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8.2 Reduction of investments in heating systems when choosing a low-temperature network schedule as the dominant one

At the current stage of human thought, when society is beginning to realize that there is a problem of growing shortage of natural energy resources, and their prices are rising rapidly and will continue to rise, the introduction of energy-saving heat generation technologies and the use of unconventional and renewable energy sources is becoming not only popular but also a vital solution that directly resonates with the direct threat of global environmental collapse.

Having drawn conclusions from the consequences of energy crises, the governments of most developed countries prepared their economies in advance for existence in the era of scarce oil and gas reserves. For example, according to [344], in Sweden, energy saving issues have been widely implemented since the 1970 oil energy crisis, and in 43 years the country has managed to significantly reduce the dependence of the energy sector on organic and nuclear fuels. Thus, while in 1970 more than 80 % of thermal energy in Sweden was produced from fossil hydrocarbon fuels, by 2012, as a result of the introduction of energy-saving technologies and the transition to non-traditional energy sources, this share had dropped to 32 %. And by 2020, according to the Minister of Energy [344], the combustion of gas, coal and liquid fuels will be completely excluded from the processes of generating heat for municipal needs in the country's heating and hot water supply systems. One of the ways to achieve such results is the large-scale introduction of heat pump technologies and low-temperature heating systems [345 – 347, 349].

A modern low-temperature heating system is special because its heat transfer medium usually heats up to 50 to 55 °C (for example, at a temperature of -22 °C outside the window). But in high-temperature systems, the temperature of the coolant reaches 80 °C.

Low-temperature heating is the basis of heating design in almost all countries. Its evolution can be traced back to 2014, when traditional gas boilers in Europe gave way to condensing boilers, and those, in turn, to air-to-water heat pumps. The latter are capable of generating 3.5 kW of heat from 1 kW of electricity, which is twice as efficient as condensing boilers.

Thanks to low-temperature heating, the house will always have the most comfortable microclimate with minimal energy consumption.

Current trends in the energy market dictate strict energy saving conditions, in particular, the use of low-temperature heating. Condensing technology, which has become widely used in the 21st century, meets these conditions. Since natural gas on average consists of 95% methane, let's consider the process of gas combustion based on methane oxidation:

$$CH_4 + 2O_2 = CO_2 + 2H_2O + \Delta Q$$

During the combustion of natural gas, a certain amount of heat is released with the formation of water vapor, and its condensation makes it possible to use the latent heat of vaporization. In other words, condensing technology is characterized by the use of the higher calorific value of fuel.

The effect of using condensing technology can be most clearly demonstrated using heat balance diagrams of traditional (Fig. 1) and condensing boilers (Fig. 2) [350].

From Fig. 1 and Fig. 2 shows that the use of condensing technology makes it possible to reduce heat losses with flue gases from 17 % to 5 %, i.e. more than three times. The heat balances are given taking into account the heat of water vapor, i.e., the higher heat of combustion. If we use the traditional calculation method, the efficiency of condensing equipment will reach 108 %, and that of traditional boilers – 90 – 93 %. This means that condensing equipment is much more economical than traditional boilers.

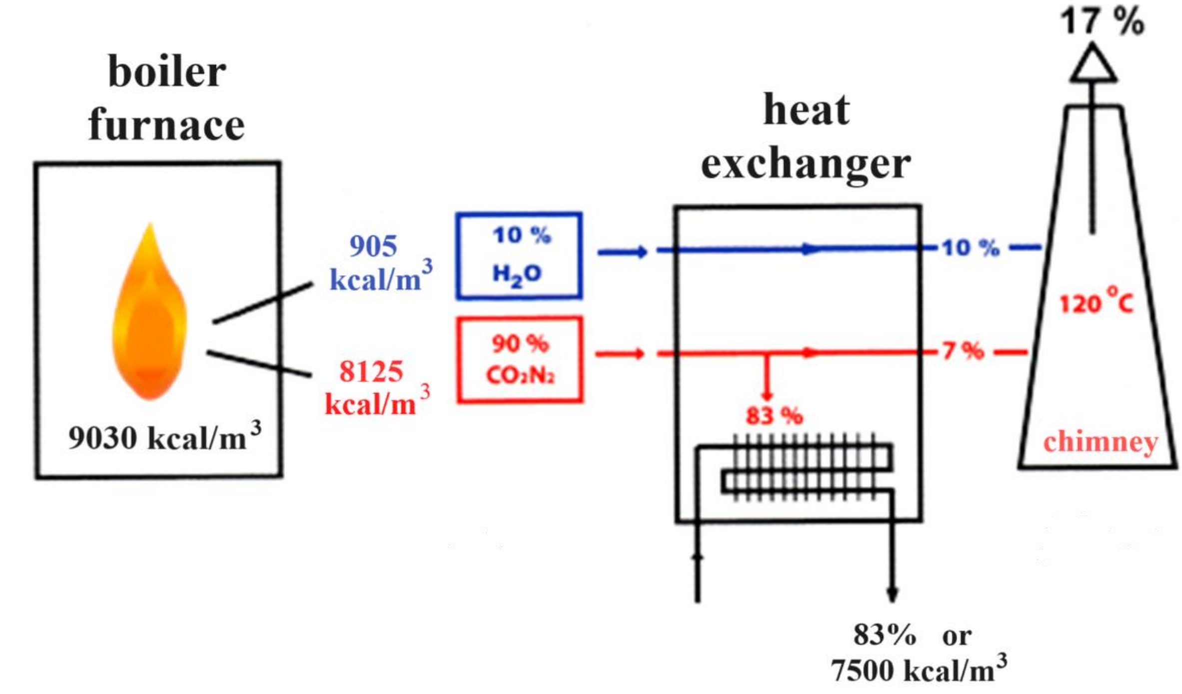

Fig. 1. Heat balance diagram of a traditional boiler

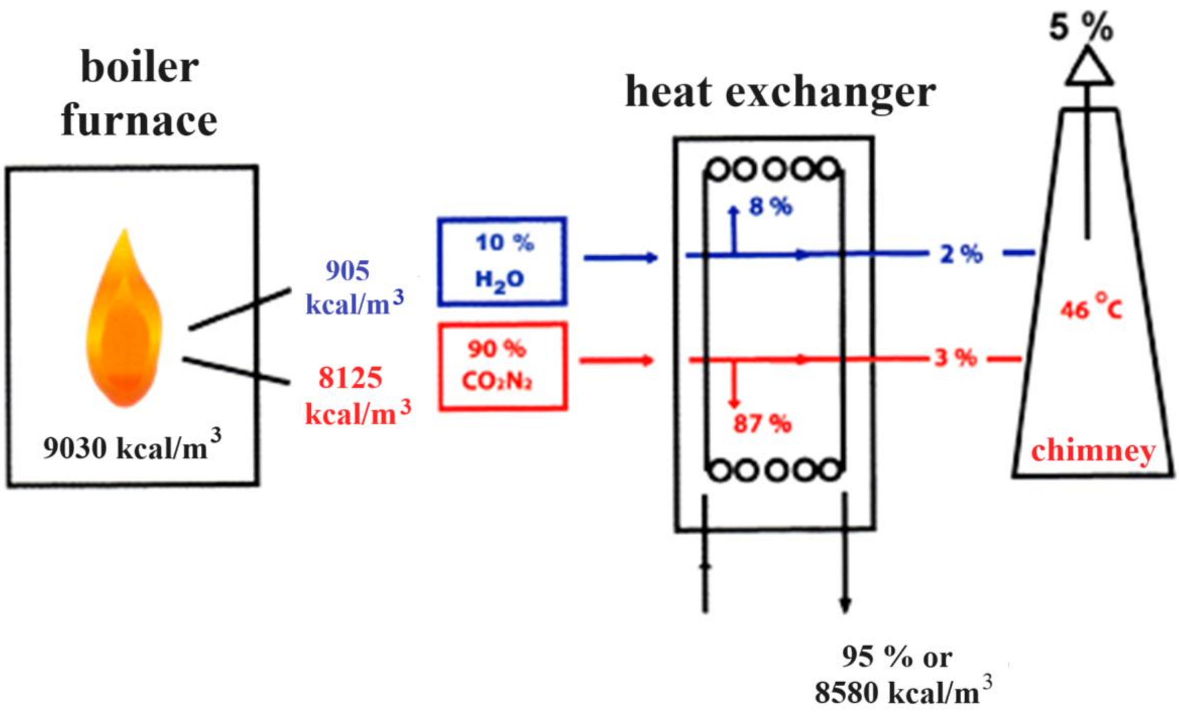

Fig. 2. Heat balance diagram of a condensing boiler

The peculiarity of condensing boilers (Fig. 3) is that they use energy from the condensation of flue gas moisture, which is not used in other types of boilers. Thanks to a special heat exchanger with a large surface area, condensed water vapor gives off its heat to the heating medium of the heating system. This makes it possible to more fully utilize gas energy and reduces harmful emissions, especially nitrogen oxides [347]. The flue gas temperature is below 100°C.

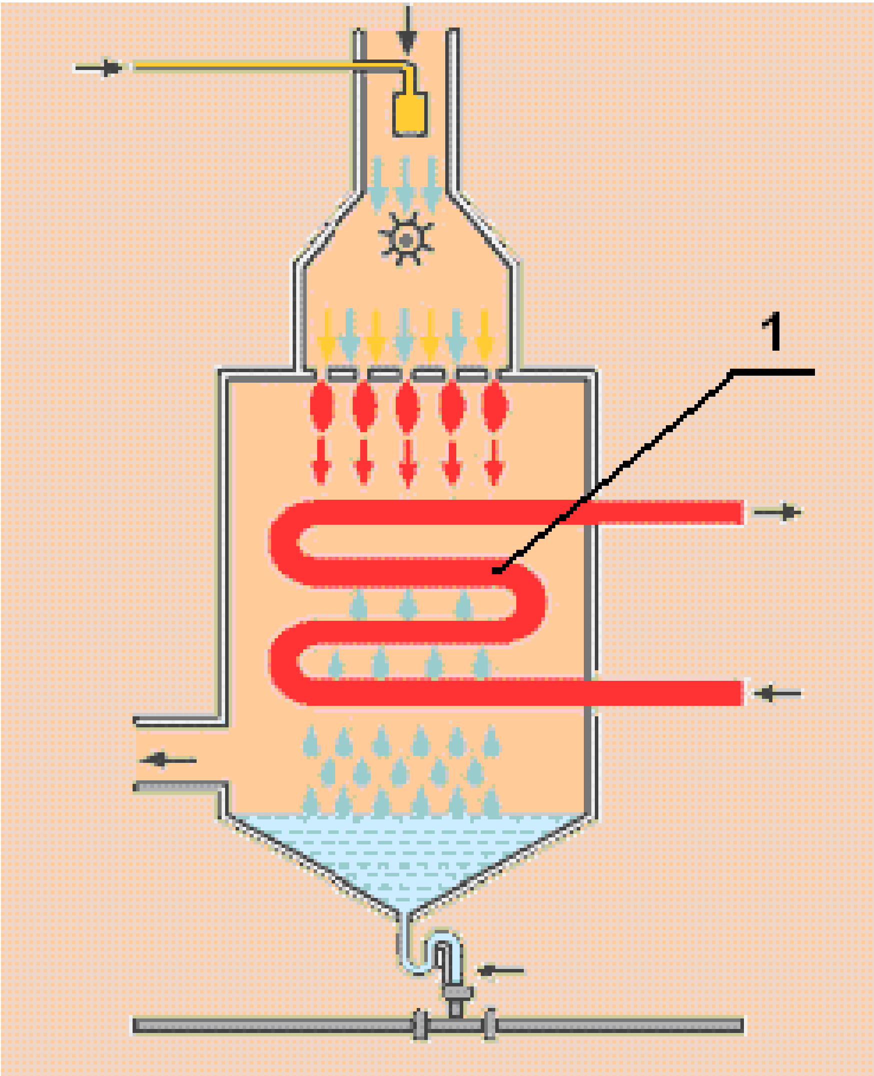

Fig. 3. Scheme of a condensing boiler

Water vapor is condensed using the return water from the heating system. This means that condensation efficiency depends heavily on the return water temperature. The lower it is, the more efficiently the equipment operates. This results in the following advantage of condensing technology: such equipment is perfectly adapted for use in low-temperature heating systems.

Another important advantage of condensing boilers is the low emission of pollutants, primarily nitrogen oxides. This is achieved through the action of two main factors: precise dosing of air in the fuel mixture (which is necessary for efficient condensation) and lowering the temperature in the burner flame core (due to the special design of the burner).

If necessary, condensing boilers can be connected in a cascade - up to 3 or 5 in a cascade, depending on the additional automation used. Such a cascade will operate in a weather-dependent mode. All condensing boilers are equipped with a closed combustion chamber and are connected to a special coaxial chimney.

From the point of view of the technological features of this technique, in order to obtain the desired condensation phenomenon, the heat carrier should have a temperature of approximately 60 °C. It is at this temperature that water vapor condenses on the walls of the primary heat exchanger 1 (Fig. 3), on the side of the exhaust gases [346]. That is, the temperatures of the heating system heat carriers should be as close as possible to the 60/40 °C schedule, provided the air temperature in the heated room is 20 °C. An effective choice of radiators for this system operation mode will make it possible to reduce capital investments when designing heating systems.

In practice, when designing heating systems, the calculation using the «cold five-day» temperature is widely used. Therefore, we will perform such a calculation, which is applicable to all types of existing boilers, but in view of energy efficiency, we will focus on a condensing boiler and a temperature regime of 60/40 °C, as such, at which it operates with maximum efficiency.

Let's take a house with a total area of S = 300 m^2 as an example. The temperature of the «cold five-day period» for the city of Lviv is $t_{outside}$ = –20 °C. The existing SNiP [349] regulates its acceptance equal to -19 °C, but in order to have an additional power reserve of the designed system, the value of -20 °C is used.

The room temperature is assumed to be t_{room} = 20 °C. For a well-insulated wall, the specific heat loss under these conditions will be q = 0.075 kW/m^2 (this value is calculated at an ambient temperature of 20 °C). This is the maximum calculated heat loss of the house to the environment:

$$Q_{\text{house}} = q \cdot S = 0.075 \cdot 300 = 22.5\ \text{kW}. \tag{1}$$

The required boiler capacity, taking into account a 15% margin, will be:

$$Q_{\text{boiler}} = Q_{\text{house}} \cdot 1.15 = 22.5 \cdot 1.15 = 25.9\ \text{kW}. \tag{2}$$

To simplify the calculation, let's assume that n = 18 identical radiators are to be installed. We also assume a 10 % power reserve for each radiator, given the potential use of thermostatic devices [348]. That is, the power of one radiator will be:

$$Q_{\text{rad}} = \frac{Q_{\text{house}} \cdot 1.1}{n} = \frac{22.5 \cdot 1.1}{18} = 1.4\ \text{kW}. \tag{3}$$

Using the Kermi technical data sheet [347] for Profil-X2 radiators, we obtain the following distribution of radiators for different temperature graphs, under the given calculation conditions (Table 1 - the power is listed in brackets according to the passport data).

Table 1.

№	The temperature graph, °C	Power conversion ratio k_{pass}	Radiator size
1	75/55	1.17	K22-600-900 (1.64 kW)
2	60/40	2.03	K22-600-1600 (2.842 kW)
3	50/30	3.7	K22-600-3000 (5.18 kW)

That is, the choice of radiators, applying the conditions for calculating the «cold five-day period» for temperature conditions up to 60/40 °C (at which the maximum efficiency of a condensing boiler is observed), entails an increase in the size of radiators, namely an increase in the capital costs of the designed heating system. So, you need to take into account that the outside air temperature is constantly fluctuating during the heating season. However, when calculating the boiler, this will lead to a lack of heat output and the need to install a peak hot water boiler. Such a scheme is possible when using a main boiler, say, a solid fuel boiler, and a peak boiler, say, a gas boiler. However, this also significantly increases the capital investment, and this calculation aims to reduce it.

The aim of the work is to reduce the capital cost of purchasing radiators when designing heating systems by reducing their size without losing heat output during the «cold five-day period» and optimizing their use at average monthly temperatures on a low-temperature heat transfer schedule.

There is an option to take into account the fluctuating temperature processes of the outside air when calculating the radiators of the heating system, in order to reduce the purchase costs when selecting them for a low-temperature schedule. The main factor in the calculation of a single-boiler system – the «cold five-day period» - is left unchanged and taken from the previous calculation (1), (2), i.e. it should be emphasized that the total heat output of the boiler unit is calculated for a temperature of –20 °C.

Let's dwell on this step: the boiler is matched to the temperature of the «cold five-day period», according to the existing SNiP. This means that its capacity is enough to cover the heat losses of the house. Next, it is proposed to calculate the radiators relative to the average temperature of the coldest month, as the dominant temperature during the heating season, for a temperature schedule of up to 60/40 °C.

The average annual temperature distribution for the city of Lviv is as follows (Table 2) [348]:

Table 2

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Yearly
The average tempe-rature	-4.6	-3.1	1.1	7.7	13.2	16.1	17.3	16.8	13.0	8.0	2.5	-2.1	7.2

That is, the average temperature of the coldest month is t_{average} = -4.6 °C. We propose to introduce a temperature load factor for radiators that will take into account the transition from -20 °C to -4.6 °C as the most likely temperature:

$$k_{\text{rad}} = \frac{(t_{\text{room}} - t_{\text{average}})}{(t_{\text{room}} - t_{\text{outside}})} = \frac{(20-(-4.6))}{(20-(-20))} = 0.62\,. \tag{4}$$

We recalculate the unit power of the radiator under these conditions (we leave the output power from the previous calculation):

$$Q'_{\text{rad}} = Q_{\text{rad}} \cdot k_{\text{rad}} = 1.4 \cdot 0.62 = 0.87\ \text{kW}. \tag{5}$$

For a given power, we get the following distribution of radiators (Table 3).

Table 3

№	The temperature graph, °C	Power conversion ratio k_{pass}	Radiator size
1	60/40	2.03	K22-600-1000 (1.77 kW)
2	50/30	3.7	K22-600-1800 (3.23 kW)

We analyze the data from Table 1 and Table 3:

1. The radiators (Table 3) for the temperature schedule of 60/40 °C and 50/30 °C are smaller in size compared to (Table 1), and this is the schedule we are interested in as the one at which the condensing boiler has the highest efficiency;

2. If the ambient temperature is likely to drop to - 20 °C, the radiators (Table 3) are of sufficient size to fully meet the heat demand during the transition to the 75/55 °C temperature schedule (compared to radiator No. 1 in Table 1).

It should be emphasized that the reduction in the size of the radiators occurred when the temperature load factor of the radiators, which takes into account the transition from -20 °C to -4.6 °C as the most likely temperature, was introduced into the power calculation.

Additionally, we check the correctness of the judgment about heat supply at -20 °C. In order to remove the bindings to specific numbers, we enter the value of the heat loss of the room under the conditions of the «cold five-day period» for which the radiator is selected, Q_{rad}.

Then, for a 75/55°C schedule, the power for which the radiator size is selected will be equal:

$$Q'_{\text{rad}} = Q_{\text{rad}} \cdot k_{\text{pass}} = 1.17 \cdot Q_{\text{rad}} . \tag{6}$$

And for the proposed calculation with a temperature load factor for a temperature of -4.6 °C and a 60/40 °C schedule:

$$Q''_{\text{rad}} = Q_{\text{rad}} \cdot k_{\text{pass}} \cdot k_{\text{rad}} = Q_{\text{rad}} \cdot 2.03 \cdot 0.62 = 1.26 \cdot Q_{\text{rad}}. \tag{7}$$

That is: $Q''_{\text{rad}} / Q'_{\text{rad}} = 1.26 / 1.17 = 1.077$ – a radiator with the power selected according to the proposed calculation, when switching from a 60/40 °C schedule to a 75/55 °C schedule, has a sufficient margin for full heating of the room.

To summarize, it should be added that the price (as of 2023.11.01) of the K22-600-1600 radiator (Table 1) is approximately 330 euros, and the K22-600-1000 (Table 3) is 230 euros. Only one radiator can reduce capital costs by 100 euros.

For the convenience of calculating the power of radiators when using Excel spreadsheets, it is proposed to introduce an additional coefficient that will not only take into account the power conversion factor according to the radiator manufacturer's passport, but also the power coefficient of radiators at the average monthly temperature of the coldest month. For the city of Lviv, with a temperature schedule of 60/40 °C, the coefficient will look like this:

$$k = k_{\text{rad}} \cdot k_{\text{pass}} = 0.62 \cdot 2.03 = 1.26 . \tag{8}$$

Conclusion. The considered methodology makes it possible to reduce capital costs in the design of heating systems in terms of reducing the size of radiators without changing the heat output of the boiler. Under the conditions of the «cold five-day period», the radiators cover the required heat demand during the transition to the 75/55 °C schedule.