic of the building water supply system.}\]
Figure 2. Contribution of cold and hot water supply system to the total electric characteristic of the building water supply system.

5. Conclusion
In this paper, there is a methodology for calculating the 5th component of the specific building's thermal and electrical characteristics of engineering life support systems - cold water supply system. Comparing the specific thermal and electrical characteristics of building's cold and hot water supply systems in a sewage pumping station, it can be concluded that for this building the contribution of the specific thermal characteristic of the cold water supply system is much less (1.36%) than the contribution of the hot water supply to the total specific thermal characteristic of the overall water supply system. The contribution of the specific electrical characteristic of the building's cold water supply system to the overall specific electrical characteristic of the water supply system is significantly higher (31.4%) than the thermal part.

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