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Energy, economic and environmental assessment of heating a family house with biomass

Mariusz Jerzy Stolarski [a,b,*], Michał Krzyżaniak [a,b], Kazimierz Warmiński [b,c], Malwina Śnieg [a]

[a] Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn, ul. Oczapowskiego 2, 10-719 Olsztyn, Poland
[b] Centre for Renewable Energy Research, University of Warmia and Mazury in Olsztyn, ul. Oczapowskiego 2, 10-719 Olsztyn, Poland
[c] Department of Environmental Toxicology, University of Warmia and Mazury in Olsztyn, ul. Oczapowskiego 2, 10-719 Olsztyn, Poland

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ABSTRACT

The aim of this study was to evaluate energy consumption, energy cost and emission of greenhouse gases from the combustion of wood briquettes for heating a family house in north-eastern Poland during three heating seasons.

The quantity of briquettes and its energy content was used to determine heat consumption. Subsequently cost of space heating and domestic hot water was determined. Obtained results were compared to other biomass and fossil fuels. The annual consumption of heat was used to calculate emission of greenhouse gases from burning the analysed fuels.

The average consumption of briquettes ranged from 6.00 to 7.13 t/year, while consumption of energy was 109–130 GJ/year. The cost of heat production from briquettes ranged 713–785 €/year. This cost was low when compared to fossil fuels and pellets but high in comparison with willow chips. Utilisation of wood briquettes to heat a family house reduced emission of greenhouse gases from 17.4 to 34.3 t $EqCO_2$ compared to fossil fuels.

Therefore, briquettes can successfully compete with fossil fuels in the residential heating market and can be recommended as a cost-effective energy source with a small impact on environment. However systems of support is needed due to high price of biomass boilers.

1. Introduction

In the EU countries, 41.5% of the population live in flats, 34.4% live in detached houses and another 23.3% live in semi-detached houses. Altogether, this makes up nearly 58% of the EU population who live in houses. The highest percentage of the population living in houses is found in Croatia (71.7%). In Poland, 53.2% of the population live in houses, with 48.8% of them living in detached houses and 4.4% in semi-detached houses. The remaining part of the population live in blocks of flats (46.7%) or in other establishments (0.1%) [1].

In the climate which prevails in Poland, households consume a significant amount of energy. They use considerable portions of the heat (40.04%) and electricity (19.46%) consumed in Poland [2]. Therefore, households were the largest final energy consumers (32%). Energy was consumed by households mainly for heating over the period of 1993–2009 (73.1–70.2%). However, the consumption of energy for heating has been slowly decreasing as a result of replacing low-efficiency coal-fired boilers with more efficient ones. Moreover, efforts have been made to thermo-upgrade existing buildings and apply stricter construction standards. The consumption of energy for house heating was followed by that used for heating water (14.4%). Energy used for preparing meals accounted for 8.0% of energy and different electric appliances and lighting consumed 5.4% and 1.8% of energy, respectively. The increase in the amount of consumed energy is attributed to furnishing households with more electric equipment and to changing behaviour patterns of the population [3].

Therefore, the cost of heating is still a large burden for household budgets. According to statistical data, 24.1% of household income was spent on energy and running a household [4], which is the largest portion of the household budget. The expenditures made for running a household and heating houses in other EU countries are also high and account for 21.9% of the budget [5]. Therefore, seeking an opportunity for reducing the cost of generating heat for households is a topical issue. This is especially important in the north of Europe, which also includes north-eastern Poland, where the heating season may be as long as 230 days in a year.

* Corresponding author at: Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn, ul. Oczapowskiego 2, 10-719 Olsztyn, Poland. Tel.: +48 5234838; fax: +48 5234880.
E-mail address: mariusz.stolarski@uwm.edu.pl (M.J. Stolarski).

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There are approximately 7.3 million detached houses in Poland [6], which accounts for 63% of all the households. A considerable part of them use mainly fossil fuels for heating. Solid fuels (mainly hard coal) account for the largest portion of energy produced for heating houses. This is a unique and specific situation because the consumption of coal in Poland accounts for 73% of its consumption in all the EU countries [7]. It is highly disadvantageous because burning so much coal in obsolete low-efficiency boilers produces large amounts of noxious gases and dust emitted to the atmosphere, especially sulphur dioxide and respirable dust and soot, which contain carcinogenic substances. Furthermore, burning coal results in the emission of greenhouse gases to the atmosphere, which has an adverse impact on the condition of the climate, the quality of air and living conditions of the population in the area, which is especially perceptible during the heating season [8]. For this reason, some towns in Poland have banned installing coal-fired boilers in new family houses. Moreover, boiler users are becoming increasing interested in renewable fuels, mainly briquettes and pellets. In rural areas, biomass (straw and wood chips) is used for heating. This is caused by economic and environmental factors, and also by the convenience of using such improved, compact fuels in automatic house boilers [9,10].

Therefore, the aim of the study was to perform an evaluation of heating a family house with sawdust briquettes from an energy and economic point of view, compared to other renewable and fossil fuels, as well as to analyse the emission of greenhouse gases to the atmosphere.

2. Materials and methods

2.1. Location and scope of the experiment

The experiment was conducted in a family house situated in Olsztyn (53°47′ N, 20°30′ E). The total surface area of the house was 247 m^2, including the garage (24 m^2). The materials used for the building construction were characterised in detail and the boiler room was described in an earlier paper [11]. The experiment was started in October 2006. Thermal energy (for heating up water in the central heating system and for producing domestic hot water) was generated mainly from briquettes produced from a mixture of pure sawdust of broadleaved and coniferous trees. An automatic unit for biomass combustion enables one to burn biomass, such as briquette, pellets, seasoned wood chips, sawdust and grain. This study covered three successive heating seasons (2009/2010, 2010/2011 and 2011/2012) and offers a detailed analysis of the use of the boiler room and production of thermal energy during the 6-year period.

2.2. Evaluation of the fuel quality

The quality and quantity of briquettes used for heat production was analysed. The briquettes used during the successive years of the study were acquired from one producer. The fuel was evaluated three times (each time upon delivery) in September 2009, 2010 and 2011. As in the previous studies, the quality of pellets produced from a mixture of oak and pine sawdust, willow chips from coppice cultivated in a field and coal (20–30 mm fraction) as an alternative to the renewable fuels was determined. Representative samples of each fuel were taken for laboratory analyses in each year of the study. The bulk density of solid fuels was determined.

Thermophysical and chemical properties of each fuel were determined in each year in three replications. First, the moisture content was determined with the oven-dry method. For this purpose, the biomass was dried at 105 ± 2 °C in a Premed KBC G-65/250 dryer until solid mass was obtained (PN 80/G-04511). Afterwards, the dried biomass was ground in an analytical mill IKA KMF 10 basic (IKA Werke Gmbh&CO.KG, Germany) using a 1 mm mesh sieve. Next, the higher heating value (HHV) of dry biomass was determined with the dynamic method using an IKA C 2000 calorimeter (IKA Werke Gmbh&CO.KG, Germany) according to standard PN-81/G-04513. Samples weighing 0.5 g each were pelleted in an IKA WERKE C-21 press and left until dry. Biomass tablets were dried in a laboratory oven at 105 ± 2 °C, weighed up to 0.1 mg, placed in a quartz crucible and inserted into a bomb calorimeter for analysis in a pure oxygen environment at 3 MPa pressure.

Based on moisture content and higher heating value, the lower heating value (LHV) of biomass was determined according to Kopetz et al. [12]. Volatile matter, fixed carbon and ash content was determined in the ELTRA TGA-Thermostep (ELTRA Gmbh, Germany) thermogravimetric analyzer in accordance with the following standard methods: ASTM D-5142, D-3173, D-3174, D-3175, PN-G-04560:1998 and PN-ISO 562. The weight of a sample for determination of ash was about 1.5 g. The content of carbon, hydrogen and sulfur in dry biomass was determined in the ELTRA CHS 500 (ELTRA Gmbh, Germany) automatic analyzer according to standards PN/G-04521 and PN/G-ISO 35. The weighted amount for analyses was about 0.15 g. Nitrogen content was determined by the Kjeldahl method with a K-435 mineraliser and a B-324 BUCHI distiller (BÜCHI Labortechnik AG, Schwitzerland), and chlorine content – with the use of an Eschka mixture.

2.3. Economic and energy analysis

During the analysed period, briquettes used for heat production was packed in foil bags, 25 ± 1 kg in each. During the three years of the study, each charge of the fuel to the boiler bin was weighed. This made it possible to determine the actual consumption of fuel during the three full years, in each month, starting with October 2009 and ending with September 2012. This paper presents the consumption in three full cycles: 2009/2010, 2010/2011 and 2011/2012, during the periods from 1 October to 30 September. The amount of briquettes used for heating and its average price was used to determine the monthly and annual cost of heating the house and the production of hot domestic water. The analysis did not take into account the cost of depreciation, the cost of operating the heating unit or the cost of electricity. The inflation rate during the research period amounted to 3.5% in 2009, 2.6% in 2010, 4.3% in 2011 and 3.7% in 2012.

The quantity of briquettes used for heating and its actual lower heating value was used to determine the consumption of heat in GJ/year. The data were used to estimate the annual cost of heating the house with other fuels burned in automatic boilers. Renewable fuels (pellets, willow chips) and fossil fuels (hard coal, natural gas and heating oil) were taken into account. It was assumed that pellets produced from mixtures of oak and pine sawdust, as well as willow chips, were burned in the unit under study with an efficiency of 85%, coal was burned in a coal-fired boiler with an efficiency of 85%, while natural gas and heating oil were burned in a boiler with an efficiency of 90%. Based on the amount of heat produced from briquettes (GJ/year) and the lower heating value of alternative fuels, the amounts which were needed to produce the same amount of energy as from briquettes were determined. The lower heating value of the solid fuels was based on the studies conducted by these authors, where the lower heating values of natural gas and heating oil was taken as 35 MJ/m^3 and 36 MJ/dm^3, respectively. Subsequently, the amount of consumed fuels and their unit prices in the years of the study were used to estimate the annual cost of heating the house. The cost of production of 1 GJ of heat from each fuel was also calculated. Since the study was conducted for 6 years, the value of the Polish zloty was converted into Euros according to