V entilation
I nformation
P aper
n° 45.1

July 2022

Operating Agent
and Management
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International Energy Agency's
Energy in Buildings and Communities
Programme

Air Infiltration and Ventilation Centre

Trends in building and ductwork airtightness in Estonia

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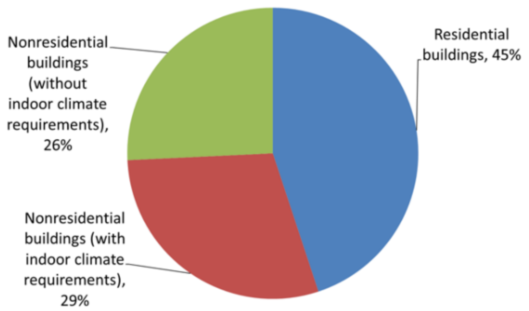
1 Introduction on the building market in Estonia

Estonia is a country of 1.3M inhabitants. According to the Estonian Building Registry, the number of private houses of known area taken into use before 2000 (included) is 155.150, their total floor area amounting to 19.998.000 m². The number of apartment buildings of known floor area taken into use before 2000 (included) is 22.600, their total area amounting to 28.378.000 m². The Building Registry includes 375.000 non-residential buildings that are in use and have been taken into use before 2000 (included). Their total floor area amounts to 62M m². As illustrated in Figure 1, there are non-residential buildings with climate control (office, educational and commercial buildings, etc.) and without climate control (ancillary buildings of residential buildings, agricultural buildings, pumping stations, etc.). There are around 32.000 such buildings with a total floor area of 28M m². Most of the Estonian residential buildings are under private ownership. According to the population and housing census of 2011, 97% of dwellings were under private ownership. State or local authorities owned just 2% of dwellings.

In recent years, about 10.000 building permits and 6.400 use permits have been issued annually (see Figure 2). The difference between the number of the building and use permits is because not every building permit has been subject to realization and the permit for use has not always been applied for.



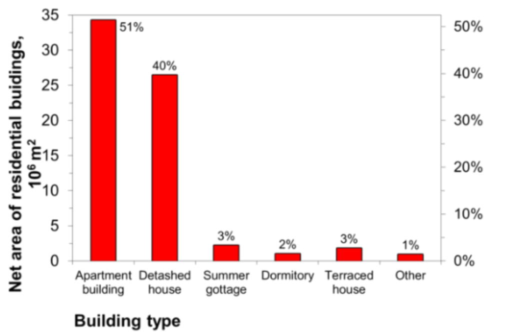


Figure 1: Division of all buildings (top) and residential buildings (bottom) in Estonia constructed before 2011.

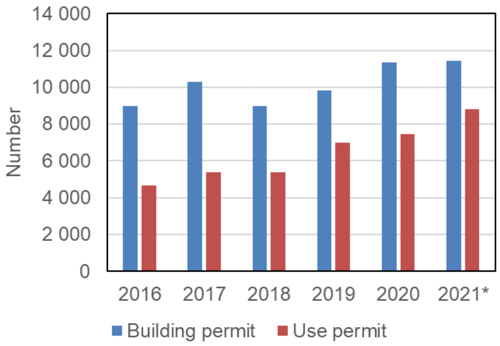


Figure 2: Annual building permits and building use permits issued

2 Building airtightness

2.1 *Introduction*

Airtightness of building envelopes directly affects indoor quality (health, thermal comfort), hygrothermal performance, noise and fire resistance, and energy consumption of the building. In cold climates, infiltration is responsible for about 15–30% of the energy use for space-heating, including ventilation, in a two-story detached house, when the building leakage rate is typically (n_{50}=3.9 h^{-1}), while the corresponding proportion is about 30–50% in a leaky house (n_{50}=10 h^{-1}). Due to the fact that the correlation between the airtightness of the building envelope and the infiltration rate is almost linear, the heating energy use of the houses also increases almost linearly at the same time. Therefore, the preceding correlation is reduced to a simple rule of thumb: a one-unit change in n_{50} corresponds to a 7% change in the energy use for space heating, including ventilation. At the same time, the change in the total energy use for heating is about 4%. In the studied cases, these increment percentages vary from 4% to 12% regarding space heating, or from 2% to 7% regarding the total energy use. The variation of these percentages mainly results from different wind conditions [1].

According to a survey conducted, fluctuating room temperature, cold floors and draught from electric sockets were linked to the houses with air leakage rate >3 $m^3/(h·m^2)$ at 50 Pa [2].

The laboratory measurement and simulation results show that in a cold climate, for the assemblies being studied with mineral wool sheathing, leakage rates of 0.1—0.2 l/(s·m) at a 10Pa pressure difference may be used as performance criteria for moisture convection in a two-storey house with dimensioning moisture excess 4g/m³ and a cold outdoor climate [3].

2.2 *Airtightness Indicator*

In Estonia the airtightness indicator is q_{50}, $m^3/(h·m^2)$. It corresponds to the air leakage rate in m³/h at reference pressure of 50Pa divided by the building envelope area in m². This indicator is selected because the building envelope is leaking, not the internal volume.

2.3 *Requirements and drivers*

2.3.1 Building airtightness requirements in the regulation

In Estonia, the first requirement on the envelope's airtightness for apartment buildings was set in 1995: air leakage rate should be q_{50} < 3$m^3/(h·m^2)$ (ET-1 0113-0568 Piirdetarindid. Osa 1. Üldnõuded EPN 11.1). In 2007[1], minimum requirements on energy performance of buildings came into force, that suggest the air leakage rate should be q_{50}<1 $m^3/(h·m^2)$ in general (non-mandatory recommendation), and to avoid problems due to moisture convection critical joints should be made airtight.

Today, air leakage rate of the building envelope is driven mainly by energy performance (EP) requirements. The reference to the need to make critical joints airtight to avoid moisture convection is in the explanatory memorandum of the regulation, but no longer in the regulation. Lawyers did not like such an approximate reasoning: the regulation's requirements must be measurable.

If the base value from the EP requirements is used, then on-site testing is not mandatory. However, the use of base values often makes it hard to fulfill EP requirements. Frequently q_{50} = 1.5 $m^3/(h·m^2)$ is assumed in the EP calculations and in these cases the on-site testing is mandatory to prove the estimated values.

2.3.2 Sanctions

If a building does not comply with the requirements, the constructor should improve the airtightness until the client agrees on the result.

[1] https://www.riigiteataja.ee/akt/12903585

2.4 *Building airtightness in the energy performance calculation*

2.4.1 Calculation and base values

Base values for the air leakage rate used in the EP calculation were implemented fifteen years ago and modified twice since then.

In 2007, minimum requirements on energy performance of buildings came into force. Where the building's air leakage rate has not been measured or proved in any other manner, the energy calculation uses the base values of air leakage of buildings for energy performance modelling i.e., $q_{50} < 6$ m³/(h·m²) for detached houses and $q_{50} < 3$ m³/(h·m²) for other buildings (including non-residential buildings). Where the design air leakage value is greater than the base value, the design air leakage value is used. Where the air leakage was measured according to the standard EVS-EN 13829 or proved by the supplier of the house, the measured or proved value is used in the energy calculation.

These base values were later specified based on data from field measurements with values for buildings with minor renovation: $q_{50}<9$ m³/(h·m²) for detached houses and $q_{50}<6$ m³/(h·m²) for apartment buildings. The value of the major renovation was equated with that of the new building[2].

The infiltration air flow rate q_i (l/s) is calculated by means of the formula [4]:

$$q_i = \frac{q_{50}}{3,6 \cdot x} A,$$

With:

- q_{50}: average air leakage rate of the building envelope (m³/(h·m²))
- A: area of the building envelope (including floors) (m²)
- x a factor which is 35 in the case of a single-storey building, 24 in the case of a two-storey building, 20 in the case of a three or four-storey building, and 15 in the case of a five-storey or higher building, the height of a storey being 3 metres
- 3.6 is the factor which converts the airflow rate unit from m³/h to l/s

[2] https://www.riigiteataja.ee/akt/109062015021

Where the exhaust air flow rate exceeds the supply air flow rate, the infiltration air flow rate may be calculated by means of the following formula [4]:

$$q_i = \frac{0,25 q_{50} A}{1 + 2780 \left(\frac{q_v - q_s}{q_{50} A} \right)^2},$$

With:

- q_v: exhaust air flow rate (l/s)
- q_s: supply air flow rate (l/s)

According to the latest version of the regulation[3], starting from January 2019, the value of the air leakage rate of 1.5 m³/(h·m²) can be used for energy performance calculations for all building types but it has to be proved through on-site testing before the building gets official use permit; otherwise the declared air leakage rate can be used. If this is not achieved, the EP calculations have to be repeated with measured q_{50} to prove that the building still complies with the minimum EP requirements for this type of usage.

The declared air leakage rate $q_{50,decl}$ represents the median value (50% fractal) with a confidence level of 90% for airtightness. The reference value of airtightness is applicable for energy calculations, when airtightness is not measured or the airtightness base value given in energy performance regulation is not suitable to use (too large or too small).

$$q_{50,decl} = \overline{q_{50}} + k \cdot \sigma_{q50}, \text{ m}^3/(\text{h} \cdot \text{m}^2)$$

With:

- $\overline{q_{50}}$: mean value of airtightness of this building type (m³/(h·m²))
- σ_{q50}: standard deviation of airtightness measurement results for this building type
- k: factor which considers the median value with a confidence level of 90%:

$$k = \frac{1.645}{\sqrt{n}}$$

With:

[3] https://www.riigiteataja.ee/akt/107072020012

- n: number of air leakage tests

If the air leakage of an external boundary has not been measured or otherwise verified, the energy calculation shall be performed with the base value of the air leakage number of the building specified in Table 1.

Table 1 : Base value of air leakage rate for energy performance calculations (currently used values)

	Base value or air leakage rate for energy modelling q_{50} (m³/(h.m²))	
	New building, major renovation	**Non-renovated building, minor renovation**
Detached house	4	6
Other buildings (including non-residential buildings)	2.5	4

2.5 *Building airtightness test protocol*

The Blower Door test is the main method to measure buildings' air leakage. There is no national guideline to perform airtightness tests (no national annex to ISO 9972), and no qualification scheme for airtightness testers. Calibration is needed according to measurement device requirements.

2.6 *Building airtightness tests performed*

2.6.1 Tested buildings

The state's real estate company requires almost all constructed and renovated buildings to be measured. Many construction companies also conduct measurements of their buildings to be sure of their quality and reduce the risk of complaints.

It is roughly estimated that about a quarter of the buildings will be measured.

2.6.2 Evolution of the airtightness level

There is no database which is constantly updated. The university has however collected and published measurement data several times, as detailed below. It gives an overview of the evolution of building envelope airtightness in Estonia.

A decade ago the database of airtightness measurements was statistically assessed and the focus was on residential apartment buildings built between 2001 and 2010 [5]. The study showed that these buildings were substantially more airtight compared to buildings from the period 1960-1990 with a mean air leakage rate at 50 Pa pressure difference of 1.7 (in the range of 0.8 … 4.6) m³/(h·m²). A large variation of air leakage rate within similar structural solutions referred to quality of workmanship as a driving factor. Typical air leakages were found around the windows and doors, around different penetrations through building envelope and around junctions between external wall and roof, floor, internal wall or intermediate ceiling.

An older study of the Estonian building stock that concentrated on lightweight single-family detached houses, also confirmed that the most significant factors affecting the airtightness were the quality of workmanship and supervision as well as the number of storeys of the house, both showing a more than two-fold effect [2].

The most recent article that focused on wooden buildings showed that for newer buildings, the number of storeys has no longer any systematic effect on air leakages [6]. It was shown that a systematic approach to designing the airtight building envelope, avoids large air leakages related to external wall and intermediate ceiling junctions in older buildings. A non-existent correlation between airtightness and compactness of the building envelope referred to the assumption that if systematic quality assurance with a proper airtightness concept in all junctions is used, the geometric and structural complexity of the building envelope is no longer a key factor while achieving airtightness in Estonia. The study concludes that the airtightness of Estonian wooden buildings has improved by a factor of 10 since the minimum requirements for energy efficiency have taken effect with a median value of q_{50} = 1.1 m³/(h·m²). The use of prefabricated building elements combined with systematic quality assurance mechanisms and regular airtightness measurements seems to be superior to traditional on-site building showing measured air leakage rates well below $1 m^3/(h·m^2)$ at 50 Pa pressure difference.

2.7 Guidelines to build airtight

This guideline is under development. The guideline will be an Estonian national standard coordinated by technical committee EVS/TK 14 “Thermal performance” of standards and developed by researchers of the Tallinn University of Technology.

2.8 Conclusion

Year after year, the airtightness of the building envelope has become an increasingly important issue in Estonia. The increasing prices in the building market make it harder to use the base values of air leakage rate which tend to overestimate the actual air leakages and need to be compensated by improving other elements of the building. The overall knowledge and quality of workmanship related to airtightness has increased in the market and this trend is expected to continue.

3 Ductwork airtightness

3.1 Introduction

In Estonia, there is no detailed studies on the impact of ductwork leakage on fan energy consumption or indoor air quality (IAQ). At the same time, there has been quite a lot of studies about the ventilation renovation in old apartment buildings that also concern the airtightness of ductwork [7]–[10]. The main problem of ventilation systems in old Estonian apartment buildings is the low airtightness of old shafts and existing steel ductwork. If the old parts of the ductwork are used, the renovated ventilation systems are often unbalanced and very noisy. It means the air flow rates are reduced in operation. That is the reason why the main recommendation of these studies include the recommendation to install new ventilation ducts in the old natural ventilation channels or install new ductwork inside the insulation layer on the façade [6].

According to the Estonian requirements to the ductwork components of the ventilation system, the airtightness classes of the duct and the other parts of the ductwork range from class A to D. The airtightness class (ATC) of ventilation ductwork should be at least 4 (previous name B), that is to say with an air leakage limit (f_{max}) according to the test pressure (p_t) of $0{,}009*p_t^{0{,}65}*10^{-3}$ $m^3.s^{-1}.m^{-2}$. The airtightness of ventilation ductwork is not playing a role in energy performance calculations or IAQ requirements in Estonia.

3.2 Airtightness indicator

By definition, the airtightness of ventilation ductwork is the maximum permissible leakage air flow for a ventilation system and its parts per casing surface area. The airtightness indicator of ventilation ductwork is f_{max}, $m^3.s^{-1}.m^{-2}$. The reference test pressure is not directly defined in requirements.

3.3 Requirements and drivers

According to the Estonian requirements for the ductwork components of the ventilation system, the airtightness classes of the duct and the other parts of the ductwork range from A to D. The main requirements for the airtightness of different types of ductwork and components are pointed out in standards EVS-EN 12237:2003, EVS-EN 1507:2006 and EVS-EN 12599:2012, EN 12599, EN 13180, EN 1751, EN 13180, EN 13403, WI 00156179 and EN15727. In general, the requirements for ventilation systems in buildings require minimum class B for the whole system and recommend ducts and components of Class C or better. The requirements for the airtightness class of the ventilation ductwork are usually set by the ventilation designer based on the specific requirements of the building or room. The main requirements for the ductwork components are brought out in standards in force (EVS-EN 12237:2003 for the circular sheet metal ducts and EVS-EN 1507:2006 for the sheet metal air ducts with rectangular section). Before the aforementioned standards the first airtightness requirements for the circular ductworks were established in 1997 (EVS 739-1:1997). The declaration of conformity must be provided to all ductwork components, for which there is a valid harmonized product standard, technical approval or which have been provided for safety.

The airtightness of ventilation ductwork should be measured and a report of the ductwork airtightness measurements should be attached to the building inspection documents. The maximum air leakage rate for a ductwork airtightness of Class B is $f_{max}=0.009*p_t^{0.65}*10^{-3}$ $m^3.s^{-1}.m^{-2}$, where p_t is the test pressure (Pa).

There is no specific programme or subsidy that promotes the ductwork airtightness.

3.4 Ductwork airtightness in the energy performance calculation

The airtightness of the ventilation ductwork is not directly an input for the building energy calculations. It has been decided that the EP-calculation requirements should be clear to the various parties and not go into too much detail.

3.5 Ductwork airtightness test protocol

3.5.1 Qualification of ductwork airtightness testers

The airtightness of ductwork is measured by the ventilation airflow measurement specialists, but there is no qualification scheme for ductwork airtightness testers.

3.5.2 National guidelines

In Estonia the only guidelines to perform the measurements of the ductwork airtightness are the requirements that are pointed out in standards EVS-EN 12237:2003, EVS-EN 1507:2006 and EVS-EN 12599:2012, EN 12599, EN 13180, EN 1751, EN 13180, EN 13403, WI 00156179 and EN15727.

Riigi Kinnisvara AS (RKAS) which is a public real estate development and management company, has compiled technical requirements for the different type of governmental buildings. This document mentions in the airtightness section the same standards already referred above[4].

To describe the method of the ductwork airtightness test, the references to the Finnish standard (Standard SFS 3542) can be often found in various ventilation projects. The allowed methods and test procedures also depend on the standards of specific ductwork components.

3.5.3 Requirements on measuring devices

There are no specific requirements for the measurement equipment.

3.6 Ductwork airtightness tests performed

3.6.1 Tested ductwork

When the ductwork system consists of ducts and ductwork components that correspond to at least airtightness class C and are tested and checked for quality, airtightness can be measured by random tests. Random tests can be carried out on at least 20% of the surface area of the ductwork. In the cases where the ductwork system incorporates ducts or ductwork components whose airtightness class is lower than C, the extent of the random tests shall be increased by a surface area that corresponds to such parts. If the surface area of these ducts or ductwork components is more than 25% of the total surface area of the ductwork system, then the entire ductwork system shall be measured. The test is always required for the vertical shafts of ductwork.

3.6.2 Database

The systematized field data of the ductwork airtightness is not available in public databases. As previously reported, the airtightness of ventilation ductwork should be measured and a report of the ductwork airtightness measurements should be attached to the building inspection documents. If the airtightness of ventilation ductwork is measured, the measurement reports should be uploaded to the Estonian building registry[5]. Therefore, if the measurement report is added to the registry, it can be downloaded publicly in some new buildings.

3.6.3 Evolution of the ductwork airtightness level

According to the standard EVS-EN 12599:2012 „Ventilation for buildings. Test procedures and measurement methods to hand over air conditioning and ventilation systems", it is necessary to carry out the ductwork airtightness test only in the case of contracted agreement. So, as reported above, the airtightness test is not

[4] https://nouded.rkas.ee/ventilatsioon

[5] https://livekluster.ehr.ee/ui/ehr/v1

always mandatory, and it depends on the customer's requirements and designer's requirements in HVAC Project. For example, in case of state objects, the airtightness report is almost always necessary (this requirement is also mentioned in RKAS technical guidelines). At the same time, in the case of detached houses, the airtightness test is usually not performed.

There is no data in which the share of buildings includes a measurement of ductwork airtightness. The authors estimate that the range of tested buildings is 10 – 15 % of all new buildings.

3.7 *Guidelines to build airtight ductwork*

The only local guideline in Estonia is compiled by RKAS. This document mentions the same standards already referred above[5].

3.8 *Conclusion*

Ductwork airtightness is an insufficiently researched and poorly regulated field in Estonia. To change the situation, the first thing that could be done is to study the current situation of ductwork airtightness. Some scientific research could certainly help to raise awareness on this problem.

At the moment, there is no plan to update standards or regulations of ductwork airtightness. In the following years, it is planned to update the quality requirements for ventilation installation. The requirements for the airtightness of the ventilation ductwork can also be added to the guidance manual of quality requirements for ventilation installation..

4 Acknowledgements

This research was supported by the Estonian Research Council with Personal research funding PRG483 "Moisture safety of interior insulation, constructional moisture and thermally efficient building envelope", Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant TK146 funded by the European Regional Development Fund.

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The **Air Infiltration and Ventilation Centre** was inaugurated through the International Energy Agency and is funded by the following countries: Australia, Belgium, China, Denmark, France, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Republic of Korea, Spain, Sweden, United Kingdom and United States of America.

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