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Impact of the EPBD on Changes in the Energy Performance of Multi-Apartment Buildings in Lithuania

Edmundas Monstvilas [1], Simon Paul Borg [2], Rosita Norvaišienė [1,*], Karolis Banionis [1] and Juozas Ramanauskas [1]

1 Institute of Architecture and Construction, Kaunas University of Technology, 44405 Kaunas, Lithuania
2 Department of Environmental Design, Faculty for the Built Environment, University of Malta, MSD 2080 Msida, Malta
* Correspondence: rosita.norvaisiene@ktu.lt; Tel.: +370-6030-0508

Abstract: As per general provisions of European Directive 2010/31/EU on the energy efficiency of buildings (recast), the Lithuanian government transposed the Directive into Lithuanian national law. In the process, the Lithuanian government prepared strategic documents in the field of energy performance and renewable energy that were integrated together through the National Energy and Climate Plan for 2021–2030 (NECP). To better understand the current situation vis-à-vis energy performance, the main characteristics of buildings pertaining to the Lithuanian multi-apartment building stock, classified according to their energy performance class, are analysed and discussed in this paper. Through the exploitation of data from the national Energy Performance Certificate (EPC) register, an overview of the energy performance of the existing Lithuanian residential building stock is presented along with an analysis of the unused potential energy savings pertinent to this building category. The results obtained from the analysed data of energy consumption in buildings shows that the policies adopted over the years were successful in improving the building stock, promoting the move towards the specifications required by a Class A++ (nearly zero energy buildings—NZEB) by 2021. The results show that this was primarily achieved by a significant reduction in the thermal energy used for space heating.

Keywords: energy performance certificate; CO_2; multi-apartment buildings; heating; energy consumption; cooling

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1. Introduction

Building energy consumption is a significant area of research, often leading to direct policy action aimed at improving energy efficiency. This is often performed using various strategies and often accompanied by the requirements set through voluntary and sometimes binding international agreements, aimed at reducing greenhouse gas emissions.

Since 2010, the amount of energy-related Carbon Dioxide (CO_2) emissions by buildings has been steadily increasing by around 1 percent per year, until 2020 when it dropped to 9Gt due to the decreased activity in the services sector [1]. Notwithstanding the fact that minimum energy performance standards are becoming stricter, and the installation of heat pumps and renewable equipment is growing, the energy sector continues to increase the amount of greenhouse gases emitted. In fact, in 2019, the direct and indirect amount of greenhouse gas emissions emitted by buildings reached an all-time high of 10Gt [2]. It was the highest level of CO_2 ever recorded and was mainly due to the growing demand for energy-related space heating and cooling. The continuous consumption of fossil fuels, the lack of clear policies, and insufficient investments in sustainable buildings are also often blamed for the limited achievements being obtained in the area of energy efficiency in buildings. This is irrespective of the huge potential in energy savings available.

1.1. Directives as a Tool towards Achieving Energy Efficiency in Buildings

Over the years, to counter this inertia in improving energy efficiency in buildings, the main tool adopted by the European Union has been in the form of European Directives, typically requiring Member States initially to legislate minimum building energy efficiency requirements, and eventually to reach a situation where all new buildings have to be nearly Zero Energy Buildings. Starting in 2002 with the Energy Performance of Buildings Directive (EPBD) (2002/91/EC) [3], up until the latest revised Energy Performance of Buildings Directive in 2018 (2018/844/EU) [4], the EU has used these Directives to promote energy performance in buildings through a harmonised European approach. The EU Directives on the Energy Performance of Buildings in 2010, and more recently in 2018, specifically obliged EU member states to comply with minimum requirements for energy performance in new and present buildings, to drive a reduction in energy consumption and greenhouse gas emissions, and indirectly create an increased demand for the consumption of energy produced from renewable sources [1–3].

The latter version of the Directive aims at minimizing even further the use of fossil fuel for the energy provision of buildings, specifically aiming to make the energy performance requirements even stricter and move towards the construction of zero-emission buildings [5]. To implement this goal, the following indicators are set to be achieved by 2050 (compared to 2020):

- To reduce the annual primary energy consumption of the building stock to 16.2TWh (−60%);
- To reduce the annual consumption of primary energy from fossil fuels in the building stock to 0TWh (−100%); and
- To reduce the annual CO_2 emissions of the building stock to 0mtCO_2 (−100%).

1.2. Building Certification

Throughout the years, and generally since the first version of the Directive, the level of energy performance of buildings and hence their environmental impact has been assessed through certification. Although certification in EU Member States may take slightly different forms, not so much in the scientific methodology, but rather how this is practically carried out, building energy performance certification typically is a procedure regulated by legal acts, covering the calculation of the energy consumption of the building, the evaluation of the energy performance of the building, and the assignment of its performance to a specific energy performance class. The original main idea of Energy Performance Certificates (EPC) was to create a document that would be used to provide information to the participants in the construction sector (landlords, tenants, real estate agents, etc.) about the energy performance of buildings [4–6], and hence make an informed decision on the 'value' of a particular building.

EPCs were initially introduced more than 20 years ago; however, very little research has been conducted to analyse the results and impact of the certification policy on the construction market [7–13]. There is a lack of a comprehensive overview of the available data in the EPCs used in each country across the EU, and although numerous studies on EPCs have been carried out in Northern and Southern Europe [14–21], detailed analysis of energy consumption by individual building engineering systems in the context of total energy consumption and CO_2 emissions is severely lacking.

1.3. Energy Efficiency in Buildings: Progress in Lithuania and Scope of Research

In the process of implementing the provisions of a number of EU directives, the Lithuanian government has also prepared many strategic documents in the field of energy performance and renewable energy that were integrated together through the National Energy and Climate Plan for 2021–2030 (NECP) [22].

Specifically, the Lithuanian government is making great efforts to improve the energy performance in buildings. In this regard, being an essential element of the Lithuanian Energy Strategy for 2030, the decrease in current energy consumption of buildings needs to necessarily start by defining the Lithuanian building stock, especially the residential sector, distinguishing the various specific characteristics and elements of buildings. This is with the scope of determining the unused potential of energy savings. To this end, a thorough analysis of the EPC data could help to disclose the response of the construction market to increasingly stricter energy performance regulations.

To this effect, following a thorough review of the literature of the development of energy performance regulations in Lithuania, presented in Section 2, the article hereby being presented discusses and analyses the main characteristics of Lithuanian multi-apartment buildings that determine the energy performance class of buildings within the context of energy performance. Based on this, Sections 3 and 4 present the main purpose of this article, that is, to determine the differences between buildings that satisfy the requirements of the EPBD of 2006 (buildings of class C) and those that satisfy the demands of the EPBD directive of 2021 (buildings of class A++); that is, to determine the impact that increasingly stricter requirements set by subsequent revisions of the EPBD directives have had on the various energy performance indicators of buildings in Lithuania. Such indicators include the heated area, building compactness index, envelope average U-value, and energy consumed for hot water production. Results are presented in Section 5.

2. Development of Energy Performance Regulations in Lithuania

The inception of environmental protection and energy-saving policies in Lithuania dates back to 1992 when the first energy performance specifications for buildings were approved. The values of the normative thermal transmittance coefficients of the envelopes were reduced by approximately three times due to this newly approved regulation.

The energy performance requirements of buildings were updated for the second time in 1999 and for the third time in 2005. The obligations approved in 2005 were based on the EPBD regulation of 2002. The requirements for the certification and classification of energy performance were provided, and the plan was made to improve the overall building energy performance before 2020.

The certification of energy performance of buildings in Lithuania first began in 2006, with the transposition of the first European Directive (2002/91/EC) [3]. Certification is carried out using an approved calculation methodology that takes into consideration aspects such as building envelope, heating and cooling systems, lighting, and other energy systems present. On the other hand, the impact of user behaviour on energy performance indicators of buildings is not taken into account. The certification calculation methodology has been regularly updated since it came into use. Before 2012, it was calculated according to the annual calculation method [3]. Later, however, the monthly method was applied. Primary energy consumption was included in the calculation method in 2014. Currently, the Technical Building Regulations STR 2.01.02: 2016 '*Design and certification of energy performance of buildings*' [6] provides the background for the certification methodology, according to which the following aspects of building energy consumption must be evaluated:

- The thermal and primary energy consumption attributed to the heating of the building, including air heating of ventilation systems;
- The thermal and primary energy consumption attributed to the hot water production in the building, including the energy consumption of the water heating devices and the energy losses because of piping;
- The thermal and primary energy consumption attributed to the cooling of the building; and
- The primary energy in the form of electricity used for lighting systems, devices, electricity consumed outside of the building, and electricity consumed by ventilators present in the ventilation system.

The energy efficiency of buildings in Lithuania is not related to a particular numerical value of energy consumption but rather is defined according to the energy performance characteristics satisfied by a particular building. Buildings are divided into nine classes, namely: A++, A+, A, B, C, D, E, F, and G, according to their energy performance characteristics. Based on this principle, the legal acts set normative minimum requirements for the thermal characteristics of building envelopes, such as the U-value for roofs, external walls, windows, doors, etc., which must be satisfied for a building to be included in a particular energy performance class [23]. Whereas this applies to all energy performance classes, from energy performance class C upwards, the performance of the building's engineering systems and other building characteristics, such as the calculated air tightness of the building, the efficiency of the ventilation heat recovery system, and the presence of renewable energy sources, is also taken into consideration in awarding a building with a particular energy performance class.

Based on this premise, the research being presented in this paper analyses data collected from multi-apartment residential buildings certified during the period of 2014–2020, stored in a central repository held at the Centre of Certification of Construction Production, as will be discussed later on. Buildings' certification is compulsory when buildings are sold, purchased, rented, inherited, and before renovation, with the goal of improving energy performance [4]. In order to complete construction procedures of new buildings, the EPC is also compulsory. The same applies to buildings after major renovations. In the case of purchase, sale, or rental of the building, an individual apartment may be certified if the whole building has not been certified as yet. A typical EPC without detailed measurements and calculations may also be issued for building units (apartments) in old buildings. Such a procedure was established by the Lithuanian government in order to reduce residents' expenses for certification when apartments are sold or rented and is valid only for individual apartments not entire buildings.

From a preliminary analysis, it results that most of the renovated buildings belong to class C. This occurred because, when the buildings were being renovated, in most cases, it was not attempted to simply satisfy the minimum requirements but rather to achieve economically substantiated energy-saving results, that is, to improve the level of energy performance of buildings up to class C or even possibly to class B.

The requirements for classes B, A, and A+ were established during the period of 2014–2020, so these in most cases reflect the level of energy performance of newly built and certified buildings. Starting in 2016, buildings had to have a minimum energy performance class equal to A, followed by a class equal to A+ for buildings built after 2018. The demands for class A++ were not yet mandated in the analysed period, as these became obligatory only in 2021, but as real estate developers saw the benefit of building energy-efficient buildings, they started designing and constructing buildings having such an energy performance class. This means that in the analysis carried out (covering the certification period of 2014–2020), a number of EPCs of class A++ buildings (albeit small) complying with such energy characteristics were also included in the analysis.

As part of this analysis, it is important to note what were the necessary requirements for buildings in Lithuania over the years. In 1992, the year of entry of the first minimum building performance energy classes, the requirement was for class G or better. Later, the requirements were made stricter, leading to the current energy class requirement of A++ for new buildings set in 2021. When analysing the shift of indicators from class G to A++, it is therefore important to read this in conjunction with the year the class for that particular building was established. The changes in building energy performance requirements along the years are presented in Table 1. In 2006, when Lithuania started adopting the provisions of the EU energy performance directive, the valid requirements at the time in Lithuania matched those required by class C of the EU energy performance directive. From then onwards, the shift which occurred from class C to A++ may be seen as a result of stricter EU directives and other international agreements.

Table 1. The requirements for Energy Performance of Buildings over the years.

Year of Entry into Force of the Energy Performance Requirements	2006	2014	2016	2018	2021
Energy performance class requirement	C	B	A	A+	A++

3. Multi-Apartment Buildings in Lithuania: Certification

According to the data available from the Lithuanian Real Estate Property Register, the total building stock in Lithuania consists of around 661 thousand buildings with a total area of 201.7 million m^2 [24], of which 41 thousand buildings are multi-apartment residential buildings, having a total area of around 59.5 million m^2. In terms of their year of constriction, it can be seen in Table 2 that the majority of these multi-apartment residential buildings were built between 1961 and 1992.

Table 2. Multi-apartment residential buildings sub-divided according to their year of construction.

	Construction Year								Total
	Until 1900	1901–1960	1961–1992	1993–2005	2006–2013	2014–2016	2017–2018	2019	
Number of Multi-apartments buildings	1500	12,882	22,669	1784	1045	417	454	270	41,021
Percentage of Total (%)	3.7	3.1	55.3	4.4	2.6	1.0	1.1	0.7	100

Source: Real Estate Property Register (RPR) (31 December 2019).

Based on the figure of 41,021 multi-apartment buildings at the beginning of 2020 in Lithuania, the total floor space of these multi-apartment residential buildings amounted to 29% of the total area of the Lithuanian building stock. Table 3 shows the multi-apartment building stock area in Lithuania, sub-divided by size of individual property.

Table 3. Multi-apartment residential building stock in Lithuania.

Subgroup of Buildings	Buildings No. of Units	Total Area (m^2)	Area (Percentage, %)
Multi-apartments buildings (floor-space area <1 thousand m^2)	24,113	9,334,072	16
Multi-apartments buildings (floor-space area 1-5 thousand, m^2)	15,072	37,805,494	64
Multi-apartments buildings (floor-space area >5 thousand, m^2)	1836	12,324,006	20
Total	41,021	59,463,572	100

Source: Real Estate Property Register (RPR) (31 December 2019).

The typical energy consumption designed for these houses is between 160 and 180 kWh/m^2 year. In terms of heating systems, according to data published by the Lithuanian Heating Association [24], 46.97% of multi-apartment buildings are supplied by a district heating system, with the remaining share of multi-apartment residential buildings using either a centralised boiler supplying the entire building or else an individual boiler module placed inside each apartment. A smaller percentage of multi-storey residential buildings are heated via the use of electric radiators [25]. Notwithstanding the high percentage of multi-apartment buildings connected to a central district heating system, on an area basis, this is still small, given that only 26% of the total area comprising the entire Lithuanian multi-apartment building stock is currently connected to a centralised heating system. To address this, the Lithuanian long-term strategy is to transform the current building stock in a way that would lead to a much more efficient use of energy (with conditions mature enough to transform these buildings into almost zero energy buildings) and make the country independent of fossil fuels by 2050.

In all this, the energy certification of buildings plays an important role, positioning itself as one of the most important tools of the energy policy of buildings in Lithuania. Over the period between 2007 and 2021, 257,196 EPCs were issued and registered in Lithuania. For the purpose of this research, the data comprised the certification calculations of 5558 multi-apartment buildings registered between the period of 2014–2020 [26]. Figure 1, to this effect, shows the distribution of energy performance certificates issued for these 5558 multi-apartment buildings. More certificates of energy performance of buildings are present in central registries, but these were unfortunately not available.

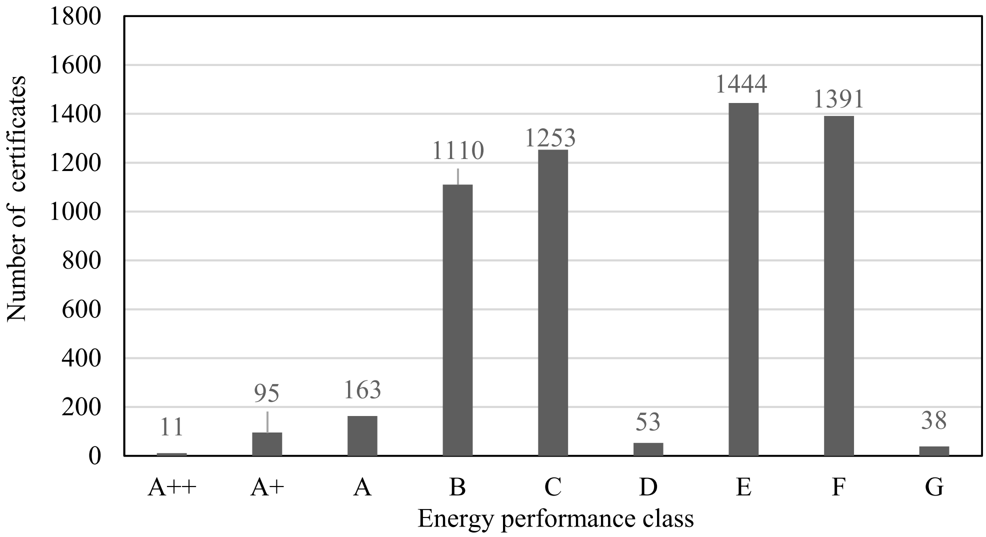

Figure 1. The number of multi-apartment building certificates analysed from December 2014 to April 2020.

4. Methodology

In order to better understand the properties of the various energy performance classes, specific detailed data from the 5558 multi-apartment building were checked using the NRG6 certification software, prepared according to the energy efficiency specifications set by the building evaluation methodology presented in STR 2.01.02–2016 [26], and then analysed using Microsoft Excel. Data from the 5558 EPCs was then divided into nine sections according to the classes of building energy performance, that is, A++, A+, A, B, C, D, E, F, and G. The data categories analysed included heated area (m^2); thermal transmittance coefficient (W/m^{2}K); energy consumption (kWh/m^2) for space heating, space cooling, and hot water production; CO_2 emission; and the distribution of predominant heating systems in buildings.

The indicators present in each section were calculated using a weighted average methodology, which the authors feel is most suited for this type of analysis. Using this methodology, K_{avg} could be found using the heated area of the building as the weighting factor. The calculation utilised is that shown in Equation (1):

$$K_{avg} = \frac{\sum \left(K_x \cdot A_{p.x}\right)}{\sum A_{p.x}} \quad (1)$$

where K_x is the value of the respective analysed index of the individual building 'x', for example, length, width, area of windows, energy consumption, etc.; A_x is the heated area of the individual building 'x' in m^2.

The average value of the thermal transmittance coefficient, U-value in W/(m^{2}K), of the entire building of an individual building 'x', including windows, $U_{x.avg}$ was calculated as follows:

$$U_{x.avg} = \frac{H_x}{A_{env.x}} \quad (2)$$

where H_x is the specific heat losses of the individual building 'x', including losses in linear thermal bridges, W/K; $A_{env.x}$ is the total envelope area of the individual building 'x' in m^2.

The value of the building compactness index of the individual building 'x', $L_{c.x}$, (m^{-1}) was calculated using Equation (3):

$$L_{c.x} = \frac{A_{env.x}}{V_x} \quad (3)$$

where $A_{env.x}$ is the total area of envelopes of the individual building 'x', m^2; V_x, is the volume of heated premises of the individual building 'x' in m^3.

Although in the Lithuanian energy performance calculation methodology there are no requirements for the compactness index of the building, the building compactness index is an important parameter when assessing the effect architectural shape and form [27] have on the heating energy consumption, as is the ratio of the area of the outer building structure to the heated volume. In cold climates, compact forms should be used to minimise the heat loss part; therefore, a reduction in the compactness index is a desirable energy-efficient strategy [28].

Apart from this, other aspects were also analysed, including the energy consumption for hot water production, space heating and cooling, and the electrical energy consumed for electrical appliances and lighting.

In terms of climatic zone, hence, the outdoor conditions to which the analysed building stock is exposed, Lithuania belongs to a cool temperate climate zone, where summers are moderately warm and winters are moderately cold. The average temperature in July is around +17 °C and, in winter, this goes down to −5 °C. The difference between the average temperatures is therefore approximately 20 °C. Although the Lithuanian territory is in a cool, temperate climate zone, the western part of the country falls under the impact of the Baltic Sea, where higher annual precipitation, faster wind speed, and higher average yearly temperature are recorded. The part of the building stock in the western territory amounts to approximately 11% of the total area of the building stock. All residential buildings that fall under this investigation are in the same climatic zone, which, according to the Köppen–Geiger climate classification, is defined as a Dfb climatic zone [29]. Lithuania has an annual heating season of between 5 and 6 months when the outside temperature is lower than +10 °C.

5. Results and Discussion

5.1. Analysis of the Heated Area and Compactness Index of Multi-Apartment Buildings

Looking at the overall heated area, it can be observed in Figure 2a that, as the minimum energy performance class of buildings increased from a minimum of G to A++, an increasing trend with respect to the heated area within multi-apartment buildings was experienced.

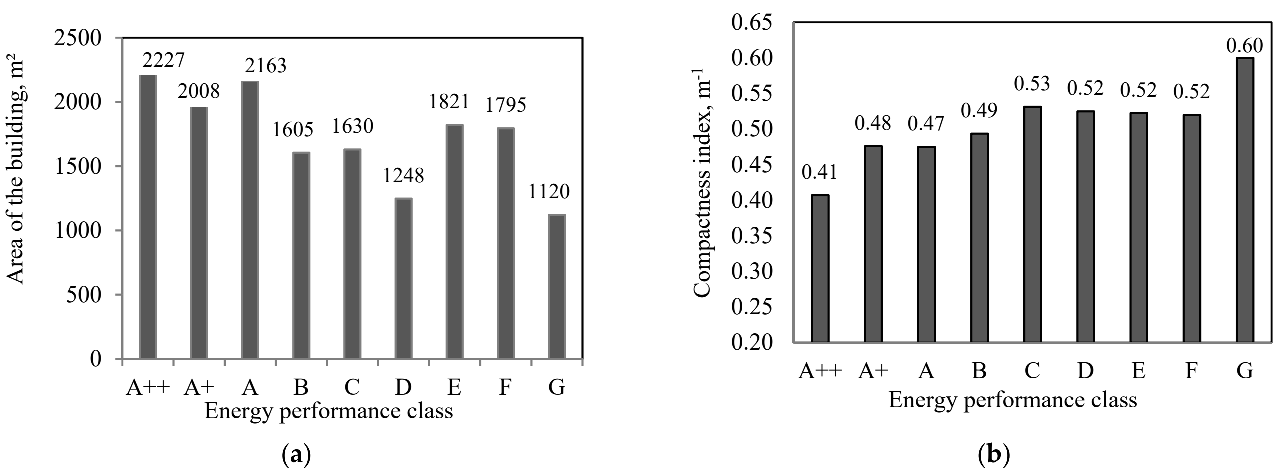

Figure 2. Average heated area of the building (**a**) and average value of the building compactness index, in m^{-1} (**b**).

On the contrary, during the same period, a decreasing trend with respect to the building compactness index was observed, as shown in Figure 2b. Using the compactness index of a building as a tool to assess the impact the shape of a building has on the energy efficiency of a building, it can be deduced that, as the energy performance class was being improved, an improved compactness index was being obtained through the increase of the volumetric design of the buildings and the use of better targeted design solutions. As discussed, the compactness index has a substantial influence on the need for heating; therefore, it is necessary to optimise the energy concept solution in the initial building design. According to the data presented, it can be stated that the stricter directives on energy performance and their implementation (data from class C to A++) are reflected in the 36% increase in heated area (from 1630 m^2 to 2227 m^2) and the reduction in compactness index by 23% (from 0.53 m^{-1} to 0.41 m^{-1}).

In line with most modern architectural trends, the design tendencies of glazed envelopes also evolved. The trend shown in Figure 3 shows that, over the analysed period, there was an overall increase in the use of glazing in building envelopes by almost 25% (from 21.8% to 27.4%). Although this is beneficial as it increases the amount of natural light available, the increased area within the building envelope lets in more sunlight, which has resulted in an increase in the thermal and primary energy consumed to cool buildings.

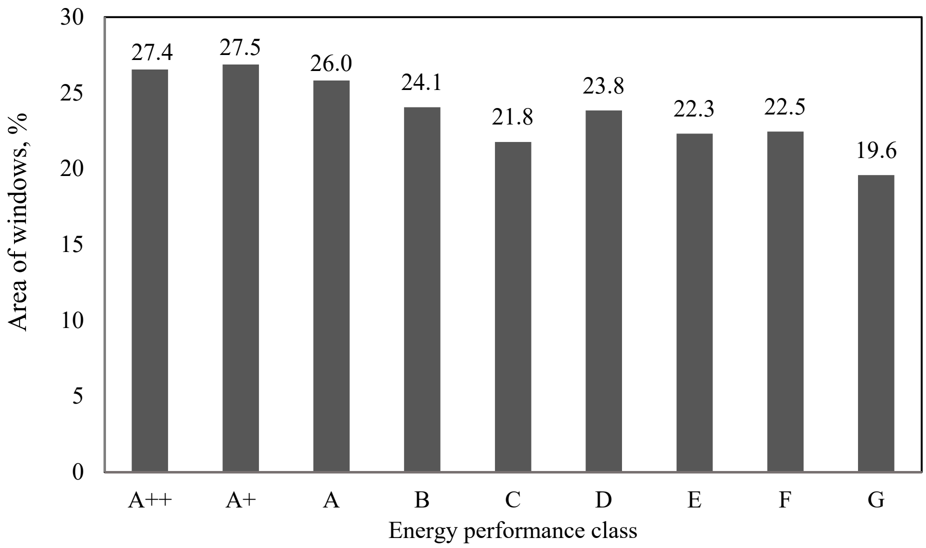

Figure 3. The average of window area in building facades, %.

5.2. Analysis of the Level of Thermal Insulation and Energy Consumption for Heating

According to the data inspected and the analysis performed, the thermal insulation level of buildings has, over the period analysed, that is, between a minimum requirement of class G and a minimum requirement of class A++, improved almost five fold. In fact, the average envelope U-value decreased from 1.04 W/(m^2K) for class G to 0.215 W/(m^2K) for class A++, as shown in Figure 4. Observing the specific impact of the EU directives from 2006 (class C), that is, from the transposition year of the first EPBD in Lithuanian law up until class A++ became the minimum mandated requirement, the thermal insulation level improved by approximately 1.6 times, with the average envelope U-value decreasing from 0.35 W/(m^2K) for class C to 0.2154 W/(m^2K) for class A++.

Due to the increased level of thermal insulation of the building envelope, the average final energy consumption used for heating purposes decreased from 262 kWh/m^2 year for buildings having an energy performance class G compared to 13 kWh/m^2 year for buildings having an energy performance class A++; as shown in Figure 5a, there was a decrease of almost 95%. Likewise, primary energy consumption decreased from 440 kWh/m^2 year for buildings having an energy performance class G compared to 19 kWh/m^2 year for buildings having an energy performance class A++, as shown in Figure 5b. Truth be told, the marked decrease can also be partly attributed to the air permeability in building requirements introduced in Lithuania in 2014 [30].

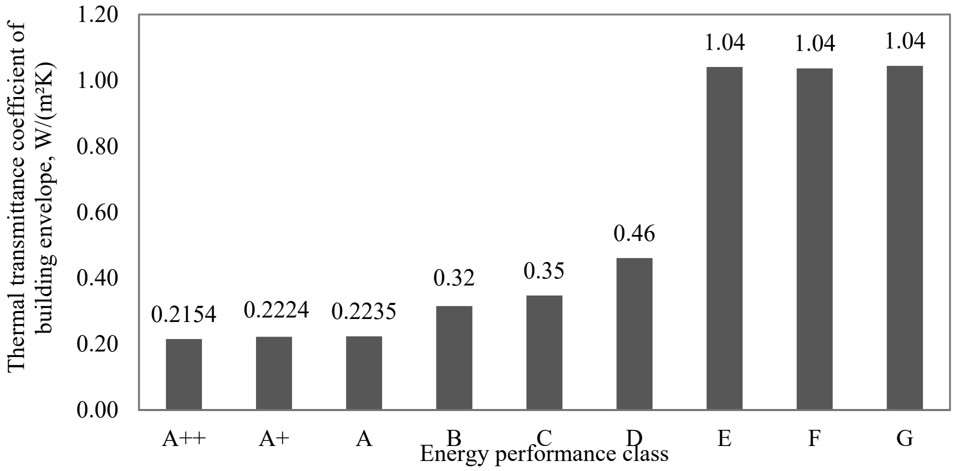

Figure 4. Average thermal transmittance coefficient of the building envelope, in W/(m^2K), in buildings of various energy performance classes.

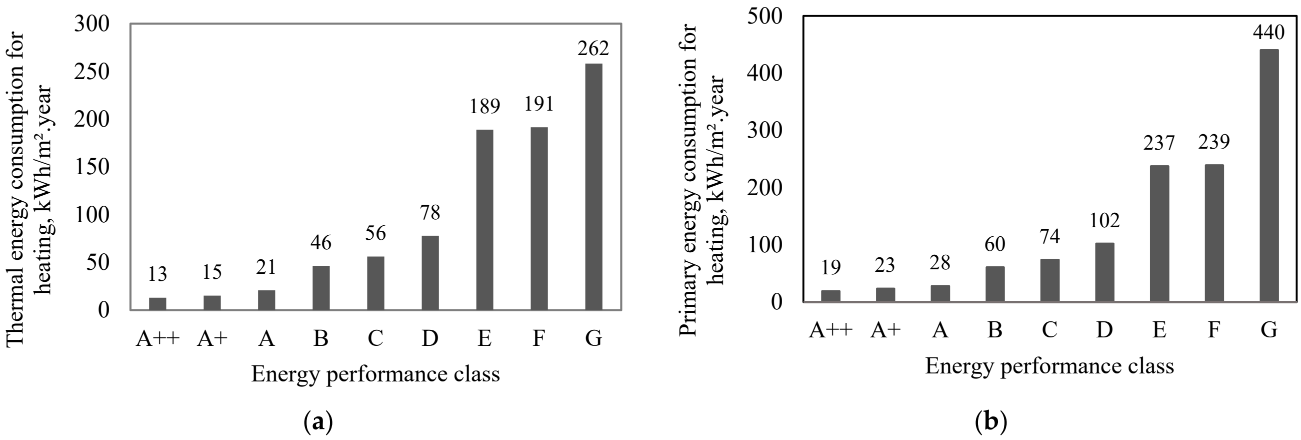

Figure 5. Average of (**a**) thermal and (**b**) primary energy consumption for heating in buildings, in kWh/m^2 year, in buildings of various energy performance classes.

Similarly, to the analysis performed for the building envelope, considering exclusively the period when the EU directives were in effect, that is, from 2006 onwards, it can be observed that, in reality, there was no marked reduction over that period compared to the entire duration of the analysis. In fact, the reduction in annual heating energy consumption between class C compared to class A++ is only 43 kWh/m^2 year (56 kWh/m^2 year for class C compared to 13 kWh/m^2 year for class A++), whereas comparing the entire range of energy performance classes, that is, from class G to class A++, the reduction was 249 kWh/m^2 year (262 kWh/m^2 year for class G compared to 13 kWh/m^2 year for class A++). This means that significant work in terms of promoting and legislating in favour of energy efficiency in buildings had already been carried out even before the transposition of the Energy Performance of Buildings Directive, and that once the law was enacted in 2006, the requirements imposed by the directive most likely found an already receptive and favourable environment.

The analysis between the thermal energy consumption for heating (Figure 5a) and cooling (Figure 6a) of buildings revealed an important trend, that is, that thermal energy consumption for cooling has increased significantly in importance with the increase in the energy performance of buildings.

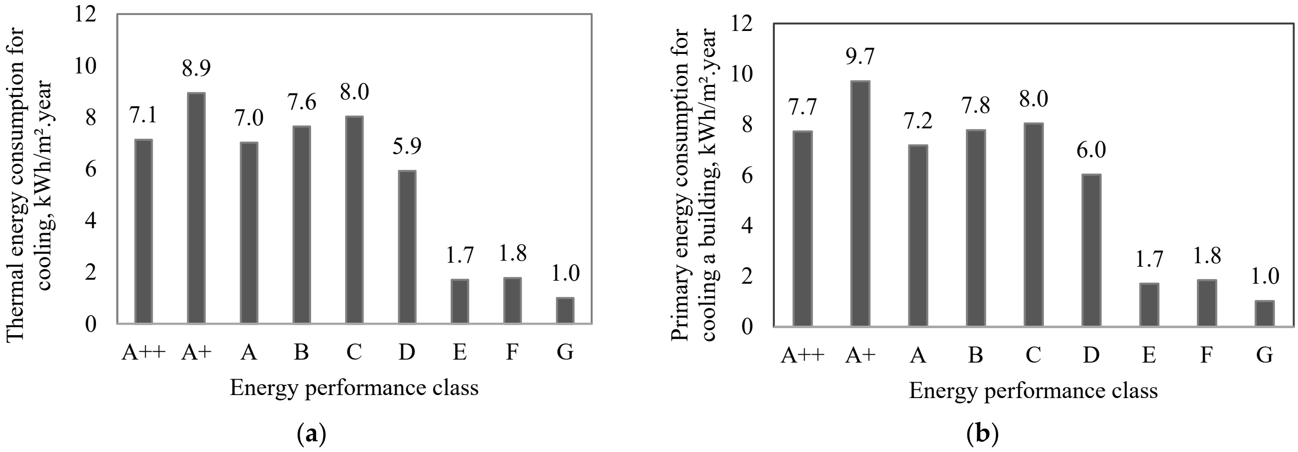

Figure 6. Average of thermal (**a**) and primary (**b**) energy consumption for cooling in buildings, in kWh/m^2 year.

Thermal energy consumption to cool buildings of class C accounts for only 14% of the energy consumption for heating (8 kWh/m^2 year used for cooling against 56 kWh/m^2 year used for heating), while thermal energy consumption to cool buildings of class A++ accounts for 55% of the energy consumption for heating of energy consumption for heating (7.1 kWh/m^2 year used for cooling against 13 kWh/m^2 year used for heating). Whereas the reason for this may be attributed to an absolute increase in cooling demand, this is only partially true. The reality is, in fact, that there has been such a concerted effort at decreasing heating demand that the overall importance of the two in terms of the overall percentage of energy consumption has seen a shift towards each other. A very similar trend is seen in primary energy consumption for the cooling and heating of buildings.

Although this is positive in terms of absolute energy consumption, as it shows that the policies which have been enacted to reduce the heating demand have been successful, it also means that in the future, especially during summers, the means of protecting the buildings against overheating and the energy efficiency performance of cooling systems will become increasingly important. It is also possible to foresee that the increased construction of buildings of class A++ will cause a growth in the need for cooling devices in buildings and, hence, the associated electricity energy required.

5.3. Analysis of Energy Consumption for Hot Water Production

The need for thermal energy for the production of domestic hot water covers the following:

- Thermal energy consumption from the building heat source to produce hot water; and
- Thermal energy consumption for heat losses in pipelines between hot-water generation and distribution.

As has already been discussed, the growing level of thermal insulation of the envelope stemming from stricter directives and legislation has created the preconditions for the decrease of thermal energy consumption used for heating buildings. However, the same cannot be said for the reduction in thermal and primary energy consumption for the production of domestic hot water. The need for domestic hot water in buildings has not had a significant change over time. Typically, reductions in final energy consumption for domestic hot water in buildings can be achieved through a number of actions, some of which are technology-based, while others are driven by human behaviour. For the former, these actions include the shortening of the length of the system pipes, insulating hot water supply pipes, and increasing the performance of the equipment used to heat water. The latter actions typically relate to educating building occupants on aspects such as the duration and use of hot water, etc. These are not always easy to implement because often technology advancement is slow to respond or because of reluctant behaviour from the consumer side.

Figure 7 shows the energy consumption of the aforementioned systems in buildings based on the energy performance class. Compared to the energy consumption in buildings of class C, the thermal energy consumption in hot water production systems in buildings of class A++ decreased only by 25% (from 52 kWh/m^2 year to 39 kWh/m^2 year), with a corresponding reduction in primary energy consumption (from 71 kWh/m^2 year to 49 kWh/m^2 year).

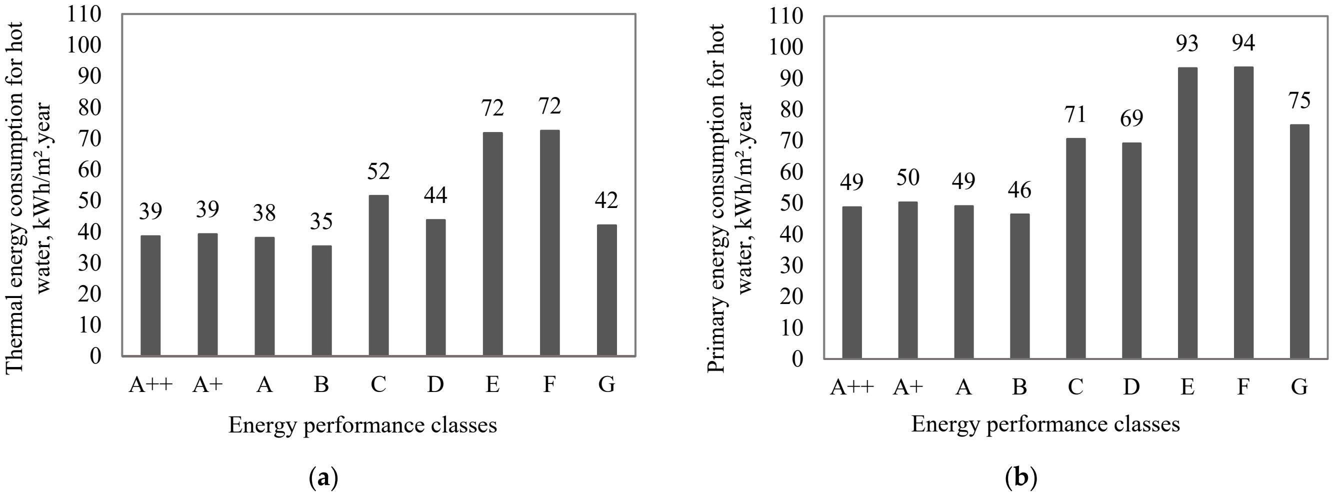

Figure 7. Average of (**a**) thermal and (**b**) primary energy consumption for hot water production, in kWh/m^2 year, in buildings of various energy performance classes.

5.4. Analysis of Energy Consumption for Electrical Consumption

Figure 8 shows how the average primary energy consumption due to electricity also diminished with increasing energy performance class. As is to be expected however, the decrease is not so expansive as in the case of, for example, space heating. In part, this is because, similarly to hot water production, energy efficiency improvements are not only technology driven but are also dependent on human behaviour. Additionally, in certain cases, there has been an overall increase in the electrification of certain activities leading to an overall increase in electricity consumption [31].

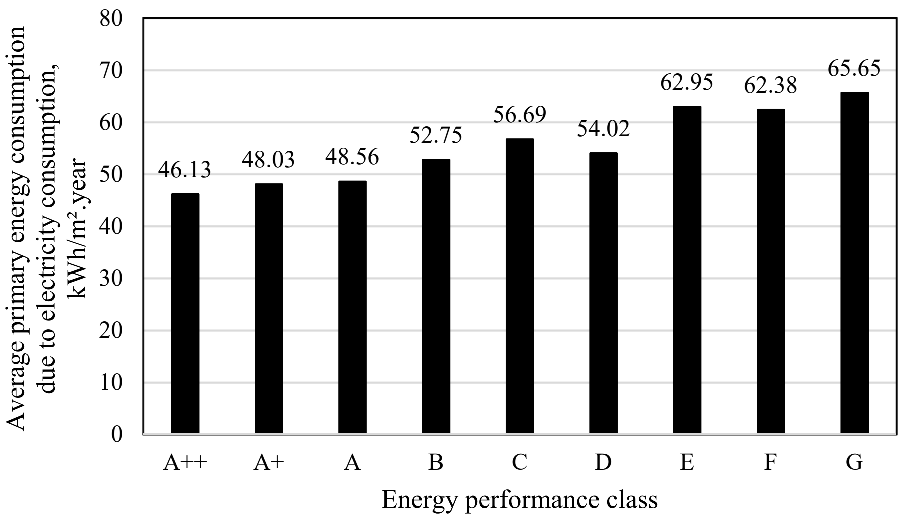

Figure 8. Average primary energy consumption due to electricity consumption, in kWh/m^2 year, in buildings of various energy performance classes.

5.5. Overall Share of Energy Consumption in Lithuanian Multi-Apartment Buildings

Whereas the overall primary energy consumption consumed by multi-apartment residential buildings has gone down, it is also interesting to note how the final overall share of primary energy consumption in buildings has changed over the years. In this regard, Figure 9 shows the primary energy consumed by use for a class C building and a class A++ building.

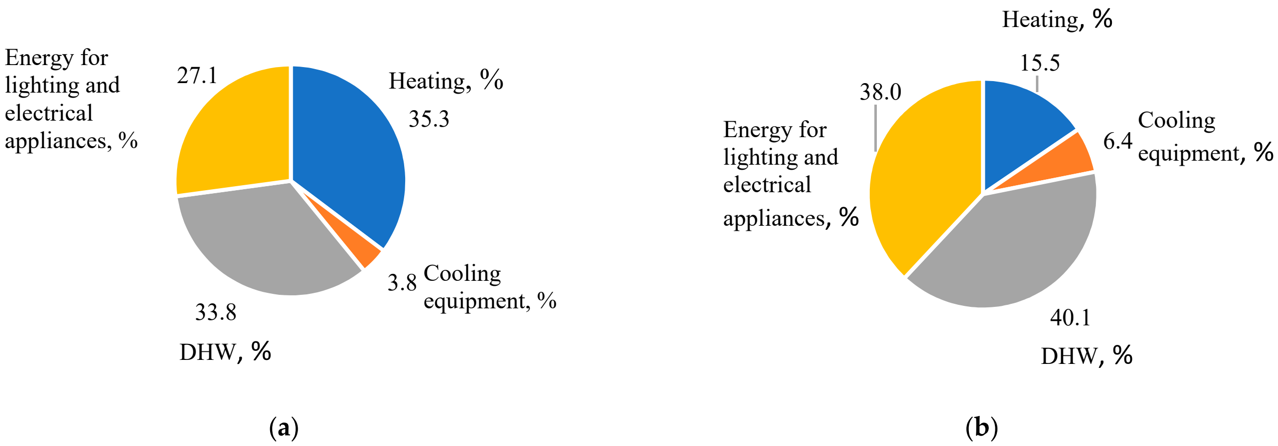

Figure 9. Primary energy consumption in building systems of energy performance class C (**a**) and energy performance class A++ (**b**), (%).

Taking as an example the primary energy used to heat buildings, buildings having an energy performance class of class C utilise a share of around 35% of their total primary energy consumption for heating. This is significant compared to class A++ buildings which consume only 15% of the total. This is by far the most marked difference, also showing how effective policies were in reducing energy consumption used for heating in buildings.

On the other hand, the other main categories, such as the energy used for lighting and electrical appliances, space cooling, and domestic hot water, have all shown increases in their share of primary energy consumed. Again, this is not to say that the overall final energy consumption in these three categories has increased, but rather that their share within the overall balance of final energy consumption has increased.

In terms of domestic hot water production, despite a significant reduction in the amount of primary energy necessary for the production of hot water in buildings of class A++ compared to buildings of class C, this consumption use has increased its share from 33.8% (class C) to 40.1% (class A++); likewise, for the second individual largest primary energy consumer, that is, energy used for lighting and electrical appliances. In terms of space cooling, although an increase has been observed in terms of share, this is still small compared to the former two uses indicated above.

These overall results indicate that, whereas significant work has been performed on the aspect of producing better building envelopes, much still needs to be done in order to reduce primary energy consumption in buildings even further. Moreover, future research, policies, and legislation will need to start looking more actively at reducing energy from uses other than merely heating and cooling and focus much more on other energy uses in buildings.

Summarizing the results of the primary energy consumption analysis allows one to conclude that the requirements demanded by the energy performance directives to move to the construction of buildings of class A++ (NZEB) in Lithuania from 2021 were successfully implemented. This led to a significant reduction in primary energy consumption for heating and, to a lesser extent, in primary energy consumption for the production of hot water, lighting, and electrical appliances. In fact, relatively high primary energy consumption remains in class A++ buildings with regard to hot water production, where the primary energy consumption (48.6 kWh/m^2 year) is almost three times higher than the primary energy consumption (18.8 kWh/m^2 year) to heat buildings was witnessed.

6. Conclusions

The purpose of the directives for the energy performance of buildings in the residential sector is to gradually reduce the consumption of non-renewable primary energy used in buildings and thus reduce CO_2 emissions. Similarly, one of the key priorities of the Lithuanian National Energy Independence Strategy is to increase the energy performance of buildings. To better understand the success or failure achieved so far, it is essential to adequately assess energy performance indicators and to select appropriate energy saving tools to determine unused energy savings potential and reduce energy consumption in buildings.

The research presented in this paper describes the differences between buildings that comply with the requirements of the first transposition of the EPBD Directive of 2006 (buildings of class C) and buildings that comply with those set by the latest EPBD Directive of 2021 (buildings of class A++). Specifically, it describes the impact that the increasing requirements of EPBD directives had on various energy performance indicators of buildings. To provide a better perspective, results are also compared to earlier requirements dating back to the first energy efficiency legislation enacted in Lithuania. The was performed using Energy Performance Certificates or EPCs as the source of data.

The statistical analysis of certificates revealed that, when the energy performance requirements became stricter following the transposition of the first EPBD in 2006, the average heated area of multi-apartment buildings increased by 36%. This was, however, countered by an increase in the building compactness index, which resulted in an increase in the volumetric efficiency of buildings and the use of better target solutions, increasing the quality of the designed buildings.

The primary energy consumption analysis shows that the requirements set by the energy performance directives to move to NZEB constructions were successfully implemented with a significant reduction in the primary energy used, particularly for space heating. Relatively high primary energy consumption remains present in class A++ buildings with regard to lighting, electric appliances, and hot water production, where primary energy consumption is 2.6 times higher than the energy consumption for space heating. Primary energy consumption could therefore be further reduced if the aforementioned energy consumption for the production of hot water, lighting, and electric appliances could become more energy-efficient.

In relation to cooling, results show that, with the higher level of insulation and increased percentage of glazing in building envelopes, space cooling in NZEB buildings will most likely be a significant energy consumer, at least regarding the overall share of energy consumption.

Finally, this paper should not be seen on its own but rather as a first step towards understanding energy performance trends in buildings in Lithuania. Specifically, future work analysing other building typologies and making use of the results obtained for the production guidelines can be considered a natural follow-up to this study.

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