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ASSESSMENT OF THE POSSIBILITY OF TRANSFERRING UKRAINIAN DISTRICT HEATING SYSTEMS TO LOW-TEMPERATURE COOLANTS

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The analytic research was conducted for a residential building built according to a typical project in Lviv. As the research data showed, the requirements of the existing normative documents of Ukraine do not allow to significantly reduce the heat load on the heat source. Thus, the value of the maximum heat flow to the heating system decreased by 36 %, and the maximum heat flow to the hot water supply system – by 7.7 %, and the total maximum hourly heat consumption, respectively, decreased by 23 %. In addition, studies have established that for such values of the thermal power of the heat source, a decrease in the temperature parameters of the heat carrier can lead to an increase in the consumption of the heat carrier to provide thermal energy to the house by almost 3 times. And this, in turn, for the same diameter of the pipeline, leads to an increase in specific pressure losses by more than 5 times, and, accordingly, to an increase in the power of circulation pumps, the consumption of electrical energy and the cost of these pumps. This means that at present, the transition of large systems of district heating system of Ukraine to low-temperature coolants is possible only during the reconstruction of heat networks.

Key words: district heating system, renewable energy sources, low-temperature coolant, heat network, heat consumption, consumption of network water.

Introduction

The introduction of district heating systems in the EU countries is considered as one of the ways to reduce the use of non-renewable (fossil) fuels and reduce the release of greenhouse gases into the environment. In this case, renewable energy sources are used as an energy source, in particular biomass, geothermal energy from the depths of the earth and waters, waste heat from industrial and public buildings, solar energy. (Millar, Burnside & Yu, 2019; Geletukha, Zheliezna & Bashtovyi, 2021; Savchenko et al., 2018; Lepiksaar, et al., 2021; Zhelykh, et al., 2019; Pakere, et al., 2021; Savchenko, et al., 2023; Voznyak, et al., 2023). One of the caveats when using renewable sources as an energy source in district heating systems is their low temperature potential. It requires appropriate temperature parameters of the coolant in district heating systems. So, in 4th generation (4G) low-temperature district heating systems, the coolant temperature in the supply pipelines should not be higher than 70 °C, and the coolant temperature in the return pipeline should be 25 °C (Glamazdin, Baranchuk & Priymak, 2021). When using high-temperature heat supply systems 2G and 3G, the temperature of the coolant in the supply pipeline exceeds 85 °C, therefore, a significant drawback of such systems is significant heat loss from the pipelines to the environment. To reduce heat loss, pipelines are insulated with various heat-insulating materials and various options for installing insulating materials are offered, (Zhelykh, et al., 2016; Chicherin, et al., 2020; Dobáková, et al., 2020; Demchenko, 2018) however, one of the effective directions for significantly reducing heat loss during coolants transportation is lowering their parameters. A coolant temperature decrease also leads to the energy resources consumption decrease. Thus, coolant temperature decrease in the supply pipeline from

135 °C to 120 °C and in the return pipeline from 70 °C to 60 °C allows reduce the organic fuel consumption by 12 % (Sekret, 2019). Thermodynamic and economic analysis of the quasi-stationary combined operation of the 370 MW power unit, which provides a network of district heating systems with the parameters of heating network water 135/70 °C and 110/70 °C, confirms the feasibility of such a measure (Bartnik, Buryn, 2014). The vast majority of district heating systems in Ukraine belong to high-temperature systems of the 2G and 3G (Fialko, Tymchenko, 2023). Therefore, in order to increase the energy efficiency of Ukraine's district heating systems, it is advisable to evaluate the possibility of their transfer to coolants with low parameters without significant reconstruction of heat networks.

That is why, the aim of this article is to assess the possibility of transferring Ukraine's high-temperature district heating systems to the parameters of low-temperature systems.

Materials and methods

Ukraine has one of the highest saturation of cities with heat networks in the world. The total length of heat pipelines in our country as of 2018 is 20.6 thousand kilometers in two-pipe calculation (Karp, et al., 2021). The share of heat from district heating systems in the overall structure of heat supply of Ukraine is about 42 %. At the same time, the centralized heat supply system provides heat for about 60 % and hot water for more than 40 % of the total area of the housing stock of Ukraine in 121 cities (Sistani, et al., 2020).

The vast majority of district heating systems in Ukraine were built in the 1970s and 1980s, and some even in the 1960s. Most of these systems meet the criteria of only 2G heat supply systems, sometimes in new houses of the so-called elite buildings; the heat supply systems have signs of 3G (Fialko, Tymchenko, 2023). That is, district heating systems do not use renewable energy sources, they do not have proper smart accounting of thermal energy, and there is no smart dispatching of energy consumption at each link of production, transmission, distribution and final consumption of thermal energy. In addition, due to the high coolant temperature in the existing networks of district heating systems, the total heat energy losses are on average 30 %, and in some regions they reach 40 % (Kyzim, Kotlyarov, 2021).

Therefore, the main direction of the development of district heating systems in Ukraine is their modernization in accordance with the requirements of existing regulatory documents of Ukraine and the EU to ensure climate neutrality. Modernization of district heating systems should be carried out in the following directions:

1. Implementation of cogeneration plants, the latest technologies of combined production of heat and electricity with a high level of efficiency – steam-gas, gas turbine plants with utilization of waste heat.
2. Ensuring the use of renewable energy sources and secondary energy resources.
3. Use of pre-insulated heat pipelines for the construction and reconstruction of heat networks.
4. Implementation of heat energy consumption accounting throughout the district heating system chain, improvement of the pricing mechanism and collection of payments for consumed heat.
5. Conversion of boiler rooms to mini-CHPs, which will allow to ensure the company's own needs in electric energy, as well as to reduce the total fuel consumption for the production of thermal and electric energy.
6. Establishing low-temperature regimes of generation and consumption of thermal energy.

All these measures require the development of mechanisms for coordinating the interests of heat supply system operators and heat energy consumers with the introduction of state legislative processes. In addition, the proposed measures are expensive, and accordingly require significant investments for their implementation.

Results and discussions

During the 30 years of Ukraine's independence, minor steps were taken to improve the energy efficiency of buildings and heating networks (Sergeychuk, 2017). In particular, the requirements for the heat-technical characteristics of the buildings enclosing structures increased. In the Table 1 shows the heat transfer resistances for various enclosing structures for the 1st temperature zone in accordance with the normative documents in force at that time.

Table 1

Heat transfer resistance of the enclosing structures in accordance with regulatory documents

Enclosing structure	Heat transfer resistance of the enclosing structures in accordance with regulatory documents				
	1991–1993 (SNiP II-3-79*. Building heat engineering)	1993 (Order of the Ministry of Construction and Architecture of Ukraine No. 247 of 12/27/1993)	2006 (DBN V.2.6-31:2006 Thermal insulation of the building)	2017 (DBN V.2.6-31:2016 Thermal insulation of the building)	2022 (DBN V.2.6-31:2021 Thermal insulation and energy efficiency of the building)
External wall	1.6	2.2	2.8	3.3	4.0
Attic flooring	2.2	2.7	4.95	4.95	6.0
Basement ceiling	2.2	2.3	3.75	3.75	5.0
Window	0.3	0.5	0.5	0.75	0.9
Outer door	–	–	0.44	0.6	0.7

As can be seen from the Table 1, over the past 30 years, the requirements for the thermal characteristics of building enclosures have increased 2.5 times. Such requirements of regulatory documents contribute to reducing the heat load on the heating system of both new and existing buildings. Thus, recently thermo renovation works have been carried out in existing buildings, aimed at reducing the heat losses of buildings, which lead to a decrease in the needs of heating systems for thermal energy.

In addition, there is a tendency in Ukraine to disconnect both individual consumers and entire facilities from district heating systems. In connection with this, and with high energy prices, heat generating enterprises have significant financial losses and are trying to adapt to the conditions that have developed. One of the possible directions is the transfer of existing heat networks to low-temperature coolants without significant reconstruction of the district heating systems themselves, which does not require significant capital investments.

Reducing the heat load of the district heating system, under certain conditions, makes it possible to reduce the parameters of the coolant with the existing diameters of the heat pipes. As an example, consider a section of the heating network with a diameter $d_{out} \times \delta = 159 \times 4.5$ mm, lay in an impassable concrete channel. At the speed of the coolant v = 0.98 m/c, its consumption in the pipeline is G = 60 t/h (16.66 kg/s).

It was calculated how the amount of heat, kW, which is supplied by this area, will change when the parameters of the coolant are reduced, using the formula:

$$Q = G \cdot c \cdot (t_{1,c} - t_{02,c}), \tag{1}$$

where G is coolant flow rate, kg/s, c is specific heat capacity of water, kJ/(kg K), $t_{1,c}$, $t_{02,c}$ is the temperature of the coolant, respectively, in the supply and return pipelines of the heat network, °C.

At the same time, we will determine how the heat loss from one linear meter of the pipeline will change. The amount of heat loss, W/m, is calculated by the formula:

$$q = k \cdot (t_w - t_a), \tag{2}$$

where t_w is water temperature in the pipeline, ºC. In accordance with DBN B.2.5-39:2008, the estimated temperature of network water in the supply pipeline of heat networks is accepted, as a rule, equal to the temperature of the water at the exit from the heat supply source according to its passport data. In existing systems of district heating systems, this temperature is mostly within the range of 130–150 °C. t_a is ambient temperature, ºC. During channel laying, the ambient temperature is the air temperature in the channel and is assumed, in most cases, to be equal to the soil temperature, i. e. in the range of t_a = -5...+10 °C. It is accepted in the calculation t_a = 0 °C. k is linear heat transfer coefficient, W/(m^2·K).

The results of the calculations are summarized in Table 2

Table 2

A decrease in the capacity of the district heating system depending on the decrease in the temperature of the heat coolant in the pipelines

No.	t_1 / t_{02}, °C	Q, MW	Heat flow, %	Heat loss through the supply pipeline, %
1	150/70	5.58	100	100
2	130/70	4.19	75	86.6
3	115/70	3.14	56	76.7
4	95/70	1.75	31	63.3
5	70/55	1.05	19	46.6

As can be seen from Table 2 the existing level of thermal renovation and the share of disconnections only in some cases lead to a decrease in the load on the heat source more than 50 %, so the possibility of reducing the coolant temperature up to 95 °C and 70 °C (variants 4 and 5) is unlikely. However, with increased coolant speeds up to V = 2.5 m/c, the flow rate will increase to G = 152 t/h (42.2 kg/s), which at temperatures t_1/t_{02} = 70/55 will correspond to the heat capacity Q = 2.65 MW (47 %), which is quite realistic. It should be borne in mind that such a decrease in the parameters of the coolant requires a significant reconstruction of the local heating system.

After that, we will analyze whether the requirements of existing regulatory documents, and, accordingly, the implementation of thermal renovation to comply with them, can contribute to a significant reduction in the heat load of the heat source. Analytical studies were conducted for a 9-storey building, built in Lviv according to a typical project in 1988 with the following geometric characteristics: the area of the house – 603 m^2, perimeter – 114.4 m, the area of external walls – 1920 m^2, windows area – 509.65 m^2, height house – 30 m, volume of the house – 18100 m^3.

The total maximum hourly heat consumption by the dwelling house, W, is determined by the formula:

$$\Sigma Q = Q_{hs\max} + Q_{DHW\max}, \tag{3}$$

where $Q_{hs\max}$ is the maximum heat flow for heating system, W; $Q_{DHW\max}$ is maximum heat flow on domestic hot water system, W.

The maximum heat flow for heating system, W, is determined by the formula:

$$Q_{hs\max} = q_0 \cdot V \cdot a \cdot (t_{in} - t_{out}) + Q_{vent}, \tag{4}$$

where q_0 is the specific thermal characteristic for heating, W/(m^3·K); V is house volume, m^3; a is the coefficient that takes into account the climate zone; t_{in} is the temperature of the inner air in the house, ºC; t_{out} is calculated outside air temperature for heating systems, ºC, for Lviv t_{out} = -19 ºC; Q_{vent} is the thermal flow for heating the inflow ventilation air, which enters the room due to leakage in external fences and when opening windows and doors, W.

The specific thermal characteristic for heating, W/(m^3·K), calculated by Ermolaev's formula:

$$q_0 = 1.08 \cdot \left[\frac{P}{S} \cdot \left(\frac{1}{R_{EW}} + \frac{A_w}{A_w + A_{EW}} \cdot \left(\frac{1}{R_w} - \frac{1}{R_{EW}} \right) \right) + \frac{1}{h} \cdot \left(\frac{0.9}{R_{AF}} + \frac{0.6}{R_{BS}} \right) \right], \tag{5}$$

where P is the house perimeter, m; S is the house area, m^2; A_w is total window area, m^2; A_{EW} is the total area of the surfaces of the house external walls, m^2; H is house height, m; R_{EW}, R_w, R_{AF}, R_{BS} are heat transfer resistances, (m^2·K)/W, respectively for external walls, windows, attic flooring, basement ceiling.

The coefficient that takes into account the climate zone:

$$a = 0.54 + \frac{22}{t_{in} - t_{out}}. \quad (6)$$

The thermal flow for heating the inflow ventilation air, W, is determined by the formula:

$$Q_{vent} = \frac{c_{air}}{3.6} \cdot L_{air} \cdot \rho_{out} \cdot (t_{in} - t_{out}), \quad (7)$$

where c_{air} is specific heat of air, kJ/(kg K); L_{air} is air exchange in the house, m^3/h; ρ_{out} is density of outside air, kg/m^3.

The maximum heat flow on domestic hot water system, W, is determined by the formula:

$$Q_{DHW\max} = 1.163 \cdot q_{hr}^{h} \cdot \rho_t \cdot (t_h - t_C) \cdot (1 + k^t), \quad (8)$$

where q_{hr}^{h} is the maximum hourly consumption of hot water in domestic hot water system, m^3/h; ρ_t is water density, kg/m^3, t_h is the hot water temperature in the tap, ºC; t_C is the cold tap water temperature during the cold period, ºC; k^t is a coefficient that takes into account the heat losses in the pipelines of the domestic hot water system.

It should be noted that the standards for determining the heat flow for heating the inflow ventilation air and the maximum heat flow on domestic hot water system were also changed, were also changed. This was taken into account when calculating the total maximum hourly consumption of heat with a dwelling house. Analytical studies were carried out for the periods specified in Table 1. Their results are presented in Table 3.

Table 3

The results of calculating the total maximum hourly heat consumption of an apartment building for different time periods

Years	1991–1997	1997	2006	2017	2022
q_0, W/(m^3·K)	0.27	0.18	0.16	0.12	0.10
Q_{vent}, W	122990	122990	136922	136922	136922
$Q_{hs\max}$, W	334198	267323	258514	229370	213227
Thermal load decrease on the heating system, %	–	20	23	31	36
$Q_{DHW\max}$, W	302249	302249	302249	278691	278691
Thermal load decrease on the domestic hot water system, %	–	0	0	7.7	7.7
ΣQ, W	636447	569572	560763	508061	491918
The decrease of the total maximum hourly heat consumption, %	–	10	12	20	23

As can be seen from Table 3, by increasing the requirements for the thermal characteristics of the outer shell of the house, the value of the maximum heat flux on the heating system for 30 years decreased by 36 %, and the maximum heat flow on the hot water system due to the change of the calculation method decreased by 7.7 %. As a result, the total maximum hourly heat consumption of the apartment building and accordingly, thermal load on heat generation source has decreased by only 23 %.

According to the known values of total maximum hourly heat consumption we can determine the amount of coolant that is required to cover this heat load. The total calculated water consumption for closed district heating system of a apartment building is determined by the formula:

$$G_d = G_{hs\max} + G_{DHW\max}, \tag{9}$$

where $G_{hs\max}$ is calculated consumption of network water for heating system, t/h; $G_{DHW\max}$ is calculated consumption of network water for domestic hot water system, t/h.

The calculated consumption of network water for heating system, t/h, is determined by the formula:

$$G_{hs\max} = \frac{3.6 Q_{hs\max}}{c\left(\tau_{1,c} - \tau_{02,c}\right)}. \tag{10}$$

The calculated consumption of network water for domestic hot water system, t/h, is determined by the formula:

$$G_{DHW\max} = \frac{3.6 Q_{DHW\max}}{c\left(\tau_1' - \tau_3'\right)}, \tag{11}$$

where c is specific heat capacity of water, kJ/(kg K); $\tau_{1,c}$, $\tau_{02,c}$ is water temperature, respectively, in the supply and return pipelines of the heat network at the calculated outside air temperature t_{out}, °C; τ_1' is the water temperature in the supply pipeline of the heat network at the breaking point of the water temperature graph, °C, is assumed to be 70 °C; τ_3' is the water temperature after the water heater connected in parallel at the break point of the water temperature graph, it is recommended to take 30 °C.

Determination of heat coolant flow rate was carried out for different values of heat loads on the district heating system (Table 3) and their various operating parameters. The calculation results are given in Table 4.

Table 4

The calculated consumption of network water, t/h

Years	$\tau_{1,c}/\tau_{01,c}/\tau_{02,c}$ 150/95/70			$\tau_{1,c}/\tau_{01,c}/\tau_{02,c}$ 115/95/70			$\tau_{1,c}/\tau_{01,c}/\tau_{02,c}$ 95/95/70			$\tau_{1,c}/\tau_{01,c}/\tau_{02,c}$ 70/55/30		
	$G_{hs\max}$	$G_{DHW\max}$	G_d	$G_{hs\max}$	$G_{DHW\max}$	G_d	$G_{hs\max}$	$G_{DHW\max}$	G_d	$G_{hs\max}$	$G_{DHW\max}$	G_d
1991 – 1997	3.59	6.50	**10.09**	6.39	6.50	**12.89**	11.49	6.50	**17.99**	19.16	10.39	**29.55**
1997	2.87	6.50	**9.37**	5.11	6.50	**11.61**	9.19	6.50	**15.69**	15.32	10.39	**25.72**
2006	2.78	6.50	**9.28**	4.94	6.50	**11.44**	8.89	6.50	**15.39**	14.82	10.39	**25.21**
2017	2.47	5.99	**8.46**	4.79	5.99	**10.38**	7.89	5.99	**13.88**	13.15	9.58	**22.73**
2022	2.29	5.99	**8.28**	4.07	5.99	**10.06**	7.33	5.99	**13.32**	12.22	9.58	**21.81**

As can be seen from Table 4, the lower the coolant temperature in the supply and return pipelines of the district heating system, the greater the consumption of network water that should be supplied to consumers for the needs of the heating and domestic hot water systems. For such values of the thermal power of the heat source, a decrease in the temperature parameters of the coolant leads to an increase in the flow of the coolant in the pipelines by almost 3 times. An increase in the amount of heat coolant leads to an increase in the diameters of the heat network pipelines and (or) to an increase in the specific pressure losses and coolant speed in the pipeline.

Pipeline diameters, specific pressure losses, and the speed of movement of the coolant in the pipeline were determined from the reference literature for coolant consumption calculated according to the current norms of 2022. In Table 5 the values of specific pressure losses and coolant velocities for the same pipeline diameter are given.

Table 5

Pipeline diameters, specific pressure losses and the coolant speed in the pipeline

G_{d}, t/h	$\tau_{1,p}$, °C	$d_{out}\times\delta$, mm	R, Pa/m	v, m/s
8.28	150	89×3	40	0.46
10.06	115	89×3	60	0.55
13.32	95	89×3	100	0.72
21.81	70	89×3	250	1.20

As can be seen from the Table 5, when the coolant temperature in the supply pipeline is reduced from 150 °C to 70 °C with the same pipeline diameter, the specific pressure loss increased by more than 5 times, and this leads to an increase in the power of the circulation pumps, and, accordingly, to an increase in the consumption of electrical energy and the cost of these pumps.

Conclusions

1. As the research data showed, the requirements of the existing regulatory documents of Ukraine do not allow district heating system to switch to low-temperature parameters of coolants without reconstruction of heat networks. This makes it impossible at this stage to switch to low-temperature heat carriers of large district heating system, but a gradual transfer to low-temperature heat carriers of certain groups of consumers is possible.

2. Since the heat flow for the needs of heating systems has decreased by 36 % in recent years, and the heat flow for the needs of domestic hot water systems has decreased by only 7.7 %, it is expedient to switch to low-temperature coolants the heat networks that provide heat to the blocks of residential buildings where thermal renovation measures, and hot water needs are provided by instantaneous gas water heaters.

3. In further research, it is expedient to establish which criteria of district heating system can be changed for the possibility of introducing low-temperature parameters of coolants.

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ОЦІНКА МОЖЛИВОСТІ ПЕРЕВЕДЕННЯ СИСТЕМ ЦЕНТРАЛІЗОВАНОГО ТЕПЛОПОСТАЧАННЯ УКРАЇНИ НА НИЗЬКОТЕМПЕРАТУРНІ ТЕПЛОНОСІЇ

Основними причинами активного впровадження централізованих систем теплопостачання у країнах Євросоюзу є підвищення енергетичної незалежності країни та скорочення шкідливих викидів у довкілля. У таких випадках як джерела енергії застосовують відновлювальні джерела енергії. Одним із застережень під час використання відновлювальних джерел як джерела енергії є їх низький температурний потенціал, оскільки це потребує відповідних температурних параметрів теплоносія у системах централізованого теплопостачання. Досліджено можливість переходу систем централізованого теплопостачання України на параметри низькотемпературних систем. Дослідження були проведені для багатоквартирного житлового будинку, побудованого за типовим проєктом у Львові. Як показали дані дослідження, вимоги існуючих нормативних документів України не дозволяють суттєво зменшити теплове навантаження на джерело теплоти. Так, значення максимального теплового потоку на систему опалення зменшилося на 36 %, а максимальний тепловий потік на систему гарячого водопостачання – на 7,7 %, а сумарна максимальна годинна витрата теплоти, відповідно, зменшилася на 23 %. Крім того, у дослідженнях встановлено, що для таких значень теплової потужності джерела теплоти зменшення температурних параметрів теплоносія може призвести до збільшення витрати теплоносія для забезпечення тепловою енергією будинку майже у 3 рази. А це, своєю чергою, за однакового діаметру трубопроводу, призводить до збільшення питомих втрат тиску у понад 5 разів та, відповідно, до збільшення потужності циркуляційних насосів, споживання електричної енергії та собівартості цих насосів. Це означає, що на сьогодні перехід великих систем централізованого теплопостачання України на низькотемпературні теплоносії можливий лише за реконструкції теплових мереж. Можливим є поетапне переведення на низькотемпературні теплоносії окремих груп споживачів, зокрема теплові мережі, які забезпечують теплотою квартали житлової забудови, де проведено термореноваційні заходи, а потреби гарячого водопостачання забезпечуються протічними газовими водонагрівачами.

Ключові слова: система централізованого теплопостачання, відновлювані джерела енергії, низькотемпературний теплоносій, теплова мережа, теплоспоживання, споживання мережевої води.