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# RENEWABLE AND NON-RENEWABLE PRIMARY ENERGY FACTORS FOR LITHUANIAN A++ BUILDINGS' HEATING

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**Abstract.** Lithuanian A++ buildings are highly energy-efficient, but their heating systems still require energy to operate, and the type of energy used can have a significant impact on the environment. By considering both non-renewable and renewable primary energy sources, policymakers, builders, and building owners can make informed decisions about reducing carbon emissions, improving energy efficiency, and promoting sustainable energy use. This article examines the impact of different heating systems on primary energy (PE) consumption in buildings of different functions (single-dwelling residential building, multi-dwelling residential building, office building) with the same energy class (A++), to determine how much primary energy (renewable and non-renewable) is consumed for building operation and investigate changes in $CO_2$ emissions depending on heat source. Primary energy use is a crucial benchmark for achieving energy efficiency goals in the European Union, but the use and calculation of primary energy factors can be contentious as they can affect the results of various analyses. The study demonstrates that the choice of the heat source is a complex task, as it requires considering the share of renewable primary energy in the final primary energy consumption, particularly in "Nearly zero energy buildings" (Lithuanian A++ buildings) where most of the energy consumed should come from renewable sources.

**Keywords:** primary energy, non-renewable energy, renewable energy, energy class, energy efficiency; $CO_2$ emissions.

**JEL Classification:** P18.

## Introduction

The built environment has become a key area of focus for reducing carbon emissions and addressing the impacts of climate change. The energy consumption of buildings is a major contributor to global greenhouse gas emissions, with heating being one of the largest energy demands. The current decade is crucial for achieving a secure, sustainable, and affordable energy system, and there is significant potential for accelerating progress if decisive measures are taken promptly. According to the World Energy Outlook report (2022), through investments in clean electricity, electrification, and modernized grids, there are clear and cost-effective means to reduce emissions more swiftly while simultaneously lowering electricity costs from their current levels (IEA, 2022).

Before the first "oil crisis" in 1973, energy efficiency building codes and other measures to decrease energy use in buildings were almost non-existent (Deringer et al., 2004). Subsequently, numerous definitions such as "low energy", "net energy", "passive", and "plus energy houses" have been formulated, in addition to designations like "zero carbon" and "carbon neutral buildings" (Mlecnik, 2012). Low-energy buildings with highly efficient heating and cooling systems are emerging as a promising solution, as they offer a significant reduction in energy use and greenhouse gas emissions. In the European Union, primary energy use is used as a benchmark for achieving energy efficiency goals. As a result, the accurate determination of Primary Energy Factors [PEFs] is important (Gustafsson et al., 2017). Primary energy consumption and $CO_2$ emissions depend heavily on energy supply for both $CO_2$-neutral and low-energy buildings. Hamels (2021) highlighted the European Union's commitment to significant reductions in both $CO_2$ emissions and primary energy consumption, with the electrification of transportation and heating services playing an increasingly important role. To properly assess the impact of electricity-consuming technologies in this context, it is necessary to use appropriate conversion

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factors, such as $CO_2$ intensities and primary energy factors. The use and calculation of conversion factors can be a contentious matter, as they have the potential to impact the results of various analyses. PEFs can have an impact on a building's qualification as a nearly zero energy building, as they are involved in the interactions between electric Heat Pumps [HP] and solar panels (Reda & Fatima, 2019). Studies show that conversion factors are utilized in a range of applications, with the most common applications being the evaluation of building renovation scenarios or the assessment of design choices for new construction projects (Asim et al., 2020; Barrella et al., 2020; Chen et al., 2020; D'Agostino et al., 2019, 2021; Las-Heras-Casas et al., 2021; Mata et al., 2019; Niemelä et al., 2017).

The use of PEFs is an essential part of energy statistics and policy-making, as it allows for the comparison of energy consumption and efficiency across countries. However, the way PEFs are calculated varies across European countries. Some countries have adopted different approaches to calculate Primary Energy Factors (PEFs) for energy sources. For instance, Germany and Sweden use a physical approach based on the energy source's physical properties, such as the calorific value, while the United Kingdom uses a market-based approach that considers factors such as the cost and availability of the source. In the physical approach, the PEFs are calculated based on the amount of primary energy required to produce a unit of usable energy from the source. In contrast, the market-based approach reflects the market conditions of the source, such as supply and demand, and can vary over time. Both approaches have their advantages and disadvantages, and the choice of method depends on various factors, including the country's energy policy goals and data availability. The differences in PEFs calculation can affect how energy efficiency and consumption are perceived in different countries and can impact the development of energy policy and targets. Therefore, understanding the variations in PEF calculation methods is crucial for international energy comparisons and policy-making. Hamels' (2021) study shows that conversion factors based on the electricity mix from a past time, also known as retrospective conversion factors, continue to be the prevailing approach in the literature (Bianco et al., 2017; Hitchin, 2019; Jarre et al., 2018; Stinner et al., 2017; Vandermeulen et al., 2017). When using retrospective conversion factors, there is a high likelihood of the results becoming obsolete, considering the fast-changing electricity mix in Europe. For instance, if a primary energy use calculation for a heat pump is based on a PEFs that corresponds to an electricity mix from a few years back, it could lead to issues, particularly if the results are intended for future policy-making. To account for potential modifications in the electricity mix, some recent studies have chosen to use prospective conversion factors (Bastida-Molina et al., 2020; González-Prieto et al., 2020; Hirvonen et al., 2019; Jarre et al., 2018; Lausselet et al., 2021).

Over the last few years, significant changes have taken place in the areas of energy regulation, certification, and implementation in Lithuania. Lithuania entered the A++ energy efficiency building era in 2021, and the standard for the energy performance of buildings calls such buildings "Buildings that are almost energy-free", which, according to the Energy Performance of Buildings Standard, is "Nearly Zero Energy Buildings" (nZEBs). In Lithuania, the non-renewable energy ($f_{PRn}$) and renewable energy factors ($f_{PRr}$) as well as $CO_2$ emission factors ($M_{CO2}$), described in the technical Regulation for construction – STR 2.01.02:2016 "Design and certification of the energy performance of buildings", have been changed for several consecutive years through amendments to the Regulation (2016, 2019, 2020, 2022).

The aim of this study is to evaluate how the primary energy consumption in buildings changes when the heat demand for heating is met using different energy sources in buildings of different functions (single-dwelling residential building, multi-dwelling residential building, office building) but with the same energy class (A++). This study will help evaluate which heating sources consume more renewable than non-renewable primary energy. Such an analysis may be valuable to update the Lithuanian technical Regulation for construction and to understand the impact of heating sources on nZEB buildings.

Different heating systems are being studied to determine how much primary energy (renewable and non-renewable) is consumed for buildings operation. Changes in the amount of $CO_2$ emissions from buildings due to changes in heat production are being investigated. The research questions answered in this article are as follows:

1. How does the amount of primary energy in the buildings being studied change when heat is supplied by: (1) a biomass boiler, (2) natural gas boiler, (3) heat pump, and when (4) district heating (DH) is used in the building?
2. How does the amount of primary energy in the buildings change when the energy source for the heat pump is (1) renewable energy (biomass) and (1) non-renewable energy (electricity from non-renewable sources)? What portion of primary energy is made up of renewable primary energy and non-renewable primary energy?
3. How does the overall amount of $CO_2$ emissions from the buildings change when heat is supplied by different fuels and production unit compositions of (1) heat pump, compared to when heat is obtained from (2) a biofuel boiler, (3) a natural gas boiler and when the building has a (4) DH system installed?

## 1. Methodology

### 1.1. Primary Energy and Primary Energy Factors

Primary energy refers to the energy contained in raw materials such as coal, oil, natural gas, and uranium, which have not undergone any conversion process. It is the energy that is extracted from nature and used to produce electricity, heat, and other forms of energy. Primary energy factors are coefficients that are used to convert primary energy into useful energy forms such as electricity, heat, or mechanical energy. They are used in energy calculations to determine the amount of primary energy that is required to produce a certain amount of final energy. Primary energy factors depend on the type of primary energy source and the technology used to convert it into usable energy. As per the Energy Performance of Buildings Directive, the computation of energy performance ought to be based on a methodology that may vary at national and regional levels while incorporating established European standards (D'Agostino, 2015; Gustafsson et al., 2017). The assessment of a building's energy performance is heavily influenced by the numerical values assigned to Primary Energy Factors, making it crucial to exercise caution in the selection of appropriate PEFs (Gustafsson et al., 2017). Primary energy factors and $CO_2$ emission factors used in Lithuanian regulation are presented in Table 1.

Table 1. Values for the non-renewable primary energy factor $f_{PRn}$ (units), the renewable primary energy factor $f_{PR,r}$ (units) and the $CO_2$ emission factor $M_{CO2}$ ($kgCO_2$/kWh) of the energy sources used for energy production (STR 2.01.02:2016)

| Source of energy for heat production [1] & electricity production [2] | $f_{PRn}$, unit | $f_{PRr}$, unit | $M_{CO2}$, $kgCO_2$/kWh |
|---|---|---|---|
| Biofuels (wood, straw, biogas, bio-oil, etc.) [1];[2] | 0.2 | 1 | 0.04 |
| Natural gas [1] | 1.1 | 0 | 0.22 |
| Heat from district heating (Lithuanian average) [1] | 0.62 | 0.63 | 0.10 |
| Average of different ways of generating electricity (for electric air-to-air heat pump) [2] | 2.3 | 0.2 / (1*) | 0.42 |

* According to the order determined by the LST EN 15450:2008 Standard, renewable primary energy from heat pump (unit) $f_{HP.PRr}$ = 1.

Heat pumps with an SPF higher than 2.5 are considered a renewable source according to ISO 52000-1: 2017. The non-renewable primary energy of the electric air-to-air heat pump analysed in this study is calculated using the PEF of the average of the different electricity generation methods (fPRn = 2.3), but the renewable part of the primary energy is calculated using fHP.PRr = 1 (see Table 1). Air-to-air heat pump's (energy source – biomass) primary energy is calculated using the PEFs for biofuel.

### 1.2. Reference buildings

Reference buildings of this study are a single-dwelling residential building (average heat demand – 82.63 kWh/m$^2$), a multi-dwelling residential building (average heat demand – 48.91 kWh/m$^2$), and an office building (average heat demand – 40.68 kWh/m$^2$). The average heating demand is calculated by taking the values given in Table 2 and according to the methodology (Eq. 1) for calculating normative thermal energy demand for building heating, described in Lithuanian regulation (STR 2.01.02:2016). The following PE calculations and $CO_2$ emissions are calculated using the average heat demand of the reference buildings. The energy efficiency class of the buildings is A++, which means that the "standard" parameters of the building: the thermal characteristics of the external barriers, tightness, the efficiency of the mechanical ventilation heat return (recuperator) meet the Lithuanian regulation requirements of the A++ building, only the heat source is changed.

Normative thermal energy consumption for heating a building (part of a building) in energy performance class A++, kWh/(m² year):

$$k_h \cdot y \cdot A_p^{-x}, \quad (1)$$

where: $k_h = 1$; $A_p$ – usable floor area of the building; $y = 451$ (for single-dwelling residential building), $y = 197$ (for multi-dwelling residential building), $y = 221$ (for office building); and $x$ are respectively – 0.39; 0.23; and 0.28.

Table 2. Reference buildings' average heat demand for heating

| Single-dwelling residential building, heated area, m$^2$ | Heat demand for heating, kWh/m$^2$ | Multi-dwelling residential building, heated area, m$^2$ | Heat demand for heating, kWh/m$^2$ | Office building, heated area, m$^2$ | Heat demand for heating, kWh/m$^2$ |
|---|---|---|---|---|---|
| 40 | 107.00 | 100 | 68.31 | 100 | 60.87 |
| 50 | 98.08 | 200 | 58.24 | 200 | 50.13 |
| 60 | 91.35 | 300 | 53.06 | 300 | 44.75 |
| 70 | 86.02 | 400 | 49.66 | 400 | 41.29 |
| 80 | 81.65 | 500 | 47.17 | 500 | 38.79 |
| 90 | 77.99 | 600 | 45.24 | 600 | 36.86 |
| 100 | 74.85 | 700 | 43.66 | 700 | 35.30 |
| 110 | 72.12 | 800 | 42.34 | 800 | 34.00 |
| 120 | 69.71 | 900 | 41.21 | 900 | 32.90 |
| 130 | 67.57 | 1000 | 40.22 | 1000 | 31.94 |
| Average heat demand for heating, kWh/m$^2$ | 82.63 | Average heat demand for heating, kWh/m$^2$ | 48.91 | Average heat demand for heating, kWh/m$^2$ | 40.68 |

The Seasonal Performance Factor [SPF] used in the heat pump primary energy demand calculations and the Coefficient of Performance [COP] of the other heating equipment used in the PE calculations are shown in Table 3.

Table 3. COP and SPF values for different heating equipment (COP – Coefficient of Performance…, 2022; STR 2.01.02:2016)

| | COP pellets boiler | COP natural gas boiler | SPF electric air-to-air heat pump |
|---|---|---|---|
| Value | 0.85 | 0.94 | 3.0 |

In this study, the COP values of the pellet boiler (biomass) and the natural gas boiler have been taken as the average of the reference values for conventional boilers. Meanwhile, the SPF of the heat pump is taken from the Lithuanian Regulation (STR 2.01.02:2016, 2022).

## 2. Results and discussion

The calculated total (renewable and non-renewable) primary energy consumption (kWh/m²) for investigated buildings is presented in Figure 1. The results are given for values of the PE factors shown in Table 1. The primary energy consumption of a heat pump is measured when the heat pump's energy source is electricity (the average from various production methods in Lithuania) and biofuel. In calculations, an electric heat pump's non-renewable primary energy share is determined when PEF = 2.3, while the renewable primary energy share is determined when PEF = 1. The primary energy of a heat pump that uses biofuel as its energy source is calculated using PEF for biofuel.

Figure 2 shows a significant drop in non-renewable primary energy consumption when the energy source for air-to-air HP is biomass. The total primary energy

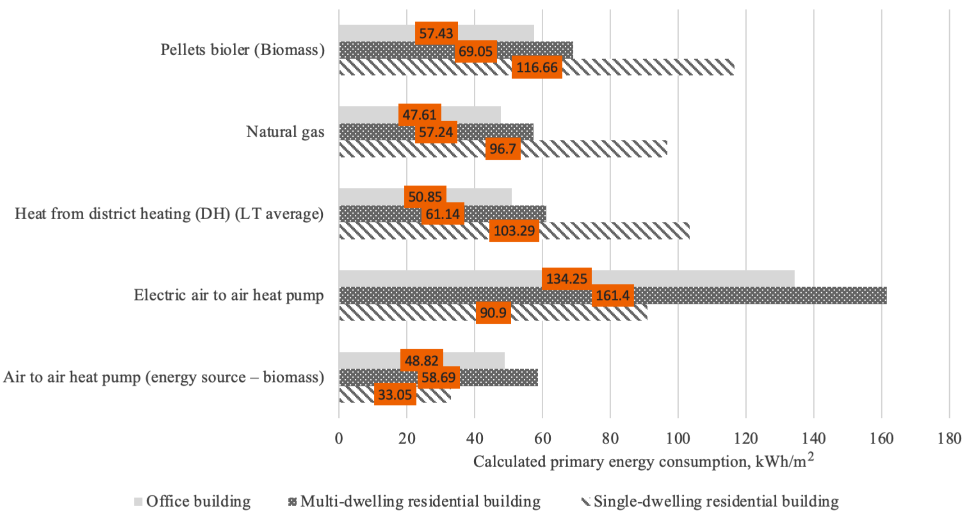


Figure 1. Calculated primary energy consumption of reference buildings

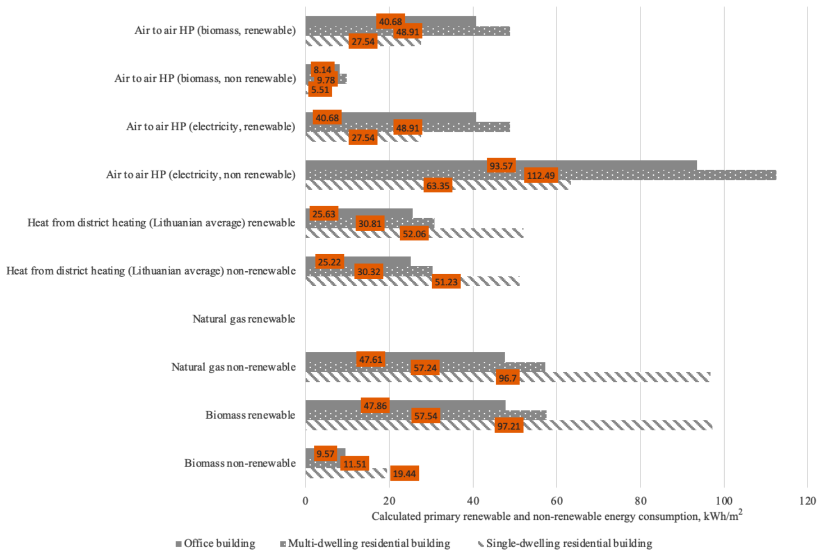


Figure 2. Renewable and non-renewable primary energy shares of reference buildings with different heating sources

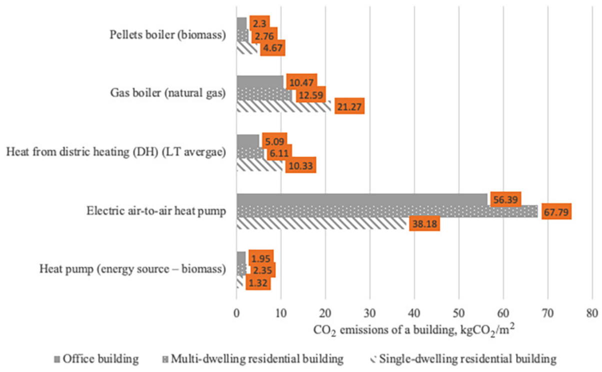


Figure 3. $CO_2$ emissions for different heating sources

consumption in all three reference buildings using the HP with energy source biomass is also significantly lower compared to the HP using electricity from the grid.

The changes in $CO_2$ emissions (kg/kWh) for different heating sources and if an electric HP or an HP (heat source biomass) is used, compared to if the buildings are heated with district heating, natural gas, or biomass only, are shown in Figure 3. The significantly lower $CO_2$ emissions are when HP uses renewable energy (this time – biomass).

## Conclusions

1. The amount of primary energy consumed in reference buildings varies depending on the method of heat supply. This study has shown that PE factors, COP and SPF values, and renewable and non-renewable PE ratios are all very important in determining the energy class of a building. When considering a heat pump with an SPF of 3, which is considered a renewable energy source but using the PE factor for electricity, where the non-renewable PEF is 2.3, primary energy consumption for multi-dwelling residential and office buildings is higher than PE from DH, natural gas, or biomass boiler.
2. It is important to note that in the calculations of renewable primary energy of the electric heat pump, a PEF of 1 was used, according to the order determined by the LST EN 15450:2008 Standard, renewable primary energy from heat pump (unit) fHP.PRr = 1. The Lithuanian Regulation (STR 2.01.02:2016) does not mention which PEF should be used for heat pumps. This practice is only described in LST EN 15450:2008, which is based on the international standard Heating systems in buildings – "Design of heat pump heating systems". Therefore, consideration should be given as to whether PEFs should be explicitly specified for heat pumps.
3. However, in the case of a biomass boiler or a natural gas boiler, primary energy consumption is generally higher compared to using a heat pump with a biomass energy source. Thus, this analysis shows the importance of not only PEF but also the COP of heating sources, as a more efficient natural gas boiler consumes less primary energy compared to a less effective biomass boiler.
4. Yet, this study indicates that the estimated renewable primary energy consumption of a less efficient biomass boiler is almost the same as the non-renewable primary energy consumption of a natural gas boiler. $CO_2$ emissions also vary considerably depending on the energy source used by the heat pump. Therefore, the choice of a heating source is a complex task that requires considering what share of the final primary energy consumption is renewable primary energy, as most of the energy consumed in "Nearly zero energy buildings" must come from renewable sources.
5. This study also shows that biofuels are considered a renewable resource in Lithuania. The heat pump is driven by "total electricity consumption," which increases significantly because the heat pump is the same as electric heating but much more efficient than direct electric heating. At the same time, it is clear that if standard requirements for A++ buildings in Lithuania are met (external barriers, airtightness, heat recovery efficiency, etc.), achieving an A++ energy class building is easiest without additional renewable energy installations by using a local biofuel boiler and connecting to a "green" heat network. The use of heat pumps as a source of heat, particularly cooling (air conditioning), and electricity from the grid requires additional renewable energy sources (e.g., solar power plants).

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