TOMSK POLYTECHNIC UNIVERSITY

Power supply

Lecture No 1

Lecturer:
Assistant, candidate of phys.-math. sciences
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2020

Calendar rating-plan of the course

Modules:

- *Module 1.* Heat consumption, power supply systems and their equipment
- *Module 2.* Methods of heat load control. Hydraulic calculation and regimes of heating networks operation
- *Module 3*. Heating systems, heat load calculation
- *Module 4.* Hydraulic calculation of water heating systems

Lectures:

- 1-2 weeks - *Lecture 1.* Basic concepts and facts about heat consumption, power supply systems and their equipment;
- 3-4 weeks - *Lecture 2.* Methods of heat load control. Hydraulic calculation and regimes of heating networks operation;
- 5-6 weeks - *Lecture 3.* Basic concepts and facts about heating systems, heat load calculation;
- 7-8 weeks - *Lecture 4.* Hydraulic calculation of water heating systems;

Practical lessons (overall 20 points):

- *Practical 1-2. Heat load calculation* – **2.5 points**
- *Practical lesson 3.* Calculation of heat losses of building through enclosure – **2.5 points**
- *Practical lesson 4.* Hydraulic calculation of water heating systems of domestic building – **2.5 points**
- *Practical lesson 5.* Load graphs for heating, ventilation and hot water supply. Calculation of the increased and corrected graphs – **2.5 points**
- Practical lesson 6. Hydraulic calculation of heating networks – **2.5 points**
- Practical lesson 7. Selection of heaters, shut-off and control valves – **2.5 points**
- Practical lesson 8. Determination of characteristics of pumps – **2.5 points**

Calendar rating-plan of the course

Laboratory works (overall 30 points):

- *Laboratory work 1.* Arrangement and principle of operation of an autonomous heating system. Preparing for operation, filling the system with a coolant, starting the hydraulic circuit and measuring system – **10 points**
- *Laboratory work 2.* Experimental determination of the nominal power of the heater and its specific characteristics – **10 points**
- *Laboratory work 3.* Implementation of qualitative and quantitative methods for controlling the load of a heating system – **10 points**

Seminars (overall 30 points):

- *Seminar 1.* Characteristics of heat supply systems – **15 points**
- *Seminar 2.* Characteristics of heating systems – **15 points**

Exam – 20 points

Total points – 80+20=100 points

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Lecture 1.
Basic concepts and facts about heat consumption, power supply systems and their equipment

Content of Lecture No 1

1. Heat consumption: classification of heat loads and ways of their calculations.
2. Heat supply systems: classification.
3. Equipment of the main parts (CHPP – Central Heating and Power Plant (cogeneration), district heating substations; heat networks) of heat supply systems.

Tomsk CHPP-3

Individual heating substation

Heat networks

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1. Heat consumption

Heat load

seasonal

space heating, ventilation

year-round

technological needs, hot water supply

Methods of heat load calculation:

- using generalized characteristics;
- heat losses calculations through the elements of building envelope.

Heat load on space heating

Thermal equilibrium of a building:

$$Q_{sum} = Q_{env} + Q_{inf} + Q_{int\,em}, \text{W}$$

where Q_{sum} is total heat loss of the building;

Q_{env} is heat loss through the envelope;

Q_{inf} is heat loss by infiltration due to entering cold outside air through the leakages in the envelope;

$Q_{int\,em}$ is internal heat emission.

- <u>Calculation method with using generalized characteristics</u>:

Maximum heat flow for heating residential and public buildings without infiltration:

$$Q_{hf}^{p} = q_{hf} F (1 + K_1) 10^{-6}, \text{MW}$$

$$Q_{hv}^{p} = \beta q_{hv} V_{ext} (t_{int}^{p} - t_{h}^{p}) 10^{-6}, \text{MW}$$

q_{hf}, q_{hv} are specific heat flow, W/m², for heating 1m² of total area and specific heating characteristic, W/(m³ ·K);

K_1 is a coefficient taking into account the heat flow for heating of public buildings, in the absence of data, is taken to be 0.25;

β is a correction coefficient taking into account the climatic conditions of the region;

t_{int}^{p} is a predicted temperature of the internal air in the heated buildings, °C;

t_{h}^{p} is a predicted temperature of ambient air for heating, °C.

Average heat flow for heating for the average for heating season outside temperature:

$$Q_h = Q_h^p \frac{\left(t_{int}^p - t_{ext}^{av}\right)}{\left(t_{int}^p - t_h^p\right)}, MW$$

t_{ext}^{av} is an average outside temperature for the heating season, °C

- <u>Heat losses calculations through the elements of building envelope:</u>

$$Q_{hl} = \sum Q_{env} + Q_{inf} - Q_{int\,em}, MW$$

Q_{hl} is total heat losses of the room;

$\sum Q_{env}$ is the sum of the main heat losses through the envelope;

Q_{inf} is the additional heat loss for heating the infiltration air;

Q_{intem} is internal heat emission in the room.

The main heat losses in the room through the envelope:

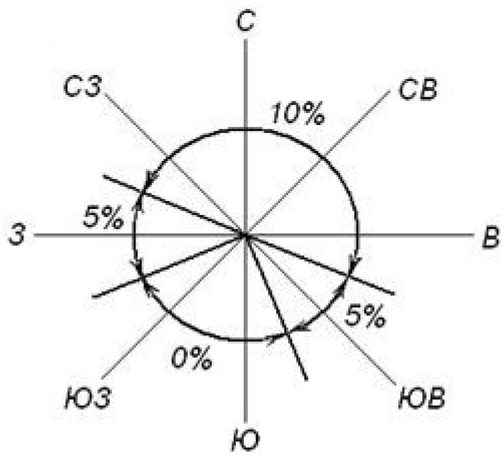
$$Q_{env} = A / R \cdot \left(t_{int}^p - t_h^p\right) \cdot \left(1 + \sum \beta_i\right) \cdot n, MW$$

A is the predicted area of the envelope, m^2;
R is the resistance to the heat transfer of the envelope, (m^2 ·°C)/W;
β is the additional heat losses in fractions from the main for various types of rooms and envelopes;
n is the coefficient adopted for the envelopes separating the heated room from unheated.

Additional heat losses

$$Q_{env} = A / R \cdot \left(t^{p}_{int} - t^{p}_{h}\right) \cdot \left(1 + \sum \beta_i\right) \cdot n, MW$$

- Additive on orientation according to cardinal point



- Additive on cold outside air leakage through exterior doors.

Heat loss for heating the infiltration air

$$Q_{hl} = \sum Q_{env} + Q_{inf} - Q_{intem}, MW$$

$$Q_{inf} = 0.28 L_{vent} \rho_{out} c \left(t^{p}_{int} - t^{p}_{h}\right),$$

The specific air flow rate for residual buildings according to norms:

L_{vent}=3 m^3 /hour for 1 m^2 of the area of residual buildings and kitchen;

ρ_{out} is density of outside air, kg/ m^3;

c is mass heat capacity of outside air, 1kJ/(kg ·°C);

0.28 is numeral coefficient adjusting the accepted dimensions of air flow rate, kg/hour, and heat flow, W (0.28=1005/3600).

Types of internal heat emission in the room

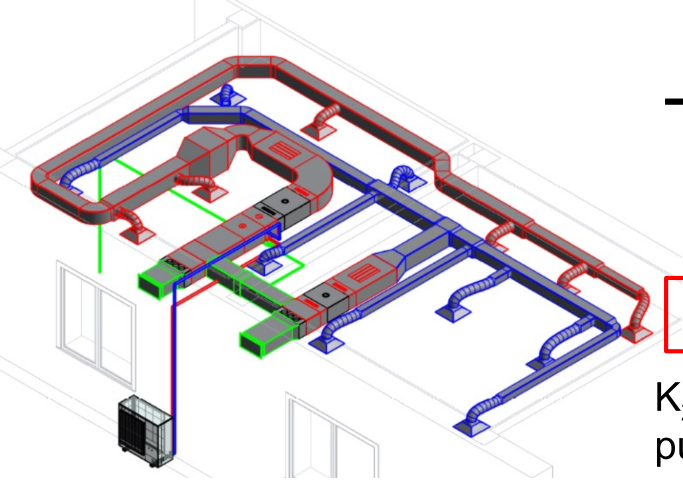
$$Q_{hl} = \sum Q_{env} + Q_{inf} - Q_{intem}, MW$$

- Heat emissions from technological equipment;
- Lighting;
- Solar radiation;
- People.

Q_{intem}= 10 W per 1 m^2

for residual buildings

Heat load on ventilation



- <u>Calculation method with using generalized characteristics</u>:

Maximum heat flow for ventilation of public buildings:

$$Q_{vf}^{p} = K_2 K_1 q_{hl} F 10^{-6}, MW$$

$$Q_{vv}^{p} = \beta q_v V_{ext} \left(t_{int}^{p} - t_{v}^{p}\right) 10^{-6}, MW$$

K_2 is coefficient taking into account heat flow on ventilation of public buildings, for buildings up to 1985 - 0.4, after 1985 - 0.6;

q_{hl} is the specific heat losses;

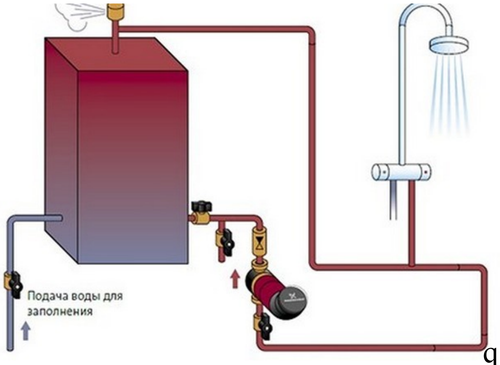
q_v is the specific ventilation characteristic, W/(m³K);

t_v^p is predicted temperature of outside air for ventilation.

Average heat flow for ventilation for the average during heating season outside temperature:

$$Q_v = Q_v^p \frac{\left(t_{int}^{p} - t_{ext}^{av}\right)}{\left(t_{int}^{p} - t_{v}^{p}\right)}, MW$$

t_{ext}^{av} is an average outside temperature for the heating season, °C



Heat load on hot water supply (HWS)

Average heat flow for HWS of residential and public buildings:

$$Q_{HWS}^{av} = \frac{1.2m(a+b)(55-t_{cold})c}{24\cdot 3.6}10^{-6}, MW$$ or $$Q_{HWS}^{av} = q_{HWS}^{av}\cdot m, MW$$

m is predicted numbers of hot water consumers;

q_{HWS}^{av} is generalized parameter of the average hourly heat flow for HWS taking into account public buildings, taken depending on a;

a is a standard of water flow on hot water supply at 55°C per person per day, L/day;

b is a standard of water flow on hot water supply in public buildings at 55°C, 25 L/day per person;

c is mass heat capacity of water, 4.187 kJ/(kg ·°C);

t_{cold} is temperature of cold water during the heating season (in the absence of other data it is assumed equal to 5 ° C)

Maximum heat flow for HWS of residential and public buildings: $$Q_{HWS}^{max} = 2.4Q_{HWS}^{av}10^{-6}, MW$$

Average heat flow for HWS during non-heating (summer) season:

$$Q_{HWS\ summer}^{av} = Q_{HWS}^{av}\frac{(55-t_{summer})}{(55-t_{winter})}\beta, MW$$

t_{summer}, t_{winter} are temperatures of cold (tap) water during heating (5°C) and non-heating (summer) period (15°C);

β is a coefficient that takes into account the change in average water flow during non-heating season in relation to the heating season, for the housing and communal sector - 0.8, for enterprises - 1.0.

2. Heat supply systems: classification

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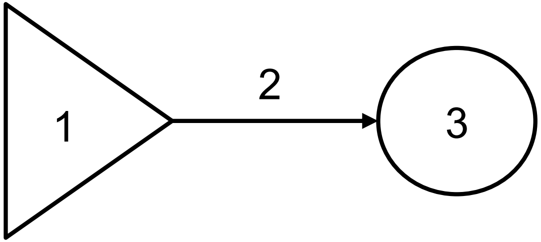
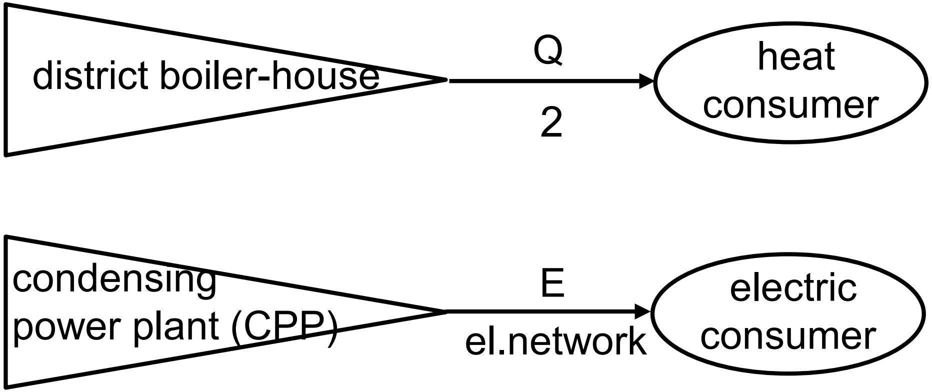
According to type of heat source:

- <u>Centralized heat supply systems from district boiler-house</u>

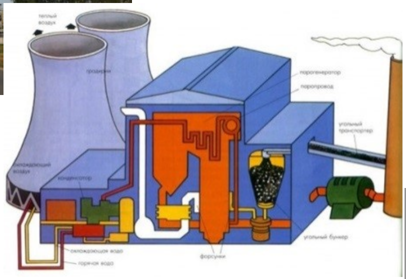


1 – heat source (boiler-house: steam or hot water), 2 – heat networks (pipelines, shut-off and control valves, booster pump stations), 3 – heat consumers (industrial, housing and public utility)

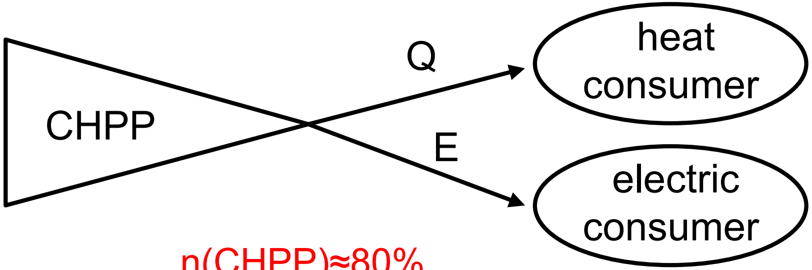
The main feature is a separate production of thermal and electrical energy:



η(CPP)≈35-43%



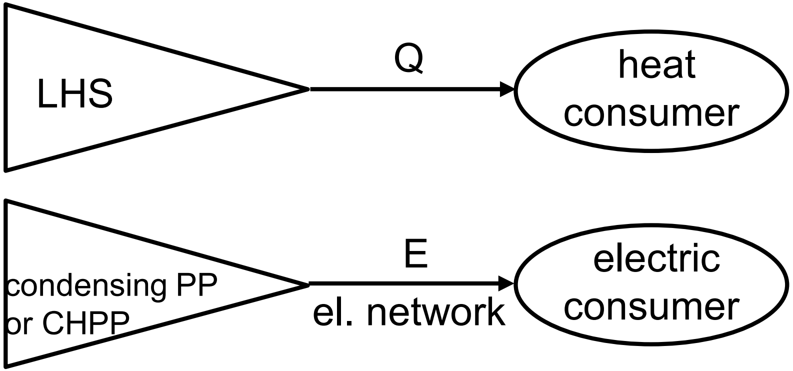
- System of cogeneration (heat-and-power supply system)



η(CHPP)≈80%

Tomsk CHPP-3

- Decentralized heat supply systems



LHS (local heat source):

- individual boiler houses and apartment heating;
- quarterly boiler-houses;
- microdistrict boiler-houses;
- factory boiler rooms.

Principal schemes of separate heat and power generation and cogeneration

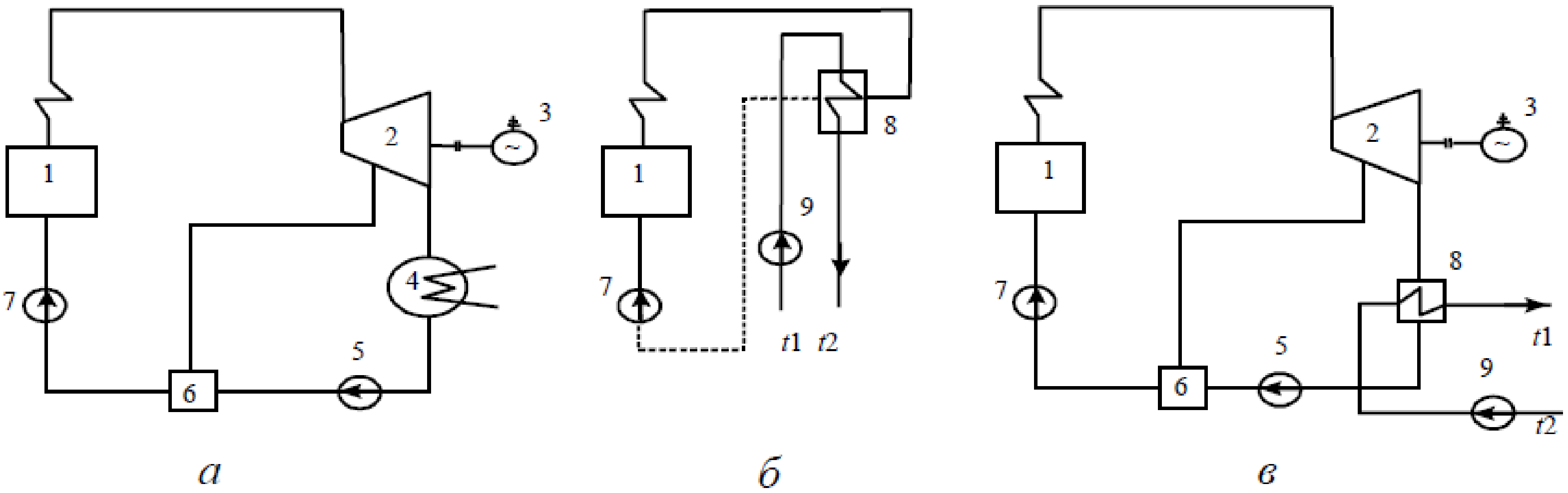


Рис. 2.7. Упрощенные принципиальные схемы раздельного и комбинированного процессов выработки тепла и электроэнергии: Раздельный процесс: *а* – конденсационная электрическая станция (КЭС); *б* – районная котельная (РК); *в* – комбинированный процесс (ТЭЦ); 1 – котел; 2 – турбина; 3 – генератор; 4 – конденсатор; – конденсатный насос; 6 – регенеративный подогреватель; 7 – питательный насос; 8 – подогреватель сетевой воды; 9 – сетевой насос

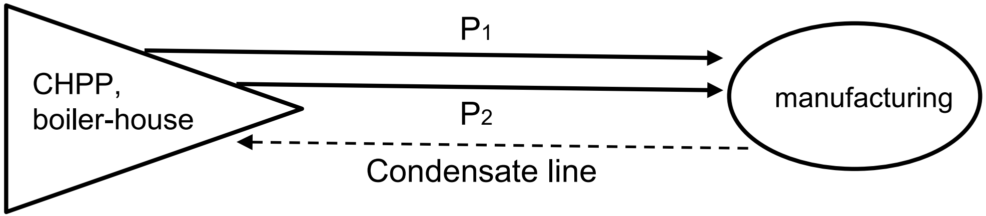
According to type of heat carrier:

- Water systems

used mainly for the heat supply of seasonal consumers and hot water supply, and in some cases, for technological processes.

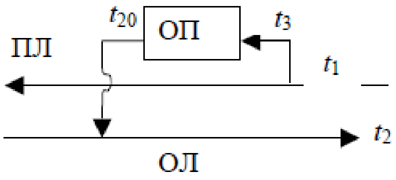
- Steam systems

mainly distributed in industrial enterprises where high-temperature heat load is required. The percentage of return of condensate ranges from 90 to 30%.



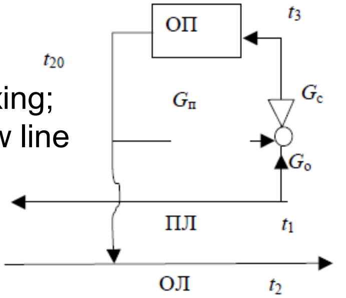
- Dependent schemes

Without mixing



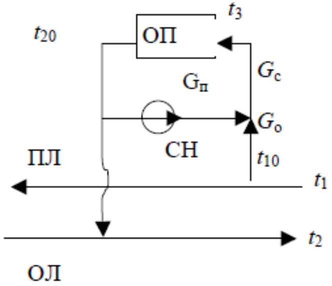
With elevator

$G_п$ is added flow rate;
G_c is flow rate after mixing;
G_o is flow rate from flow line to the elevator inlet.

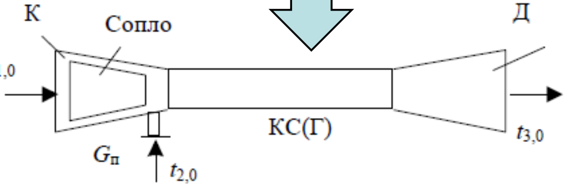


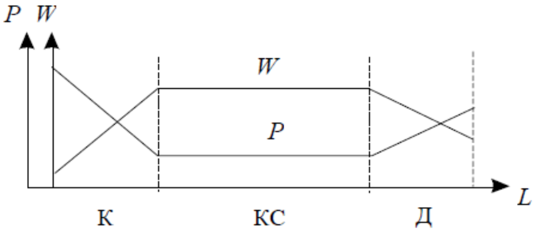
Scheme with mixing pump

t3>t1



K – confuser,
Д – deffuser,
KC – mixing chamber.





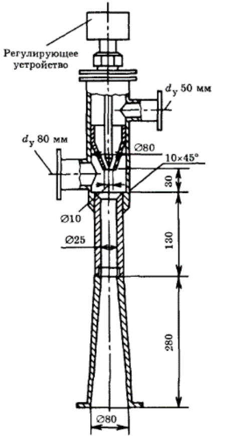
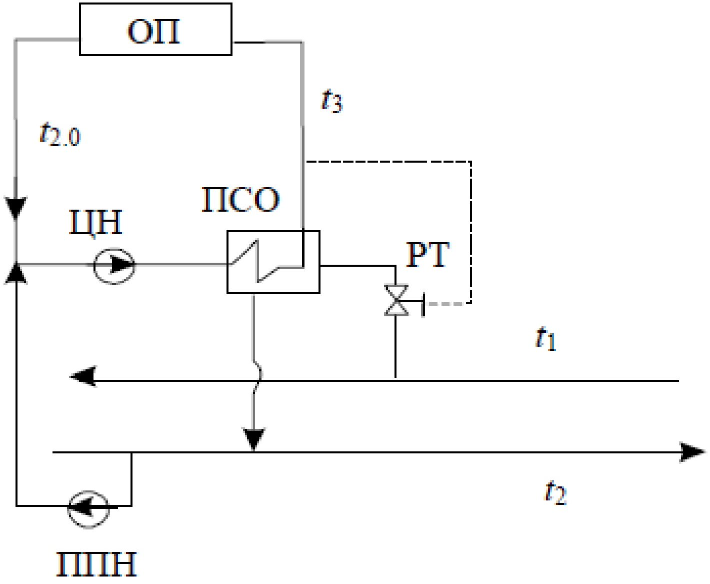


Рис. 8.15. Элеватор № 3 с регулируемым выходным сечением рабочего сопла

- Independent scheme

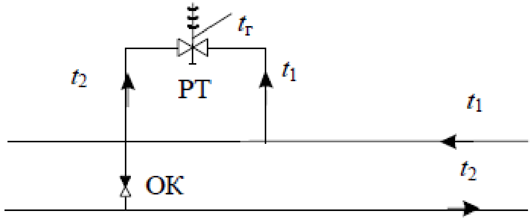


ПСО – heater of the heating system; ЦН – circulation pump; ППН – boost pump of the heating system; РТ – temperature regulator of water in the system

According to the way of supplying water to hot water supply:

- Open systems

Hot water comes directly from the heating networks to the water distribution devices of the local hot water supply system.



The heat flow rate transmitted over the heat networks with open system:

$$Q = G_1 c(t_1 - t_c) - G_2 c(t_2 - t_c), MW$$

G_1, G_2 are water flow rates in flow and return pipelines, kg/s.

- Closed systems

Water from heat networks is used as heating medium for heating in surface-type heaters water which then fed to a local hot water supply system.

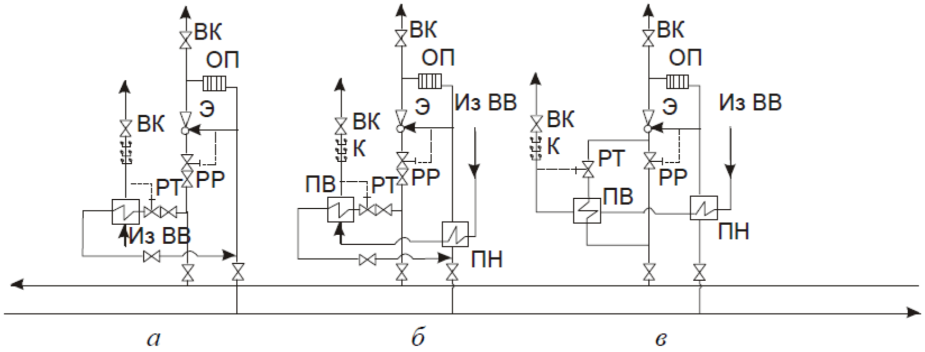
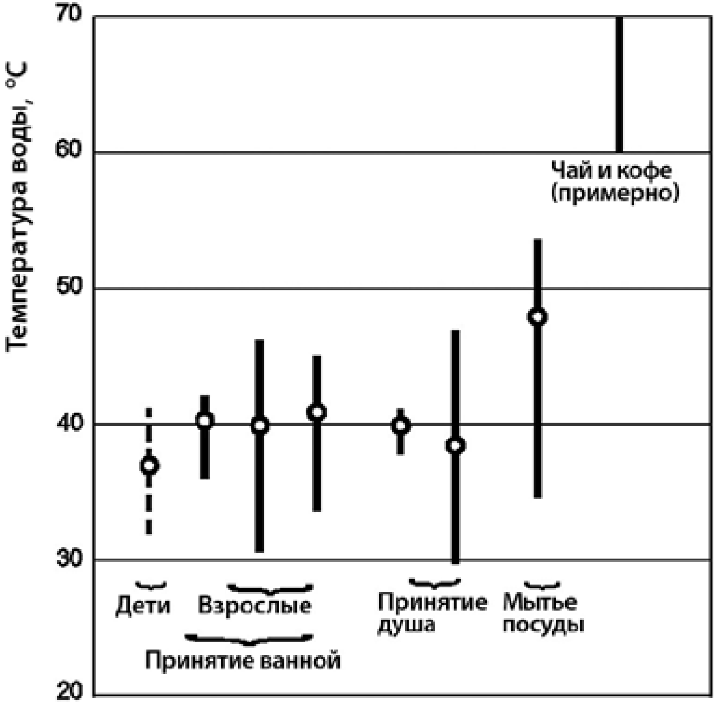


Рис. 2.19. Схемы подключения систем отопления и горячего водоснабжения к тепловым сетям: *а* – параллельная схема включения установки горячего водоснабжения и отопительной установки по зависимой схеме со струйным смешением; *б* – смешанная двухступенчатая схема; *в* – последовательная двухступенчатая схема

Hot water supply

A typical preference in the temperature of the hot water consumers



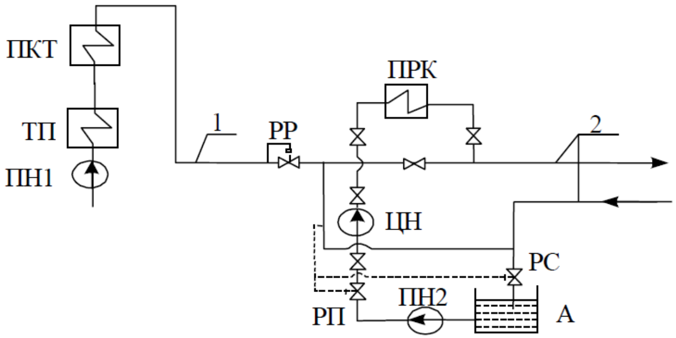
Minimal and maximal temperature of HWS in different countries

Страна	Температура горячей воды	
	минимальная, °C	максимальная, °C
Австрия	-	50
Дания	50	65
Финляндия	50	60
Франция	50	60
Германия	50	55...60
Венгрия	40	65
Италия	48	53
Польша	45 (до 15.06.02)	55 (до 15.06.02)
	55 (с 15.06.02)	60 (с 15.06.02)
Словения	-	60
Швеция	50	65

Russia – t of water in HWS system is **55-60°C**

According to numbers of pipelines of the system:

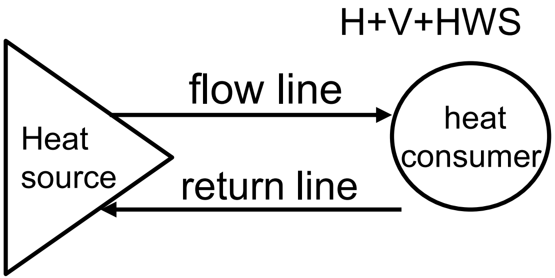
- Single tube (transit) systems



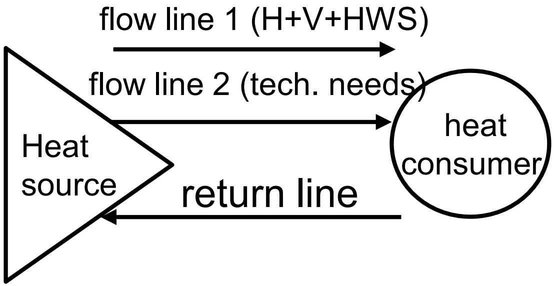
1 – transit main pipeline; 2 – distribution networks; ПКТ, ПРК - peak boiler houses of CHPP and district (пиковые котельные ТЭЦ и района); ТП – cogenerative heater (теплофикационный подогреватель); ЦН – circulation pump (циркуляционный насос); ПН1, ПН2 – boost pump (подпиточные насосы); A – accumulator.

- Multi tubes systems

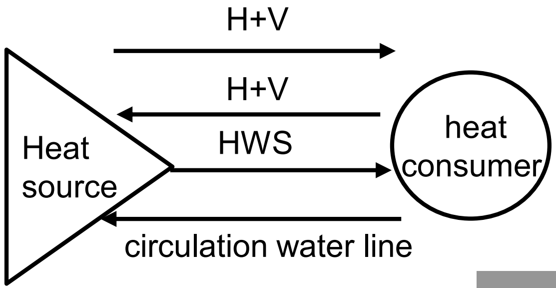
two-tubes



three-tubes



four-tubes



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3. Equipment of Heat Supply System

- Equipment of CHPP for cogeneration

Water systems

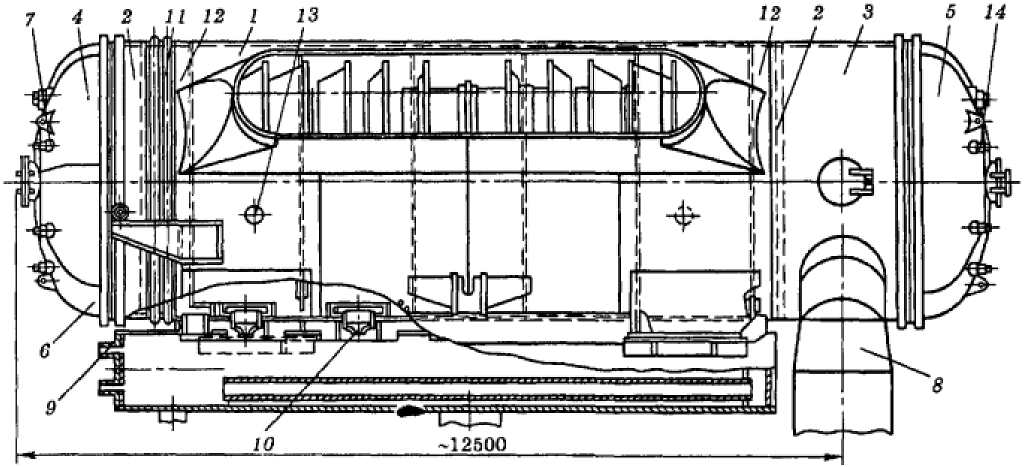
- Steam-water heaters;
- Network pump;
- Units for make-up water (подпиточная вода) preparation: water treatment, deaerator, accumulators of hot water and boost pumps.

Steam systems

- Systems of reservoirs and pumps for collecting, controlling and pumping of condensate;
- Steam-convertion units for the production of secondary steam from chemically purified water used for heat supply;
- Compression units for increasing pressure of steam from extraction;
- desuperheating and pressure reducing system for cooling and reducing pressure of fresh steam sometimes used for heat supply systems.

- Two main types of cogeneration turbines (50-250 MW of power) on high and supercritical initial parameters (13 and 24 MPa pressure): condensing turbine with steam extraction (T and PT) and backpressure turbine.

Horizontal Steam-water heater



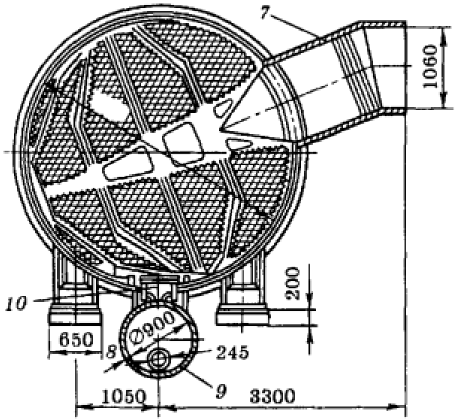


Рис. 7.1. Горизонтальный теплофикационный подогреватель ПСГ-5000-3,5-8-1

1 — корпус подогревателя; *2* — трубные доски; *3* — входная водяная камера; *4* — поворотная водяная камера; *5* — крышка входной водяной камеры; *6* — крышка поворотной водяной камеры; *7* — подвод пара; *8* — подвод сетевой воды; *9* — конденсатосборник; *10* — щелевой патрубок; *11* — линзовый компенсатор; *12* — солевой отсек; *13* — отвод паровоздушной смеси; *14* — анкерная связь

- Equipment of heating points

Water heat carrier

- Water-jet elevator and radial-flow pump;
- Water-water heat exchangers;
- Accumulators of hot water;
- Devices for regulating and controlling parameters of network water;
- Devices for protection of local hot water supply units from corrosion and scale deposition.

Steam heat carrier

- Steam collector;
- Devices for regulating and controlling steam parameters (pressure temperature, flow rate);
- Heat exchangers;
- Condensate-collecting reservoir;
- Pump units for pumping condensate.

Water-water heat units

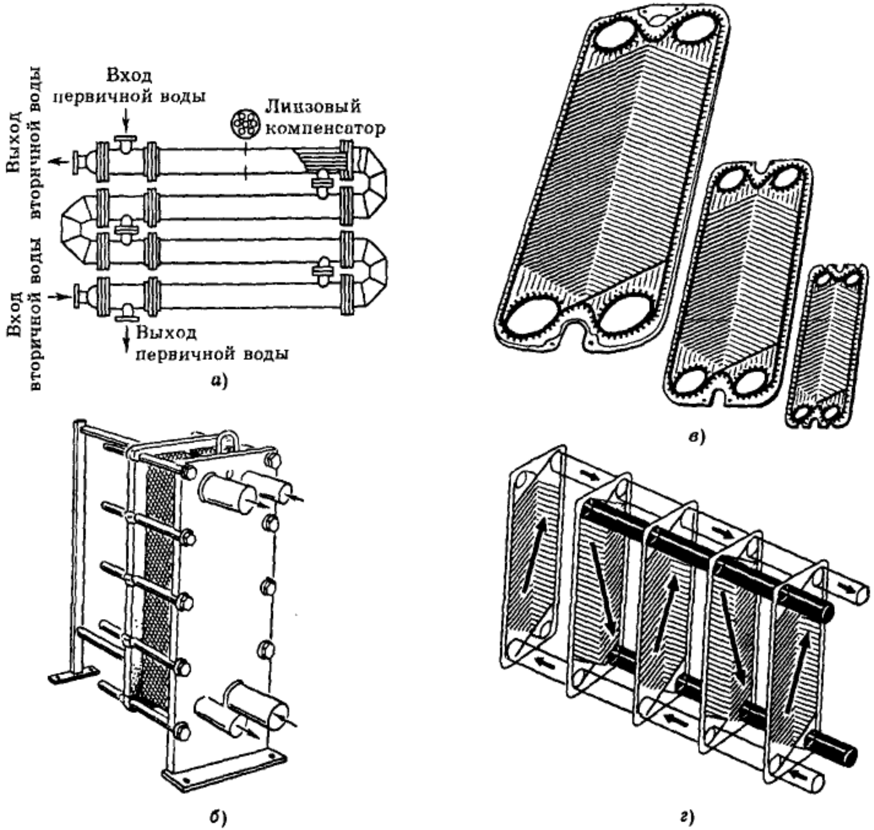


Рис. 8.6. Схема водо-водяных теплообменников

а — секционный; *б* — пластинчатый; *в* — тонкостенные гофрированные пластины; *г* — схема движения теплоносителей

Anticorrosion water treatment

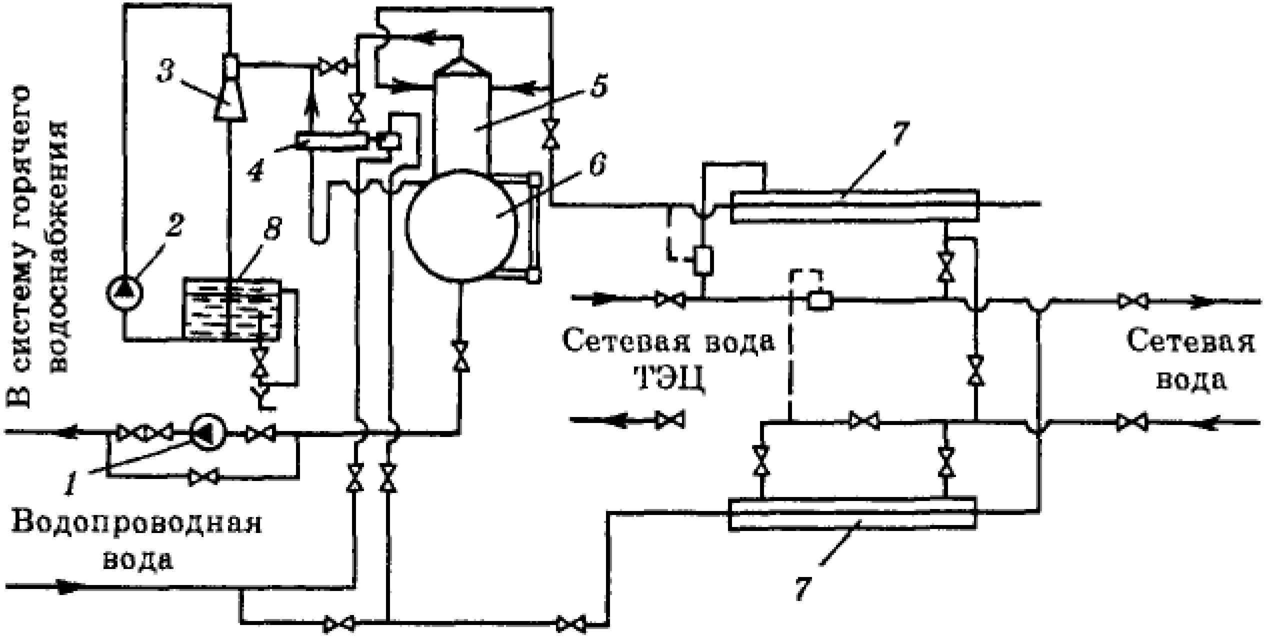


Рис. 8.23. Принципиальная схема вакуум-деаэрационной установки для систем водоснабжения

1 — насос горячего водоснабжения; *2* — насос рабочей воды эжектора; *3* — водоструйный эжектор, *4* — охладитель выпара; *5* — деаэрационная колонка, *6* — деаэрационный бак; *7* — водо-водяной подогреватель, *8* — бак эжекторной установки

- Equipment of heating networks

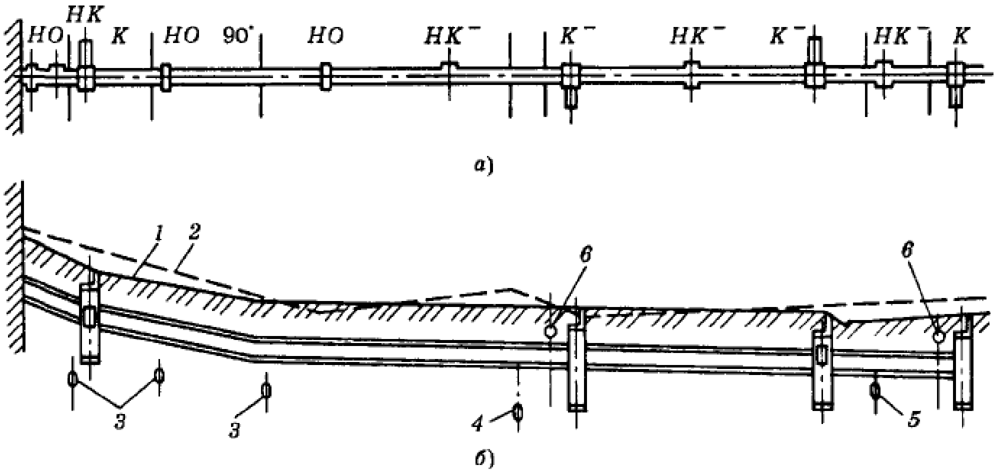


Рис. 9.1. План трассы (а) и профиль теплопровода (б) в непроходном канале

К — камера, *НК* — ниша компенсатора, *НО* — неподвижная опора, *1* — черные отметки земли, *2* — планировочные отметки земли, *3* — водосток, *4* — канализация, *5* — водопровод, *6* — электрокабель

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Heat pipeline consists of:

1) Working pipe for transporting heat carrier;
2) insulation construction for protection of outer pipe surface from corrosion and heat losses;
3) Load-carrying construction perceiving the load of pipe with insulation.

Trenched laying for underground pipelines

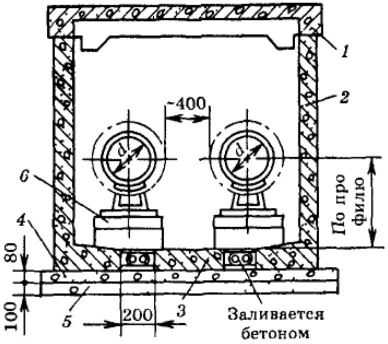


Рис. 9.4. Сборный *полупроходной* канал из железобетонных блоков

1 — ребристый блок перекрытия, *2* — стеновой блок, *3* — блок днища, *4* — бетонная подготовка *5* — щебенчатая подготовка, *6* — опорные плиты

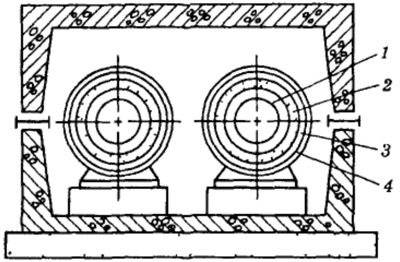
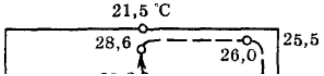


Рис. 9.5 Теплопровод в непроходном канале с воздушным зазором

1 — трубопровод, *2* — антикоррозионное покрытие, *3* — теплоизоляционный слой *4* — защитное механическое покрытие



Trenchless pipe laying

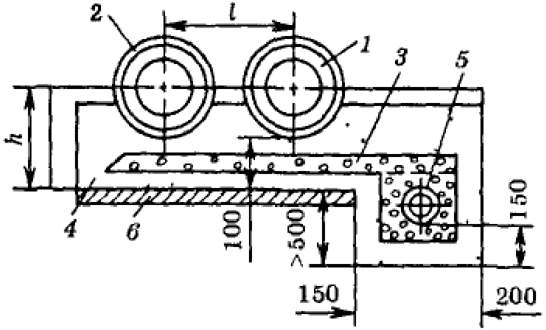


Рис. 9.7. Общий вид двухтрубного бесканального теплопровода в монолитных оболочках

1 — подающий теплопровод, *2* — обратный теплопровод, 3 — гравийный фильтр, *4* — песчаный фильтр, *5* — дренажная труба, *6* — бетонное основание (при слабых грунтах)

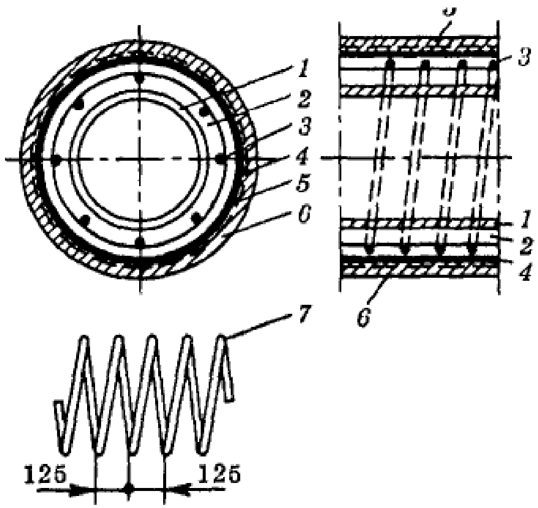


Рис. 9.8. Конструкция монолитной армопенобетонной изоляционной оболочки

1 — труба, *2* — автоклавный пенобетон, *3* — арматура, *4* — гидрозащитное трехслойное покрытие из битумно-резиновой мастики, *5* — стальная тканая сетка, *6* — слой асбоцементной штукатурки, *7* — деталь спирали

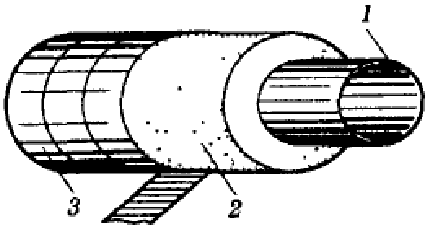


Рис. 9.9. Монолитная битумоперлитная изоляция

1 — трубопровод, *2* — битумоперлит по антикоррозионному покрытию, *3* — бризол в два слоя

Compensators of temperature deformations

Expansion gland

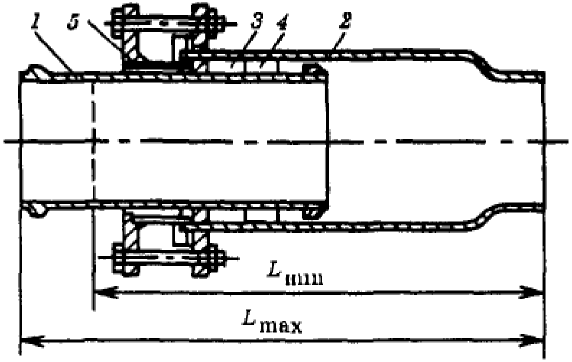


Рис. 9.32. Односторонний сальниковый компенсатор

1 — стакан, *2* — корпус, *3* — набивка, *4* — упорное кольцо, *5* — грундбукса

Corrugated expansion joint

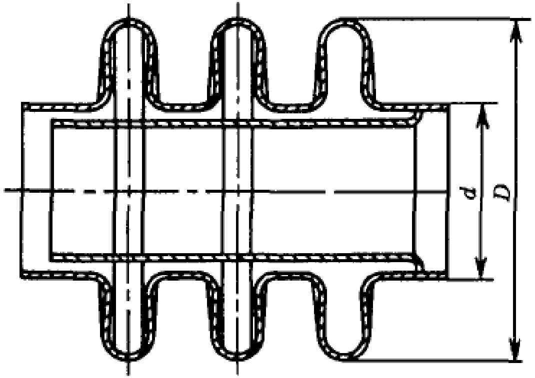


Рис. 9.34. Трехволновой сильфонный компенсатор

Compulsory reading:

1. Sokolov E.Ya. Power-and-heat generation and heating networks. – Moscow. MEI, 2009. – P. 472.
2. Lyalikov B.A. Sources and systems of heat supply of industrial enterprises. – Tomsk, Publishing house of Tomsk polytechnic university, 2008, part 1. – P.155.
3. Lyalikov B.A. Sources and systems of heat supply of industrial enterprises. – Tomsk, Publishing house of Tomsk polytechnic university, 2008, part 2. – P.171.
4. International District Heating Association. District heating handbook. – 4th edition. – 1983. – P.516.
5. Frangopoulos C. A. Cogeneration: Technologies, Optimisation and Implementation. – IET, 2017. – P. 360.
6. Greene A. M. The elements of heating and ventilation; a Text-book for students, engineers and architects. – Hard Press Publishing, 2012. – P. 349.
7. Heat supply, a handbook, ed. by V.E. Kozin. – Moscow, Integral, 2013. – P.408.
8. Bespalov V.E. Systems and sources of power supply. – Tomsk, Publishing house of Tomsk polytechnic university, 2011.

Additional reading:

1. Rosen M. A., Koohi-Fayegh S. Cogeneration and District Energy Systems: Modelling, Analysis and Optimization. – IET, 2016. – 344.
2. Advanced District Heating and Cooling (DHC) Systems, ed. by Robin Wiltshire. – Woodhead Publishing, 2015. – P.364.

J. Marecki. Combined heat & power generating systems. – Peter Peregrinus Ltd., London, 1988.

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Calculation of water flow rate for consumers