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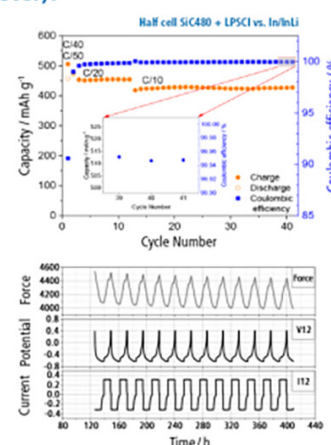
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Airtightness of renovated residential buildings: the case of Lithuania

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Abstract. Since 2006, requirements for the energy efficiency of buildings have been introduced in Lithuania. Buildings have been divided into energy efficiency classes from "F" (least efficient) to "A++" (most efficient). All new buildings constructed after 1st of January 2021 must fulfil the requirements of the "A++" energy efficiency class. Meanwhile, old buildings (built before 1990) usually meet only the requirements of the lowest "F" class. Currently, these buildings are encouraged to be renovated (modernised) to meet at least the requirements of the "B" energy efficiency class. The aim of the study was to determine which measures can be applied to ensure that modernized buildings meet these "B" class requirements. As the study showed, improved energy efficiency of a building is achieved by adding appropriate thermal insulation, replacing windows and doors and ensuring the tightness of the building envelope. Furthermore, the study showed that airtightness is important factor which could influence energy class of building. The airtightness depends on defects of windows and door, plumbing and electricity installation, wall junction, socle and roof.

1. Introduction

Buildings in Europe are responsible for 40 % of the total energy consumption [1, 2]. With the recast of Energy Performance of Buildings Directive (EPBD), Europe has adopted an ambitious vision for energy performance of its buildings [3]. The need for better energy performance of buildings has led to energy policies that limit the energy use of buildings. In recent years, the focus of European countries has been on the the implementation of nZEB [2, 4-6]. To obtain an energy-efficient building, one can either design new buildings that comply with the energy policy or/and renovate existing buildings [7]. Retrofitting of buildings is one of the widespread solutions [7] and it is at the forefront of EU policies [1, 5] because currently, about 35% of buildings in Europe are over fifty years old [8]. Building renovation could significantly reduce both energy and material consumption in the next decades [1, 9], improving health and comfort of occupants [2, 10].

In many European countries, the need for building renovation is receiving increased attention [11] and various directives have been released. Directives 2018/844 and 2012/27/EU [12, 13] require Lithuania to prepare a long-term renovation strategy to support the renovation of the national building stock by ensuring: 1. energy efficiency in the building stock; 2. A decarbonised building stock by 2050; 3. favourable conditions for the cost-effective conversion of existing buildings into nearly zero-energy buildings [14]. The implementation of this directive is vital for Lithuania because most (about 80%) of residential buildings were built in Lithuania



before 1992 [14]. These residential buildings are divided into private houses (92%) and multi-apartment buildings (8%) [14].

It is common practice to determine the thermal performance of building envelope units based on the limits specified in energy-saving standards. [11]. Energy renovation of residential buildings in hot and temperate Mediterranean zones of the EU can result in nearly zero-energy buildings, with correct insulation thickness being a critical factor. Meanwhile, in the EU's cold climate regions, heating energy demand dominates, and achieving nearly zero-energy buildings is more challenging. Energy consumption can be significantly reduced, and indoor thermal-conditions can be improved by using optimal thermal insulation, high-performance energy-efficient windows and doors, and balanced ventilation systems with heat recovery [15].]. Since infiltration plays an important role [16] regarding the energy consumption of dwellings, many European countries have already established standards aiming to limit the energy consumption through the envelope [17 - 19]. From the practical building technology point of view, it is rational to combine insulation with the air tightening of the building envelope [9, 20]. The aim of this study was to determine which measures can be applied to ensure that modernised buildings meet the "B" energy performance class requirements. It is well known that air leakage is a key factor influencing the energy performance of buildings [4, 21], hence air leakage measurements are commonly performed in order to evaluate building design and construction practices [17]. Airtightness affects the energy performance of buildings because it influences the ability of heat storage of the building [22]. Recent studies have estimated that infiltration is responsible for up to 30% of heating demand [18, 23]. Minimizing air infiltration by tightening the building envelope is a common practice [24]. Attention should therefore be paid to the airtightness of buildings at all levels i.e., the overall airtightness of buildings should be evaluated as well as the airtightness of the building envelope on a component level and also on a material level, e.g. windows, joints between different components such as the window-wall interface, joints at penetrations, joints between facade panels, etc. [16, 23, 25].

2. Methodology

2.1 Test algorithm

The evaluation of the buildings was performed according to the procedure given in Figure 1.

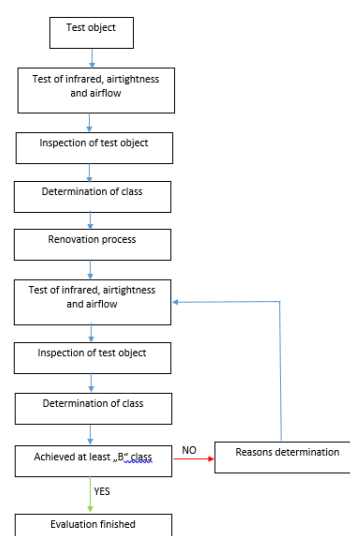


Figure 1. Test process.

A total of 36 individual houses built in period 1960-1990 were chosen for assessment. The 18 masonry and the 18 timber houses were analysed respectively (Table 1 and Table 2). Seven masonry houses had wall and ceiling thermal insulation, installed during building construction. The remaining eleven masonry buildings had insulation only in the ceiling. The thickness of wall insulation was approximately 5cm while ceiling insulation ranged from 10 to 15 cm. Some of houses had new entrance doors and windows installed, others - only windows. Changed windows accounting for up to 50% of the total window area. Meanwhile timber houses had insulation only in the ceilings (thickness ranging from 10 to 15 cm.) Some of house had new entrance doors and partially changed windows. The new windows accounting for up to 30% of the total window area. The area of tested houses ranged from 120 to 150 m² and the volume varied from 310 to 370 m³.

Table 1. Masonry houses

House	Year of construction	Before renovation			After renovation	
		Thermal insulation	Windows/ Doors	Heating energy consumption kWh/m ² /year	Changes	Heating energy consumption kWh/m ² /year
M1	1985	walls/ceiling	old ^a /new	290.75	I/IV/V	96.60
M2	1971	ceiling	new/new	632.47	I/II/IV	84.74
M3	1965	ceiling	old/old	990.96	I/II/IV/V/VI	47.20
M4	1969	ceiling	old ^a /old	478.17	I/IV/V/VI	145.32
M5	1973	ceiling	old/old	730.11	I/II/II/IV/V/VI	28.81
M6	1980	walls/ceiling	old ^a /new	344.19	II/IV/V	106.87
M7	1988	walls/ceiling	old ^a /new	374.09	I/IV/V	81.41
M8	1979	ceiling	old/old	578.23	I/IV/V/VI	112.66
M9	1981	ceiling	old/new	431.15	I/IV/V	132.29
M10	1977	ceiling	new/new	409.59	I/II/III/IV	53.77
M11	1984	walls/ceiling	old/old	464.53	I/IV/V/VI	114.93
M12	1975	ceiling	old/old	685.19	I/IV/V/VI	108.37
M13	1985	ceiling	old/old	367.58	I/II/III/IV/V/VI	24.40
M14	1988	walls/ceiling	new/new	252.38	I/II/III/IV	46.94
M15	1979	ceiling	old/new	301.26	I/IV/V	137.46
M16	1980	walls/ceiling	old ^a /new	566.07	I/IV/V	143.31
M17	1980	walls/ceiling	old/old	248.63	I/IV/V/VI	110.15
M18	1975	ceiling	old/old	487.71	I/IV/V/VI	118.86

^a Partially changed

I – Walls insulation; II – Ceiling insulation; III – Floor insulation; IV - Basement insulation; V – New windows; VI- New doors

Table 2. Timber houses

House	Year of construction	Before renovation			After renovation	
		Thermal insulation	Windows/ Doors	Heating energy consumption kWh/m ² /year	Changes	Heating energy consumption kWh/m ² /year
T1	1960	ceiling	old/old	731.97	I/III/IV/V/VI	135.27
T2	1962	ceiling	old ^a /new	616.38	I/II/IV/V/VI	113.22
T3	1962	ceilings	old/old	961.61	I/II/III/IV/V/VI	55.95
T4	1965	ceilings	old ^a /old	643.48	I/II/III/IV/V/VI	32.78
T5	1961	ceilings	old/old	764.95	I/II/IV/V/VI	68.14
T6	1975	ceiling	old ^a /new	530.29	I/III/IV/V	86.58
T7	1970	ceiling	old/old	744.92	I/II/IV/V/VI	108.74
T8	1961	ceiling	old/old	678.39	I/III/IV/V/VI	97.29
T9	1966	ceiling	old/old	633.71	I/II/III/IV/V/VI	47.66
T10	1965	ceiling	old ^a /new	750.85	I/II/III/IV/V	61.41
T11	1963	ceiling	old/old	897.57	I/II/IV/V/VI	112.37
T12	1960	ceiling	old ^a /new	836.23	I/III/IV/V	150.55
T13	1971	ceiling	old/old	717.29	I/IV/V/VI	98.82
T14	1975	ceiling	old/old	749.86	I/II/III/IV/V/VI	62.28
T15	1970	ceiling	old/old	792.47	I/II/IV/V/VI	42.09
T16	1969	ceiling	old ^a /new	882.18	I/III/IV/V	112.36
T17	1967	ceiling	old/old	752.80	I/II/III/IV/V/VI	51.47
T18	1964	ceiling	old ^a /new	501.53	I/IV/V	120.55

^a Partially changed

I – Walls insulation; II – Ceiling insulation; III – Floor insulation; IV - Basement insulation; V – New windows; VI- New doors

The tests of the selected buildings were performed during the cold season (before renovation - 2023 autumn/2024 spring; after renovation – 2024 autumn/2025 spring) when the temperature difference between the indoor and outdoor air was at least 15 °C. The equipment used for the measurements is described in 2.2 section. The airtightness tests were performed according to the standard LST EN 13829 [26]. In this study, the airtightness parameter n_{50} was used, which indicates the number of air volume changes per hour at a pressure difference of 50 Pa. In Lithuania of “B” energy class residential buildings n_{50} should not exceed 1.5 1/h [27]. The airtightness results of masonry and timber houses are given in the Figure 2 and in Figure 3 respectively. The infrared (IR) tests were performed according to standart LST EN ISO 6781-1 [28]. The airflow test was performed according to standart LST EN ISO 9972 [29]. IR and airflow tests were performed to identifying the possible defects (weak places) and air leakages of building. The heating energy consumption of building and building energy performance class before and after renovation was determined using the NRG-sert software (version 7) [30]. The

renovation process of buildings included instalation of thermal insulation, replacing windows and doors and ensuring the tightness of the building envelope (Table 1 and Table 2).

2.2 Test equipment

The airtightness measurements were performed using Retrotec Blower Door equipment (Fan 3300HP (expended uncertainty 1.5%) with micro manometer DM32 (expended uncertainty 0.6 Pa)). The infrared (IR) test was performed using the FLIR ThermaCAM B640 (expended uncertainty 0.204 °C). Airflow measurements were performed using air velocity and temperature meter Testo 425 (expended uncertainty 0.03 m/s) with anemometer sensor. All the test equipment was verified at an accredited laboratories [31 - 33].

3. Test results

The measured airtightness values of masonry and timber houses are given in the Figure 2 and in Figure 3 respectively. During airtightness test examination of houses (search of defects and weak places) were performed using FLIR ThermaCAM B640 and Testo 425.

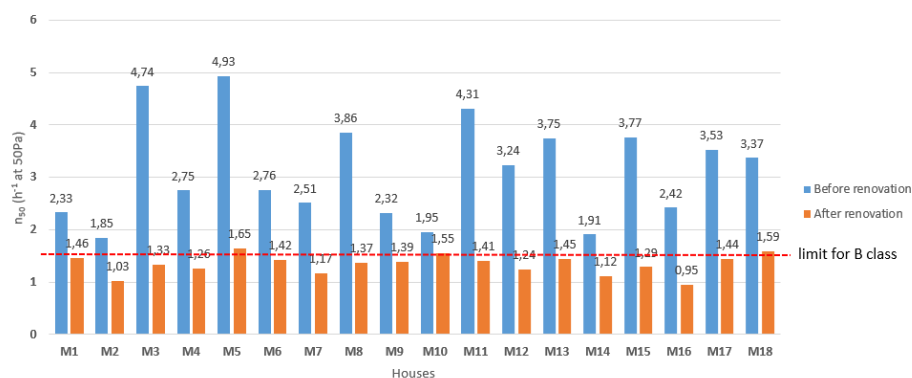


Figure 2. Airtightness of masonry houses

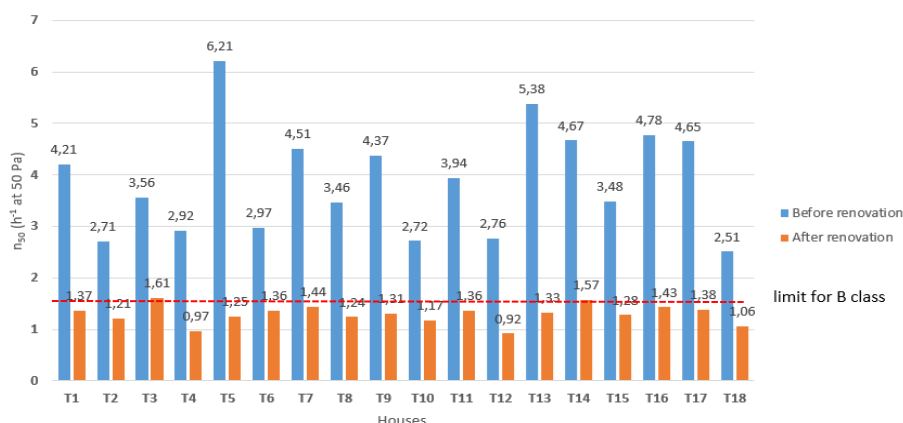


Figure 3. Airtightness of timber houses

As shown in Figure 2 and Figure 3 airtightness value (n_{50}) for masonry houses is ranged from 1.85 to 4.93 before renovation and from 0.95 to 1.65 after renovation, while for timber houses airtightness value n_{50} varied from 2.51 to 6.21 and from 0.92 to 1.61 respectively. The limit for "B" class is 1.5 - this means that after renovation almost all buildings fulfilled "B" energy class requirements, with the exception of 3 masonry houses (M5, M10 and M18) and 2 timber houses (T3 and T14). After correction of defects (sealing gaps, adjusting windows with doors), the airtightness of these houses were improved (n_{50} value as follows: M5 – 1.32, M10 – 1.48, M18, - 1.26, T3 – 1.05 and T14 – 1.19). Building owners carry out insulation work on their own initiative. This is the main problem with the modernization of individual houses, as good quality of work is not always ensured and the required tightness of buildings is not achieved. The energy efficiency class of the tested houses was determined both before and after renovation. Before renovation half of the masonry houses were classified as "F" energy class and the other half as "E" class, while among timber houses, only 5 out of 18 house were classified as "E", the the remaing as "F" class. The houses that had their old windows and doors replaced with new, achieved a better energy class (see Table 1 and Table 2), as new windows and door are more tight, than thoes with old ones. Overall, low energy classes before renovation were mainly due to insufficient thermal insulation and poor airtightness. The energy consumption for heating varies from 501.53 to 961.61 kWh/m²/year before renovation and from 32.78 to 150.55 kWh/m²/year after renovation (difference 5-15 times) of timber building and from 248.53 to 990.96 kWh/m²/year and from 46.94 to 145.32 kWh/m²/year respectively (difference 5-6 times) of masonry buildings. After renovation, which included the addition of thermal insulation to walls, roofs, and socles, as well as the replacement of windows and doors with new units, most houses achieved a "B" energy class (28 houses). Some houses reached an "A" class (3 houses), while five houses were classified as "C" due to insufficient airtightness. After further improvement of airtightness by correcting defects, all of these buildings achieved a "B" energy class.

Figure 4 presents the most common defects affecting the airtightness of the tested houses in percentage terms.



Figure 4. Defects of houses indicated during inspection

As shown in Figure 4, the most common defect of masonry houses were those of windows and doors; as well as electricity and plumbing installations. In timber houses, common defects included windows and doors, electrical and plumbing installations, wall junctions, socles, and roofs. Timber houses exhibited more defects due to the specific characteristics of timber construction, which makes sealing of building elements more difficult. The most common defects were associated with windows and doors. Window sash leaks occurred due to outdated and worn gaskets, improperly adjusted sashes, and deformed frames caused by exposure to climatic conditions such as rain, snow, ice and varying temperatures. One of the most important reasons for these leaks was the quality of installation: the windows had been installed without additional sealing strips.

4. Conclusions

All tested houses were classified as “F” or “E” before renovation. The improvement of energy class was achieved by addition thermal insulation, installation of new windows and doors. After renovation, most houses achieved at least the “B” energy class, with some reaching the “A” class. However, five houses initially remained at the “C” class due to insufficient airtightness. Additional defects detection and fixation let to improve airtightness and fulfil “B” energy class requirements of those houses. This means that airtightness is important factor, which could influence energy class of building. The results showed that airtightness of buildings depends strongly on the quality of construction work and design solutions, and it can vary significantly. The main leakages places were: wall junction defects; window and doors installation defects and adjustment; wall junction defects; electrical and plumbing installations, and defects in the socle and roof. Also the defects in timber houses are more common than in masonry houses.

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