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Article

Impact of Air Tightness on the Evaluation of Building Energy Performance in Lithuania

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Abstract: In order to fulfil the European Energy Performance of Buildings Directive (EPBD) requirements for the reduction of energy consumption, European national requirements have been created for building envelope thermal properties and calculation methodology to determine if building energy efficiency is created. This is however not true in all methodologies. The necessity of building air tightness appears only for new A class buildings, and there are no requirements for air tightness for other building classes. Therefore, the aim of this work is to improve the methodology for the calculation of energy efficiency of buildings, while taking into account the air tightness of the buildings. In order to achieve this aim, the sum energy consumption of investigated buildings was calculated, energy efficiency classes were determined, air tightness of the buildings was measured, and reasons for insufficient air tightness were analyzed. Investigation results show that the average value of air tightness of A energy efficiency class buildings is 0.6 h^{-1}. The results of other investigated buildings, corresponding to B and C energy efficiency classes, show insufficient air tightness (the average n_{50} value is 6 h^{-1}); herewith, energy consumption for heating is higher than calculated, according to the energy efficiency methodology. This paper provides an energy performance evaluation scheme, under which performed evaluation of energy performance of buildings ensures high quality construction work, building durability, and the reliability of heat-loss calculations.

Keywords: infiltration; blower door; air tightness; energy; building

1. Introduction

In order to fulfil the European Energy Performance of Buildings Directive (EPBD) [1,2] requirements for the reduction of energy consumption, European national requirements have been created for building envelope thermal properties, and a calculation methodology to determine a building's energy efficiency was created. Each European country has a methodology to determine a building's energy efficiency (DIN 18599 [3] in Germany, DOCET (Simplified Software for energy performance requirements to existing buildings) in Italy, CALENER (Simplified Software for energy performance requirements to existing buildings) in Spain, *etc.*), which differs by the type of buildings and the climatic area, minimum thermal requirements, and indexing of certification [4]. These methodologies are applied to a set of metrics, such as primary energy consumption, final energy consumption, or CO_2 emissions.

The aim of all methodologies is to reduce the energy consumption of buildings. This requires not only improving of the building envelope thermal properties, but also selecting the right technology solution to ensure a high quality of insulation work and air tightness of the buildings. Air tightness is one of the most important factors influencing a comfortable, energy efficient living environment [5,6]. Studies are showing that properly sealed and insulated building envelopes, with effective heating and ventilation systems, can save up to 50% heating energy, and ensure comfortable indoor environmental conditions [7,8]. Effectiveness of the thermal insulation of a building envelope depends on the properly selected technological solutions, qualified work, and a proper understanding of the value of air tightness [9,10].

The main air tightness indicator, n_{50}, meaning the air changes per hour at 50 Pa pressure, was determined by field measurements. Such measurements were carried out in many countries in order to evaluate the overall level of air tightness of buildings according to various criteria, such as building type, height, geometric forms, structure of envelope, ratio between envelope and floor area, *etc.* [11–16]. The main reason of these studies was to investigate the level of air tightness of buildings in analyzed regions, and to determine the requirements for building tightness.

The following levels of air tightness of buildings are set according to the Lithuanian standard, STR 2.09.04:2008 [17]:

- Buildings with more than two residential apartments:
  low air tightness > 5 h^{-1};
  medium—from 2 to 5 h^{-1};
  high < 2 h^{-1}.
- Buildings with one or two residential apartments:
  low air tightness > 10 h^{-1};
  medium—from 4 to 10 h^{-1};
  high < 4 h^{-1}.

The described levels of air tightness depend on the size of the building. Another national standard, STR 2.05.01:2005, “thermal technology of building elements” [18], has the following requirement:

- n_{50} = 3 h^{-1}—rooms without ventilation devices;
- n_{50} = 1.5 h^{-1}—rooms with ventilation devices.

However, values presented in the standards mentioned above do not define air tightness requirements according to the desired energy efficiency class. Standard STR 2.01.09:2005, “Energy Performance of Buildings. Certification of Energy Performance” [19], has the following requirement for the air tightness of buildings with A energy efficiency class: measured air exchange ratio in the building, where the external and internal air pressure is 50 Pa, must be no greater than 0.6 times per hour. However, there are no requirements for air tightness for buildings with other energy efficiency class (B, C, D, E, *etc.*).

Studies indicate that if air tightness of buildings is not ensured, then high, uncontrolled air change rates are present. The more cold air that enters a building, the higher the energy consumption required for heating it is [20]. Therefore, the energy consumption for heating, calculated according to the energy efficiency methodology, is not accurate [21,22]. Therefore, the primary aim of this work was to improve the methodology for the calculation of energy efficiency of the buildings, while taking into account air tightness.

2. The Air Tightness Requirements of Buildings in the EPBD

As mentioned, European national requirements have been created for building envelope thermal properties, and a calculation methodology to determine building energy efficiency created. The requirements for the air tightness of buildings are different in these methodologies. There are requirements for the air change rate of residential buildings in some EU methodologies (Germany). In the methodologies of other countries, air permeability (Italy), air-tightness (Austria), and air leakage (Bulgaria) are evaluated. However, there are some countries, such as Lithuania, where building tightness requirements for building classes lower than A are not included at all in the energy certification methodology [23]. In order to accurately determine the energy consumption of buildings, many EU countries are preparing new requirements for energy performance calculation methodologies to assess the impact on the air tightness of buildings.

3. Methods

3.1. Studied Houses

Investigations were carried out in 27 single-family detached houses, built from 2005 to 2011, and located in the central part of Lithuania. Most of the houses were relatively new, built, on average, 2–3 years prior to the measurements. The average floor area of the studied houses was 189 m^2 and the average volume was 639 m^3. Characteristics of the investigated buildings are presented in Table 1.

All investigated buildings were made from massive supporting structures, *i.e.*, bricks or masonry blocks, with external wall insulation and render systems or ventilated facades. Vapor barriers were not used for the installation of external wall insulation and render systems. External building envelope, from the wind insulation layer, was made of a thermal insulation layer of ventilated facades in order to avoid convective air movement. The roof structures of the investigated buildings were: wood frame with a thermal insulation layer, and reinforced concrete slab with a thermal insulation layer. The floor construction consisted of flooring, reinforced concrete layer, thermal insulation, and waterproof layers. Windows were plastic, with one insulating glass unit of second air conductivity class.

Table 1. Building characteristics.

House	Heated Floor Area, A, m^2	Height of the Building h, m	Volume V, m^3	Number of Exposed Facades	Number of Levels	Type of Ventilation System
1	210.2	6.2	651.6	4	2	Recuperation
2	190.2	6.6	627.7	4	2	Recuperation
3	170.1	6.0	510.4	4	2	Recuperation
4	188.8	6.5	615.4	4	2	Recuperation
5	200.8	6.0	602.3	4	2	Recuperation
6	190.0	7.0	665.0	4	2	Recuperation
7	208.8	6.5	678.6	4	2	Recuperation
8	201.3	6.5	654.2	4	2	Recuperation
9	168.1	7.0	588.4	4	2	Recuperation
10	210.6	9.1	638.9	3	3	Mechanical
11	134.2	7.5	503.2	3	2	Mechanical
12	233.5	7.1	828.9	4	2	Mechanical
13	340.2	8.9	757.1	4	4	Mechanical
14	168.0	5.9	991.5	3	1	Mechanical
15	209.4	7.1	743.4	4	2	Mechanical
16	163.7	6.2	511.6	4	2	Mechanical
17	210.5	7.0	736.8	4	2	Recuperation
18	210.6	9.1	638.9	3	3	Recuperation
19	182.2	7.3	665.0	4	2	Mechanical
20	140.2	6.2	438.3	4	2	Natural
21	107.3	4.0	432.4	4	1	Mechanical
22	115.7	6.8	393.5	4	2	Mechanical
23	167.1	7.5	626.6	4	2	Natural
24	173.7	7.6	658.3	4	2	Natural
25	203.7	9.2	627.5	4	3	Mechanical
26	107.5	5.8	623.5	4	1	Mechanical
27	289.4	8.7	838.2	4	3	Mechanical

3.2. Building Energy Performance Assessment Methods

The main energy performance requirements for new buildings, in relation to the EPBD (Article 5) [1,2], are described in the Building Technical Regulation, STR 2.01.09:2005 [19]. While performing building energy evaluations, the following values are calculated for 1 m^2 of heated floor area: sum normative, $Q_{N.sum}$, reference sum, $Q_{R.sum}$, and calculated, Q_{sum}. Reference sum energy consumption for 1 m^2 of building heated area, $Q_{R.sum}$, is calculated (Equation (1)) according to the reference values that are approved by the Ministry of Environment of Lithuania [19]:

$$Q_{R.sum} = \frac{(Q_{R.env} + Q_{R.vent} + Q_{d1} + Q_{R.\inf} - Q_e - Q_i)}{\eta_{R.h.s.}} + Q_E + Q_{h.w.} \quad (1)$$

where: $Q_{R.env}$ reference heat loses through building envelope for 1 m^2 of heated floor area, $kWh/m^2 \cdot year$ (approved value [19]);

$Q_{R.vent}$ reference energy consumption for ventilation, $kWh/m^2 \cdot year$ (approved value [19]);

Q_{d1} calculated heat loses due to entrance door opening, $kWh/m^2 \cdot year$;

$Q_{R.inf}$ reference heat loses due to over norm infiltration through windows and external doors, $kWh/m^2 \cdot year$ (approved value [19]);

$\eta_{R.h.s.}$ reference efficiency coefficient of building heating system, by parts of units (approved value [19]);

Q_e heat gains in building due to solar radiation, $kWh/m^2 \cdot year$;

Q_i heat gains due to internal heat sources, $kWh/m^2 \cdot year$;

Q_E annual electricity consumption, $kWh/m^2 \cdot year$;

$Q_{h.w.}$ annual energy consumption due to domestic hot water, $kWh/m^2 \cdot year$.

Sum normative, $Q_{N.sum}$, values of building energy consumption, for 1 m^2 of heated floor area, is calculated (Equation (2)) by normative values, which are approved by the Ministry of Environment of Lithuania [19]:

$$Q_{N.sum} = \frac{(Q_{N.env} + Q_{N.vent} + Q_{d1} + Q_{R.\inf} - Q_e - Q_i)}{\eta_{N.h.s.}} + Q_E + Q_{h.w.} \quad (2)$$

where: $Q_{N.env}$ normative heat loses through building envelope for 1 m^2 of heated floor area, $kWh/m^2 \cdot year$ (approved value [19]);

$Q_{N.vent}$ normative energy consumption for ventilation, $kWh/m^2 \cdot year$ (approved value [19]);

$Q_{N.\inf}$ normative heat loses due to over norm infiltration through windows and external doors, $kWh/m^2 \cdot year$ (approved value [19]);

$\eta_{N.h.s.}$ normative efficiency coefficient of building heating system, by parts of units (approved value [19]).

According to the methodology presented in the mentioned regulation, the sum energy consumption of a building, Q_{sum}, was calculated for the heating season, per square meter of building floor space (Equation (3)):

$$Q_{sum} = \frac{Q_{env} + Q_{vent} + Q_{d1} + Q_{\inf} - Q_e - Q_i}{\eta_{h.s.}} + Q_E + Q_{h.w.} \quad (3)$$

where: Q_{env} calculated heat loses through building envelope for 1 m^2 of heated floor area, $kWh/m^2 \cdot year$;

Q_{vent} calculated energy consumption for ventilation, $kWh/m^2 \cdot year$;

Q_{inf} calculated heat loses due to over norm infiltration through windows and external doors, $kWh/m^2 \cdot year$;

$\eta_{h.s.}$ efficiency coefficient of building heating system, by parts of units.

In the building energy consumption methodology, the following constant values were used: 0.6 °C, the average external air temperature during the heating season; 20 °C, the average indoor air temperature during the heating season; and 220 days, the duration of the heating season [19]. The duration of the heating season and the average external air temperature are calculated according to annual graphics of the external air temperature (which are produced by the histogram method, using the average temperature norms of the 1961–1990 period) [24].

Evaluation of building energy performance is carried out according to the value of the qualifying *C*, which is calculated according to the sequence:

$$if\ \frac{Q_{sum}}{Q_{N.sum}} \leq 1,\ C = \frac{Q_{sum}}{Q_{N.sum}} \tag{4}$$

$$if\ \frac{Q_{sum}}{Q_{R.sum}} \geq 1,\ C = 1 + \frac{Q_{sum}}{Q_{R.sum}} \tag{5}$$

The energy performance class of new buildings (or buildings parts) must not be lower that *C*, *i.e.*,

- A class, if $C < 0.5$;
- B class, if $0.5 \leq C < 1$;
- C class, if $1 \leq C < 1.5$.

3.3. Measurement Methods

The total energy consumption for the heating season was calculated per square meter of the investigated buildings, according to standard methodology (STR 2.01.09:2005) [19]. According to this data, the value of the qualification index C was calculated and the energy efficiency class was set.

Measurements of air tightness were performed in all tested buildings. Air leakage value was determined according to standard procedure (LST EN 13829) [25] using method B, when all openings in a building (windows, doors, *etc.*) have been closed and ventilation channels are sealed. Measurements were performed with Blower Door Model 4 (Infiltec, Waynesboro, VA, USA) equipment with an automated performance testing system (uncertainty 8.3%, accuracy ±3%).

If low air tightness is detected, leakages in the building are detected with a ThermaCAM B640 infrared camera (FLIR systems, Munchen, Patent, Germany), whose accuracy is 2% or 2 °C). All the thermography tests were made later, during the winter period. The difference between the indoor and the outdoor air temperature was at least 20 °C. Thermography investigations were done twice. First, to determine the normal situation, the surface temperature measurements were performed without any additional pressure difference. Next, to determine the main air leakage places, the 50 Pa negative pressure under the envelope was set with fan pressurization equipment. After the infiltration airflow, the surface temperatures were measured with the infrared camera from the inside of the building.

4. Results

4.1. Evaluation of Building Energy Efficiency

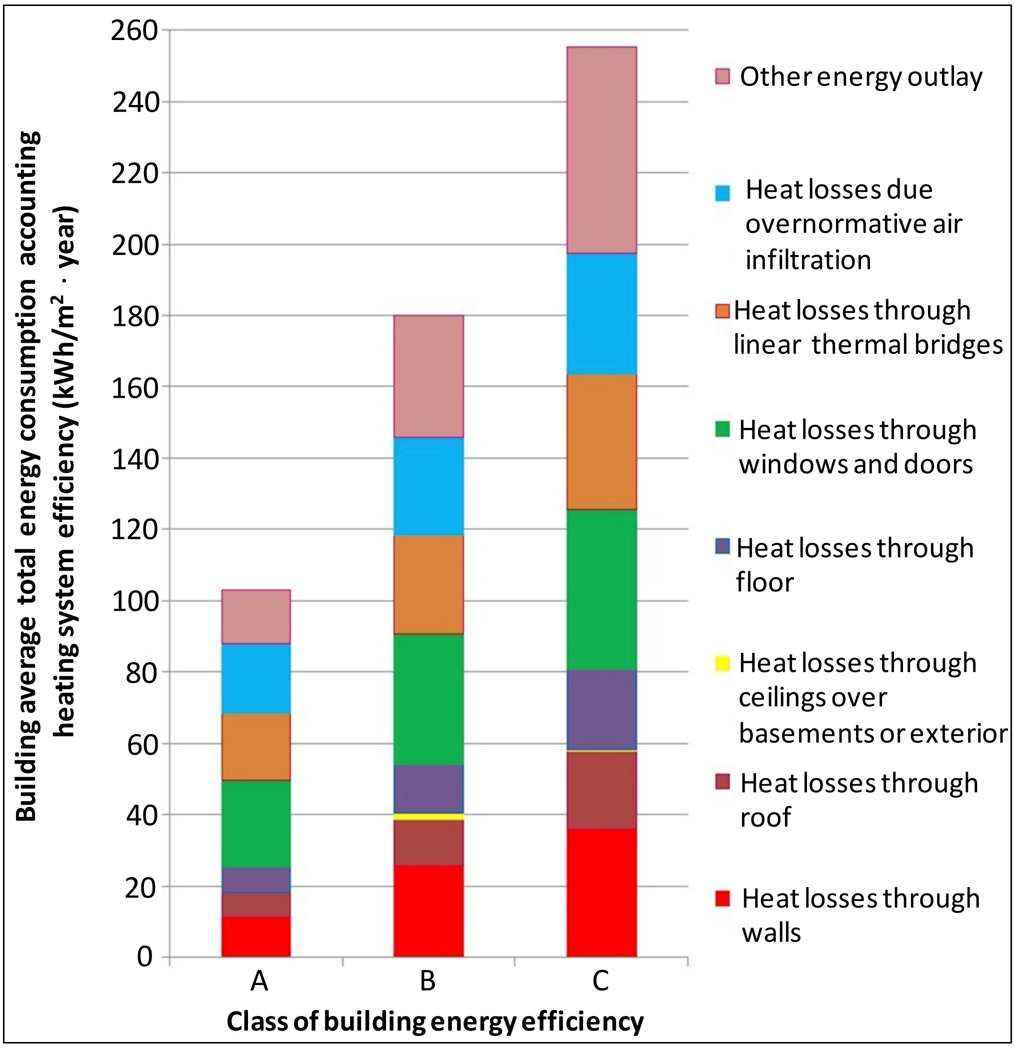
Calculated sum energy consumption for investigated buildings, values of qualifying indicator C, and determined energy performance classes are presented in Table 2.

Table 2 presents results of the measured average air exchange rates, per hour, at 50 Pa pressure, n_{50}, and the air leakage rates of building envelopes, q_{50}. The q_{50} value of low-rise buildings is lower than multi-story buildings. However, with the increase in height of the building, the q_{50} value increases compared with the n_{50} value because the ratio between the external envelopes and floor-roof areas of the multi-story buildings is higher then the same ratio in low-rise buildings. Calculations of the mean sum energy consumption, according to the energy performance class (Figure 1), shows that changes of heat loss are proportional to the building energy efficiency class. If the heat loss of the building is reduced by such means as thermal properties of walls, roofs, windows, *etc.*, it means that the building energy efficiency class increases.

Table 2. Calculated sum energy consumption for investigated buildings, energy consumption due to over norm infiltration through windows and external doors, energy consumption for ventilation, values of qualifying indicator C, determined energy performance classes, results of measured average air exchange rates per hour at 50 Pa pressure, and the air leakage rate of building envelopes.

House	Q_{sum}, kWh/m^2·Year	Q_{inf}, kWh/m^2·Year	Q_{vent}, kWh/m^2·Year	Value of Qualifying Indicator C	Energy Performance Class	n_{50}, h^{-1}	q_{50} m^3/(h × m^2)
1	87.45	10.68	10.04	0.38	A	0.41	0.40
2	126.35	24.06	10.21	0.38	A	0.69	0.74
3	90.56	20.89	10.10	0.37	A	0.74	0.68
4	130.50	11.25	9.91	0.38	A	0.55	0.52
5	89.60	26.34	10.04	0.40	A	0.64	0.50
6	100.15	15.74	9.99	0.38	A	0.58	0.71
7	119.16	18.61	10.01	0.38	A	0.61	0.62
8	95.36	24.00	10.20	0.38	A	0.52	0.68
9	87.36	26.00	10.19	0.37	A	0.65	0.81
10	204.24	42.16	24.60	0.84	B	5.01	7.71
11	129.72	16.48	21.78	0.98	B	9.25	9.34
12	152.00	10.68	34.54	0.85	B	3.50	5.54
13	151.13	13.79	29.47	0.97	B	7.21	8.19
14	192.00	33.04	32.21	0.97	B	5.54	6.37
15	201.81	32.16	36.30	0.99	B	5.86	7.22
16	216.06	24.06	39.85	0.97	B	2.19	3.01
17	222.08	63.90	16.37	0.70	B	11.30	14.61
18	152.07	10.68	12.31	0.65	B	8.15	12.55
19	236.02	34.06	37.26	1.14	C	5.50	7.21
20	307.30	36.78	24.04	1.06	C	3.41	2.94
21	207.88	19.74	33.79	1.23	C	10.85	8.11
22	246.87	25.40	35.58	1.06	C	8.60	7.46
23	292.66	40.84	24.04	1.41	C	7.50	7.69
24	273.76	41.27	24.04	1.02	C	5.83	8.55
25	246.42	32.60	33.26	1.03	C	4.55	6.57
26	231.83	47.69	43.86	1.31	C	5.00	4.55
27	255.41	24.06	43.15	1.29	C	2.99	3.60

Figure 1. Sum energy consumption of the building according to the energy efficiency class.



Heat loss due to over norm infiltration of external air, through windows and external doors, Q_{inf}, are taken into account during calculations of sum energy consumption of a building during the heating season (Equation (1)). This is about 20% of the total heat loss of a building.

Normative heat losses, $Q_{N.inf}$, are set with the condition that there should be no higher infiltration of external air than is needed for the ventilation of buildings, thus, $Q_{N.inf} = 0$. This amount of air is regulated by standards [26].

However, if sum areas and air leakage values of the windows, skylights, and other transparent envelopes, as well as external doors, are evaluated, according to the manufacturer's declaration of product air conductivity class, it might be $Q_{N.inf} > 0$. Heat loss, because of extra normative infiltration of external air through the windows and external doors, Q_{inf}, is calculated according to Equation (6):

$$Q_{inf} = 1.77 \cdot \left(\frac{K_R \cdot (A_{wd.sum} + A_{d.sum})}{A_p} + v_1 - v_o\right) \cdot (\theta_{iH} - 0.6) \tag{6}$$

where: $A_{wd.sum}$, $A_{d.sum}$ total areas of windows, doors, roof windows, skylights or other transparent partitions, and entrance doors, in m^2;

K_R air leakage value of windows, doors, roof windows, skylights or other transparent partitions, and entrance doors, $(m^3/(m^2 \cdot h))$. This value is determined by a 50 Pa pressure difference;

v_o amount of external air for ventilation of 1 m^2 of building, ($m^3/(m^2 \cdot h)$);
v_1 amount of external air infiltration through the entrance door due to opening, ($m^3/(m^2 \cdot h)$);
A_p building heated floor area, m^2;
θ_{Ih} average internal temperature during the heating season, °C.

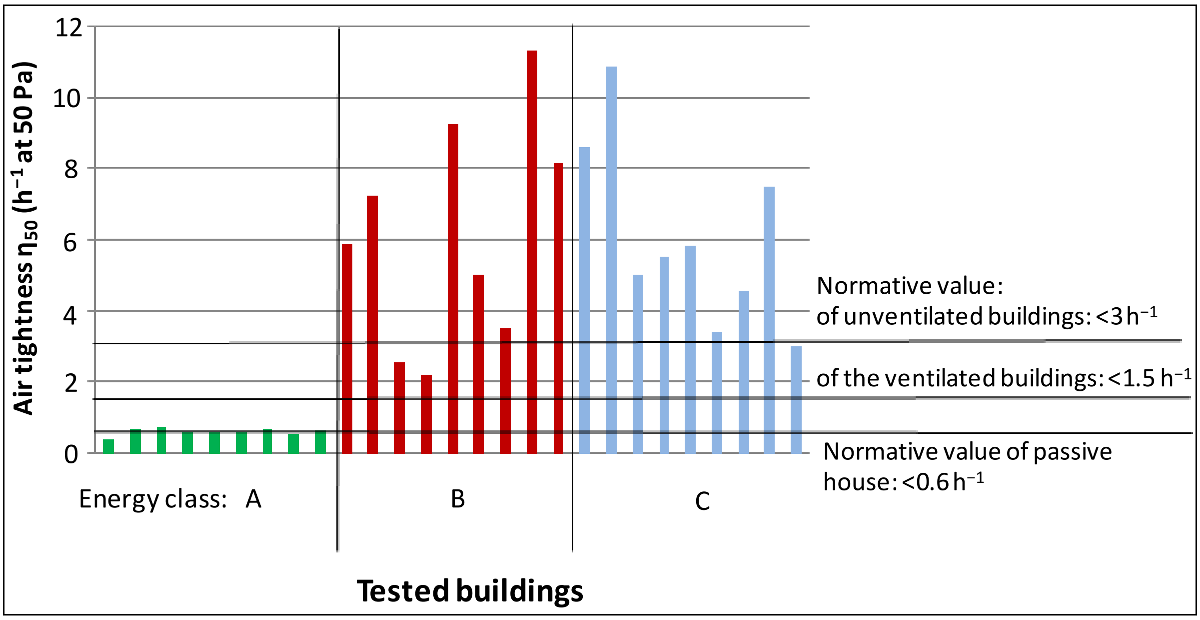
Calculated Q_{inf} values are presented in Figure1. From Equation (6), it can be stated that the main criterion, determining the value of heat loss due to extra normative infiltration of external air, is the ratio between windows (roof windows, skylights or other transparent envelopes, and external doors) and the heated floor area in buildings. Heat loss, due to over norm infiltration of external air, become greater if more glassed and opening parts of the building are present. These calculations take into consideration the air permeability characteristic of windows or other glassed areas, *i.e.*, the air leakage value of opening parts.

However, these calculations underestimate over norm infiltration due to insufficient tightness between separate construction elements (windows, walls, roof, *etc.*). Building energy performance calculation methodology is based on the assumption that the air tightness of a building complies with national requirements and that construction and mounting quality is assured. Therefore, the next step of this research was to determine air tightness level in new Lithuanian buildings and to verify the earlier mentioned assumption regarding the reliability of the building energy performance calculation methodology.

4.2. Air Tightness

Air tightness was determined after evaluating the energy efficiency and energy consumption for the heating of tested buildings. The results are presented in Figure 2.

Figure 2. Air tightness of the research buildings.



The obtained results of air tightness of buildings indicate that the average air change rate with an air pressure of 50 Pa, was 4.73 h^{-1}; the minimum rate was 0.41 h^{-1} and the maximum was 11.3 h^{-1}.

The minimum values are attributes of the A energy efficiency class, and the maximum to the B energy efficiency class.

In fact, the results presented in Figure 2 indicate that the air tightness measurement results of low energy buildings do not differ from the results presented in STR 2.01.09:2005 [19]. The average air change rate is $n_{50} = 0.6\ h^{-1}$. However, air tightness values in buildings with B and C energy efficiency classes are higher than normative ones. None of the investigated average air change rates in B and C class buildings, when an air pressure of 50 Pa was present, was lower than 1.5 h^{-1}, despite the fact buildings were equipped with ventilation devices. Two energy efficiency class B buildings had air change rates lower then 3 h^{-1}, and one class C building had reached the limit value of $n_{50} = 3\ h^{-1}$.

Mean values of air tightness, standard deviation, and a confidence interval of 90% are presented in Table 3. Statistical evaluation of data show that the air tightness of low energy buildings (A class) is high, and sampling data are very concentrated if compared to the data of other building classes. Monitoring data of B and C energy efficiency class buildings are widely dispersed and partly overlapping. The results do not indicate any significant difference between average values obtained. Summing up the obtained results, it can be stated that the air tightness of low-energy Lithuanian buildings is assured and meets normative requirements. However, new buildings in Lithuania, with B and C energy efficiency classes, are not air tight enough and do not meet STR 2.05.01:2005 "Thermal technology of building elements" requirements [18]. Therefore, it is probable that energy consumption in buildings with B and C classes would be higher if calculated according to methodology presented in STR 2.01.09:2005 [18].

Table 3. Statistical data of air tightness of the tested buildings.

Energy Efficiency Class of the Building	Mean Value of Air Tightness n_{50} (h^{-1} at 50 pa)	Standard Deviation	90% Confidence Interval
A	0.6	0.10	0.55–0.67
B	6.1	3.13	4.17–8.05
C	6.0	2.54	4.45–7.60

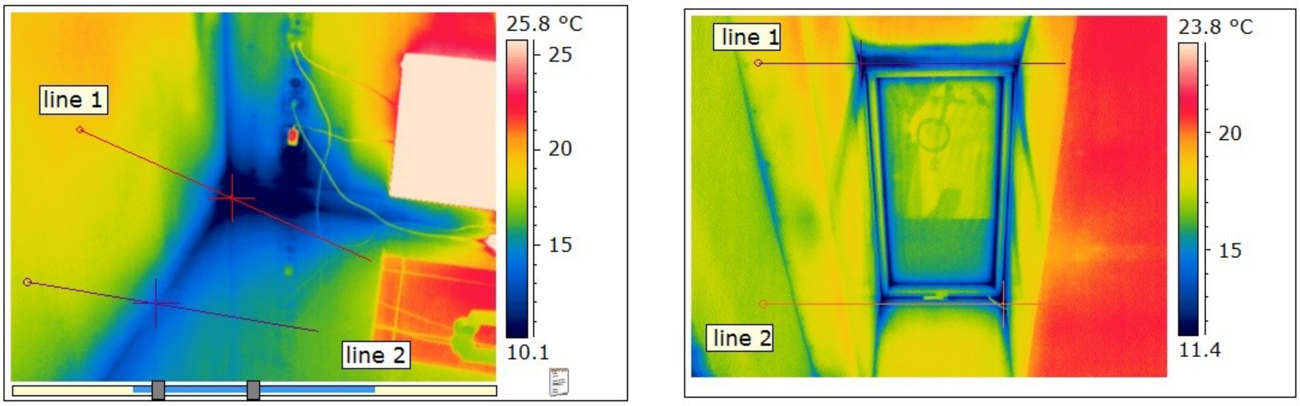
4.3. Thermographic Survey

Thermographic surveys were performed in order to determine the causes of low air tightness of buildings, which revealed defects associated with poor quality mounting work and inappropriate construction decisions. The most common defects are presented in Figure 3, where cracks in the construction joints can be seen. Distribution of buildings' surface temperatures is presented in Figure 4.

Line 1, drawn in Figure 3a, includes leakage places of junctions of the wall and floor. The maximum temperature of wall surfaces, θ_{si} = 19.7 °C, and minimum wall and floor angle surface temperature θ_{si} = 5.5 °C (Figure 4a). The difference between surface temperatures is approximately 14 °C. It is likely that condensation processes will take place in these leakage places, and conditions for mold growth will appear. The indoor environment of the building will have a negative influence on people: air movement will be felt during the cold season because of the large temperature difference between the surface and air temperature; and cold air flow will be felt, which results in the requirement of more energy to heat the building.

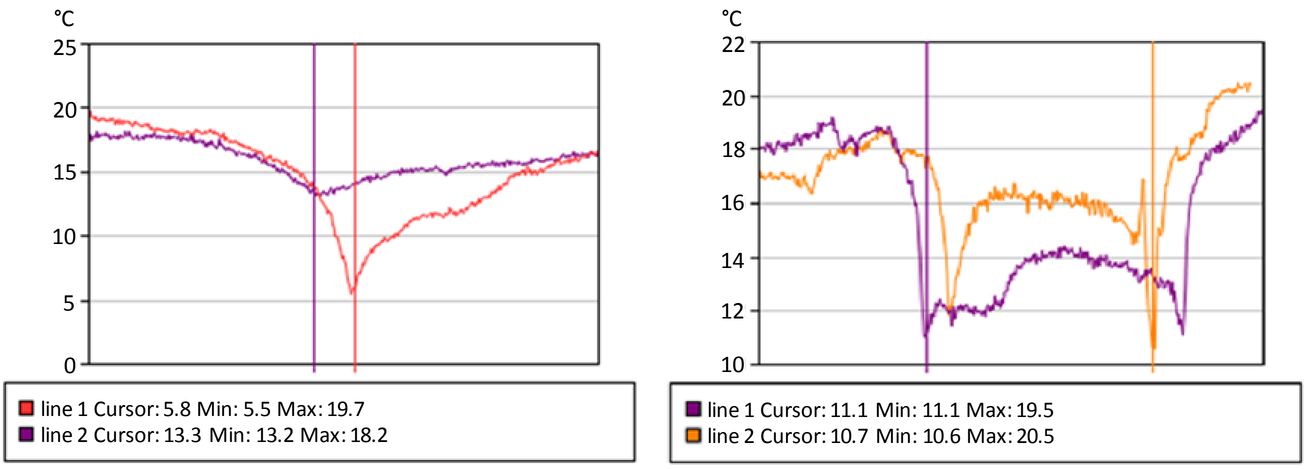
The mounting of windows, skylights and other glassed enclosures, and external doors, is another common case of poor quality work. Skylight mounting defects are presented in Figure 3b. The heat is lost through the skylight's sash, and cracks around construction's frame. Thermographic analyses presented in Figure 4b indicate that maximum temperature of ceiling surface is θ_{si} = 20.5 °C and the minimum temperature at the skylight's frame is θ_{si} = 10.7 °C.

Figure 3. (**a**) Thermographic photo the leakage point of a wall and floor; (**b**) Thermographic photo of a skylight's mounting leakage points.



(**a**) (**b**)

Figure 4. (**a**) Thermographic analyses of a wall and floor leakage points; (**b**) Thermographic analyses of a skylight's mounting leakage points.



(**a**) (**b**)

Thermal bridges (values are considerably higher than normative ones [17]) are formed as the surface temperature at the window frames is twice decreased. Investigations indicate that, if the influence of thermal bridges on heat losses through the windows is not taken into consideration, then it is possible that the actual heat loss could be twice larger than calculated. In most critical cases, not only water vapor condensation, but also frost (at negative temperatures) or mold (when condensation is not evaporating for a long time) may occur at thermal bridges [27].

Typical air leakage places in the studied houses were:

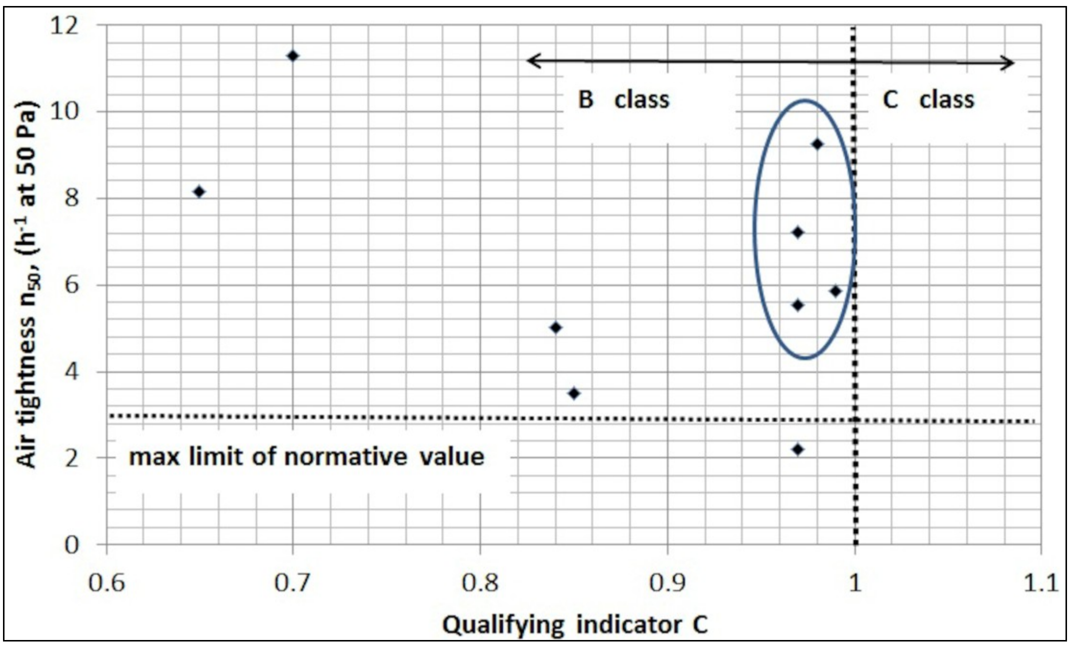
- junction of the ceiling and floor with the external wall;
- junction of the separating walls with the external wall and roof;
- penetrations of electrical and plumbing installations through the air barrier systems;
- leakage around and through the windows and doors.

5. Discussion

The principle for ideal home construction corresponds to A energy efficiency class buildings. Additional requirements, to ensure air tightness of these buildings, are presented in Lithuanian national standards. However, an air tightness test is not mandatory for buildings with lower energy classes. Energy consumption of these buildings depends on the thermal characteristics of external envelopes, energy consumption, energy consumption for ventilation during the heating season, *etc.* However, without assurance that a building is air tight, energy efficiency calculations are meaningless because these estimates do not reflect the real energy consumption for heating. For example, energy efficiency class of one of the investigated buildings was B (Figure 2), which indicates that this building is attributed to energy efficiency building groups. Sum energy consumption of such a house is 222.08 kWh/m^2·year. However, after an air tightness test it was revealed that the air tightness is four times lower then is required in construction technical documents. This indicates that the building is of poor quality and cannot be attributed to energy efficiency building groups as a large part of the heat is lost through the cracks and leakage areas of the building.

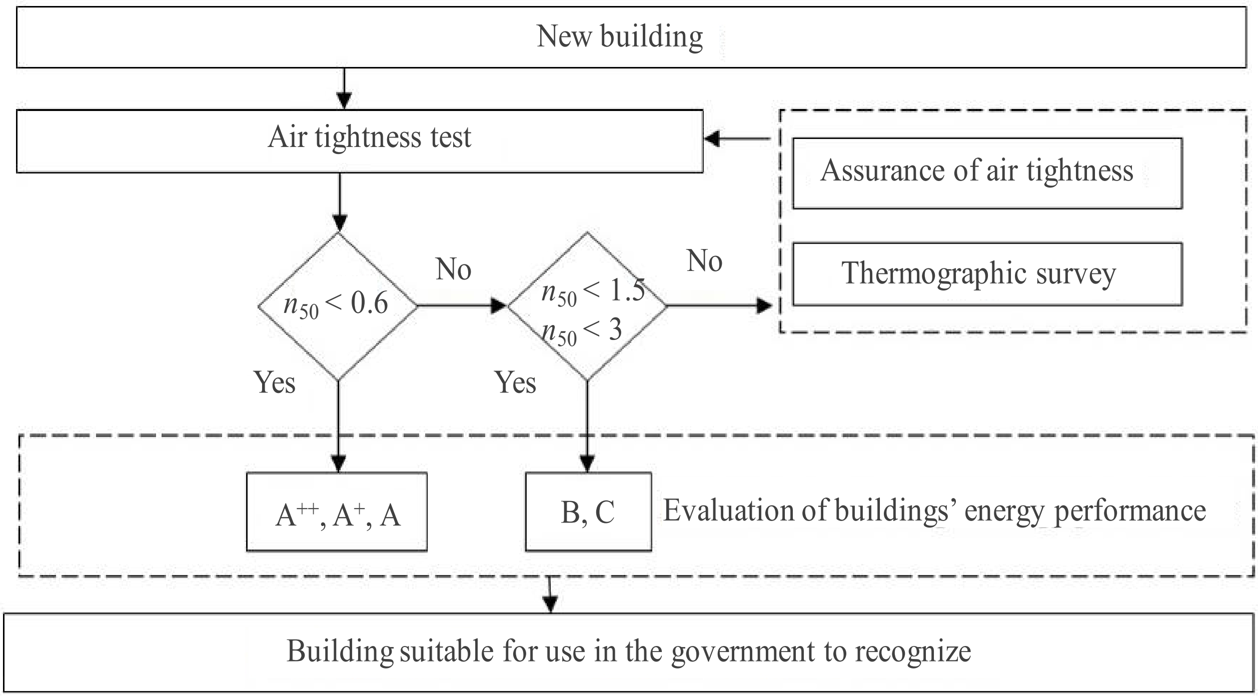
The conclusion can be made that the calculated energy consumption of the buildings, by the presented methodology, when air tightness is not considered, is not the real energy consumption of the buildings. Figure 5 presents the rankings of the tested class B buildings. When air tightness of the buildings is evaluated, B energy efficiency class buildings (marked in Figure 5) can become C class.

Figure 5. The rankings of B energy efficiency class buildings according to the qualifying indicator *C*.



In order to fulfil the European Energy Performance of Buildings Directive (EPBD) requirements [1,2] for the reduction of energy consumption, it is necessary to rely on, not only theoretical calculations, but also to evaluate technical solutions for the investigated buildings and quality of the performed work. It is possible after performance of an air tightness test. Therefore, in order to increase the reliability of the evaluation of buildings' energy efficiency, it is proposed to perform building energy certification according to the following scheme (Figure 6).

Figure 6. Building energy certification scheme.



The level of air tightness is a significant factor in the assessment of building energy performance. Air tightness, along with other complex building solutions reduces the heat cost, increases thermal comfort, and ensures a healthy environment and durability of the building. Air tightness depends on the human factor, the technical solutions and materials which are used. Therefore, each case will be different. Before the start of the evaluation of energy efficiency of the building, it is necessary to perform an air tightness test according to EN 13829 requirements [25]. If the obtained results satisfy national Building Technical Regulation requirements, calculations of sum energy consumption are made and the value of the qualifying indicator C is determined, which identifies energy efficiency class of the building. If the average air change rate of the tested building is $n_{50} < 0.6$ (h^{-1}), the building could be A, B, or C class. It will depend on the thermal properties of the external walls, use of electrical power, energy used for the ventilation of the building during the heating season, *etc.* If buildings with ventilation equipment have $n_{50} < 1.5$ (h^{-1}), and if buildings with natural ventilation have $n_{50} < 3$ (h^{-1}), the buildings can be B or C energy efficiency class. If the average air change rate values are higher than presented in the national requirements, then newly constructed buildings cannot be certified. According to the Building Technical Regulation STR 2.01.09:2005 [19], the energy performance class of new buildings (or buildings parts) must not be lower than C class. Buildings, which are not air-tight should be adjusted, in order to ensure air tightness.

According to the presented energy performance evaluation scheme, under which performed evaluation of energy performance of buildings ensures a high quality of construction work, a building's durability, and the reliability of calculations of heat losses.

6. Conclusions

Air tightness of low energy buildings is sufficient and meets STR 2.01.09:2005 requirements [19]. The average value is $n_{50} = 0.6\ h^{-1}$.

The results of this work show that new Lithuanian buildings (2005–2011) of B and C energy efficiency classes are not sufficiently airtight. The average air change rate, when an air pressure of 50 Pa is present, is two times higher the normative value ($n_{50} = 3\ h^{-1}$).

Typical air leakage places in the studied houses were as follows: junctions of ceilings and floors with the external walls; junctions of separating walls with the external walls and roofs; penetration of the electrical and plumbing installations through the air barrier systems; and leakage around, and through, windows and doors.

Building energy efficiency calculation methodology is reliable only after verifying that a build is air-tight, otherwise, the heating energy consumption in buildings can significantly differ from the calculated ones.

According to the energy performance evaluation scheme presented in this paper, under which the performed evaluation of energy performance of buildings ensures a high quality of construction work, a building's durability, and the reliability of heat loss calculations. It is recommended to introduce a requirement in building standard to perform air tightness tests for B and C energy efficiency class buildings before evaluating a building's energy performance.

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Author Contributions

All authors contributed equally to this work. All authors designed the calculations, discussed the results and implications, and commented on the manuscript at all stages. Karolis Banionis and Valdas Paukštys performed the measurements of the air tightness of buildings and performed thermographic analyses. Jolanta Šadauskienė performed the energy consumption work for investigated buildings. Valdas Paukštys identified the energy performance classes of investigated buildings. Jolanta Šadauskienė lead the development of the paper and Lina Šeduikytė performed the statistical analysis.

Conflicts of Interest

The authors declare no conflict of interest.

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