

Analysis of the Criteria for Selecting Heating Systems for Residential Buildings in Cold Climate

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How to choose a heating system for a residential building? That is an important question for builders and owners of the buildings in Lithuania. Approximately the heating season in Lithuania starts by October 15th and ends on April 15th. During this period, the average outdoor air temperature is about 0°C. Many of the new single-family buildings in Lithuania are sold not completed as the new owners want to be free in choosing interior materials and engineering equipment. For this reason, many engineering decisions must be taken by the owner of the building, who is usually not a professional in the field of engineering. When choosing a heat source, it is always necessary to distinguish between many “for” and “against” arguments. Every heating option has both advantages and disadvantages. There is also a striking balance: the same heating method can never be either very comfortable and at the same time very cheap. When making a final decision, it is always recommended to compare the ratio of heat to the price and comfort, of course, taking into account energy and fuel price forecasts.

The article provides information that helps the building owner to navigate in the field of different engineering solutions that affect the future maintenance costs, efficiency, environmental aspects and comfort level of the building.

Keywords: residential building, heating system, energy prices.

The building sector accounts for 40% of the final energy consumption and 36% of CO₂ emissions in Lithuania and EU countries (European Commission 2018). Space heating and hot water accounts for about 26% of all final energy consumption in the EU (Bosh et al. 2008). European Commission has set the new target of reducing the CO₂ emissions by 90% for the building sector by the year 2050 (European Commission 2011). As reported in the 2014/15 European work program, more than 17% of the primary energy savings potential of the EU for 2050 (European Commission 2015) to the building retrofit is related.

The largest part of buildings in Lithuania was built in the second part of 20th century. About 60% of Lithuanian population resides in multi-family buildings constructed during 1961–1990. About 40% of people in Lithuania lives in one or two-family buildings (EHPA 2017).

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Introduction



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Approximately heating season in Lithuania starts by October 15th and ends on April 15th. According Lithuanian legislation for thermal energy supply and consumption heating season can be started when the average outdoor air temperature is below +10 °C for three consecutive days, and complete when the temperature is three consecutive times higher than + 10 °C (Rules for supply and consumption of thermal energy). During this period, the average outdoor air temperature is about 0 °C. According to the regulations comfort temperature in living rooms and offices during a heating season should be in the range of 18 to 22 °C. Average energy consumption for space heating is 101kWh/m², domestic hot water heating takes 11.2kWh/m² and 75.1kWh/m² is used for other's needs (EHPA 2017). Compared to the other EU countries with similar climate conditions, energy consumption for residential heating is approximately 1.8 times higher in Lithuania (Streimikiene 2014).

The survey (ESO 2017) performed in 2016 showed that in the major Lithuanian cities two-thirds of the population use centralized district heating (CDH), the remaining - gas heating (18%) or solid fuel - firewood or charcoal (15%). Other heat sources, such as electricity, geothermal heating or pellet boilers, are used by a very small proportion of the population. According to the results of the survey, the choice of the heating method is influenced by the price and convenience. The priority for these heating criteria was provided by 42% and 39% of respondents during the survey, respectively. The comfort was especially emphasized by those residents whose home was heated by natural gas (44%), but the price was also a very important factor for them (38%).

When choosing a heating source, it is always necessary to distinguish between many arguments. Clearly, every heating option has both advantages and disadvantages. This article aims to provide information that helps the building owner to navigate in the field of different engineering solutions that affect the future maintenance costs, efficiency, environmental aspects and comfort level in the building.

Lithuania has typical European continental climate with warm, dry summers and fairly severe winters. January is the coldest month with daytime temperatures usually around -5 °C. However, periods with temperatures of about -20 °C or above 0 °C can last for few days or weeks. Furthermore, heavy snowfall or even snowstorms are also possible. The weather is often windy, cold and humid due to proximity to Baltic Sea. Temperature in summer can reach 20-25 °C. July is the warmest month with an average temperature of 18 °C. Temperature peaks above 30 °C can occur and last for few weeks. Rain with heavy thunderstorms is common occurrence. On another hand, climate change cannot be ignored; winters are getting warmer with only a few days or weeks with snowfall.

According to Lithuanian regulations it is still recommended to use a climatic data from 1961 to 1990 (RSN 156-94) although official data from later period (average temperature of period 1981-2010) also exists (Galvonaitė A. *et al*). The average temperatures in Kaunas city are presented in Table 1. These temperatures are near the average values of Lithuania with 0.7÷0.8 deviation from Lithuanian average values. (Galvonaitė A. *et al*)

Climate conditions of Lithuania

Table 1

Average (1981-2010), highest and lowest (1900-1990) monthly temperature in Kaunas city

Temperature, °C	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Avg. (7.25)	-3.25	-3.25	0.75	7.25	12.75	15.75	18.25	17.75	12.75	7.75	1.75	-2.25
Highest	9.3	14.8	20.2	27.9	31.4	32.8	34.9	34.7	29.7	23.9	16.7	11.1
Lowest	-35.8	-36.3	-26.3	-12.0	-4.9	-0.2	4.4	0.3	-3.2	-13.7	-22.5	-28.5

Lithuanian energy market is quite unique in the European context; district heating occupies more than 55% of the total thermal market (LSTA 2011). Quite frequently, natural gas 11.9%, biofuel 25%, coal 5.2% or in some cases electricity 0.22% is used for building heating systems (EHPA 2017).

The average price of district heating in Lithuanian cities is 0.05€/kWh (Table 2). In recent years, district heating energy price dropped by 8% (LSTA 2018). Switching from natural gas to biofuel reduced the district heating energy price significantly in the last five years. Due to a dramatic decline in oil and natural gas prices, conventional fuel prices also decreased by 35% in the last five years. Global events show that in the near future, the price of energy tends to increase.

In 2017 natural gas prices in Lithuania for citizens varied from 0.38 to 0.64€/m³, depending on the consumption per year. Electricity prices varied from 0.077 to 0.124€/kWh, depending on a selected tariff (Regula 2018).

The international situation in the price of biofuels (firewood) does not have an important direct impact, but the price of petroleum products has, as these are needed for the production of biofuels and transportation. Therefore, it is also expected that prices will increase in the field of biofuel.

Despite the minor fluctuation in recent years, it is noticeable that traditional energy (biofuel, natural gas, electricity, centralized district heating) prices are increasing slowly.

Year	Eur/MWh				
	CDH ¹⁾	Natural gas ²⁾	Electricity ³⁾	Firewood ⁴⁾	Wood pellets ⁵⁾
2015	62.6	45.2	127.0	31.6	37.8
2016	57.1	41.9	113.0	35.5	33.0
2017	50.1	40.3	113.0	37.3	36.5

¹⁾ average CDH energy price for residents (LSTA 2018);

²⁾ the price of energy from natural gas for residents using from 500m³ to 20 000m³ of gas per year (Regula 2018);

³⁾ one-time zone tariff, "Standard" source (Regula 2017);

⁴⁾ the price of energy from chopped birch firewood with 20% humidity;

⁵⁾ the price of energy from deciduous trees wood pellets.

There are different traditions of purchasing of residential buildings in different countries. It is popular to buy a residential building with unfinished construction works in Lithuania as the owner feels free to make most acceptable interior and building comfort solutions. One of the decisions that owners prefer to make according their lifestyle and employment is selecting the heat source. Apart from other criteria discussed in the paper, it is necessary to evaluate how the selected heat source influences the overall energy efficiency of a building. The energy efficiency of a building (energy performance class - EPC) is a state-regulated criterion, introduced as one of the means to implement the adopted cross-border agreements (Directive 2010/31/EU) and thus to manage climate change.

The energy performance class of buildings, that has the building permit issued after 1st January 2016, should not be lower than A, after 1st January 2018 - not lower than A+ and after 1st January 2021 - energy performance class must reach A++ class (STR 2.01.02:2016).

During the energy performance assessment, the building is analyzed according to 7 criteria for classes A and A+ and 8 criteria for class A++. Heat source used in heating and domestic hot water systems has direct influence for two criteria used in A and A+ evaluation and for 3 criteria in A++ evaluation.

In most cases, the selection of heat source for a building and the modeling of its energy performance class is already provided during the design stage. Therefore, it is important for the owner of

Energy prices in Lithuania

Table 2

Energy price dynamics in 2015-2017 (VAT included)

The influence of the heating system and the heat source to the energy efficiency of the building

the building to know if the heating alternative he wants to choose is not worse than the designed case. For example, for a residential building of 150m² with specific heat losses of 82.39W/K, natural ventilation, and a heat pump used for heating (with thermal energy source – air) – energy performance class A+ would be qualified. If the owner would change the designed heat source into solid fuel or gas boiler, such building would be qualified as a B class building.

One of the quantitative indicators according to which the owner can compare different heating sources is the calculated efficiency of the building heating system η_{hs} , which is calculated according to the formula (STR 2.01.02:2016)

$$\eta_{hs} = \eta_1 \cdot \eta_2 \cdot k_{2.reg}, \quad (1)$$

where η_1 - coefficient of the heating system automatic regulation level (Table 3), η_2 - coefficient of the thermal efficiency of the heat source (Table 4), $k_{2.reg}$ - correction factor for evaluating the efficiency of a heat source when coefficient of the efficiency is declared by the producer of the heat source (Table 5).

Table 3

The coefficients of the heating system automatic regulation level η_1

Regulation equipment	η_1
No regulation equipment	0.88
Regulation equipment controls the heating system in the whole building: only thermostatic regulators for heat emitters or inside/outside thermostat are installed	0.93
Regulation equipment controls the heating system in the whole building: both thermostatic regulators for heat emitters and inside/outside thermostat are installed	0.98
Regulation equipment controls the heating system in the part of the building	0.90

Table 4

The coefficients of the thermal efficiency of the heat source η_2

Heat source	η_2	Heat source	η_2
Central heat networks, manual regulation	0.90	Electric heating, manual regulation	0.90
Central heat networks, automatic regulation	1.00	Electric heating, automatic regulation	1.00
Gas boiler, manual regulation	0.80	Heat pump, energy taken from the air	$\eta_{SPF} = 3.00$
Gas boiler, automatic regulation	0.94	Heat pump, energy taken from the soil	$\eta_{SPF} = 4.00$
Radiant gas heater	1.00	Heat pump, energy taken from the water	$\eta_{SPF} = 4.50$
Liquid fuel boiler, manual regulation	0.75	Furnaces	0.50
Liquid fuel boiler, automatic regulation	0.87	Open fireplace	0.20
Solid fuel boiler, manual regulation	0.70	Fireplaces with a capsule, when the combustion process uses warm indoor air	0.30
Solid fuel boiler, automatic regulation	0.85	Fireplaces with a capsule, when the combustion process uses outdoor air	0.50

Table 5

Correction factors $k_{2.reg}$ for evaluating the efficiency of a heat source when the coefficient of the efficiency is declared by the producer of the heat source

Heat source	$k_{2.re}$
Gas boiler	0.85
Liquid fuel boiler	0.86
Solid fuel boiler	0.82
Electric heating	0.90
Other cases	1.00

If the efficiency of the selected heating system alternative of the building η_{hs} is not lower than the one according which the energy performance class of the building has been modeled, the user can make a decision without additional calculations, otherwise it is necessary to make additional calculation and check if the requirements of the legislation are met. Due to unfavorable results of calculations, i.e., when the required energy performance class cannot be achieved, it may be necessary to increase the insulation layers of the building partitions or maintain a design heat source.

The other criteria according to which decision of heating source selection can be made are more related to habits and individual situation of a resident. One of these criteria is space for equipment, which is essential for modern homes. It is important to emphasize that the peculiarities of daily maintenance remain an urgent issue for building residents. Furthermore, environmental pollution has long been ignored; nowadays local environment pollution is one of the most important criteria. To have a more reliable heat source, an additional (alternative) heat generator is often considered. Therefore, the chosen heat source should be compatible with other alternatives.

In this case, the heat source is a boiler room, i.e., components, that can vary widely depending on the selected heating type. Meanwhile, the heating system includes pipelines with heating devices or without them (in underfloor and panel heating systems).

Detailed descriptions of different heating system alternatives are presented in Table 6.

Heating source	Criterion			
	Space for equipment	Smooth/fast power control	Daily maintenance	Local environment pollution
Solid fuel (firewood) boiler without accumulation tank	~ 6m ² + space for firewood storage (required area depends on the amount of firewood that is needed to accumulate)	uneven power regulation	bringing firewood to the boiler room, removing ashes	a significant amount of particulate matter, carbon dioxide, nitrogen oxides are released into the local environment
Solid fuel (firewood) boiler with accumulation tank	~ 8m ² + space for firewood storage (required area depends on the amount of firewood that is needed to accumulate)	accumulation tank ensures smooth power control		
Wood pellet boiler	~ 8m ² + space for wood pellet storage (required area depends on the amount of wood pellets that is needed to accumulate)	wide power regulation	filling wood pellet tank, removing ashes	
Natural gas boiler (condensing boiler with heat exchanger for domestic hot water)	up to 2m ²	wide and smooth power regulation	no need	an insignificant amount of particulate matter, carbon dioxide, nitrogen oxides are released into the local environment
Heat pump, type "air to water"	up to 4m ²			no local pollution
Heat pump, type "soil to water"	up to 4m ²			
Centralized district heating	up to 2m ²			

Criteria for selecting heating systems for residential buildings

Table 6

Description of heating system alternatives according to different criteria

The solid fuel boiler room consists of a solid fuel boiler, a stack unit, a storage tank for heat storage, a domestic hot water tank, circulating pumps, regulating equipment, controller, and pipelines. In recent years, the level of automation of solid boilers has been improved, which has simplified boiler care and increased system efficiency (Cerneckiene et al. 2018).

The natural gas boiler room is the simplest. Gas boiler can be installed in the kitchen or bathroom. On the other hand, specific technical requirements for a room must be fulfilled before gas boiler installation. The height of the room must be at least 2.2m. The room must have a window of 0.05m² for each cubic meter of the room. If the volume of the room is 20.0m³ or more, the window area must be at least 1.0m². In most cases the gas boiler with domestic hot water preparation function is mounted on the wall, and the pipelines from the heating system as well as gas supply pipe are connected to the boiler. This option of the gas boiler was evaluated in further calculations. Evaluating the alternative heat source - the heat pump, the underground collector (horizontal or vertical) in the yard must be included in the boiler room installation. Instead of underground collector outdoor air can be used as heat source. However, in cold climates efficiency of this type of heat pump is lower (Honkapuro and Koreneff 2017; Stuart et al. 2013). Other elements of the boiler room with the heat pump are the heat pump module with compressor and circulation pumps, the domestic hot water tank and other auxiliary boiler control equipment. An important factor is that heat pumps work effectively only with low-temperature heating systems, e.g., underfloor heating. The boiler room is very compact for those buildings that can connect to district heating network: it consists of the equipment for reducing the district water parameters (temperature, pressure, etc.), a heat exchanger for heating systems as well as for domestic hot water system, circulating pumps, thermal energy accounting devices.

There are other heating types such as direct electric heating, liquid gas boilers or liquid fuel boiler. However, due to the low popularity of such heating types in recent years, these heating types were not evaluated.

The economic benefit is often the most urgent issue when evaluating and choosing the source of heat generation. The economic benefit in this study was estimated by calculating the discounted price of thermal energy. It is an economic indicator that estimates cost over a period of 10 years. It was assumed that the temperature in the building is +20°C and the annual heat demand for heating and hot water is 15,000kWh. It was also assumed that the entire cost of the heating system is covered during the installation. The lifespan of the heating system was considered to be ten years. Parameters used for financial assessment of the heating systems are presented in Table 7.

Investments into the heat source vary widely and depend on the chosen equipment, manufacturer, the level of automation, cost of gas, cost of energy from district heating and the complexity of the installation work. Average investment into a heating source of 150m² A class single-family building in Lithuania with underfloor heating is presented in Table 8. Investments in the heat source

Table 7

Parameters used for economic calculations

The lifespan of the heating system, years	10
Specific district heating energy price (average), Eur/kWh	0.050
Specific energy from natural gas price (average), Eur/kWh	0.040
Specific energy from solid fuel (average), Eur/kWh	0.047
Specific energy from wood pellets (average), Eur/kWh	0.106
Specific electricity costs (standard), Eur/kWh	0.113
Index for energy prices, % per year	2.0
Interest capital, %	2.5
Running costs, %	1.5

Heating source	Average primary installation cost, Eur	Fuel cost for the 10-year period, Eur	Total installation and fuel cost for the 10-year period, Eur
Solid fuel (firewood) boiler without accumulation tank	1800	6249	8566
Solid fuel (firewood) boiler with accumulation tank	4300	5873	11441
Wood pellets boiler	4100	5809	11089
Condensing gas boiler with heat exchanger for domestic hot water	2900	7490	10849
Heat pump, type "air to water" SPF*=3.5	6500	5504	12349
Heat pump, type "soil to water" SPF*=4.5	11800	4526	16750
Centralized district heating	3200	8377	12304

* Seasonal Performance Factor

were evaluated by comparing prices of at least three suppliers (gas and district heating) during the first quarter of 2018 in Kaunas city. It was assumed that distance (connection length) from the building to the gas or district heating network is up to 10m.

In Lithuania, some limited subsidy systems and funds for renewable energy installations exists since 2005. Depending on a project, it is possible to apply for a subsidy covering from 25 to 100% of initial costs. For example, it is possible to get a subsidy up to 30% for the single-family building (but only for buildings older than five years), up to 40% for multifamily buildings and up to 100% for hospitals. In this study subsidy for a heat source installation were not assessed.

The obtained data (Fig. 1) shows that heating systems with solid fuel or wood pellets boilers are the cheapest way to cover the heating and domestic hot water demand of the residential building, especially if it is possible to buy firewood cheaper than the average market price. The average

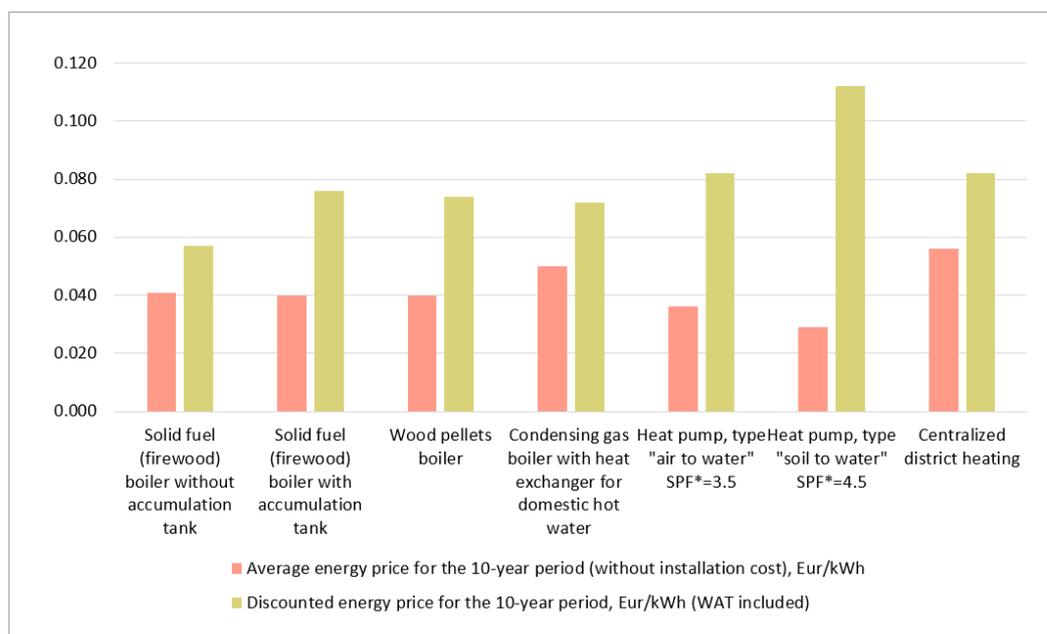


Table 8

Average investments into a heating source of 150m² A class single-family building in Lithuania with underfloor heating

Results

Fig. 1

Energy prices for heating (VAT included)

energy price of this system for the 10-year period (without installation cost) is 0.040Eur/kWh. The most expensive heating system is a system with a heat pump (type “soil to water”). However, if investments in the installation of this type of heating system are not evaluated, this type of heat source would give an energy price of 0.029Eur/kWh.

Regarding the comfort level, the least comfortable heat source would be solid fuel boilers. Due to the daily maintenance of the boiler, i.e., it is necessary to bring firewood to the boiler room, clean the boiler or remove the ashes every day. It can be argued that gas boiler or centralized district heating as a heat source are the most attractive regarding comfort, investment, and energy costs for the 10-year period. However, natural gas or district heating networks are not available in all areas. Therefore, choosing a heat source for a building that cannot be connected to the natural gas or district heating networks and at the same time seeking to achieve comfort and ecological environment, a better choice would be to use “air to water” heat pump. The energy price of this system is higher and exceeds 0.036Eur/kWh excluding installation. However, the investments in this system are lower by 50% compared to “soil to water” heat pump system.

Recommendations for the selection of the heat source for a residential building in a cold climate country are presented in Fig. 2.

Fig. 2

Recommendations for the selection of the heat source for a residential building in a cold climate country

Existing infrastructure	Centralized district heating network	Natural gas network	No special infrastructure for heating				
	Individual heating substations	Condensing gas boiler with heat exchanger for domestic hot water	Heat pump		Solid fuel boiler		
Equipment			Type: “air to water” SPF=3.5	Type: “soil to water” SPF=4.5	Wood pellets boiler	Solid fuel boiler with accumulation tank	Solid fuel boiler without accumulation tank
Efficiency of the heating system of the building, η_{hs}	0.792 ÷ 0.980	0.704 ÷ 0.920	2.790 ÷ 2.940	3.720 ÷ 3.920	0.748 ÷ 0.833	0.616 ÷ 0.686	0.616
Daily maintenance needs	not required	not required	not required		depends on outdoor conditions and equipment - from 2 times per week	depends on outdoor conditions and equipment - from 2 times per week	depends on outdoor conditions - from 2 times per day
Primary installation cost in grades*	3	2	6	7	4	5	1
Fuel costs in grades*	7	6	2	1	3	4	5
Common installation and fuel costs for 10-year period*	5	2	6	7	3	4	1

*1-lowest, 7-highest

The figure shows quick evaluation of possible heating alternatives and gives qualitative and quantitative comparison of different types of heating. The efficiency of the heating system of the building (n_{hs}) is calculated evaluating possible manual and automatic regulation both of the heating source and heating system. It is noticeable that automatic regulation and additional equipment plays an important role in the whole system evaluation, because automatically regulated system with a solid fuel boiler and accumulation tank ($n_{hs}=0.686$) can be near to the condensing gas boiler without automatic regulation ($n_{hs}=0.704$). Quantitative data for the grade evaluation of the heating system installation and exploitation costs is taken from Table 8. Grade "1" indicates the lowest cost level and grade "7" indicates the most expensive implement.

Analyzing the data presented in Fig. 2 it should be noted that because of the rising economic situation in the country, increasing income and people business ones of the most important criteria for choosing the most suitable heating system is its reliability and efficiency. Operating costs of the heating systems are not so important as it was 10 or 15 years ago. The data presented in this study reflects the current state of installation and operation of heating systems.

It is assumed that the situation will change slightly in the future. Looking at the prospect of 20-30 years, oil and its price will be a major and decisive factor in the global economic development. Changes in oil prices will affect natural gas, energy for transport and other energy sources prices. The data presented in Fig. 2 should be relevant in the future while selecting the heating system for residential buildings.

Due to good infrastructure, Lithuanian consumers usually have many alternatives in choosing a heat source – from district heating to the gas boilers. Many objective and subjective criteria should be taken into account in order to determine the most suitable heat source. The main criteria that should be evaluated are: installation and exploitation costs, daily maintenance needs, additional space for the equipment and the influence of selected heat source to the energy efficiency of the building.

The lowest installation and fuel cost for the 10-year period can be reached by using solid fuel (firewood) boiler without accumulation tank (8566Eur) if daily maintenance of the boiler is acceptable. When the infrastructure of gas supply network is available a condensing gas boiler with heat exchanger for domestic hot water can give minimal maintenance and space saving with 26,6% increase of total price (10849Eur). Higher primary installation cost (11800Eur) for heat pump (type "soil to water") does not guarantee the lowest total price for the 10-year period.

Since there are many options to combine the heat source for a building, additional analysis could be made to evaluate the cost of heat pump combined with solar panels etc.

Conclusions

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