HEAT AND GAS SUPPLY, VENTILATION, AIR CONDITIONING, GAS SUPPLY AND ILLUMINATION

DOI 10.36622/VSTU.2020.48.4.001
UDC 697.341

D. N. Kitaev[1], A. T. Kurnosov[2], Z. S. Hasanov[3], S. O. Kharin[4]

CALCULATION OF ANNUAL WATER TEMPERATURES IN HEAT NETWORKS

Voronezh State Technical University[1, 2, 3, 4]
Russia, Voronezh

[1]*Cand. tech. Sciences, Assoc. Department of Heat and Gas Supply and Oil and Gas Business, tel.: +79066710284, e-mail: dim.kit@rambler.ru*
[2]*Cand. tech. Sciences, Assoc. Department of Heat and Gas Supply and Oil and Gas Business, tel.: +79066710284, e-mail: teplosnab_kaf@vgasu.vrn.ru*
[3]*Cand. tech. Sciences, Assoc. Department of Heat and Gas Supply and Oil and Gas Business, tel.: +79066710284, e-mail: teplosnab_kaf@vgasu.vrn.ru*
[4]*Graduate student. Department of Heat and Gas Supply and Oil and Gas Business, tel.: +79003046251, e-mail: kharin_sergey.93@mail.ru*

Statement of the problem. When carrying out design calculations of heating networks, in particular, calculating the thickness of thermal insulation structures, thermal elongations during thermal expansion, standard losses during the transportation of thermal energy to the consumer, it is often necessary to use the design values of the average annual temperatures of the coolant indicated depending on the design temperature schedule in modern standards [18, 24]. According to a number of researchers, the recommended values of average annual coolant temperatures do not take into account climatological characteristics and their use can lead to significant errors [1—3]. In addition, recommended temperatures have changed over the past few years and there has been a contradiction in regulations. Currently, there are no substantiated values of the design average annual temperatures of the heat carrier in the heating network, taking into account climatological data.
Results. For the design temperatures of the temperature graphs of the central quality regulation 95 / 70—150 / 70 for the settlements of the territory of the central federal district, presented in the latest edition of building climatology, the values of the average annual water temperatures in the supply line of the heating network have been determined. The averaged values of temperatures for the considered temperature graphs are obtained.
Conclusions. For most of the temperature graphs, significant discrepancies have been established between the calculated values of the average annual water temperatures in the heating network and those recommended by the JV “Heating Networks” of the latest edition. The maximum difference is observed for the 150/70 graph and is 12 ° C.

Keywords: heating network; temperature graph; average annual temperature of the heating medium.

Introduction. While designing heating networks, one of the important factors is the average annual temperature of the heat carrier. It is necessary for calculating the heat-insulating structures of the network, identifying the heat losses during the transportation of the heat carrier involved in the formation of the heat energy tariff [5, 8]. This indicator is necessary while creating promising programs and schemes for the development of heating networks and sources of heat generation, energy-saving strategies at heating network and generating enterprises [20—22]. Improving the accuracy of calculations in the design of heat supply systems is an urgent task.

In engineering practice, it is commonly necessary to employ the recommended values of the average annual temperatures for the supply and return lines of the heating network [14, 16]. In the guidelines for the design of heating networks, similar values for the supply main line are indicated depending on the design values of the temperature schedules of quality control. Average annual values of the coolant temperature are calculated as weighted averages over the monthly average values of the coolant temperature in the pipeline, which, in turn, are identified using the temperature schedule in compliance with the monthly average values of the outside air temperature [19, 23]. Such calculations are time-consuming and are thus neglected using the rules recommended by the guideline [9, 10].

The objective of the study is to identify the design values of the average annual water temperatures in the supply line of the heating network for the possible range of the employed temperature graphs of the central quality control for the heating load considering the latest climatic data for the area of the Central Federal District.

1. Identifying the average annual water temperatures in the network. With a high-quality control mode of the heating network and a heating schedule, the temperature of the heat carrier in the supply pipeline of the heating network τ_1 under conditions of an arbitrary outside air temperature is given by the formula [4.17]:

$$\tau_1 = t_в + \left(\tau_{пр.о} - t_в\right)\left(\frac{t_в - t_н}{t_в - t_{р.о}}\right)^{\frac{1}{1+n}} + \left(\tau_{1о} - \tau_{пр.о}\right)\left(\frac{t_в - t_н}{t_в - t_{р.о}}\right), \quad (1)$$

where $t_в$ is the design air temperature in facilities, ºC; $t_н$ is the arbitrary temperature of the outside air, ºC; $t_{р.о}$ is the design temperature for the heating design, ºC; $\tau_{1о}$ is the water temperature in the main pipeline of the network at $t_{р.о}$, ºC; $\tau_{пр.о}$ is the average water temperature in the heating device, ºC given by the formula $\tau_{пр.о} = \frac{1}{2}\left(\tau_{см.о} + \tau_{2о}\right)$; $\tau_{см.о}$, $\tau_{2о}$ is the water temperature in the user's setup and in the reverse pipeline of the heating supply system at the design parameters of the heating system, ºC; n is an empirical index depending on the type of a heating device and its installation scheme.

The average annual water temperature is given by the formula:

$$\tau_{1год} = \frac{\sum(\tau_{1i} n_i)}{n_{оп} + n_{ноп}}, \quad (2)$$

where τ_{1i} is the temperature of a heat carrier in the main pipeline at the average temperature of the outside air of a corresponding month, ºC; n_i is the operation period of the network in the *i*-th month; $n_{оп}, n_{ноп}$ are heating and non-heating seasons respectively.

For the climatic conditions of the city of Kashira, Moscow region, a heating temperature schedule was designed for high-quality regulation of the heating network considering the installation of modern heating devices in buildings [7, 11, 13]. The calculations were performed for the design temperatures of the supply pipeline 150, 130, 105, 95 °C. The average monthly values of the water temperatures in the network were identified considering the average monthly values of the outside air temperatures in each month of the heating season according to the latest edition of the JV "Construction Climatology". In Fig. 1 there are the considered temperature graphs considering the fracture temperature of 70 °C [6, 12, 15].

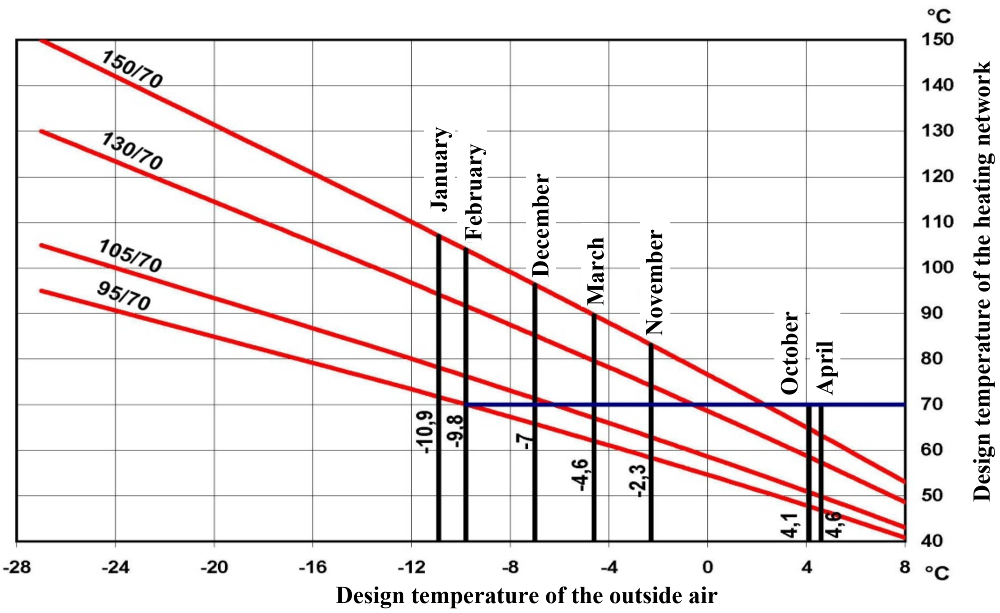

Fig. 1. Temperature graphs for the main pipe of the heating network

Fig. 1 also shows the average temperatures of the months of the heating period allowing one to conclude on the average temperature in the supply line of the heating network.

2. Average annual water temperatures for the territory of the Central Federal District. Similarly the average annual values of water temperatures in the supply line of the heating network for the settlements of the Central Federal District (CFD) were identified whose climatic data are in the latest edition of JV "Construction Climatology".

About 27 % of the total population of the Russian Federation lives on the territory of the Central Federal District and largely in cities (about 82 %). Such indicators make district heating in this area critically important. The Central Federal District includes 18 constituecies of the Russian Federation. The current Set of Guidelines (СП) on climatology contains information on 28 settlements included in the Central Federal District. According to climatology data, the calculated outdoor air temperature $t_{p.o}$ is in the range from –24 to –32 °C and the heating season n is from 190 to 230 days.

Table 1 presents the values of the average annual temperatures of the supply line of the heating network for the capitals of the subjects of the Russian Federation located in the territory of the Central Federal District for the corresponding temperature schedule.

Table 1

Average annual temperatures of the supply line of the heating network

Settlement	Design temperature graphs				$t_{p.o}$ °C	n, days
	95/70	105/70	130/70	150/70		
Voronezh	70	70.961	75.337	79.9	–24	190
Kursk	70	70.883	75.325	79.886		194
Bryansk	70	70.822	75.177	79.71		199
Belgorod	70	70.538	74.415	78.803		189
Smolensk	70	70.643	74.964	79.456	–25	209
Moscow	70	70.784	75.107	79.626		205
Oryol	70	70.782	75.125	79.648		199
Tula	70	70.715	74.93	79.54	–26	203
Ryazan	70	71.034	75.566	80.173		202
Lipetsk	70	70.629	74.686	79.126	–27	197
Vladimir	70	70.985	75.522	80.12		209
Kaluga	70	70.571	74.528	78.938		208
Tambov	70	70.703	74.887	79.365		197
Tver	70	70.286	73.734	77.994	–29	212
Ivanovo	70	70.793	75.104	79.623		214
Kostroma	70	70.446	74.171	78.513	–31	216
Yaroslavl	70	70.429	74.169	78.511		217

Fig. 2 shows the values of the average annual water temperatures in the supply pipe of the heating network for temperature graphs 150/70 and 130/70 and in Fig. 3 — for 105/70 and 95/70. Figures 2 and 3 also show the average temperatures for the corresponding temperature graphs.

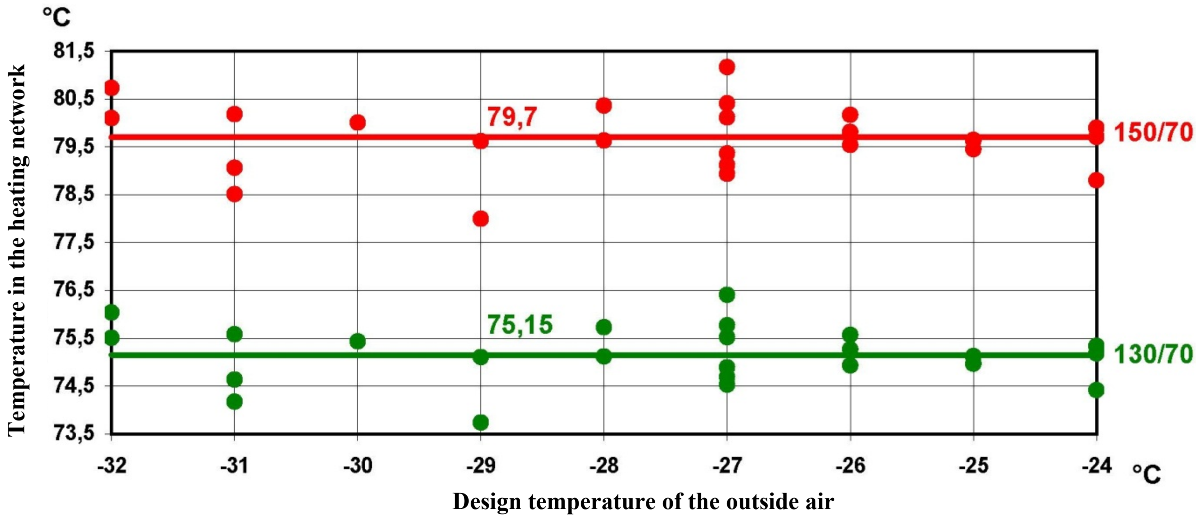

Fig. 2. Design values of the annual water temperatures in the supply pipeline for the graphs 150/70 and 130/70

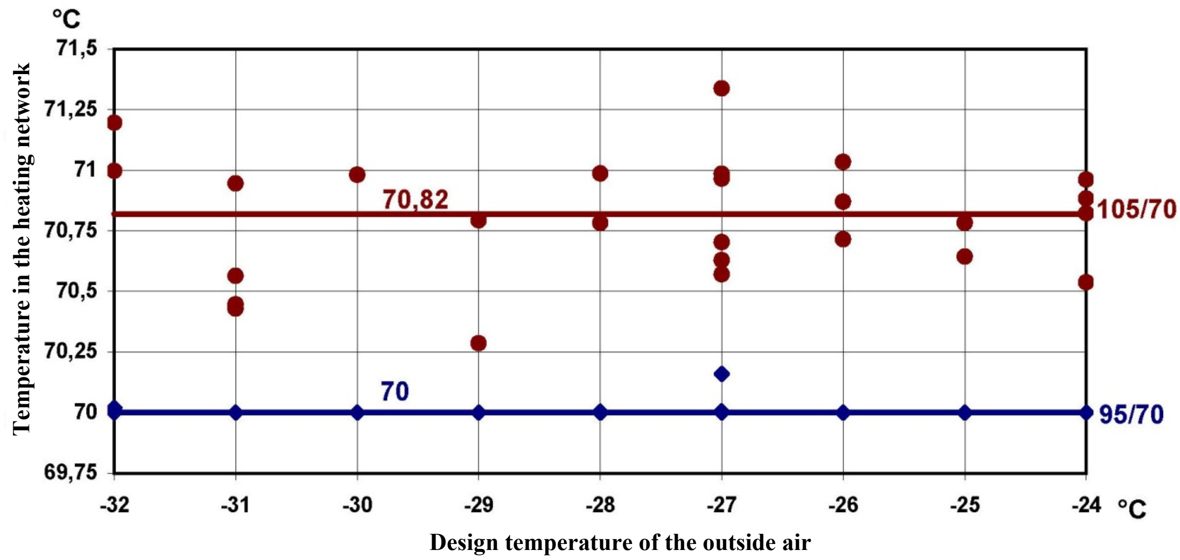

Fig. 3. Design values of the average annual water temperatures in the supply pipeline for the graphs 105/70 and 95/70

3. Analysis of the results. The data in Table 1 and Fig. 2 and 3 enable us to make the following conclusions. For almost all of the cities, while using the temperature graph of 95/70, the average annual water temperature is 70 °C. The highest value of –70.159 °C is observed for the city of Kashira, Moscow region. The temperature rise in three more cities can be considered inconsiderable. With an increase in the temperature graph, there is a rise in the temperature range spread. The difference in temperature values for the temperature graphs 105/70, 130/70 and 150/70 is 1.05, 2.67 and 3.18 °C, respectively. Due to the inconsiderable difference in the temperature values, it is recommended that the approximate constant values of the average annual temperatures for temperature graphs 105/70, 130/70 and 150/70: 70.8, 75.15 and 79.7 °C are used.

Table 2 shows the results of a comparison of the average annual water temperatures in the supply pipeline with the quality regulation recommended by the latest edition of the Set of Guidelines (СП) "Heating Networks" and obtained as a result of a calculation.

Table 2

Comparison of the recommended and design average annual temperatures

Design temperature graph	95/70	105/70	130/70	150/70
Recommended average annual temperatures in the Set of Guidelines (СП) "Heating Networks"	65	70	85	90
Design average values	70	70.82	75.15	79.68
Maximum difference	5.159	1.337	11.266	12.006
Minimum difference	5	0.286	8.595	8.827

According to Table. 2, the average calculated values of the average annual water temperatures for the temperature graph 95/70 are 5 °C higher, for 105/70 they differ inconsiderably (0.82 °C), for 130/70 and 150/70 the values are obtained, 9.85 °C and 10.32 °C lower, respectively. The use of values recommended in the Set of Guidelines (СП) for the temperature graph other than 105/70 can lead to considerable errors in the calculations of heating networks and their technical and economic parameters. It is essential to perform similar calculations in each case.

Conclusions. The design values of the average annual water temperatures in the supply pipeline of the heating network for the territory of the Central Federal District may differ considerably from the recommended guidelines. The maximum discrepancy can be 12 °C. The closest are the design values recommended by the guideline with the temperature schedule of 105/70 and as the design temperatures increase, so does the difference.

The use of the values recommended in the Set of Guidelines (СП) can lead to considerable errors in the design of heating networks and calculations of technical and economic characteristics. It is suggested that the average annual values are identified by means of a calculation that considers the average monthly temperatures of the coolant depending on the average monthly values of the outside air temperatures for each month of the heating season.

References

1. Badakh V. F., Kuznetsova A. D. Raschet normativnykh poter' tepla cherez izolyatsiyu truboprovodov teplovykh setei [Calculation of standard heat losses through insulation of pipelines of heating networks]. *Tekhniko-tekhnologicheskie problemy servisa*, 2011, no. 4 (18), pp. 60—72.

2. Bass M. S., Seredkin A. A., Batukhtin S. G [Problems of rationing of heat losses in water heating networks and boiler rooms]. *Kulaginskie chteniya: tekhnika i tekhnologii proizvodstvennykh protsessov. XVIII Mezhdunarodnaya nauchno-prakticheskaya konferentsiya* [Kulagin readings: technique and technology of production processes. XVIII International Scientific and Practical Conference], 2018, pp. 57—61.

3. Voevodin A. G. Analiz raschetov normativnykh znachenii tekhnologicheskikh poter' pri peredache teplovoi energii po setyam sistem teplosnabzheniya potrebitelei s tsel'yu snizheniya ekspluatatsionnykh zatrat [Analysis of calculations of normative values of technological losses in the transmission of heat energy through the networks of heat supply systems of consumers in order to reduce operating costs]. *Transportnye sistemy*, 2016, no. 2, pp. 31—41.

4. Gromov N. K., Shubin E. P. *Vodyanye teplovye seti: Spravochnoe posobie po proektirovaniyu* [Water heating networks: A reference guide for design]. Energoatomizdat, 1988. 376 p.

5. Zhutaeva E. N., Davydova T. E., Dubrovskaya T. N. Optimizatsiya zatrat predpriyatiya (na primere issledovaniya rynka teplosnabzheniya) [Calculation of the outside air temperature at the break point of the temperature graph]. *FES: Finansy. Ekonomika*, 2017, no. 5, pp. 29—38.

6. Kitaev D. N. Raschet temperatury naruzhnogo vozdukha v tochke izloma temperaturnogo grafika [Modern heating devices and their indicators]. *Novosti teplosnabzheniya*, 2012, no. 10 (146), pp. 46—48.

7. Kitaev D. N. Sovremennye otopitel'nye pribory i ikh pokazateli [On the influence of the coolant temperature on the technical and economic indicators of the projected heating networks]. *Santekhnika, otoplenie, konditsionirovanie, energosberezhenie*, 2014, no. 1, pp. 48—49.

8. Kononova M. S. O vliyanii temperatury teplonositelya na tekhniko-ekonomicheskie pokazateli proektiruemykh teplovykh setei [On the influence of the coolant temperature on the technical and economic indicators of the projected heating networks*]. Izvestiya vuzov. Stroitel'stvo*, 2012, no. 10, pp. 67—73.

9. Nurov M. Sh., Gordin S. A. [Optimization of the heat supply scheme according to the criterion of minimum losses when transporting energy to the consumer]. *Molodezh' i nauka: aktual'nye problemy fundamental'nykh i prikladnykh issledovanii. Materialy II vserossiiskoi natsional'noi nauchnoi konferentsii studentov, aspirantov i molodykh uchenykh* [Youth and Science: Actual Problems of Fundamental and Applied Research. Materials of the II All-Russian National Scientific Conference of Students, Postgraduates and Young Scientists], 2019. Pp. 392—395.

10. Panferov V. I., Anisimova E. Yu., Panferov S. V. Effektivnye energosberegayushchie resheniya pri teplosnabzhenii zdanii [Effective energy saving solutions for heat supply of buildings]. *Vestnik Yuzhno-Ural'skogo gosudarstvennogo universiteta. Seriya: Stroitel'stvo i arkhitektura*, 2015, vol. 15, no. 4, pp. 40—48.

11. Panferov V. I., Panferov S. V. Ob osobennostyakh vyvoda uravnenii regulirovaniya sistem tsentralizovannogo teplosnabzheniya [On the features of the derivation of the equations of regulation of centralized heating systems]. *Vestnik Yuzhno-Ural'skogo gosudarstvennogo universiteta. Seriya: Komp'yuternye tekhnologii, upravlenie, radioelektronika*, 2016, vol. 16, no. 1, pp. 21—30.

12. Kitaev D. N., Novakovski P., Sazonov E. V. e. a. *Prakticheskoe primenenie energosberegayushchikh tekhnologii* [Practical application of energy-saving technologies]. Tambov, Izd-vo Pershina R. V., 2014. 193 p.

13. Rafal'skaya T. A. Nizkotemperaturnye rezhimy raboty teplovykh setei pri kachestvenno-kolichestvennom regulirovanii [Low-temperature operating modes of heating networks with qualitative and quantitative regulation]. *Novaya nauka: Teoreticheskii i prakticheskii vzglyad*, 2016, no. 10 (2), pp. 141—143.

14. Sister V. G., Yamchuk A. I., Polivoda F. A. Matematicheskaya model' teplovoi seti i razrabotka rekomendatsii po raschetu kpd dlya proizvol'nogo temperaturnogo grafika [Mathematical model of a heating network and development of recommendations for calculating efficiency for an arbitrary temperature graph]. *Izvestiya Moskovskogo gosudarstvennogo tekhnicheskogo universiteta MAMI*, 2012, vol. 4, no. 2 (14), pp. 318—324.

15. Smorodova O. V., Kitaev S. V., Useev N. F. Sravnitel'nyi analiz metodov regulirovaniya teplosnabzheniya [Comparative analysis of heat supply regulation methods]. *Norwegian Journal of Development of the International Science*, 2018, no. 17-1, pp. 54—58.

16. Khismatullin Sh. Kh., Ucharov U. B., Kashitsyn V. P., Chulkova S. A. O temperaturnom grafike raboty teplovykh setei g. Kazani [On the temperature schedule of the heat networks in Kazan]. *Energetika Tatarstana*, 2011, no. 2 (22), pp. 39—43.

17. Sharapov V. I., Rotov P. V. *Regulirovanie nagruzki sistem teplosnabzheniya* [Regulation of the load of heat supply systems]. Moscow, Novosti teplosnabzheniya Publ., 2007. 164 p.

18. Akhmetova I., Chichirova N., Derevianko O. Revisiting heat losses calculation at district heating network. *International Journal of Civil Engineering and Technology*, 2017, vol. 8, no. 12, pp. 694—702.

19. Kitaev D., Bugaevsky D., Makarov A. Modeling the work of a steam-water injector in a heat supply system. E3S Web of Conferences. Key Trends in Transportation Innovation, KTTI 2019, 2020. P. 06037.

20. Martynenko G. N., Kitaev D. N., Sedaev A. A. Prospects for the development of the gas supply system of the city district of voronezh for the period till 2035. *Russian Journal of Building Construction and Architecture*, 2018, no. 4 (40), pp. 26—39.

21. Melkumov V. N., Kuznetsov S. N., Sklyarov K. A., Gorskikh A. A. Reliability monitoring of heat supply networks. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture*, 2011, no. 1 (9), pp. 42—49.

22. Melkumov V. N., Sklyarov K. A., Tulskaya S. G., Chuikina A. A. Criteria of optimality and condition of the comparison of design solutions of systems of heat supply. *Russian Journal of Building Construction and Architecture*, 2018, no. 1 (37), pp. 18—28.

23. Shan X., Wang P., Lu W. The reliability and availability evaluation of repairable district heating networks under changeable external conditions. *Applied Energy*, 2017, vol. 203, pp. 686—695.

24. Sharapov V. I., Rotov P. V., Orlov M. E. The improvement technologies of the thermal load regulation for cogeneration systems in urban areas. *Transactions of Academenergo*, 2010, no. 4, pp. 70—83.