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Comparative analysis of individual house heating system based on electricity and combustion of alternative and fossil fuels

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The paper reports cost analysis of house heating and preparation of hot water by means of the different heating systems. The following heating systems were analyzed: electrical heating, boilers fired with the different types of biomass (firewood, wood pellets, wood briquettes, wheat straw, sunflowers husks pellets and conventional fuels (hard coal, fine coal, natural gas, light oil fuel). Based on heat demand for house heating and preparation of hot water, properties of the fuels, current prices of the biomass, fossil fuels, electricity and boilers unit costs of heat production, operational costs and economic effect covering 15 years of exploitation were determined.

Keywords: alternative fuels, heating systems, biomass

INTRODUCTION

Climate and energy package for 2020 includes four targets: to reduce emissions of greenhouse gases by 20% by 2020 taking 1990 emissions as the reference, to increase energy efficiency to save 20% of EU energy consumption by 2020, to reach 20% of renewable energy in the total energy consumption in the EU by 2020, to reach 10% of biofuels in the total consumption of vehicles by 2020, [1]. EU countries have 3 times more renewable power per capita than the rest of the world put together [2]. In EU countries share of renewables for heating and cooling - 17%, transport -6%, electricity – 26 %, [2].

In 2013 share of renewable energy in gross final energy consumption in Poland was 11,3% [3]. Table 1 presents the share of renewable commodities in the total obtaining primary energy form renewable energy sources in 2013, **[3].**

The estimated technical potential of biomass in Poland amounts to 755 PJ/year, Janowicz [4]. Availability and competitive prices cause that biomass and biomass originated fuels are considered for energy production in individual houses, dwellings [5, 6], Zawistowski [7, 8] and for combined heat and power generation [9].

Presented paper is aimed at comparative analysis of the use of electricity, alternative and fossil fuels for heating and preparation of warm water in an individual house. Comparative analysis will be based on the previously determined energy demand for the house. The real object consists of the one floor individual house with attic and garage annex. The ground floor (without cellar) consists of: vestibule, wc, kitchen, dining room, saloon, hall, 2 bathrooms, 3 bedrooms, store room and garage. Attic is excluded from a living space. The house is covered with the gable roof of the slope 15°. The total house area of 225,5 m^2; the usable area of 146,0 m^2, the cubature of 496,1 m^3. Energy demand for heating and preparation of warm water was estimated at the following assumptions: number of the household members $n = 5$, minimal 24-hour consumption of warm water of $t = 60\ ^oC$, $V = 60\ l$ /capita, comfort temperature $t_i = 20\ ^oC$, location of the house in the region of the mean ambient temperature in winter $t_e = -16^oC$ [10, 11]. Estimated thermal power demand for the house heating and preparation of the warm water $\dot{Q} = 11,4\ kW$. House heating load $Q_{co} = 68\ 149\ MJ$ was estimated taking into account the different heating periods during a year [10, 11]. The total annual energy demand for heating and preparation of the warm water for the house in question $Q_a = 88\ 795\ MJ$.

Table 1. Share of renewable commodities in the total obtaining primary energy form renewable energy sources in 2013, [3]

RES	EU , [%]	Poland , [%]
Solid biofuels	45,83	80,30
Hydropower	16,10	2,46
Wind energy	10,53	6,07
Biogas	7,05	2,13
Liquid biofuels	6,71	8,23
Solar energy	5,54	0,18
Municipal waste	4,64	0,42
Geothermal energy	3,08	0,22

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HEATING SYSTEMS

Selection of the heating system should be preceded with an economic analysis of the use of different fuels and heating systems. It was assumed that energy demand for the house in question will be the same for each of analysed heating systems. The cost effectiveness analysis will be carried out for electric heating and heating systems based on combustion of the different fuels presented in Table 2.

Table 2 presents net calorific values of biomass and fossil fuels, current prices of the fuels, electricity and purchase prices of the different types of boilers [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23].

Table 2. Net calorific value of the fuels and current purchase prices of the fuels and boilers

Heating system	Q_i [MJ/kg]	k_f [€/t]	I [€]
Firewood (15 % of moisture)	14,7	57,9	1134,3
Willow chips	12,0	46,3	1134,3
Wheat straw	14,3	50,9	1134,3
Wood briquettes	17,8	138,9	1134,3
Pellets-wood	18,5	185,2	2083,3
Sunflowers husks pellets	20,0	92,6	2083,3
Pea-ecocoal	26,0	185,2	2083,3
Hard coal	23,0	162,0	1134,3
Fine coal	19,0	138,9	1134,3
Natural gas E	49,5	578,7	1064,8
Light fuel oil	42,6	601,9	5248,6
Electric heating G11* -24-h tariff	0,0719 [€/kWh]		1851,8
Electric heating G12* - the night tariff	0,0438 [€/kWh]		1851,8

G11 - 24-h tariff for electricity ,
G12 - the night tariff for electricity,
I - capital cost of heat source ,[€],
k_f - purchase price of the fuel, [€/t]
kf - purchase price of electricity, [€/kWh]
Qi - net calorific value of the fuel, [MJ/kg]

Purchase prices of electricity were taken from [24] for two tariffs: G11 – 24 hour tariff and G12 - the night tariff (transmission fee is not included).

For combustion of biomass and coal (hard and fine coal) the following types of the boilers were applied: Warmet 200 Ceramic [19] - boiler designed as fit for combustion of firewood (15 % of moisture), willow chips, wood briquettes, straw, hard coal, and fine coal (it is also possible combustion of coke,), then Farmer Bio [19] designed as fit for combustion of wood pellets, sunflowers husk pellets, eco-pea coal boiler.

For combustion of natural gas and light oil fuel gas boiler Junkers Ceropur Midi ZWB 24-1 AR, [18] and light fuel oil boiler Vitoladens 300-C/300-T, produdced by Viessmann [26] were applied.

For electrical heating the programmable accumulative heaters ZP DGN 30 RTS 007, [20] were applied. Purchase prices of the fuels and the boilers were taken from actual price lists presented in bids [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26]. For combustion of hard coal, pea - ecocoal, fine coal and biomass efficiency of the boilers was assumed to be η= 0,80 and η = 0,90 for combustion of natural gas and light fuel oil.

HEATING COSTS

To analyse profitability of the different heating systems, the unit cost of heat production, annual investment outlays and the running costs are determined. There are two components of heat production cost: cost of energy supplied in the fuel (electricity) and cost resulting form the investment outlays. Cost resulting from the investment outlays depends upon purchase and installation costs, annual heating consumption and the investment outlay service rate.

The unit cost of heating produced by the different heat sources can be determined from the equation presented by Rubik [27]:

$$k_c = \frac{k_z}{\eta} + \frac{p \cdot I}{Q_a} \tag{1}$$

k_z - unit cost of energy delivered in the fuel [€/GJ],
η - heat source efficiency,
p - annual investment outlays service rate,
I - capital cost of heat source ,[€],
Q_a - annual heat demand [GJ/a].

Heat production unit cost is determined from the following equation:

$$k_e = \frac{k_z}{\eta} \tag{2}$$

Annual house heating load is calculated as follows:

$$Q_a = \frac{24\, \dot{Q} \cdot S_d}{t_i - t_e} \tag{3}$$

where:
$\dot{Q}$ - heating power demand for the house, [kW],
S_d - degree-day number, S_d = 3781,[10,11]
t_i – comfort temperature, t_i = 20°C
t_e - computational temperature in space adjacent to the wall (ambient temperature) t_e = - 16 ° C, [10, 11].

Annual operating costs of the fuel is detetermined from equation;

$$k_o = \dot{B} \cdot k_f \tag{4}$$

Rate of the fuel is determined as follows :

$$\dot{B} = \frac{\dot{Q}}{\eta \cdot Q_i} \tag{5}$$

Annual service rate of the investment expenditures includes the rates of discount and depreciation. At calculation of profitability at the constant prices, usually the rate of discount is assumed to be 6 - 8 %, taken from Górzyński [28]. The real rate of discount was assumed 8 %, depreciation rate was assumed to be constant 5,6 %.

Capital costs given in equation (1) refer only to heat source, costs of the pipelines, fittings and heaters are not included. Estimated annual operating costs determined from annual heating demand and unit heat production costs are presented in Table 3.

Table 3. Production unit costs and annual operating costs for different heating systems

Heating system	**k_z** [€/GJ]	**k_e** [€/GJ]	**k_c** [€/GJ]	**k_o** [€/year]
Firewood (15% of moisture)	3,9	4,9	6,7	437,0
Willow chips	3,9	4,8	6,6	428,2
Wheat straw	3,6	4,5	6,2	395,3
Wood briquettes	7,8	9,8	11,5	866,1
Wood pellets	10,0	12,5	15,7	1111,0
Sunflower husks pellets	4,6	5,8	9,0	513,9
Pea-ecocoal	7,1	8,9	12,1	790,6
Hard coal	7,0	8,8	10,5	782,0
Fine coal	7,3	9,1	10,9	811,4
Natural gas E	11,7	13,0	14,6	1153,4
Light fuel oil	14,1	15,7	23,7	1393,9
Electric heating G11		20,0	22,8	1774,4
Electric heating G12		12,2	15,0	1081,4

k_z – unit cost of energy delivered in fuel, [€/GJ]
k_e – heat production unit cost , [€/GJ]
k_c -the unit cost of heat produced in the heating system,[€/GJ]
k_o -operating (fuel) costs, [€/year]

Estimated annual operating costs determined from annual heating demand and heat production costs are presented in Table 3. Estimates from Table 3 enable to compare the heating unit costs, taking into consideration the fuel cost, fuel net calorific value and efficiency of the heat source and the heating costs including capital costs of the heat source and annual operating costs for the different heating systems.As it follows from Table 3 the highest unit cost of heating was obtained for heating system equipped with the boiler fired with light oil fuel, then for case of electrical heating, boiler fired with wood pellets, natural gas E, eco-peacoal, wood briquett, hard coal and biomass (sunflowers husks pellets, fireewood, willow chips and wheat straw).

High unit cost of heat produced in boiler fired with wood pellets results from the high cost of the fuel and capital cost of the modern boiler designed as fit for combustion of the different types of biofuels, pea ecocoal and fine coal [19].

DISCOUNTED HEATING COSTS

Economic effect covering the whole exploitation period of the heating system is described as Net Predicted Value, NPV. In fact, it is total predicted profit discounted to year zero, expressed in currency of this year.

It is the objective function of the analysis in question Górzyński [28], Skorek and Kruppa [29]:

$$NPV = \sum_{t=0}^{t=n} \frac{\left(CI_t - CO_t\right)}{\left(1+r\right)^t} \tag{6}$$

where:
CI_t - cash inflow, €,
CO_t - cash outflow, €,
r - discount rate,
t - successive year of exploitation,
n - number of time periods

Fig. 1 shows discounted expenditure for house heating and preparation of warm water at the assumption of 15 years of exploitation.

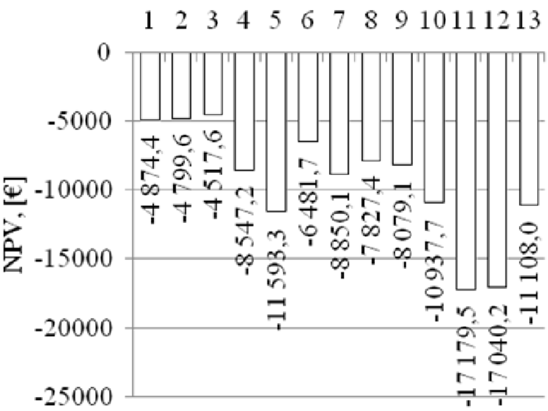


Fig.1. Discounted expenditures of heating system after 15 years of exploitation. **1-** firewood (15% of moisture), **2**- willow chips **3**-wood briquettes, **4**-wheat straw, **5-** wood pellets, **6**- sunflower husks pellets, **7-** pea-ecocoal, **8**- hard coal, **9**- fine coal, **10**- natural gas, **11-**light fuel oil, **12**-electric heating G11(24-h tariff), **13** - electric heating G12 (the night tariff)

It follows from calculations that discounted expenditures of heating system after 15 years of exploitation are the most advantageous for heating systems fired with firewood, then willow chips, wheat straw, wood briquettes, wood pellets, sunflowers husks pellets, pea-ecocoal hard coal and fine coal. The highest discounted expenditures of heating system after 15 years of exploitation were estimated for electric heating for G11 (24-h tariff) and G12 (the night tariff)), light fuel oil and natural gas E.

ECOLOGICAL EFFECTS

Emissisons arising from combustion of biomass (firewood, willow chips, wood briquetts, wheat straw , wood pellets, sunflowers pellets) and fossil fuels (hard coal, pea-ecocoal, fine coal, natural gas E, light fuel oil) in the different types of the boilers were determined using emission factors presented in [30] for the boilers of thermal power < 5 MW.

Indirect emissions, resulting from electricity consumed for house heating and preparation of warm water were determined using emission factors presented in [1,31] for public electricity and power production. Contents of sulphur and ash in the fuels used in house heating systems [15, 16, 17, 32] are presented in Table 4.

Table 4. Contents of sulphur (S) and ash (A) in the fuels

Type of the fuel	A ,[%]	S,[%]
Firewood(15% of moisture)	1,1	0
Willow chips	1,1	0,005
Wooden briquettes	1,1	0
Wheat straw	3,0	0,2
Wooden pellets	1,1	0
Sunflower pellets	4,0	0
Pea-ecocoal	6,0	0,36
Hard coal	10,0	1,5
Fine coal	10	1,5
Natural gas E	0	0,942
Light fuel oil	0,01	0,1

Estimates for emissions from combustion of the different fuels are presented in Table 5.1 and Table 5.2.

Table 5.1. Emissions of gases in combustion process

Heating system	Emission, [kg/year]		
	CO_2	CO	SO_2/SO_x
Firewood (15% of moisture)	9060,7	196,3	0,8
Willow chips	11099,4	240,5	1,0
Wood briquettes	9314,2	201,8	0,9
Wheat straw	7482,7	162,1	0,7
Wood pellets	7199,6	156,0	0,7
Sunflowers husks pellets	6659,6	144,3	0,6
Pea-ecocoal	7897,6	192,1	24,6
Hard coal	8927,8	217,2	115,8
Fine coal	10807,3	262,9	140,2
Natural gas E	5240,4	0,79	0,0025
Light fuel oil	7488,8	1,6	4,7
Electric heating G11	10208,8	9,2	36,3
Electric heating G12	41151,3	37,3	146,2

Table 5.2. Emissions of pollutants in combustion process

Heating system	Emission, [kg/year]		
	NO_2/NO_X	BAP	TSP
Firewood (15% of moisture)	7,6	0	12,5
Willow chips	9,2	0	15,3
Wood briquettes	7,8	0	12,8
Wheat straw	6,2	0	28,1
Wood pellets	6,0	0	9,9
Sunflowers husks pellets	5,5	0	33,3
Pea-ecocoal	9,4	5,98E-02	38,4
Hard coal	10,6	6,76E-02	72,4
Fine coal	12,9	8,18E-02	87,6
Natural gas E	4,0	0	0
Light fuel oil	5,5	0	0,9
Electric heating G11	9,2	3,10E-08	5,0
Electric heating G12	37,3	1,25E-07	20,3

As it follows from Table 5.1 and Table 5.2 heating systems with the boilers fired with biomass are characterized with the low emissions of sulphur and nitrogen oxides and zero emission of bezo (alfa) pyren (BAP). In case of biomass combustion carbon monoxide emissions are realtively high. TSP (Total Suspended Particulate) emissions are relatively high for biomass combustion, however lower than in case of hard coal, fine coal or pea-ecocoal.

The combustion of biomass and fossil fuels to produce heat and electricity is the largest source of CO_2 emissions. Carbon dioxide emissions resulting from combustion of biomass is considered neutral as long as carbon dioxide is sequestrated by living biomass. As it follows from [33] mean emission for EU countries is E_{EU28}= 7721,2 kg CO_2/capita, for Bulgaria E_{BG} = 5985,3 CO_2/capita and for Poland E_{PL} = 8437,5 kg CO_2/capita.

RESULTS

Economic and ecological analysis of the conventional and alternative fuels use for heating purposes of an individual house was performed. Unit costs of heating system are influenced by the quality and the unit price of the fuel and efficiency of the boiler. As it follows from analysis biomass and hard coal are the most cost effective for energy production in an individual house, however combustion of hard coal is not environmentally friendly as emissions of pollutants are high. Performed study shows that the highest costs of heat production refer to electrical heating and combustion of light fuel oil, natural gas E and wood pellets. Discounted expenditures of heating system after 15 years of exploitation are the most advantageous for combustion of firewood, then for willow chips, wheat straw, wood briquetts, wood pellets and sunflowers husks pellets.

It would be also interesting to compare obtained results with available data from the literature. Comparison of the results is difficult as the annual costs of heating depends on costs of the fuels and appliances and their efficiency. For households the end-user price comprises of the following components: fuels and electricity price as traded on the markets, fuel transport and transmission of electricity to local distribution centres, local distribution to households, administrative costs, different taxes (green taxes, VAT etc.).

Paper [34] presents calculator based on USA national averages that enables to estimate and compare fuel costs. In order to compare the results obtained from equation (2) two series of calculations were performed by means of calculator presented in [34]. To compare fuel costs current fuel prices given in [34] and in Poland were entered at the assumption that appliance efficiency for solid fuels is η = 0,8, for natural gas and light oil fuel η =0,9, for electricity η=1. Estimated comparison of the results is presented in Fig.3.

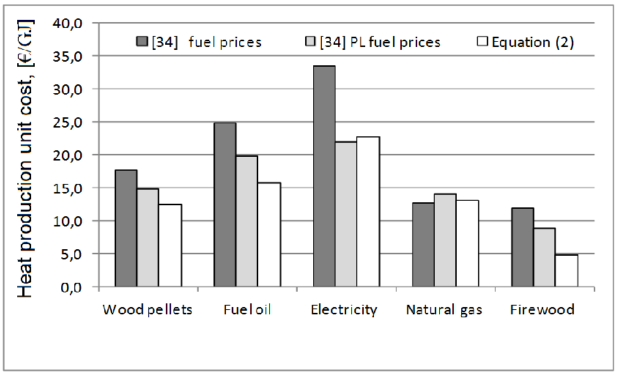


Fig.2. Comparison of heat production unit costs

As it follows from Fig.2 the results are different due to the different prices of the fuels. Heat production unit cost (equation 2) depends upon unit cost of energy delivered in the fuel. The differences in the obtained results may be considered also as the consequence of the different net calorific of the fuels given in Table 2 and included in the algorithm of calculator [34].

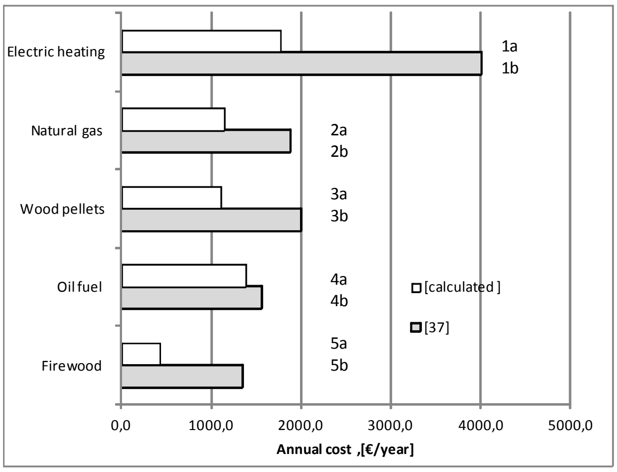
Papers [35, 36] present comparing heating costs of heating and cooling systems for different variants of the fuels and appliances, electric heating, kerosene heating and heat pump. Comparison of estimated costs of wood heating and pellet heating costs is given in Table 6.

Table 6. Comparison of heating costs

Fuel price [€/t]	Appliance	Heating cost [€/GJ]	Source
181,8	Typical pellet stove	14,8	[35,36]
185,0	Farmer Bio	12,5	
54,4	EPA Certified wood stoves η=70%	11,5	[35,36]
57,9	Boiler Warmet 200 Ceramic η=80%	4,9	

As it follows from calculations performed for boiler Farmer Bio [19] of efficiency η=0,8 fixed for combustion of pellets heating cost equals 12,5€/GJ. Data taken from the literature [35,36] shows that combustion of pellets of comparable pellet prices in typical pellet stove gives heating cost 14,8€/GJ. Calculations performed for combustion of firewood in boiler Warmet 200 Ceramic [19] of efficiency η=80% give the lower heating costs 4,9€/ GJ compared to combustion in EPA Certified wood stoves of efficiency η=70% [35,36].

Comparison of determined annual cost of heat production with available data from the literature [37] is shown in Fig.3. Comparison was performed for the different fuels and their prices and appliances of different efficiency, therefore it should be treated approximately.



1a- accumulative heaters ZP DGN[20]; **1b-** baseboard [37]; **2a-** gas boiler Junkers Ceropur Midi ZWB24 1AR [18]; **2b**-energy star boiler [37]; **3a-**boiler Farmer Bio [19]; **3b-** EPA certified wood stove [37]; **4a**-boiler Vitoladens 300-C/300-T, Viessmann, [26]; **4b**-energy star boiler [37]; **5a-**boiler Farmer Bio [19]; **5b**-EPA certified wood stove [37]

Fig.3. Comparison of annual cost of heat production

CONCLUSIONS

Heating sytems fired with biomass (sunflowers husks pellets, willow chips, wood briquettes, firewood) except wheat straw and wood pellets are characterized with the lowest unit costs of heat. Recently, current purchase prices of straw and wood pellets increased very much. In case of pellets the range of the purchase price is variable and depends upon quality. The highest heat production unit costs were estimated for electric heating (both tariffs G11 and G12) , then for light oil fuel heating, natural gas E and pellet heating systems. In case of the systems fuelled with: hard coal, pea-ecocoal or fine coal unit heating costs are between biomass systems and natural gas, light oil fuel and electric heating (both tariffs). In case of stationary combustion of fine coal , hard coal, pea-ecocoal TSP emissions are higher than for sunflowes husks pellets, wheat straw , willow chips, wood briquetts, and pellets. Combustion of light fuel oil is connected with very low TSP emission.

Analysis that has been carried out can be useful for comparison of the different heating systems. The results obtained for heating systems based on combustion of biomass might be interesting for households in the rural region of high potential in biomass.

The combustion and conversion technologies of biomass are increasingly relevant for countries to meet the targets of climate and energy package for 2020.

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