

# Evaluation of Efficiency CHP Systems for Heat Production

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**Keywords:** Cogeneration, efficiency, CHP, renewable, cogeneration, heat, production

**Abstract:** This paper analyses practical exploitation of cogeneration unit in heat production. The main idea of using combined heat and energy production is to reduce usage of primary fuels. By integration of renewable energy sources, reduced usage of traditional primary fuels and with regard to the natural environment reduction of pollutions. Presented work is analysis of CHP system producing heat and comparison to conventional systems.

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## 1 Introduction

The production of heat and electricity can be carried by many different ways. For example, the heat will be produced in boiler and electricity will be produced in a thermal power plant. Production of this type is said to be separate. The effectiveness of separate production depends on many factors such as used technology, type of fuel and many others. For heat generation, there are technologies that allow production of electricity on the same equipment at the same time by combustion natural gas in combustion engine. This type of production is called combined production of heat and electricity (CHP). The Council of the European Union started promoting the CHP concept in 1974 [9]. Integration of renewable energy and cogeneration systems for heat and electric energy are becoming very important for future energy production. Main idea of installing cogeneration unit and renewable energy sources is to reduce primary energy prices, decreasing pollutions and increasing efficiency integration into the energy production. A combined heat and power (CHP) system is proposed to minimize the production cost and to maximize the revenue from power.

CHP is considered a sustainable and economic technology to fulfill those abovementioned goals for its significant performance in primary fuel consumption reduction, pollutions reduction and independency on fossil fuel.

## 2 Combined heat and power

A combined heat and power (CHP) system is proposed to minimize the production cost and to maximize the revenue from power. Combined heat and power is technology which simultaneously produces heat and power by recovering heat that would otherwise be wasted in conventional condensing generation of electric power. For small scale CHP units is under consideration to replace conventional boilers in home installations with the production of electricity simultaneously with the generation of heat give an economic benefit for the consumer. Also, the fossil fuel consumption and CO<sub>2</sub> emissions are effectively lowered. The thermal and electrical efficiency depend on the operating hours, unit capacity and installed type of technology. The economic benefits of CHP systems depend on the specific conditions under different operation strategies. When all the thermal energy of a CHP system can be utilized, it can reach much higher efficiency than conventional separate heat and power production.

The average efficiency of fossil-fueled power plants in the Europe is around 36%. The EU Directive requires that the overall efficiency of CHP plant is at least around 75% or at least 80%, depending on the type of cogeneration unit. The types of units are referred to in the directive mentioned. The last applicable EU Directive that deals with cogeneration, as well as all other directives, gives the opportunity to harmonize national energy policies with each country's own plans for development of the energy sector. [9][2]

### 3 Cogeneration unit efficiency

This paper analyses practical exploitation of cogeneration unit in heat production. Paper is focused on describing the installed natural gas cogeneration unit operating on the diesel principle generating electricity and heat. This cogeneration system has been designed optimally according to economic and energy requirements with respect to environmental criteria and is automatically managed by computer controlled systems and by the current energy needs. The main idea for installing a cogeneration unit is to reduce energy costs, reduce pollution and increase efficiency by integrating renewable energy sources, such as biogas and cogeneration. Several existing installed systems have shown that there is excess heat in summer and therefore accumulation is needed. Average fuel consumption in year 2017 is around 81500 m<sup>3</sup> of natural gas.

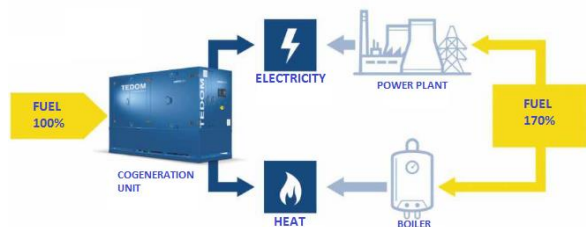


Figure 1 Combined heat and electricity fuel consumption compared to conventional production [10]

For comparison it is necessary to decompose a real plant into two virtual parts: combined heat production (CHP - Cogeneration) and non-combined (conventional). To optimize produced energy between combined and conventional production it is necessary to use around 70% more primary fuel to settle same amount of produced electricity and heat in both systems.

	January	February	March	April	May	June	July	August	September	October	November	December	Average
HEAT	379,40	368,10	410,70	330,00	367,20	347,70	320,00	331,20	322,10	322,30	426,80	400,20	360,48
ELECTRICITY	341,40	327,60	367,90	290,30	324,57	305,30	278,60	288,60	281,10	281,50	369,40	348,30	317,05
FUEL	87 454	83 683	93 699	73 590	82 670	78 105	71 831	74 559	72 801	73 623	95 883	90 598	81 541,33
CALORIFIC VALUE	10,738	10,726	10,749	10,795	10,781	10,795	10,795	10,760	10,778	10,738	10,727	10,748	10,76

Table 1 Produced heat and electricity, consumed fuel and calorific value 2017

Described cogeneration unit heat production efficiency is around 44%. To the quantity of consumed fuel, we add calorific value which is around 10,761kWh.m<sup>-3</sup> and we get theoretical energy included in that amount of fuel.

	January	February	March	April	May	June	July	August	September	October	November	December	Average
HEAT	379,40	368,10	410,70	330,00	367,20	347,70	320,00	331,20	322,10	322,30	426,80	400,20	360,48
FUEL	87 454	83 683	93 699	73 590	82 670	78 105	71 831	74 559	72 801	73 623	95 883	90 598	81 541,33
%	0,4338	0,4399	0,4383	0,4484	0,4442	0,4452	0,4455	0,4442	0,4424	0,4378	0,4451	0,4417	0,44

Table 2 Efficiency of produced heat in 2017

By summing each electric energy and heat energy and dividing it by theoretical energy included in fuel we get % effectivity of cogeneration unit which value is around 86%.

Graphics values show that cogeneration unit in summer season is very ineffective. In winter season efficiency of cogeneration unit is around 82 to 87%. From the point of view of the generation of heat, for the final customer the advantage of the central heat supply compared to other forms are relatively low prices for heat in connection with the increase of the usage cogeneration. Monitored value of produced heat is shown in figure 2. Total average effectivity of monitored cogeneration unit is around 86%. Priority on the production of cogeneration unit is in thermal energy as shown in the figures. Overall power of cogeneration unit was not recorded at this point, the only recorded values are shown at figures.

The theoretical and measured values lead to knowledge which you can read above that allows understanding the cogeneration unit effectivity and describes the effectivity. The largest differences in percentage are in produced energy is in heat from cooling fuel. Average electricity efficiency in 2017 is around 38,8 %. Compared to steam backpressure turbine which efficiency is around 10-30 %, Steam turbine condensing with vapour collection 30-35 %, combustion turbine 20-40 %.

Since natural gas is the dominant fuel for the production of heat, greater emphasis need to be placed on combined energy production methods and directly connected to cogeneration and electricity production.

As shown in Table, there is a direct correlation between the generated electricity and the heat in combined heat and energy production. Figures confirm problems with non-economical usage of cogeneration unit and shows that whole system is ineffective in summer season.

Performance of cogeneration unit in summer season is limited by operating hours while cogeneration unit mode of operation is with priority on the production of thermal energy. In the winter season cogeneration unit is operating 24hours daily, during the summer season is in operation 18-19hours.

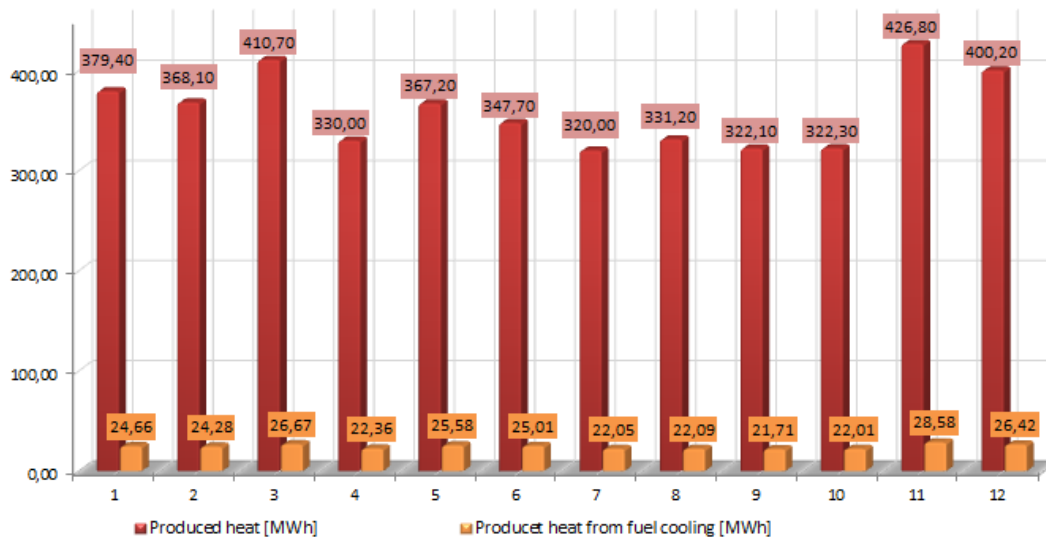


Figure 2 Produced Heat in 2017 [MWh]

Described cogeneration unit heats and prepares hot water for about 1600 apartments, elementary school, maternity school and shopping centres. Cogeneration unit itself consists of gas combustion engine MWM/TCG 2016 V12C with generator which provides 600kW of electrical rated power and 652kW of thermal nominal power as shown on figure 4 and figure 3.

#### 4 Conclusions

Compared to conventional thermal energy and electric energy production cogeneration is effective but there are still many others systems that could be more effectively.

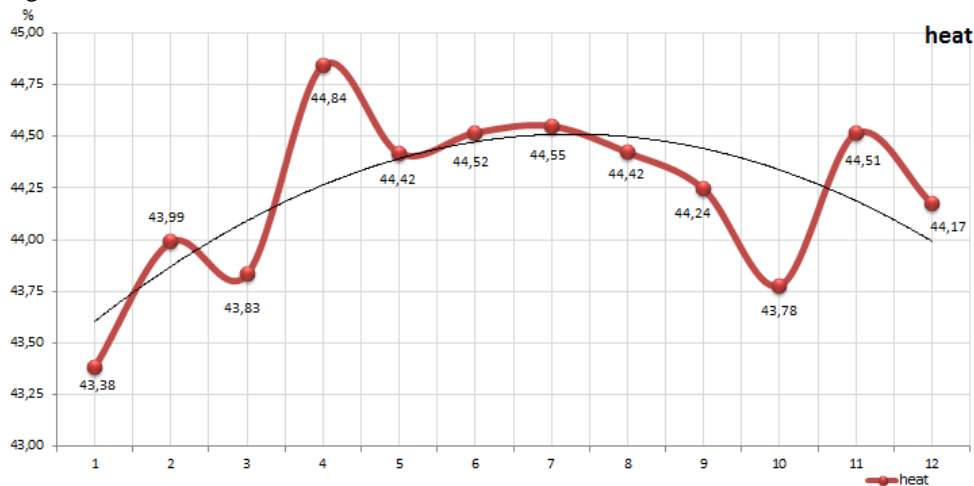


Figure 3 Heat produced in 2017 [% efficiency]

Due to the distribution of heat and electricity production where fossil fuels are predominantly used, it would be better to eliminate the use of this type of fuel.



Figure 3 Container with cogeneration unit

Cogeneration itself permits a new approach to the production of heat and electricity in the industrial sphere, where heat and electricity can be used to heat office and production areas and to engage in industrial production. An important role in this case is the appropriate annual distribution of heat and electricity demand which is negative in the overall economic balance of cogeneration units. Therefore, this technology is not yet fully implementable in decentralized systems.

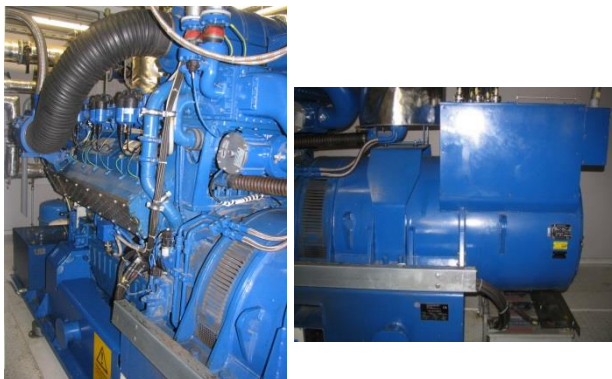


Figure 4 Cogeneration unit engine with asynchronous generator

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# Performance of Adsorptive Heat Energy Converters for Heat Supply Systems

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**Keywords :** adsorptive heat energy conversion, adsorptive heat energy storage, composite adsorbent, energy saving.

**Abstract :** This paper is devoted to performance of adsorptive heat energy converters for heat supply systems. The following calculation procedure of operating characteristics of an adsorption heat energy storage device for a decentralized space heating system is suggested: calculation of the mass transfer coefficient, adsorption amount, useful heat of adsorption, determination of the heat input, it being calculated as heat inputs for heating the adsorbent, device housing, water in the tank, evaporation of water in the tank, heating of the adsorbed water and desorption. Then coefficient of efficiency is calculated. The optimal operating conditions of the heat accumulating device which allow to operate with maximal efficiency coefficients 53 – 57 % are stated to be vapor-air flow rate 0.6 - 0.8 m/s and relative humidity of 40 – 60 %. Correlation between efficiency coefficients deduced from experiments and calculated with suggested algorithm is confirmed by the results of field trials.

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## 1 Introduction

Unrestrained growth of world prices for organic fuel and rates of energy carriers stipulates commercialization of alternative energy sources in heat supply systems. Predominantly, heat energy storage in modern heat supply systems is based on thermal capacitive materials. More promising are phase-change heat storage devices. However, the obstacles for their wide introduction are their high corrosion activity and strict requirements to potential of thermal energy during regeneration. At that time adsorbing materials are considered as promising for the absorption, accumulation and conversion of heat energy [1, 2]. Adsorptive heat storage devices combine the storage of thermal energy on the basis of reverse adsorption – desorption processes with thermal capacitive and phase-

transition mechanism. Nevertheless, units based on traditional adsorbents such as zeolites and silica gel are substantially limited in terms of temperature range and energy storage density.

Moreover, the algorithms of calculations of heat supply systems with heat accumulators are mainly based on thermal capacitive devices [3]. Simulation of adsorptive heat storage devices is limited with adsorption or desorption stages [4, 5]. Therefore, the task of developing an algorithm for calculating adsorption heat-storage devices becomes of crucial importance.

## 2 Problem description

Performance estimation of heat storage devices and the choice of their optimal design and operating parameters supposes carrying out multifactor experiments of heat



and mass transfer in these environments, which results in large material costs. So, the development of an algorithm for computing the operating characteristics of adsorption heat storage devices is task of primary importance. According to [6], a system of differential equations that describe the internal diffusion kinetics of adsorption in the almost instantaneous establishment of equilibrium between the concentration of adsorbate in the gas that fills the pores and its concentration in the adsorbed state includes:

1. material balance equation:

$$\frac{\partial a}{\partial t} + \frac{\partial c}{\partial t} = \frac{1}{\eta^K} \frac{\partial}{\partial \eta} \left( D \cdot \eta^K \frac{\partial c}{\partial \eta} \right);$$

2. adsorption isotherm equation:  $a = f(c)$ ;

3. initial data:  $a(\eta, 0) = c(\eta, 0) = 0$ ;

4. boundary data:  $c(R, t) = c_0, \left[ \eta^K \cdot \frac{\partial c}{\partial \eta} \right]_{\eta \rightarrow 0} = 0$ .

where  $a$  and  $c$  are the concentration of adsorbate in the mobile and stationary phases.  $\eta$  equals  $x$  at the grain shape parameter  $K = 0$  for a prismatic or cylindrical grain of length  $2R$ , the lateral surfaces of which are impermeable (plate);  $\eta = r$  corresponds to radial coordinate for cylindrical grain with impermeable ends ( $K = 1$ ) or spherical grain ( $K = 2$ );  $t$  is the time;  $D$  is the effective diffusion coefficient. Saturation occurs from the outer surface of the granule, where a constant concentration is maintained. The grains are assumed not to contain any amount of adsorbate at the initial instant of time, and the diffusion coefficient  $D$  is supposed to be constant.

The construction of an adsorptive heat storage device of a closed type is given on Fig. 1. The closed-

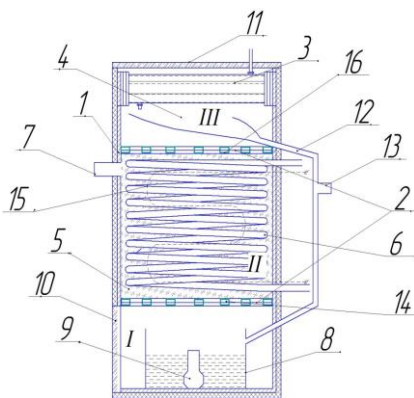


Figure1 Design of the closed-type absorption heat storage device

1 – heat-insulated case; 2 – mesh partitions; 3 – the condenser; 4 – a plate for collecting condensate; 5 – adsorption-desorption reactor; 6 – a coil pipe; 7 – a branch

pipe; 8 – a tank of water; 9 – evaporator; 10, 11 – covers; 12 – a tube; 13 – a branch pipe; 14 – steel blinds; 15 – resistive heating element; 16 – steel blinds

type adsorptive heat storage device is operated in 4 stages. At the first stage, the adsorbent (heat-storage material) is heated from the ambient temperature to the temperature of the beginning of adsorption. At the second stage adsorption of water vapor occurs. On the third, the composite material is heated to the regeneration temperature and the desorption of water proceeds. And on the fourth, the composite material is cooled to the temperature of the beginning of adsorption.

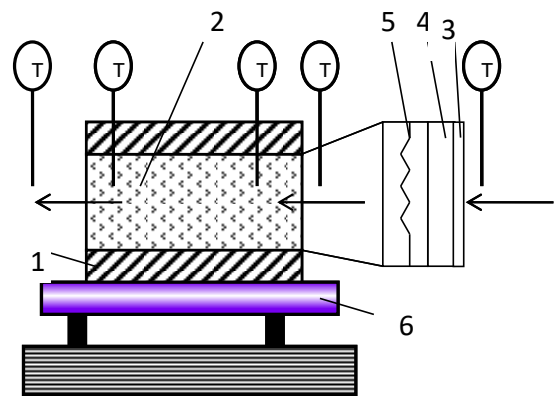


Figure2 Test heat storage apparatus

1 – thermal insulated casing; 2 – heat storage material; 3 – compressor; 4 – air humidifier; 5 – resistance element; 6 – weighing-machine

Construction of open-type heat storage device is shown in Fig. 2 [7]. The heat storage device is operated into two steps. The first step includes external air fanning by compressor 3 into humidifier 4 where its relative degree of humidity is increased to 60 – 80 %, heating of the humidified air by resistance element 5 to 30 – 40°C because of low rates of adsorption at lower temperatures. Then humidified air is directed into adsorbent. After its short-term warming (15 min.) adsorption of water from air passed through heat storage material occurs. Temperature increasing of both heat storage material and air is resulted from exothermic adsorption processes. As a consequence, temperature of the outlet air is increased upto 90 – 115 °C. On the second step (regeneration) hot air pumped through adsorbent layer to warm up sorbent up to temperatures above 90°C up, and desorption occurs.

As heat storage media the composite adsorbents ‘silica gel – sodium sulphate’ synthesized from tetraethoxysilane,  $\text{Na}_2\text{SO}_4$ , ethanol (as a solvent), hydrochloric acid (as a catalyst) and polyionenes served as organic modifiers [7].

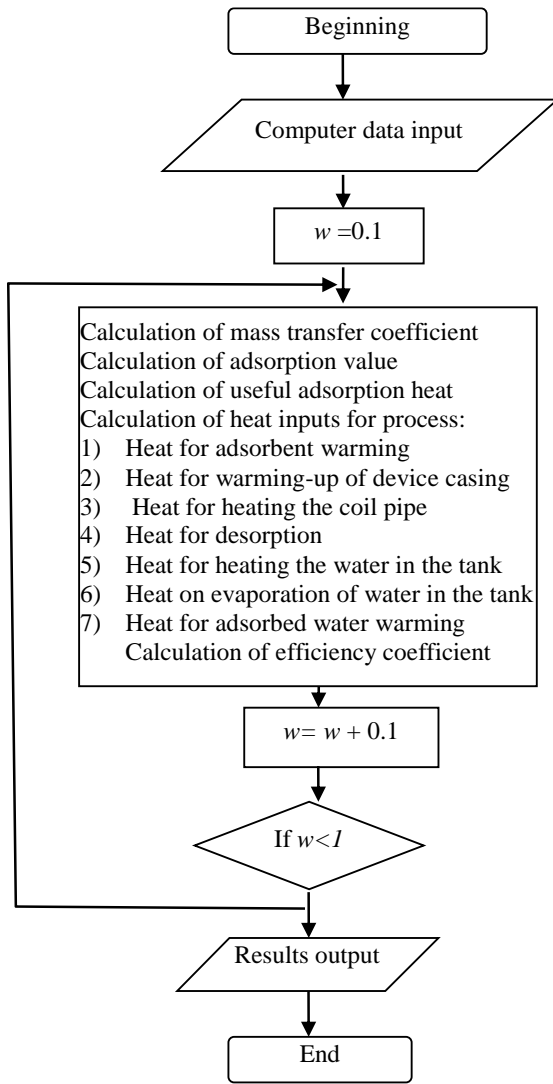


Figure3 Control-flow chart for calculation of efficiency factor of closed-type heat storage device .

It is necessary to choose operational parameters, at which the efficiency of the thermal battery is the maximum. The control-flow charts of the algorithm for calculating the efficiency of a thermal battery are given in Fig 3 and 4. The efficiency coefficient  $\eta$  was calculated as, %:

$$\eta = \frac{Q_u}{Q_{in}} \cdot 100 \quad (1)$$

where  $Q_u$  is useful heat (adsorption heat), kJ:

$$Q_u = M_{ads} \cdot \Delta H_{ads}, \quad (2)$$

where  $M_{ads}$  is adsorbent mass, kg;  $\Delta H_{ads}$  is adsorption heat, kJ/kg,  $Q_{in}$  is heat input for close-type heat storage device, kJ:

$$Q_{in} = Q_{des} + Q_{ads}^h + Q_{cas}^h + Q_{cp}^h + Q_w^h + Q_{s.w.}^h + Q_w^{ev} \quad (3)$$

where  $Q_{des}$ ,  $Q_{sorb}^h$ ,  $Q_{cas}^h$ ,  $Q_{cp}^h$ ,  $Q_w^h$ ,  $Q_{s.w.}^h$ ,  $Q_w^{ev}$  are heat inputs for desorption, heating of adsorbent, device casing, coil pipe, water in the evaporator, adsorbed water, water evaporation, kJ.

For open-type heat storage heat input is calculated as:

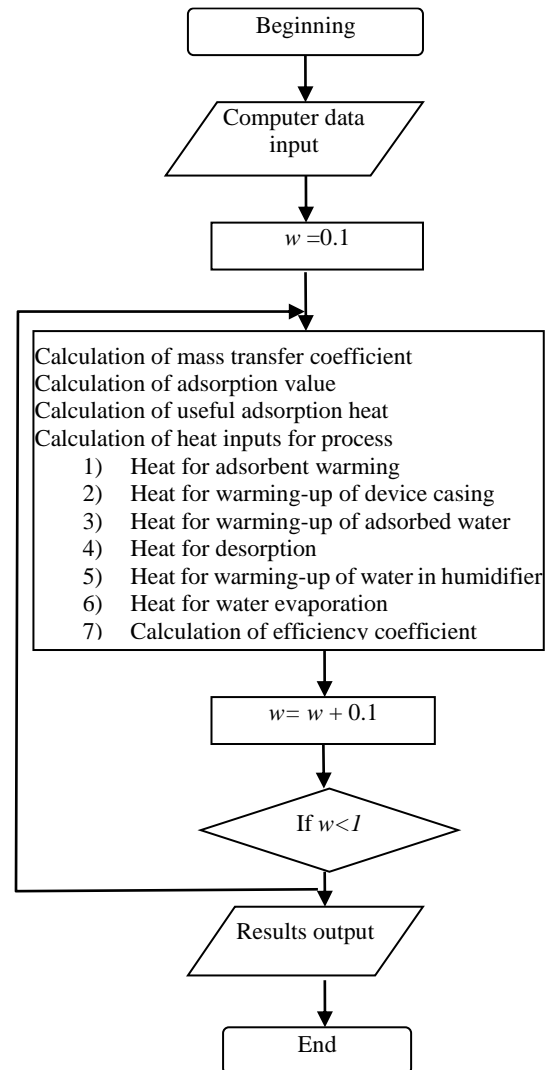


Figure 4 Control-flow chart for calculation of efficiency factor of open-type heat storage device.

$$Q_{in} = Q_{des} + Q_{ads}^h + Q_{cas}^h + Q_w^h + Q_{s.w.}^h + Q_w^{ev} \quad (4)$$

where  $Q_{des}$ ,  $Q_{ads}^h$ ,  $Q_{cas}^h$ ,  $Q_w^h$ ,  $Q_{s.w.}^h$ ,  $Q_w^{ev}$  are heat inputs for desorption, heating of adsorbent, device casing, water in the humidifier, adsorbed water, water evaporation, kJ.

Heat inputs for warming of materials and device components are calculated by conventional formula:

$$Q = M \cdot C \cdot \Delta t \quad (5)$$

The influence of air-vapor flow rate on efficiency coefficient is taken into account by adsorption value  $A$ , kg/kg. This factor is used when heat input for desorption  $Q_{des}$  and adsorbed water  $Q_{s.w.}^h$  warming calculated:

$$Q_{des} = \dot{M}_{ads} \cdot \Delta H_{des} \quad (6)$$

$$Q_{s.w.}^h = M_{ads} \cdot A \cdot C_w \cdot (t_{reg} - t_{env.}) \quad (7)$$

where  $\Delta H_{des} = 2850$  kJ/kg is heat of desorption,  $M_{ads}$  is mass of adsorbent, kg,  $C_w$  is specific heat of water, kJ/kg·K,  $t_{reg}$  and  $t_{env.}$  are temperatures of regeneration and environment, °C.

Adsorption value is computed by formula:

$$A = \frac{C_0 - C}{M_{ads}} \cdot V_{air} \quad (8)$$

where  $V_{air}$  is air volume:  $V_{air} = F_{hs} \cdot w \cdot \tau$ , m<sup>3</sup>;  $F_{hs}$  is cross-section area of heat storage device, m<sup>2</sup>,  $w$  is air-vapor flow rate, m/s,  $\tau$  is sorption time, s,  $C_0$  and  $C$  are inlet and outlet concentration of air-vapor flow, kg/m<sup>3</sup> [8]:

$$C = \frac{C_0}{e^{\frac{\beta \cdot (-\tau \cdot w \cdot C_0) + H}{A_{max} \cdot w}} + 1}, \quad (9)$$

where  $H$  is heat storage device height, m,  $A_{max}$  is adsorption capacity of adsorbent, kg/kg;  $\beta$  is mass transfer coefficient, s<sup>-1</sup>, calculated according to [130]:

$$\frac{1}{\beta} = \frac{1}{\beta_y} + \frac{1}{\beta_p} + \frac{1}{\beta_{c.s.}} \quad (10)$$

where  $\beta_y$ ,  $\beta_p$  and  $\beta_{c.s.}$  are mass transfer coefficients for gas phase, pores and coplanar stirring, s<sup>-1</sup> [9]. According to results of calculations adsorption rate is limited with rate of diffusion in pores, that being confirmed by kinetic study of water vapor sorption [7, 10].

### 3 Results and discussion

The calculation was carried out using the algorithm proposed.

As a result of simulation, the dependence of the adsorption value on the velocity of the steam-air flow at a temperature of 60°C with a relative humidity of 40, 50 and 60% was determined (Fig. 5).

Efficiency-coefficient vs. vapor-air-flow rate relationships calculated according to Eq. (1) – (9) are given on Fig. 5 when composite adsorbent ‘silica gel – sodium sulphate’ used.

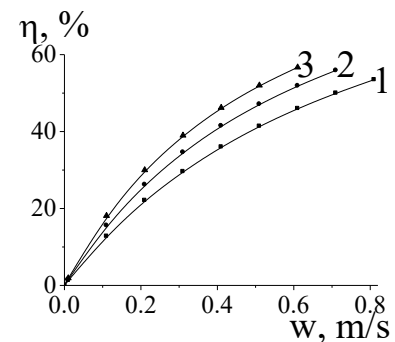
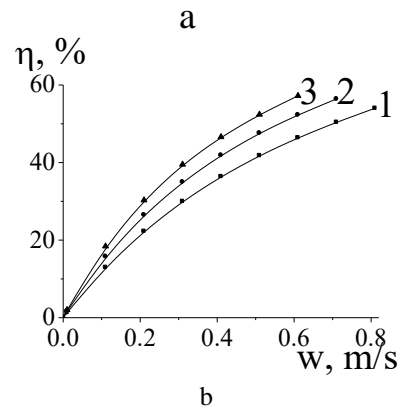
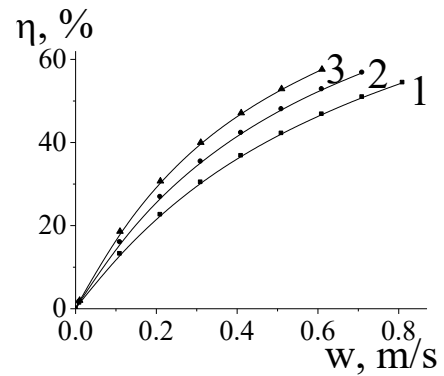


Figure 5 Efficiency coefficient vs. air-vapor flow rate and relative humidity: 1 – 40 %; 2 – 50 %; 3 – 60 %. Air-vapor flow temperature °C: 40 (a); 50 (b) and 60 (c)



Increasing of the vapor-air-flow rate and relative humidity is accompanied by raising of the efficiency coefficient of heat energy storage device of closed-type  $\eta$ . The value  $\eta$  is observed to be negligibly changed as vapor-air-flow temperature increased. Maximal values of efficiency coefficient (about of 53 – 57 %) are stated at the relative humidities of 40 – 60 % at the vapor-air-flow rates of 0.6 – 0.8 m/s.

Heat storage device was tested for heating the premise with a floor area 100 m<sup>2</sup> during period from 1 of November 2014 to 28 of February 2015. Tested device was applied for load-factoring in power systems instead of fan heater and oil heater with energy consumption of 1.5 – 2.5 kW. The initial temperature in premise was 12°C. Vapor-air flow rate was set at 0.25 m/s. Heat storage device was filled with 10 kg of adsorbent ‘silica gel – sodium sulphate’. As warmth-keeping material mineral wool (thickness 100 mm, thermal conductivity coefficient 0.035 W · m/K) was used.

Storage device was tested in two modes corresponded to the load-factoring of electric energy in the morning or in the evening (first or second half-term). As both modes applied, indoor temperature is maintained within limits from 20 °C to 22°C during day or night period. Average temperature graphs for both test modes are presented on Fig. 6.

Two peaks according to discharging and charging of heat energy device are observed on both curves, they being registered as the first and second after accumulator start. Peak sorbent temperature when discharged is almost 60°C, it being resulted from sorbent cooling with air-in flow.

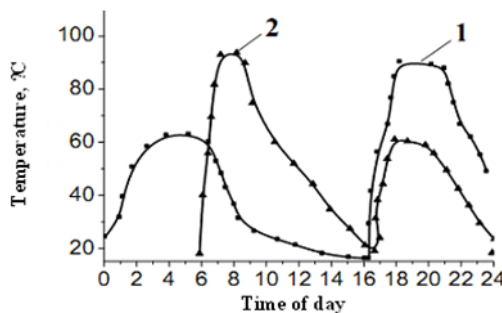


Figure 6 Averaged temperature sorbent curves when heat storage device started in the morning (1) and in the evening (2)

Higher temperature when charged is corresponded with composite adsorbent regeneration temperature. During day hours the composite can be regenerated by the heat provided by solar collector, in night hours it being carried by resistance element. Efficiency factors calculated with ratio of two peaks ratio are almost 32 % for both operating modes. These values are correlated with computed values 33 % for the same conditions.

Advisability of adsorptive heat storage device for heating premises was confirmed by comparing of energy consumption with solid fuel combustion boiler, gas-fired combustion boiler and electric boiler, when heat demand equaled to 339.5 MJ per day for floor area 100 m<sup>2</sup>. When open-type adsorptive heat accumulator used, energy consumption in heat supply system was decreased in minimum of 3.5 times versus gas-fired combustion boiler. In comparison with solid fuel combustion boiler and electric boiler energy consumption can be reduced no less than 2.9 and 2.4 times. When adsorbent regeneration provided by solar collector, energy consumption was decreased about 90, 76 and 61 times versus gas-fired combustion boiler, solid fuel combustion boiler and electric boiler, respectively.

#### 4 Conclusions

Thus, suggested algorithms allow determining operational parameters of open-type and close type heat energy storage devices or units. Optimal operating parameters of exploiting processes for heat storage devices based on composite sorbent ‘silica gel – sodium sulphate’ are stated to be vapor-air flow rate speed of 0.6 – 0.8 m/s and relative humidity of 40 - 60%, efficiency coefficient being ranged from 53 to 57 %.

Power consumption is shown to be decreasing in 2,4 - 90 times versus decentralized heating systems based on solid fuel, gas and electric boilers when open-type adsorptive heat storage device used. Application perspectiveness of adsorptive heat storage devices is shown for heat supply systems.

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# Non Traditional Energy of Zeolites and Environmental Protection

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**Keywords :** zeolites, sorption, water treatment

**Abstract :** Sorption as a separation method is becoming an important method in progressive production developing of green energy and of intelligent products of the new generation. It is also important for the treatment of drinking and waste water. The gradual development and improvement of sorbent preparation technology progressively enhances their quality, in sorption capacity, specific surface, abrasion resistance, regenerative capacity or selectivity in relation to certain types of contaminants. Among the most important usable sorbents are also the zeolites, which are also used for the water purification. The article contains the results of measurements and monitored parameters of ferric cations sorption from the aquatic environment using natural zeolite clinoptilolite.

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## 1 Introduction

At present, when human society has to deal with the pollution problems of all the components of the environment, nature provides us with material with special properties. Its properties can help at least partially to mitigate these negative consequences of human activity. A natural zeolite is this material. This rock contains a mineral with a unique aluminum silicate structure formed by tetrahedrons  $[\text{SiO}_4]^{-4}$  and  $[\text{AlO}_4]^{-5}$ . Tetrahedrons are interconnected through atomic oxygen to form cavities in which alkaline metals, alkaline earths metals and aqueous molecules are located. The mineral clinoptilolite is one of the most industrially useful zeolites.

Clinoptilolite is defined as mesoporous material mostly aggregated by colloidal dispersed nanoparticles by up to about 30%. Its surface is hydrophilic and it has various active centers, that can engage in van der Waals, hydrogen, dipole-dipole and electrostatic interactions with adsorbate [1]. Due to these properties, clinoptilolite is useful for sorption, catalytic and ion exchange purposes. The ability to exchange cations is an important feature of the zeolites. As a result, ion exchange sorption is applicable for water treatment.

## 2 Ways of Using Natural Zeolites in Practice

Application possibilities of natural zeolites result from their specific physical and chemical properties, namely ion exchange, sorption, the possibility of dehydration and hydration as well as the structure of the silicate and the micron size crystals of a very active surface area. Zeolites can bind substances such as isolated atoms, molecules, heavy metal cations from aqueous solutions. They can be used successfully for the sorption of nitrogen oxides, polycyclic aromatic hydrocarbons from the exhaust gases produced by combustion processes. After suitable modification of the zeolite, a material is also suitable for the catalytic conversion of these harmful components of the flue gas. Natural zeolites have been used in a wide variety of applications over the world. Their advantage over synthetic zeolite is their better thermal resistance and lower cost [2]. Among the applications of natural zeolites, their utilization for carrying energy in energy conservation and heat exchanging systems is noteworthy [3]. The term zeolite was created in 1756 by Axel Cronstedt, a Swedish miner, who found that some minerals, when heated, release large amounts of steam from the water that had been previously adsorbed. This mineral has therefore also attribute a boiling stone. In recent years, scientists are trying to use this process in the heat supply system. The zeolite's ability to accumulate the heat of water

vapor adsorption for energy purposes is utilized. Research works on this issue focuses primarily on methods that enable a high density of accumulated energy to be achieved with a minimum of heat loss. This criterion is met by the heat utilization method of adsorption processes. The adsorption process used for heat accumulation can be achieved up to  $1400 \text{ kJ} \cdot \text{kg}^{-1}$  [3]. For comparison, when the heat is stored in water and when the temperature changes by 20 K, it is possible to achieve  $84 \text{ kJ} \cdot \text{kg}^{-1}$  [3,4]. Adsorption systems use water vapor adsorption for solids accumulation. The exothermic effect of sorption on zeolites consists of the sum of the two reactions effects, namely the wetting of the zeolite surface and the sorption of the  $\text{H}_2\text{O}$  molecules into the interior crystalline. The highest exothermic effect results from sorption inside the crystal pore. The sorption and desorption behavior of the water correlates with the electronegativity of the zeolites and the average charge of the grid oxygen atoms [5]. The bond of the lattice remains firm even after the water has been removed. Natural zeolites have the advantage over their synthetic advantage that their crystalline structure is more heat resistant. Sorption energy storage systems that use zeolites represent advanced energy saving technology and can be used for heat exchangers as well as absorption coolers [6,7].

Scientists at experiments in 2001 at the Brookhaven National Laboratory in the U.S.A. have found that zeolite is the only material known so far on Earth, which increases its volume when compressed. The most of the materials under pressure become more compact, denser, their volume decreases and the density increases. Zeolite increases its volume under a certain pressure. Increased volume persists even though the pressure is no longer working. This property is used to pick up radioactive elements. Adsorption by pressure swing (PSA) and adsorption by temperature swing are potential techniques for removing of  $\text{CO}_2$  from high-pressure fuel gas streams. Natural zeolites are advisable for using at PSA proces. The studies of volumetric gas adsorption of  $\text{CO}_2$ ,  $\text{N}_2$ , and  $\text{O}_2$  on the three natural zeolites, with different major cations, were realised at  $25^\circ \text{C}$  and at high pressure. Preferential adsorption of  $\text{CO}_2$  was observed with all three zeolites. The natural zeolite with the highest sodium content and highest surface area showed the highest  $\text{CO}_2$  adsorption capacity [8].

Sorption and ion exchange properties of zeolites are also interesting in terms of treatment of drinking and waste water. When water is treated, the zeolites fill their cationic function in their natural - unmodified form. The ion exchange sorption process is used to remove a wide range of organic and inorganic substances from contaminated water. Most often, the zeolite is used in the secondary or tertiary stage of purification of contaminated water for the final purification of contaminated water, from ammonia and from cations of metallic elements. Metallic elements in the above-limit

quantity worsens the health status of the population of the given site. If the zeolite is treated with an aqueous solution of metallic elements cations, the water that is bound to the zeolite forms hydroxide within the cation channels. This creates a geopolymer matrix into which metal cations with a toxic effect such as  $\text{Cd}^{+2}$ ,  $\text{Pb}^{+2}$  can be sealed. Informations about the properties of the zeolite are obtained forward to introduction of the zeolite into the purification process. The most commonly data as the equilibrium isotherm and sorption kinetics are used[9].

### 3 Experimental

Access to quality drinking water belongs to the common needs of the population in the European region. The water is suitable in many cases, but there are also cases where the water needs to be treated. The iron and manganese content must be regulated in drinking water. The technological process hitherto used, is extremely demanding in terms of investment and operations are constantly looking for so ways to make this process more efficient. The zeolite mineral- clinoptilolite has been used for the treatment of drinking water in the last decades. Sufficient mechanical strength, chemical stability and nontoxic, allow the using of natural zeolite as a filter material.

Iron is a biologically important element. It is important for hemoglobin formation and oxygen transfer. However, for long-term drinking, an ferrum content higher than the limit value is not appropriate. Therefore, the iron content of the water must be monitored. Natural and synthetic sorbents, such as zeolites, can be used to regulate of their content. The application of natural zeolites to wastewater treatment results from their specific physicochemical properties, such as selective ion exchange and sorption.

The efficiency of the sorption of soluble matters on the solid matrix from the aqueous solution is most often expressed by the effective distribution coefficient  $K_D$ , which is defined as a straight line of the linear sorption isotherm, and which gives the share of the sorbed amount of the substance in the solid phase ( $C_s$ ) to its equilibrium concentration in the solution ( $C_r$ ) during the equilibrium state. This parameter is a quantitative indicator of substance distribution between the solid and liquid phases  $K_D = C_s / C_r$  [10,11]. We monitored the dependence of the adsorbed amount from the time of contact of the sorbent with the adsorbate, for determine the time required to achieve equilibrium in the system.

### 4 Materials and methods

To experimentally reduction the iron content in water, we used the natural zeolite clinoptilolite found in Nižný Hrabovec with a grain size of 2,5 to 5 mm as a sorbent. It is necessary to determine kinetic course for sorption using in the water purification process. We used a model

sample with an initial concentration of  $c_0 = 11,76 \text{ g} \cdot \text{dm}^{-3}$  of ferric cations to study the kinetic course of sorption.

Experimental measurements of ferric cations content were performed on the AC-114 OPTIMA INC photometer Tokyo, Japan in model samples. We used chemicals of analytical purity to prepare model samples. Experiments were carried out at  $22^\circ \text{C}$ . 40 g of clinoptilolite zeolite was embedded by sample model of ferric cations. Kinetic course of ferric cations sorption was monitored up to the equilibrium state of the system using model samples of aqueous ferric cations solution. In precise time intervals samples of solution were collected. Amount of ferric cations was determined by photometric method. The measured values are recorded in the table 1.

Table 1 Changes of numerous concentrations at time

Time [min]	Concentration [ $\text{g} \cdot \text{dm}^{-3}$ ]
30	11,2
60	10,0
90	8,4
120	6,7
150	6,7

The equilibrium concentration value depends for aqueous solutions, on the properties of the sorbent and on the initial concentration of the solution. Figure 1 shows a kinetic course of concentration of the ferric cations decreasing in an aqueous solution.

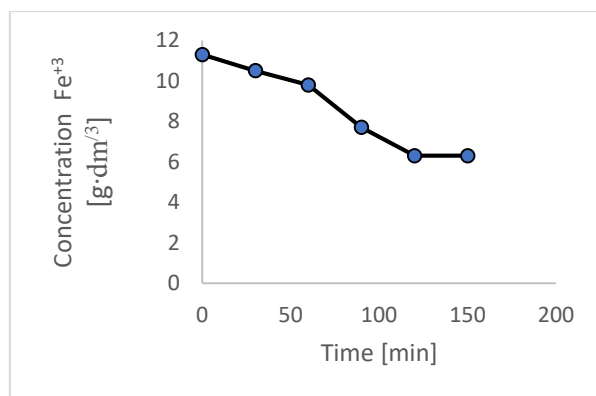


Figure 1 Kinetics course of ferric cations concentration reduction

Based on the measured concentration at regular time intervals, we have determined the amount of ferric cations adsorbed at the individual time slots and at equilibrium time. Calculated values were used to graph the depiction of the amount of absorbance at time (Figure 2).

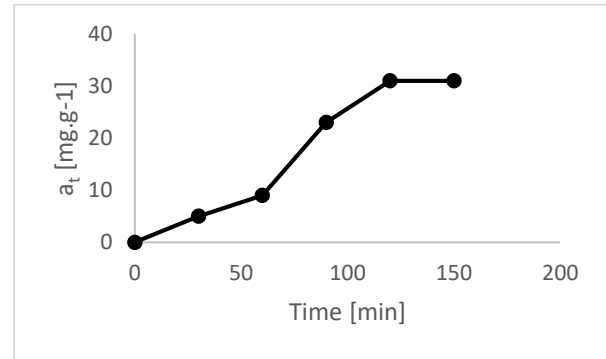


Figure 2 Sorptional curve

The amount of ferric cations sorbed on the clinoptilolite was calculated according to equation (1) as the difference between the initial concentration of  $c_0$  and the concentration in solution at the equilibrium state  $c_r$  where  $a$  is the sorbed amount [ $\text{mg} \cdot \text{g}^{-1}$ ],  $V$  is the volume of the solution and  $m$  expresses the sorbent mass.

$$a = (c_0 - c_r / m) \cdot V \quad [11] \quad (1)$$

The quantitative distribution parameter of the substance between the solid and the liquid phase is the  $K_D$  partition coefficient .

$$K_D = c_s / c_r \quad (2)$$

According to equation (3), we calculated the efficiency of clinoptilolite in reducing the concentration of ferric cations in aqueous solution.

$$\gamma = (c_0 - c_r / c_0) \cdot 100 \quad (3)$$

The course of change of clinoptilolite efficiency at time points is shown graphically in Figure 3. One of the adsorbent quality indicators is the degree of adsorption. The degree of adsorption was calculated according to the relationship (3).

$$AD = (1 - c_t / c_0) \cdot 100 \quad [11] \quad (4)$$

The degree of adsorption was calculated 44,7% under the given conditions. For the distribution parameter, we calculated a value of 0,67 under the given conditions.



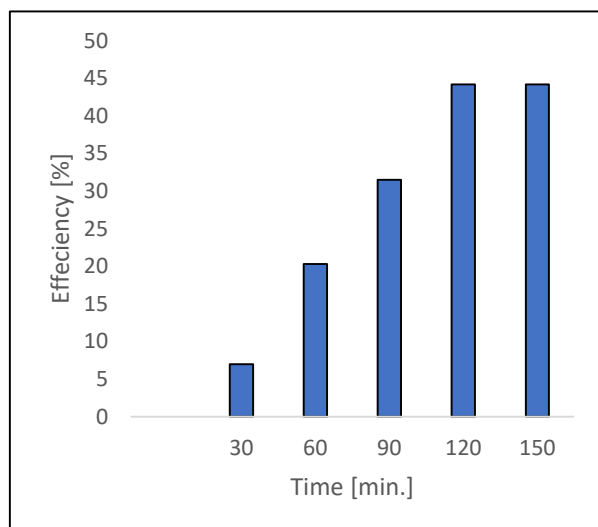


Figure 3 Efficiency of the sorbent in individual time segments

## 5 Conclusion

Since conventional water treatment methods often do not achieve sufficient cleaning efficiencies and they are costly at the same time, they are replaced by new or complementary processes that are more acceptable than traditional practices not only from the economic but also from an environmental point of view. Due to the rich deposit of natural zeolites in Slovakia and their low price, our work has been focused on reducing the amount of ferric cations in aqueous solution using natural clinoptilolite. On the basis of the above results, the ability of adsorbent based on the natural zeolite to remove ferric cations from the aqueous environment was confirmed. The observed kinetic course of sorption shows a rapid course of reduction in ferric ion with 43% efficiency.

## Acknowledgement

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# Comparing Future Heating Demand of a Family House Using Different Insulation Materials

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**Keywords :** DesignBuilder, Family house, Simulation

**Abstract :** Computer programs allowing determining accuracy of building design in advance, or its parts, from the thermal engineering point of view are on the rise. Finding the most suitable project design for optimizing future energy performance of building significantly contributes to implementation of European Directive on Energy performance of buildings 2010/31/EU in Slovakia. Using simulation software, DesignBulder in this case, became a very useful tool on the road to energy effective design. In this paper, we have placed a virtual family house (which will be built in Kosice, Slovakia) to the simulation software DesignBuilder and were finding out the most suitable design in case of future heating demand. Family house was designed taking in account architectural, environmental and constructional requirements of today's directives focusing on energy performance and energy efficiency. Results of this project are displayed in numbers as well as in graphic figures. Our goal was to find out the difference between two different types of envelope wall insulation.

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## 1 Introduction

The result of architectural and construction solution affect many parameters. Those parameters either can or cannot be affected by designer; nevertheless, first raw design usually needs to be optimized according to importance of energy efficiency of building. Finding optimal solution means knowing correlation between key parameters which are affecting energy performance of buildings (i.e. heat demand, cooling demand, thermal comfort, etc.). After simulation on energy performance of building, designers are able to optimize parameters to find the best ratio between initial cost and long term energy save. Currently, there are more than 400 applications that can be applied to analyzing building energy and thermal simulation [1]. Building thermal simulation tools predict the thermal performance of a given building and the thermal comfort of its occupants. In general, they support the understanding of how a given building operates according to certain criteria and enable comparisons of different design alternatives [2]. Evaluation of thermal

comfort involves assessment of at least six factors: human activity levels, thermal resistance of clothing, air temperature, mean radiant temperature, air velocity and vapour pressure in ambient air [3]. In this paper, we are comparing two different types of external wall insulation and their effect on heat demand for heating. First is commonly used wall thermal insulating material EPS polystyrene, part of ETICS system. On the other hand, as the age and research go further every day and new materials are being introduced into everyday construction life, insulation based on phenol insulation board is being assessed in this paper.

## 2 Theory

House that is being evaluated is located in Košice-Krasna, Slovak Republic. City of Košice lies at an altitude of 206 meters above sea level and covers an area of 242.77 square kilometers. It is located in eastern Slovakia, about 20 kilometers from the Hungarian borders, 80 kilometers from the Ukrainian borders, and 90 kilometers from

the Polish borders (figure 1). It is about 400 kilometers east of Slovakia's capital Bratislava. Košice city is situated on the Hornád River in the Košice Basin, at the easternmost reaches of the Slovak Ore Mountains. More precisely it is a subdivision of the Čierna hora Mountains in the northwest and Volovské vrchy Mountains in the southwest. The basin is met on the east by the Slanské vrchy Mountains.

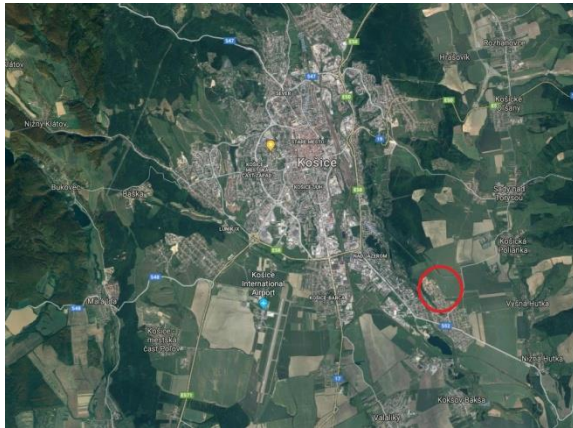


Figure 1 Location of the object near Košice

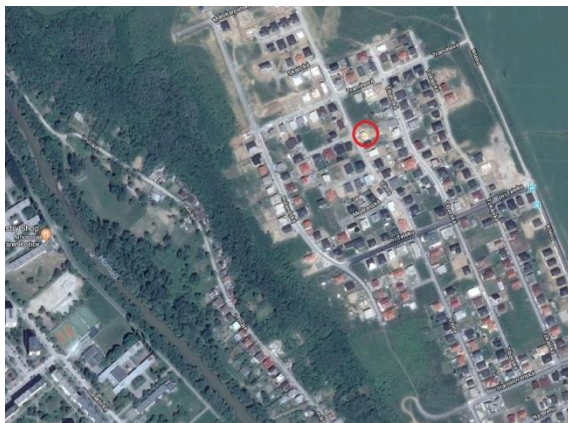


Figure 2 House position

Two-storey family house represents a typical type of residential buildings built in this area. The floor layouts were designed for a family of two parents and three kids and the concept of a whole house was made in according to the latest energy standards. Building is based on a concrete footing foundation. The family house envelope was designed using materials with high thermal capacity. As for thermal insulation - thick layer of polystyrene (ETICS system) is being used, to minimize the heat losses during the heating period as well as to prevent the heat transfer during the summer period. Roof structure creates unconditioned space between insulated ceiling and top of the roof. Transparent parts of building envelope were designed as wood-aluminum, triple glazed windows Internorm with outside louvers for a regulation of solar gains

through the windows. The table format can be colour or gray scale in the best quality possible.

## 2.1 Phenolic insulation

The main use of phenolic foam in construction is as thermal insulation, to improve its thermal efficiency. The thermal efficiency of the existing building stock is of prime concern, if carbon emissions targets are to be met. For those homes with solid walls, external wall insulation can be an effective method of improving their thermal efficiency. Phenolic foam is starting to be popular material choice for external wall insulation systems owing to its low thermal conductivity and good fire performance [4]. Phenolic foam is made from three main components: phenolic resin, a blowing agent and an acid catalyst; a number of additives can also be utilised to develop specific properties within the foam. There are patents and other information available at [5] that describe the chemicals used to manufacture phenolic foam.

## 3 Materials and methods

The external wall insulated with polystyrene represents the most common insulation type of ETICS insulating system. On contrary, phenolic insulation materials are used quite rarely – but they are on the rise. The main reason is its price, which is extensively higher than polystyrene (or any other classical insulation material). However, phenolic insulation boards allow us to design energy efficient building while keeping the external wall construction as subtle as possible due to its low coefficient of thermal conductivity of  $\lambda=0,020 \text{ W/m}\cdot\text{K}$ . With its thickness, phenolic insulation board of thickness 6 cm equals to 12 cm of polystyrene.

Table 1 Physical and thermal parameters of building

Shape factor (A/V ratio)	0.78 1/m
Volume of building space	726.18 m <sup>3</sup>
Total heat transfer surface	569.48 m <sup>2</sup>
Total floor area	222.09 m <sup>2</sup>
Wall U-Value	0.148 W/(m <sup>2</sup> ·K)
Insulated ceiling U-Value	0.123 W/(m <sup>2</sup> ·K)
Ground floor R-Value	4.38 (m <sup>2</sup> ·K)/W
Wood-aluminum U-Value	0.60– 0.95 W/(m <sup>2</sup> ·K)
Internorm HF 350	

### 3.1 Technical parameters of an envelope wall type A – polystyrene insulation

Envelope wall type A is a classic type of the external envelope wall insulated with EPS polystyrene.

Polystyrene insulation is the most common insulating material used in Slovak Republic. Polystyrene insulation is being put on masonry or any other wall structure, using adhesive mortar and anchors.

Table 2 Thermo-physical properties of an envelope wall type A

	d	$\lambda$	c	$\rho$	m
	[m]	[W/m·K]	[J/kg·K]	[kg/m <sup>3</sup> ]	[kg/m <sup>2</sup> ]
Plaster	0.020	0.570	1000.0	1300.0	10.0
Porotherm 38 Ti Profi	0.380	0.134	1000.0	750.0	29.0
EPS insulation	0.120	0.038	1050.0	18.0	45.0
Adhesive mortar	0.005	0.800	920.0	1300.0	18.0
Silicon render	0.003	0.700	920.0	1700.0	37.0

### 3.2 Technical parameters of an envelope wall type B – phenolic insulation

Envelope wall type B is a type of the external envelope wall insulated with phenolic boards, in this case Kingspan KOOLTHERM K5. The core of Kingspan Kooltherm K5 External Wall Board is a fibre-free performance rigid thermoset phenolic insulant manufactured with a blowing agent that has zero Ozone Depletion Potential (ODP) and low Global Warming Potential (GWP). The core of Kingspan Kooltherm K5 External Wall Board has a 90% closed cell structure. Phenolic board insulation is being put on masonry or any other wall structure, using adhesive mortar and anchors.

Table 3 Thermo-physical properties of an envelope wall type B

	d	$\lambda$	c	$\rho$	m
	[m]	[W/m·K]	[J/kg·K]	[kg/m <sup>3</sup> ]	[kg/m <sup>2</sup> ]
Plaster	0.020	0.570	1000.0	1300.0	10.0
Porotherm 38 Ti Profi	0.380	0.134	1000.0	750.0	29.0
Phenolic insulation	0.060	0.020	800.0	35.0	300.0
Adhesive mortar	0.005	0.800	920.0	1300.0	18.0
Sil.render	0.003	0.700	920.0	1700.0	37.0

## 4 Simulation

Using simulation software DesignBuilder, the assessed family house was simulated. In the first simulation, polystyrene was used as wall insulation. Second simulation shows the alternative to EPS insulation – phenolic insulation board.

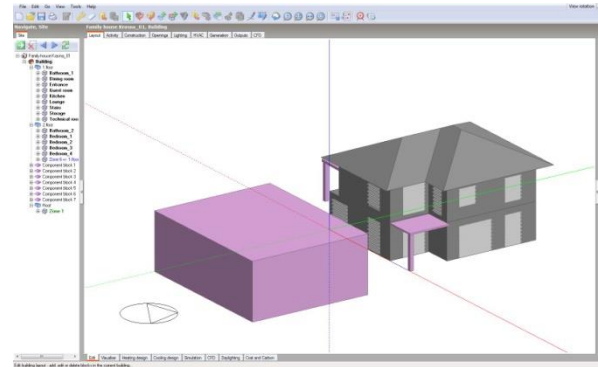


Figure 3 Family house created in DesignBuilder interface

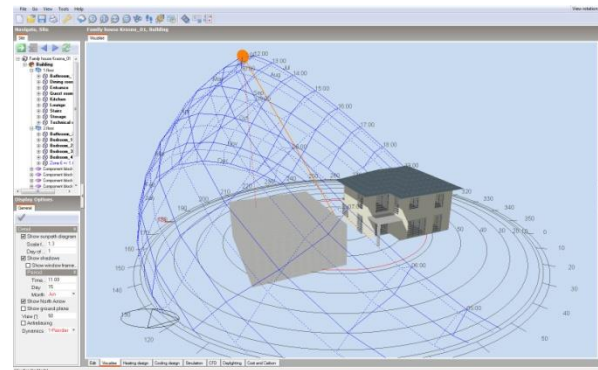


Figure 4 Family house visualization in DesignBuilder

Weather data of the reference year for Kosice were used in this simulation. They provide inputs of dry bulb air temperature, relative humidity, solar radiation, wind speed, wind direction etc., for achieving the most accurate and realistic simulation.

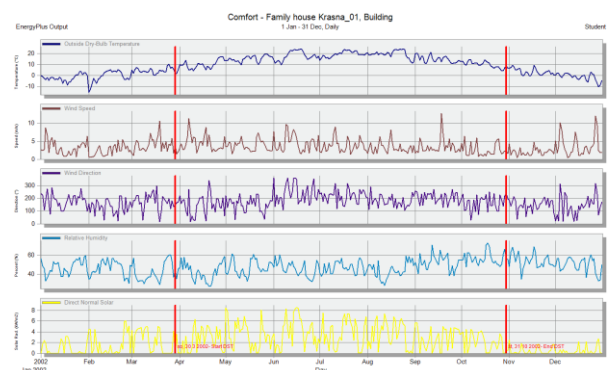


Figure 5 Weather data for the reference year in Košice, Slovakia. From the top: Outside dry-bulb temperature, wind speed, wind direction, relative humidity, solar intensity



## 5 Results

Building simulations were set up with the DesignBuilder v4 software, in which building performance data were generated by the simulation engine EnergyPlus.

### 5.1 Envelope wall type A – polystyrene insulation

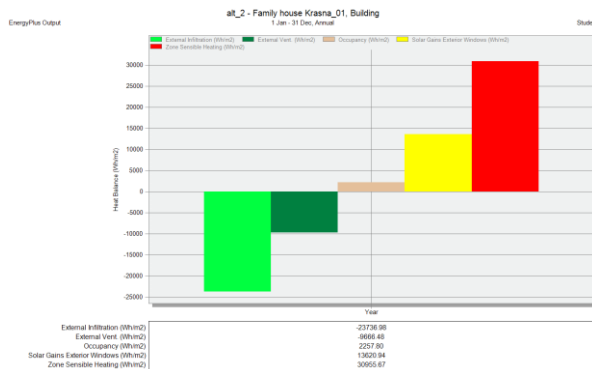


Figure 6 EnergyPlus outputs of annual heat gains, heat losses and heating demand of type A

Figure 6 shows annual heating demand of a family house, with envelope wall insulated by EPS polystyrene alternative, on square meter of floor area is 30,96 kWh/m<sup>2</sup>·a. Solar gains through the exterior windows are 13,62 kWh/m<sup>2</sup>·a and a heat gains from the occupancy 2,2 kWh/m<sup>2</sup>·a. On the other hand heat losses via external infiltration and ventilation are little higher than 32 kWh/m<sup>2</sup>·a.

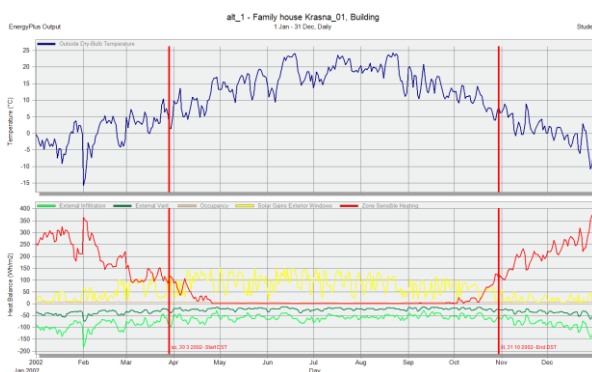


Figure 7 Daily data of heating demand, solar gains through exterior windows, heat gains from occupancy, losses from infiltration and ventilation

As seen on figure 7, daily extremes on heating demand peak on 1<sup>st</sup> of February, with over 0,35 kWh/m<sup>2</sup>. This, of course is a result of the outside dry-bulb temperature drop.

### 5.2 Envelope wall type B – phenolic insulation

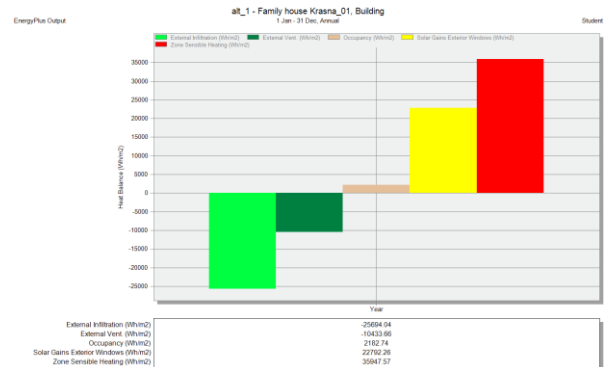


Figure 8 EnergyPlus outputs of annual heat gains, heat losses and heating demand of type B

Figure 8 shows annual heating demand of a family house, with envelope wall insulated by phenolic insulation board alternative, on square meter of floor area is 35,9 kWh/m<sup>2</sup>·a. Solar gains through the exterior windows are 13,62 kWh/m<sup>2</sup>·a and a heat gains from the occupancy 2,2 kWh/m<sup>2</sup>·a. On the other hand heat losses via external infiltration and ventilation are little higher than 32 kWh/m<sup>2</sup>·a.

## 6 Conclusion

Nowadays, not only in Slovakia but worldwide, building sector is heading towards emissions-free goal. Every day, more and more new and efficient materials are being implemented into construction process. One of these materials with future is phenolic insulation. Classical insulation used in ETICS systems such as polystyrene, mineral wool, etc., with thickness over 20cm, are being slowly replaced by thinner and subtle insulation materials – such as phenolic boards. As seen from results, envelope wall insulated by polystyrene with thickness of 12cm, can be replaced by phenolic insulation board with the thickness equal to half of polystyrene – 6cm. Heating demand is affected by 5 kWh/m<sup>2</sup> annually. Given the price for 1 kWh, total amount of finances saving equals to 35 € a year, which is not considered as a significant improvement in saving costs on heating. One of the biggest cons of phenolic insulations is its high price. Compared to polystyrene insulation material used in this paper, it doubles the price with over 17 €/m<sup>2</sup>.

With more energy efficient materials with very low coefficient of thermal conductivity, such as phenol based insulation systems, it is possible reaching goals as net-zero energy buildings or even energy plus buildings while making building envelope structure more subtle and modern. With the help of simulation tools, such as DesignBuilder, it is feasible to find the



most efficient option for building structures, taking into account costs on future energy demand as well as costs on construction itself.

### Acknowledgement

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# Evaluation of District Heating Systems Status in Countries of Visegrad Group

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**Abstract :** In the Visegrad group countries is district heating system the dominant way of production and distribution of heat in residential sector. The European Union is currently supporting the development of district heating systems and the use of more renewable sources in heat production. The article describes the current status of district heating in the Visegrad group countries.

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## 1 Introduction

In countries of the Visegrad group is district heating an important source of heat. District heating has a high share in the production and supply of heat. This condition is due to the past when the district heating was the ideal way of heating the panel housing estates. The highly developed district heating network has begun to be reduced in the last 25 years but is still the main source of heat and heat distribution in the countries of Visegrad group. The European Union's goal is to redevelop and build up the systems of district heating and use renewable energy sources in heat generation.

## 2 District heating

District heating can be defined as the supply of multiple objects from a common heat source and the distribution of heat through the thermal network, which at least partially passes through the free space between the objects. Heat is transmitted through pipelines using water and steam. The most widely used are hot-water distributions. Steam distributions are used to supply heat to industrial consumers. District heating systems are composed from three parts:

- one or more heat sources
- thermal networks
- consumer

District heating systems can supply a limited number of consumers. This limitation is due to the distance on which heat can be economically conveyed. District heating system is an integrated whole that has to be designed and operated as a whole. District heating systems:

- urban – supply the residential communal sector and local industry
- industrial – supply one or more adjacent industrial plants or adjacent settlements
- regional – supply two or more locations

The development of district heating systems was similar in all countries of Visegrad group and characterized by the same signs. The primary need for the establishment of district heating systems was the provision of heating in administrative buildings and facilities (industrial, factories, hospitals, schools,...). This need arises from development of industrial production in cities, electricity and as solution of transport and storage of fuel problems. The largest development of heating systems began after World War II. The main motivation was the development of heavy industry, the integration of regional electricity grids into one system and the way of central planning and redistribution of financial resources. The second reason for development of district heating was the construction of satellite panel housing estates. After 1990, the evolution of district heating has been

influenced by the gradual liberalization of fuel and energy prices, the creation of a competitive surrounding, the arrival of foreign investors, ecologization, modernization and rationalization of district heating systems. There is stagnation in the establishment of new district heating systems and appears a phenomenon of disconnection from district heating systems.

### 3 Current status

The share of district heating use in the housing estates in countries of Visegrad group is above the European Union average. The reason for this high share is the developed infrastructure from the past. Despite the fact that the share of district heating in heating and hot water supply is high, it is still decreasing. In the Visegrad Group countries, district heating covers a significant portion of household heat consumption. Figure1 shows the share of citizens served by district heating system. A smaller share of district heating system is only in Hungary 17%. This is mainly due to geographic location and climate. The Czech Republic, Poland and the Slovak Republic have roughly the same share. This share ranges from 35% in the Slovak Republic, 40,2% in the Czech Republic to 41% in Poland.

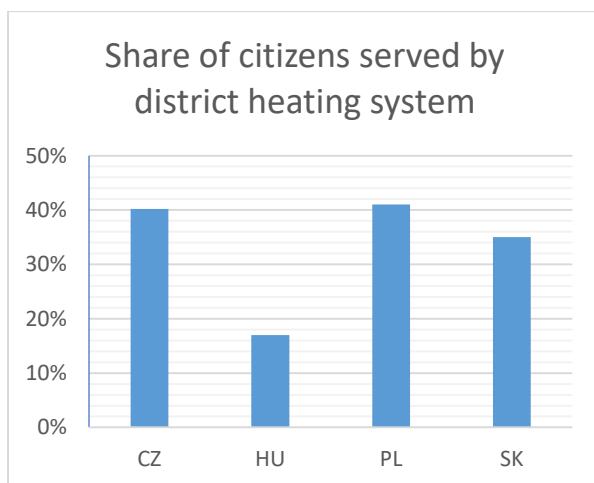


Figure 1 Share of citizens served by district heating system

The most used fuels for the production of heat are natural gas and coal. Coal is the most used fuel in the Czech Republic and Poland. Natural gas is dominant in Hungary and the Slovak Republic. The current state of district heating systems is characterized by a significant increase in the share of renewable energy sources in the production of heat. The main renewable fuels are biomass and biofuels.

#### Czech Republic

The most used fuel is coal with a share of 58%. Natural gas is 23%, biomass 9% and other fuel gases 6%. The share of fuels used in district heating systems is shown in Figure2.

#### Czech Republic - share of fuels

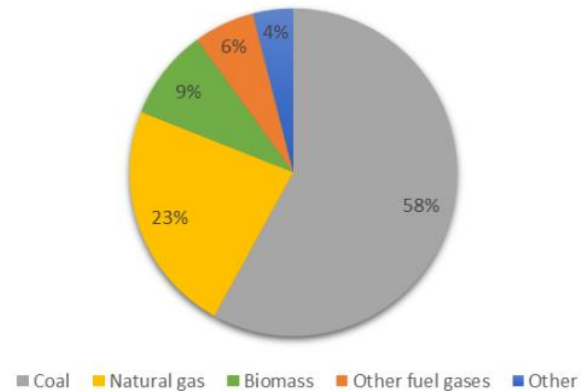


Figure 2 Czech republic: share of fuels

#### Hungary

The dominant fuel used in the production of heat is natural gas with 69% share. The share of coal and biofuels is equal to 11%. Geothermal energy is 3% and other sources like waste heat from nuclear power, solarpower and other represent a 6% share. The share of fuels used in district heating systems is shown in the Figure3.

#### Hungary - share of fuels

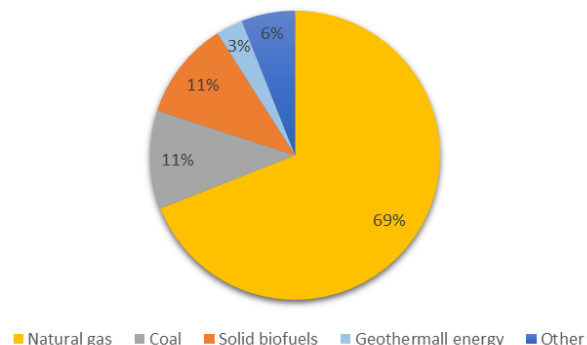


Figure 3 Hungary: share of fuels

## Poland

The main fuel used in the heat production is coal with a large share of 78%. Other fuels have a share of less than 10%. This includes oil 8%, natural gas 5%, biomass 4% and other fuels 5%. The share of fuels used in district heating systems is shown in the Figure4.

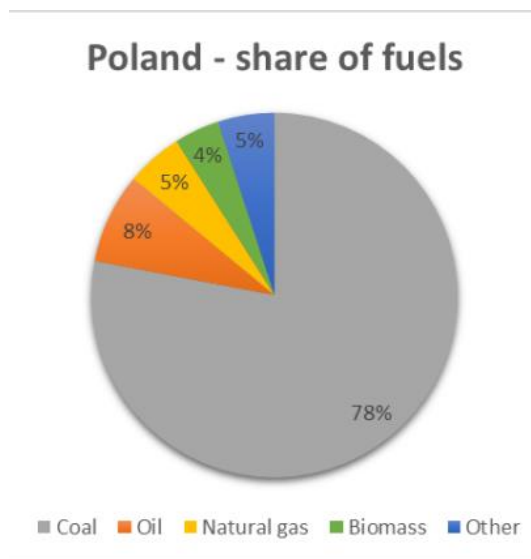


Figure 4 Poland: share of fuels

## Slovak Republic

Of the fuels used in the production of heat has a dominant share natural gas with 57,4%. Coal is 17,6%, biomass 20% and biogas 4,7%.The share of fuels used in district heating systems is shown in the Figure5.

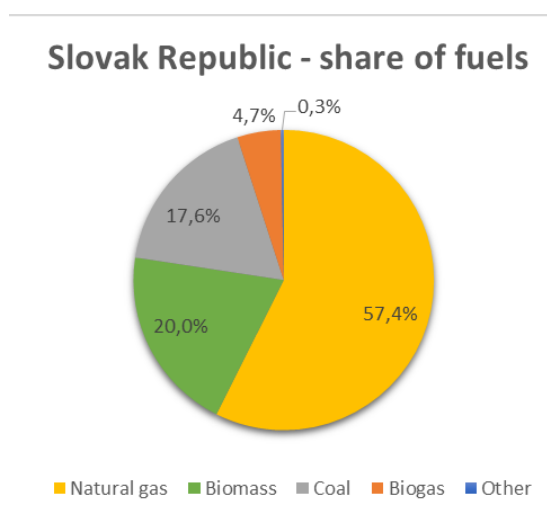


Figure 5 Slovak Republic: share of fuels

## 4 Conclusions

From this overview of the use district heating for the production and distribution of heat in the Visegrad group countries, it can be seen that this system is the most widespread system for the supply of heat to residential houses. Existing district heating systems have all the prerequisites for further development. It is mainly building new systems, modernizing existing systems and increasing the share of renewable energy sources in heat production.

## Acknowledgement

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