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Analysis of energy consumption for heating in a residential house in Poland

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Abstract

Energy consumption for heating in the residential sector is a significant share in an overall energy balance. The maximum level of energy usage in new buildings is forced by national regulations. In existing buildings, reduction of energy consumption could be achieved by modernization of the buildings or the HVAC (Heating, Ventilation and Air Conditioning) system. In this paper, a single family house located in Poland was chosen. The theoretical heat energy consumption was compared with the actual usage of natural gas recorded over a course of three years. The possible improvements like windows or boiler replacement, were proposed and the economic and environmental effects of modernization stages were estimated. To meet actual Polish law, the primary energy consumption factor EP was decreased from 132 kWh/m^{2}year to 120 kWh/m^{2}year which results in a 4 % reduction of natural gas used in the boiler room for the house's heating.

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Keywords: energy; heating; natural gas; fuels; thermal modernization

1. Introduction

Energy consumption for heating in residential buildings located in most European countries like Poland or the UK is estimated for 60–70 % of total energy usage [1–3]. The possibilities to reduce in energy usage through modernization of a building's envelope, such as in improvement of external walls or roof insulation and window replacement were discussed in [2, 4–8]. Main factors influencing heat costs were discussed in [9].

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The efficiency of different heating systems was described by Siemiończyk and Krawczyk [10]. Cholewa et al. [11, 12] showed that it was possible to achieve increase in efficiency when the system produced hot water only versus the system operating during the heating season only. Bilewicz et al. [13] investigated electricity usage patterns among consumers in Poland and Czech Republic to note the differences and similarities in behaviour models and show issues related to energy efficiency.

Nomenclature

B	total demand for fuel [m^3]
$H_{tr,adj}$	overall heat transfer coefficient by transmission [W/K]
$H_{ve,adj}$	overall heat transfer coefficient by ventilation [W/K]
K	total annual cost of fuel [€]
m	month number [-]
$Q_{H,nd}$	energy need for heating [kWh/year]
$Q_{H,k}$	final energy need for heating [kWh/year]
$Q_{H,ht}$	total heat transfer for heating mode [kWh/month]
$Q_{H,gn}$	total heat gains for the heating mode [kWh/month]
Q_{tr}	total heat transfer by transmission [kWh/month]
Q_{ve}	total heat transfer by ventilation [kWh/month]
θ_{int}	set-point temperature of the building zone [^oC]
θ_e	temperature of the external environment [^oC]
S_z	fixed fee [€/month]
t	time period [Ms]
U	heat transfer coefficient [W/m^2K]
Z_g	variable fee [€/m^3]
$\eta_{H,a}$	heating system efficiency for heat accumulation [-]
$\eta_{H,d}$	heating system efficiency for heat distribution [-]
$\eta_{H,e}$	heating system efficiency for heat regulation [-]
$\eta_{H,g}$	heating system efficiency for heat generation [-]
$\eta_{H,tot}$	total heating system efficiency [-]
$\eta_{H,gn}$	dimensionless gain utilization factor [-]

Aleksiewicz and Rajs [14] presented an analysis of conditions for the effective power source of a residential building in heat, demonstrated energy savings, importance of independence from external suppliers. Topic of energy generation was also discussed in [15–20].

In Poland a significant number of single family houses use natural gas as fuel in the heating system. The forecasts predict significant increase of natural gas consumption in Poland, despite EU energy policy that promotes technologies which are characterized by low environmental impact and high efficiency, whereas the number of coal boilers would be reduced. Gross inland consumption is some countries is shown in Table 1 [4], whereas prices are reflected in Table 2.

Table 1. Growth rate of natural gas gross inland consumption 2012–2013 [21–24].

Country	Belgium	Czech Republic	Germany	Estonia	Spain	France	Latvia	Lithuania	Netherlands	Poland	Great Britain
Growth rate, %	-1.2	3.0	8.3	1.7	-7.7	3.1	-1.0	-18.5	1.9	0.9	-0.9

Table 2. Natural gas prices for households in 2012-2014 [21–24].

Country	Gas prices 2012 [€/kWh]	Gas prices 2013 [€/kWh]	Gas prices 2014 [€/kWh]	Gas prices 2014 [€/GJ]
Austria	0.076	0.077	0.075	20.780
Belgium	0.069	0.066	0.066	18.270
Croatia	0.038	0.047	0.046	12.898
Czech Republic	0.066	0.064	0.055	15.229
Germany	0.064	0.066	0.068	18.850
Hungary	0.048	0.043	0.037	18.850
Estonia	0.050	0.052	0.049	13.620
Italy	0.077	0.083	0.080	22.140
Spain	0.066	0.073	0.075	20.920
France	0.064	0.068	0.070	19.470
Latvia	0.051	0.051	0.048	13.450
Lithuania	0.051	0.060	0.056	15.538
Netherlands	0.076	0.081	0.080	22.180
Poland	0.047	0.047	0.049	13.587
Great Britain	0.052	0.053	0.060	16.656

The aim of this paper is to show energy and fuel consumption for heating. It is a case study of a single family house located in Poland. Improvements of the envelope and installations were proposed to meet actual Polish law which established the maximum value of EP factor at 120 kWh/m^{2}year for this type of building. The reduction of natural gas consumption due to changes was estimated.

2. Description of the building and methodology

2.1. Methodology of energy consumption calculations

The annual energy consumption was calculated according to the International Standard given in PN-EN ISO 13790:2009 [25] and in the Regulation of the Minister of Infrastructure of Poland [26]. The total energy need for heating $Q_{H,nd}$ is calculated as given by Equation (1):

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \cdot Q_{H,gn} \quad [kWh/month] \tag{1}$$

Total heat transfer for heating mode is estimated on the basis of two data: total heat transfer by transmission Q_{tr} and ventilation Q_{ve}.

$$Q_{ve,} = H_{ve,adj}(\theta_{\text{int}} - \theta_e)t \quad [kWh/month] \tag{2}$$

$$Q_{tr} = H_{tr,adj}(\theta_{\text{int}} - \theta_e)t \quad [kWh/month] \tag{3}$$

Moreover total heat gains $Q_{H,gn}$ are calculated as a sum of internal heat gains and solar heat gains.

The calculations were made using the monthly method. Indoor temperature was established as θ_{int}=20 °C in rooms and θ_{int} =24 °C in bathrooms. The dimensionless gain utilization factor $\eta_{H,gn}$ was estimated separately for each month.

The energy need for heating ($Q_{H,nd}$) in kWh/year was estimated using the computer program Audytor OZC 4.8 Pro Edu. Then the total HVAC system efficiency was taken into account, according to formula (4, 5):

$$Q_{H,k} = \sum Q_{H,nd} / \eta_{H,tot} \quad [kWh/year] \tag{4}$$

$$\eta_{H,tot} = \eta_{H,g} \cdot \eta_{H,d} \cdot \eta_{H,e} \eta_{H,s} \quad [-] \tag{5}$$

The values of heating system efficiency was taken from the Minister of Infrastructure Regulation of Poland [27] for actual conditions: a natural gas boiler with the atmospheric burner, panel radiators located under windows with thermostatic valves, central and local regulation, pipes with good insulation located in heated rooms and unheated basement. Hot water was prepared in the same gas boiler and accumulated in a hot water tank. There was no circulation in the hot water system in the house, because it is not common in small houses.

2.2. Description of the investigated house

The analysis was conducted on a single family detached house built in 1965, which was renovated in 2003. Its area is about 115 m^2. It has two heated floors and a basement under half of the building. The building is located in Białystok. (53°07' North latitude and 23°10' East longitude), Poland, where a design outdoor temperature in heating seasons is set at -22 °C and the average outdoor temperature +6.9 °C.

The house's walls were made of brick and 0.08–0.1 m of foamed polystyrene. The insulation of the roof was 0.25 m of mineral wool. During thermal modernization type and size of insulation were chosen to achieve U-values which meet Polish national rules [26] from 2002. The maximum values changed in 2014 (Table 3). In fact, the heat transfer coefficient for the roof is still lower than recommended, while for external walls it is somewhat higher than the current coefficient.

Table 3. Heat transfer coefficients [27, 28].

Barrier	U in house [W/m2K]	Maximum U according to Polish law from 2002	Maximum U according to Polish law from 2014
External wall	0.26	0.3	0.25
Roof	0.161	0.3	0.2
Windows	1.5	2.0	1.3

3. Results of energy and consumption calculation versus actual gas usage

The energy consumption was estimated according to PN-EN 13790 and the total value was 13 507 kWh/year. Table 4 shows the percentage share of different parts of theoretical energy consumption.

Table 4. Theoretical energy consumption for heating.

Energy loss	Share, %
Transmission by external walls	40
Transmission by roof	10
Transmission by windows and doors	24
Transmission by floor on ground	8
Ventilation	18

After taking into account the efficiency of a boiler and the heating system, the final energy consumption was estimated for 115.1 kWh/m^{2}year, while primary energy consumption factor EP = 132 kWh/m^{2}year. According to Polish law EP factor for single family buildings should be lower than 120 kWh/ m^{2}year.

The analysis was carried out for three years. In the course of the test, the outside air temperature for individual months differed significantly (Fig. 1), but taking into account a long period it was possible to get reliable results.

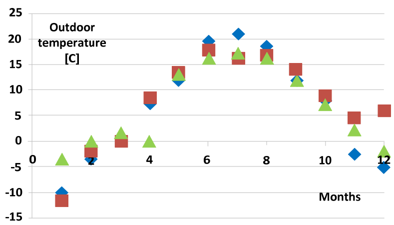

Fig. 1. Outdoor temperature during measurements.

The usage of the house heating devices and the entire system did not change and during the research no repairs or changes in equipment were made. The gas boiler was equipped with a temperature controller.

At night, the temperature controller was programmed to save energy (at night and in case of occupants' absence the temperature was lower by 2 degrees). Results of measurement are presented in Table 5. The price of natural gas included a subscription to purchase gas for heating purposes and the gross price in accordance with the applicable tariffs for gaseous fuels:

- Variable fee 0.3839 €/m^3 including price for gas fuel (0.3113 €/m^3) and network variable rate (0.0726 €/m^3);
- Fixed fee 13.45 €/month including service fee (1.95 €/month) and network fee (11.50 €/month).

The total annual cost of fuel for the building is calculated on the basis of formula (6).

$$K = B \cdot Z_g + m \cdot S_z \tag{6}$$

Table 5. Natural gas consumption and annually costs.

Month	Year I		Year II		Year III	
	Gas consumption [m^3]	gas cost [€]	Gas consumption [m^3]	gas cost [€]	Gas consumption [m^3]	gas cost [€]
1	500	190	580	269	600	281
2	361	145	351	157	383	178
3	321	130	306	124	300	143
4	200	89	205	94	138	82
5	100	51	120	62	100	60
6	57	23	78	45	33	31
7	60	38	37	37	0	17
8	60	38	5	19	34	32
9	73	45	50	48	100	64
10	100	51	150	80	200	110
11	243	117	220	108	227	122
12	300	126	295	137	300	157
Year	2375	1043	2397	1180	2415	1280

4. Analysis

The data given in Table 5 showed what the gas consumption per year for all purposes in the tested house was in the range from 2375 to 2415 m^3, with an average value of 20.8 m^3 of gas/m^{2}year. The analysis of gas consumption in months when the heating system was not operating shows that about 40–50 m^3 of gas are used for hot water preparation and cooking each month, so nearly 300 per year (about 13 % of total natural gas consumption in the household). Therefore average gas consumption for heating was 18.2 m^3 /m^{2}year.

The most significant factors contributing to gas consumption are the building type (the number of external walls), external walls and roof insulation and U-values, average indoor temperature and inhabitants' habits like for instance the frequency of cooking and water heating, length of room ventilation, length of holiday time spent away from the house. The average cost of gas used in a household was about 0.48 €/m^{3}of gas. Changes of gas prices could be observed for example in May, when estimated cost was from 51 € in first year of measurements to 60 € in the third, while the gas consumption was constant: 100 m^3 in all cases. During the test period, the highest gas cost per m^3 in summer was observed although gas consumption was low which was connected with the fact that fixed costs determine a total price of gas.

The analysis of heat transfer coefficients (Table 4) shows that the house renovated in 2003, according to Polish law from 2002 does not meet standards in 2014. Also EK and EP factors are higher than recommended in actual law. Therefore, it is possible to make some improvements in the house due to the technical conditions considered replacement of windows (typical new windows with U=1.1W/m^{2}K); replacement of boiler (new one with high efficiency).

In this case final energy consumption factor EK was calculated as 106 kWh/m^{2}year, while primary energy consumption factor EP amounted 122 kWh/m^{2}year, so slightly higher than recommended. To meet the actual requirements of Polish law, it would be necessary to install windows with U-value 1.0 W/m^{2}K. The gas consumption would be reduced by 3–4 %.

The other possibility to reduce EP value is providing a renewable source of energy in the hot water system. The easiest from a technical point of view is using panel solar collectors to prepare hot water in a bivalent system with a gas boiler. In a climate like in Poland it is not recommended to use solar collectors as the only energy source, but it becomes more and more popular to use them together with a conventional boiler. Of course in this case total heat load and final energy consumption for heating will not be changed.

5. Conclusion

The paper shows theoretical heat energy consumption and actual fuel usage in the single family house located in north Poland. The average annual cost of natural gas used for heating, hot water preparation and cooking was 1167 €, while gas consumption 2397 m^3. The factor of gas cost for a square meter was about 10.1 €/m^2.

Most houses built or renovated in Poland a few years ago have heat transfer coefficients slightly higher than is recommended nowadays so also final energy consumption factor EK and primary energy consumption factor EP could be above maximum values. To adjust the buildings' energy characteristic to the requirements of actual law, it would be necessary to decrease heat transfer coefficients of external barriers (windows replacement, external walls insulation), improve HVAC system (for instance installation of thermostatic valves, automatic control if it does not exist in the system) or implement renewable energy sources like heat pumps, biomass boilers, solar collectors or PV cells.

Nonetheless, the saving of fuel and ecological effect could be relatively low, like in the analyzed house, about 3–4 %, compared with effects of the modernization of old buildings with very poor insulation and HVAC system efficiency. According to [29] insulation of external walls in old buildings in Poland could reduce the energy consumption on average from 26.6 to 30.5 %.

After total modernization of buildings envelope and HVAC systems, it is possible to achieve even a 50–70 % reduction of fuel consumption and operating costs.

It is necessary to remember that real savings depend also on many factors connected with usage pattern (for example indoor temperature during the day and night), real heat transfer coefficient values which sometimes differ significantly from the theoretical showed in house designs or changes in variable and constant parts of the tariffs of a fuel supplier.

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