# TEHNOEKONOMSKA OPTIMIZACIJA KOMBINOVANIH NISKOTEMPERATURNIH SISTEMA GREJANJA

## TECHNOECONOMIC OPTIMIZATION OF COMBINED LOW TEMPERATURE HEATING SYSTEMS


**Aleksandar GJERASIMOVSKI[1], Maja SHAREVSKA, Natasha GJERASIMOVSKA, Monika SHAREVSKA, Milan ŠAREVSKI**

Faculty of Mechanical Engineering,
Ss. Cyril and Methodius University, Skopje, Republic of Macedonia



*Racionalno korišćenje niskotemperaturne otpadne toplote industrijskih i energetskih sistema i niskotemperaturne toplote geotermalne vode u sistemima grejanja je tehno-ekonomski opravdano, ekološki korisno i dovodi do povećane energetske efikasnosti. Prikazana je metoda uporedne tehno-ekonomske analize niskotemperaturnih sistema grejanja koji koriste industrijsku otpadnu toplotu i/ili geotermalnu vodu, sa sistemima kotlovskog grejanja na tradicionalna fosilna goriva, sistemima grejanja sa toplotnim pumpama i električnim sistemima grejanja. Oblasti njihove prioritetne primene definisane su na osnovu tehnoekonomskih kriterijuma prema cenama niskotemperaturne toplotne energije, energije za grejanje na fosilna goriva, električne energije kao i prema koeficijentu godišnje upotrebe instaliranog grejnog kapaciteta, investicionim troškovima, struktura kombinovanog sistema grejanja i koeficijent performansi toplotnih pumpi. Analizirani su pojedinačni i kombinovani sistemi grejanja. Uvedeni su kombinovani sistemi koji sadrže bazni podsistem niskotemperaturnog grejanja sa malom snagom, velikog kapaciteta (toplotna energija) i vršni podsistem grejanja velike snage, malog kapaciteta (toplotna energija), sa jednim cevnim krugom i odvojenim dvostrukim cevnim krugom i data je uporedna analiza. Karakteristike kombinovanih sistema grejanja sa niskotemperaturnim podsistemom grejanja koji se koriste za proizvodnju energije za pokrivanje osnovnih zahteva za grejanjem i podsistem kotla za proizvodnju energije za najviše potrebe za toplotom razmatraju se i upoređuju pomoću toplifikacionog dijagrama grejanja. Različiti odnosi energije i snage između osnovnog niskotemperaturnog podsistema i vršnog podsistema kotla za različite temperature termalne vode (otpadna topla voda, geotermalna voda) kao niskotemperaturnog izvora toplote prikazani su u dijagramu grejanja. Predložena je optimalna primena podsistema* toplotne pumpe *u kombinovanom sistemu grejanja. Studija pokazuje da se preferiraju niskotemperaturni sistemi grejanja kada je cena niskotemperaturne energije niska i stepen godišnje eksploatacije kapaciteta je visok. Za uslove vlažne kontinentalne klime karakteristične za centralni deo Balkana, identifikovane sa kratkim periodom relativno niskih temperatura naznačenim oštrim vrhom na dijagramu grejanja, procenjuje se koeficijent godišnje eksploatacije kapaciteta i predlažu se optimalni sistemi grejanja.*



***Ključne reči:*** *niskotemperaturni sistemi; grejni sistemi; geotermalna voda; toplinska pumpa; energetska efikasnost*



*Rational use of low temperature waste heat from industrial and energetic systems and low temperature heat of geothermal water in heating systems is techno-economically justified, ecologically beneficial and leads to increased energy efficiency. A method of comparative technoeconomic analysis of low temperature heating systems using industrial waste heat and/or geothermal water heating energy, with boiler heating systems using traditional fossil fuels, heating systems with heat pumps and electrical heating systems is presented. Areas of their priority application are defined based on the technoeconomic criteria according to the prices of the low temperature heat energy, fossil fuel heating energy, electrical energy as well as according to the coefficient of the annual use of the installed heating capacity, investment expenses, structure of the combined heating system and coefficient of performance of the heat pumps. Single and combined heating systems are analyzed. Combined systems which comprise low temperature base heating subsystems with low power, high-capacity (heat energy) and top heating subsystems with high power, low-capacity (heat energy), with*



[1] Corresponding author's email: aleksandar.gerasimovski@mf.edu.mk

*single piping circuit and separate double piping circuit are introduced and a comparative analysis is given. Characteristics of the combined heating systems with low temperature heating subsystem used to produce energy to cover the base heat demands and boiler subsystem for producing energy for the top heat demands are discussed and compared using the heating diagram. Different energy and power ratios between the base low temperature subsystem and peak boiler subsystem for different temperatures of the thermal water (waste hot water, geothermal water) as low temperature heat source are demonstrated in a heating diagram. An optimum application of heat pump subsystem in the combined heating system is proposed. The study shows that low temperature heating systems are preferred when the price of low temperature energy is low and the degree of annual exploitation of the capacity is high. For conditions of humid continental climate characteristic for the central part of the Balkans, identified with short period of relatively low temperatures indicated by a sharp peak in the heating diagram, the coefficient of annual exploitation of the capacity is estimated and optimal heating systems are proposed.*

***Key words:*** *low temperature systems; heating systems; geothermal energy; heat pump; energy efficiency*

## 1 Introduction

Rational exploitation of low temperature waste heat from industrial and energetic systems and low temperature heat of geothermal water in heating systems can be techno-economically justified, ecologically beneficial and leads to increased energy efficiency.

The subject of this paper are the combined low temperature heating systems which comprise low temperature base heating subsystem and top boiler heating subsystem.

Our planet, besides the well-known fossil fuels, also conceals another resource of industrial significance such as geothermal energy. The utilization of geothermal resources, that is, of the Earth's internal heat, is probably as old as mankind itself [1].

Rational utilization of geothermal energy for green house heating is presented in [2]. A method for techno – economic optimization of a district heating system with a heat pump is given in [3]. Optimization of the heat pump system in a greenhouse complex with the utilization of the heat from the geothermal water provides possibilities for rational application of heat pumps and low temperature waste heat for heating [4].

Comparative technoeconomic analysis of low temperature heating systems using industrial waste heat and/or geothermal water heating energy, with boiler heating systems using traditional fossil fuels, electrical heating systems and heating systems with heat pumps is presented. The analysis is obtained in accordance with the technoeconomic criteria for minimal total costs (investment and operation costs).

Areas of different systems priority application are defined based on the technoeconomic criteria according to the prices of the low temperature heat energy, fossil fuel heating energy, electrical energy as well as according to the coefficient of the annual use of the installed heating capacity, investment expenses, structure of the combined heating system and coefficient of performance of the heat pumps. Single and combined heating systems are analyzed. Combined systems which comprise low temperature base heating subsystems with low power, high-capacity (heat energy) and top heating subsystems with high power, low-capacity (heat energy), with single piping circuit and separate double piping circuit are introduced and a comparative analysis is given.

The purpose of this paper is to present an original method for technoeconomic optimization of combined low temperature heating systems and to estimate areas of priority application of the combined systems with single systems (low temperature heating systems, boiler heating systems and heat pumps).

The implementation of the combined low temperature heating systems has positive ecological effects and gives contribution in reducing the pollution of the environment.

## 2 Optimal concept of the combined low temperature heating systems

Energy for heating during the heating season, defined by the heating energy diagram (Fig. 1), depends on the weather conditions. The weather in areas with humid continental climate (central part of the Balkans) is characterized by extremely low outside temperatures in short periods. This characteristic causes the occurrence of sharp peak in the heating energy diagram (close to the design temperature) (Fig. 1) [5].

Observing the heating diagram (Fig. 1 and Fig. 2), we can conclude that with lower power heating system we can cover greater part of the basic heating energy. This means that we can suggest a long-term , expensive system that will produce relatively cheap energy (waste heat energy from industrial process or geothermal water heating energy) to cover the basic heating demands. In combination with this system we can use relatively cheap system that will produce rather expensive energy (boiler subsystem), that will work relatively short period to cover the peak heating demands.

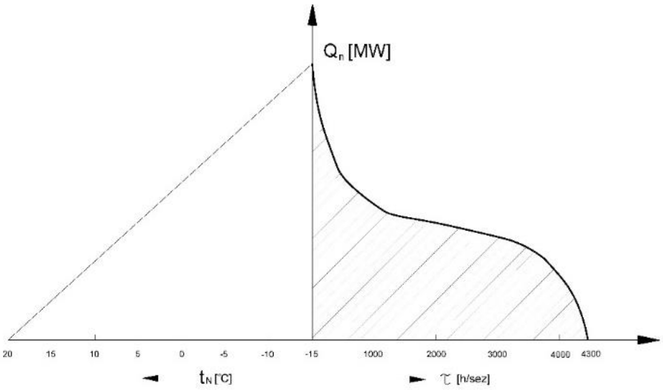


*Figure 1 Diagram for heating energy calculation [5]*

An example for this kind of system is proposed in this paper and it represents a combination of low temperature heating system for basic hating demands and boiler heating system for topping heating demands (Fig 2).

Fitting a low temperature heating system with an existing single pipped boiler room heating system (Fig. 3a) enables individual functioning of the low temperature heating system in conditions of higher outside temperatures, individual functioning of the boiler systems in conditions of lower outside temperatures and combined functioning of both systems as long as the quality of the circulating water is appropriate. From the heating diagram (Fig. 2b) it can be seen that if the surface area of the heat exchangers doesn't increase or the temperature regime (the inlet and outlet temperatures) of the system doesn't decrease respectively, the degree of exploitation of the low temperature system and the obtained heating energy will remain very low.

Double pipped combined heating systems with two flow cirlces – one for the low temparature system and the other for the boiler system (Fig. 2c) enable complete utilization of the low temperature heat. With relatively low heat capacity of the low temperature heating system greater par of the heting needs can be covered (Fig. 2d). As long as the type of the building that is heated allows the construction of these combined systems, the application of double pipped combined heating systems can be very efficient even in case of sufficiently low tempetures of the thermal water. The implementation of heat exchange station (HES) as an intermediate element between the thermal source (TS) and the heat consumer (HC) degrades the low temperature heat, especially in cases of relatively low low tempetures of the thermal water. Plate heat exchangers are suitable for these systems because they provide small temperature difference between the thermal water and the circulating water in the heat exchange station ($\Delta t = t_{tw} - t_{cw}$ = 2 - 5 °C) and they also have compact construction, they are easy to clean and they are corrosion resistant.

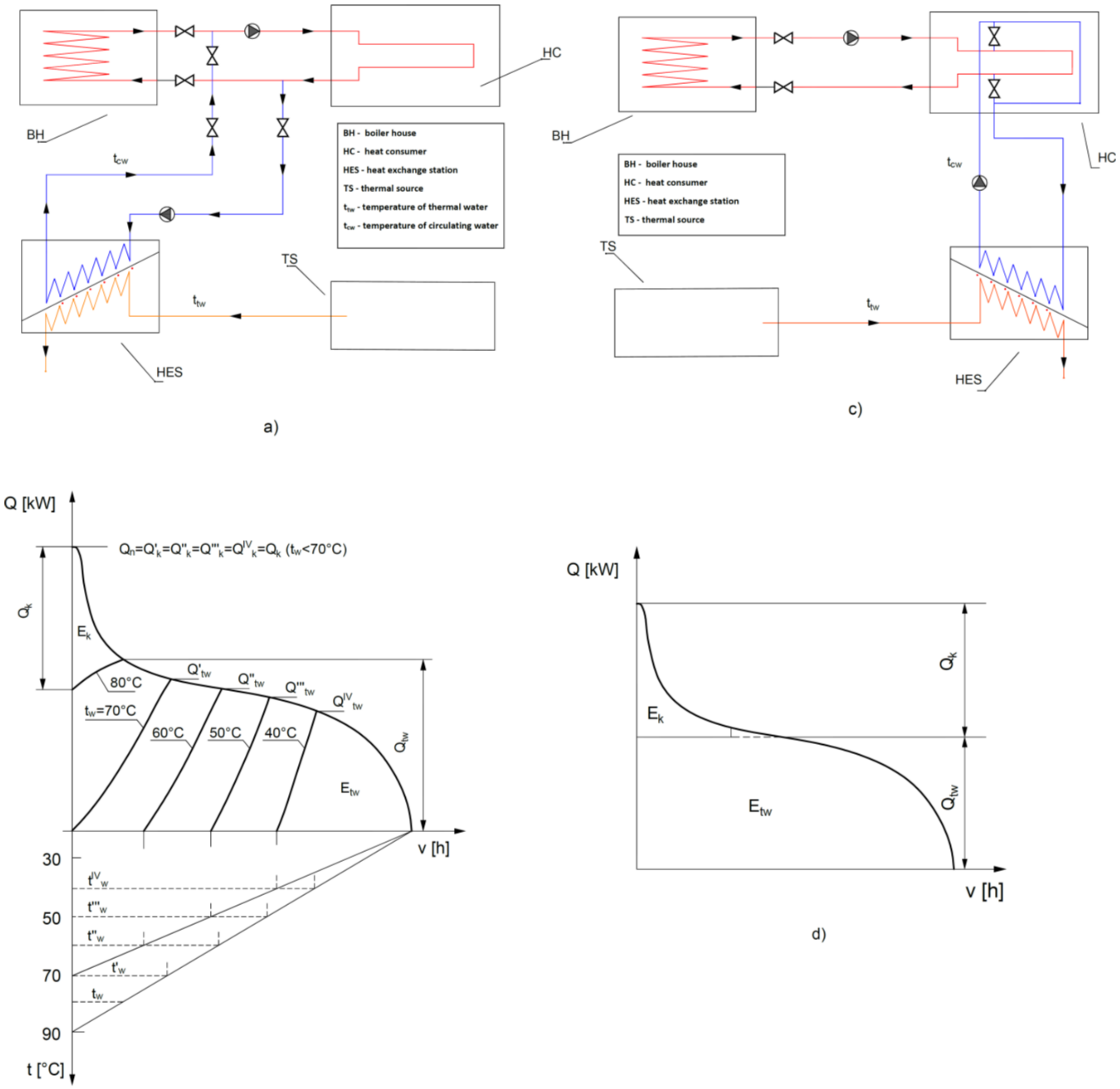


*Figure 2 Combined low temperature heating system with single pipping circuit (a) and heating diagram (b), combined low temperature heating system with double pipping circuit (c) and heating diagram (d)*

## 3 Comparative technoeconomic analysis of the combined low temperature heating systems

Specific overall expenses for heating energy ($Y_{12}$) in \$/kWh for the combined low temperature heating system composed of low temperature heating system for basic hating demands and boiler room system for topping heating demands are calculated using the equation:

$$Y_{12}=\frac{aX_1+(1-a)X_2}{\tau}\cdot\frac{1}{T}+bp_{tw}+(1-b)p_b \quad [\$/\mathrm{kWh}]$$

where:

$a = Q_{tw}/Q_n$ – share of the low temperature heating system capacity in the overall capacity,

$b = E_{tw}/E_n$ - share of the low temperature heating system energy in the overall energy for heating,

$X_1$ (\$/kW year) – specific expense for investment for the low temperature heating system,

$X_2$ (\$/kW year) – specific expense for investment for the boiler room heating system,
$p_{tw}$ (\$/kWh) – specific price of the low temperature heat,
$p_b$ (\$/kWh) – specific price of heat from fossil fuel produced in the boiler room,
T = 8760 [h/year] – number of hours in the year
$\tau$ - coefficient of capacity usage

Specific overall expenses for the low temperature heating system and for the boiler room $Y_1$ and $Y_2$ are calculated respectively:

$$Y_1 = \frac{X_1}{\tau} \cdot \frac{1}{T} + p_{tw} \quad [\$/\text{kWh}]$$

$$Y_2 = \frac{X_2}{\tau} \cdot \frac{1}{T} + p_b \quad [\$/\text{kWh}]$$

By equalizing the overall expenses for heating energy ($Y_{12}$) for the combined low temperature heating system with the specific overall expenses for each of the subsystems $Y_1$ and $Y_2$ we get the curves of equal expenses which define the areas of priority of application for the combined low temperature heating system and its subsystems (Fig.3).

$$Y_{12} = Y_2, \qquad \frac{p_{tw}}{p_b} = 1 - \frac{a}{b} + \frac{X_1 - X_2}{\tau p_b} \cdot \frac{1}{T}$$

$$Y_{12} = Y_1, \qquad \frac{p_{tw}}{p_b} = 1 - \frac{1-a}{1-b} + \frac{X_1 - X_2}{\tau p_b} \cdot \frac{1}{T}$$

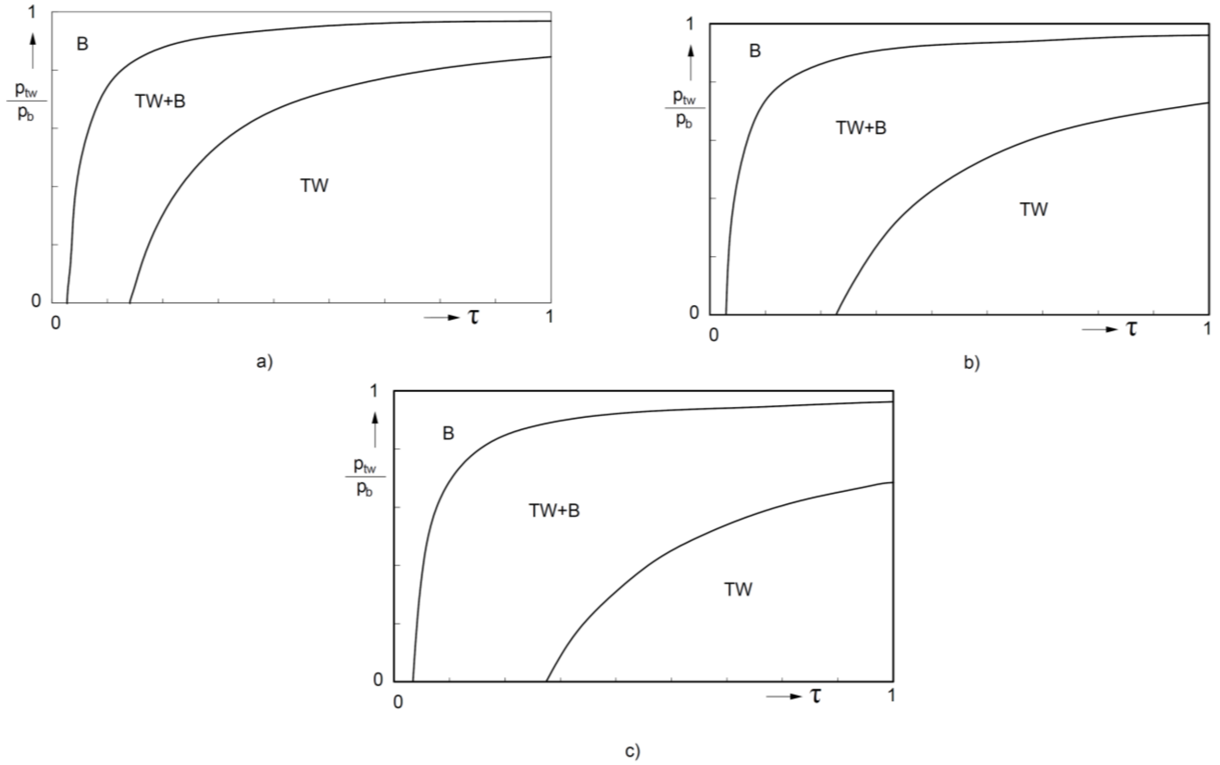


*Figure 3 Priority application for the combined low temperature heating system (TW+B), boiler room system (K) and low temperature heating system (TW)*

Priority application for the combined low temperature heating system with respect to the separate application of its subsystems is defined with:

- the ratio of the specific prices of the low temperature heat and the heat from fossil fuel produced in the boiler room ($c_{tw}/c_b$),
- the coefficient of capacity usage ($\tau$),

- specific expense for investment for the low temperature heating system ($X_1$),
- specific expense for investment for the boiler room ($X_2$),
- share of the low temperature heating system capacity in the overall capacity $a = Q_{tw}/Q_n$ [kW/kW]
- share of the low temperature heating system energy in the overall energy for heating $b = E_{tw}/E_n$ [kWh/kWh]

The diagrams in Fig. 3 are obtained for $X_1$ = 30 ($/kW year) and $X_2$ = 20 ($/kW year) and for:

- a = 0.3 and b = 0.7 Fig. 3a)
- a = 0.4 and b = 0.8 Fig. 3b)
- a = 0.5 and b = 0.9 Fig. 3c)

From the presented results it can be seen that the combined low temperature heating systems have wide area of priority application. The separate use of low temperature heating systems in addition to being limited from a techno-economic aspect, is also limited due to the need for extremely large flows of thermal water to cover the nominal thermal power, which is practically impossible to provide, and if it is provided the thermal source would be fully exploited for an extremely short time, which significantly increases the specific cost of low-temperature heat.

The priority applicability of low temperature heating systems in relation to heat pump heating systems is defined by the ratio of specific prices of low temperature heat and electricity ($c_{tw}/c_e$) and the coefficient of capacity usage of the heating system ($\tau$), specific expense for investment ($X_1$ and $X_2$) and the coefficient of thermo-transformation ($\psi$).

Specific overall expenses for the heat pump heating systems are calculated:

$$Y_3 = \frac{X_3}{\tau} \cdot \frac{1}{T} + \frac{p_e}{\psi} \quad [\$/\text{kWh}]$$

where:

$X_3$ ($/kW year) – specific expense for investment for the heat pump heating system,
$p_e$ ($/kWh) – specific price of electricity,
$\psi$ - coefficient of thermo-transformation or coefficient of performance (COP)

Areas of priority applicability are obtained by equalizing the specific total costs:

$$Y_1 = Y_3, \qquad \frac{p_{tw}}{p_e} = \frac{1}{\psi} + \frac{X_3 - X_1}{\tau p_e} \cdot \frac{1}{T}$$

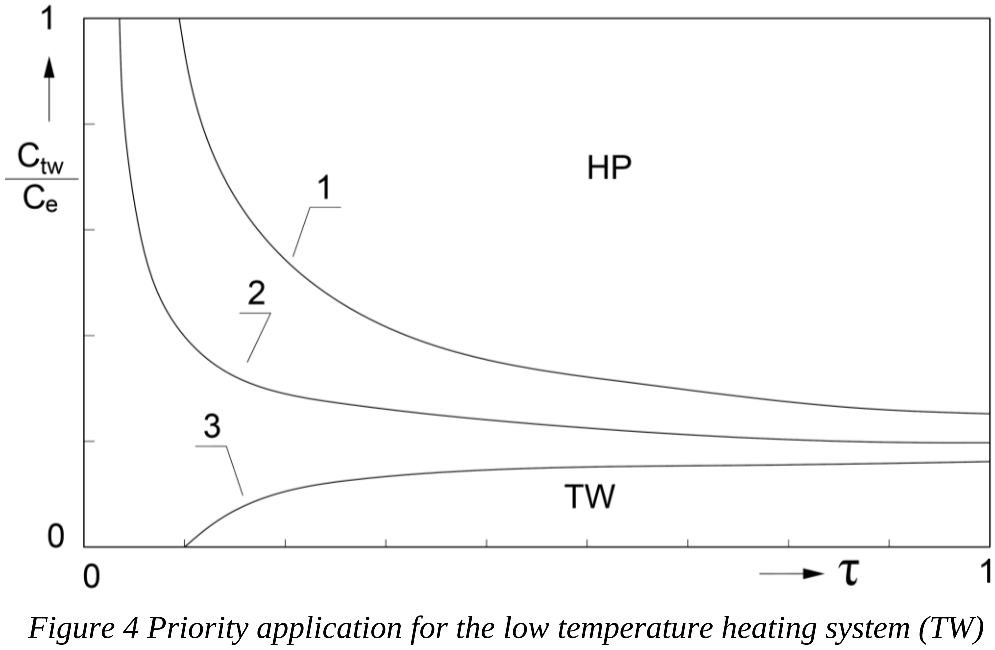


*Figure 4 Priority application for the low temperature heating system (TW) and heat pump heating systems (HP)*

In Fig. 4 curves for equal expenses which define the areas of priority of application of low temperature heating systems (TW) and heat pump heating systems (HP) are presented. The curves are obtained for X3 = 65 ($/kW year), $\psi$ = 5 and the following data for the investment expenses for the low temperature heating system and the temperature regime (inlet/outlet temperatures):

- X1 = 30 ($/kW year); tw1/tw2 = 65/45 °C - curve 1
- X1 = 50 ($/kW year); tw1/tw2 = 55/35 °C - curve 2
- X1 = 70 ($/kW year); $t_{w1}/t_{w2}$ = 45/30 °C - curve 3

From the presented results it can be seen that low temperature heating systems have priority applicability at low specific cost of low temperature heat. By lowering the temperature of the thermal water, the area of priority applicability is narrowed. For thermal water temperatures below 40 °C the application of the heat pump in the heating system for transforming the low temperature heat to a higher temperature level becomes a priority in a relatively wide area.

## 4 Conclusions

A method of comparative techno-economic analysis of low temperature heating systems, heating systems with fossil fuel boiler room and heating systems with heat pump is presented. Combined heating systems consisting of a low temperature heating system in the base and a boiler room heating system for peak heat demands have a relatively wide range of priority applicability. Considering the specifics of our climatic area, it results that with a relatively small capacity of the low-temperature heating system, a large part of the required thermal energy for heating of the building is covered. The separate application of a low temperature system in classical heating facilities is usually unjustified because the capacity equivalent to the nominal capacity would be used in a short time, and the thermal water flows are extremely large. These disadvantages are avoided by optimally designing low-temperature heating systems. At relatively low temperatures of the thermal water, it is expedient to apply a heat pump with which a heat transformation at a higher temperature level of the low-temperature heat is performed.

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