Ventilation
Information
Paper
n° 45.3

December 2022

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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 the Czech Republic

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1 General introduction

The Czech Republic is a country where the building industry has significantly changed over the past 30 years including the attitude on building and ductwork airtightness.

The estimated number of residential buildings in the Czech Republic is 2.4 million according to the data of the Czech Statistical Office. This figure includes single-family houses, multi-family residential buildings and other long-term residences e.g., students' residences, children's homes, retirement homes, cloisters, etc. as well as non-residential buildings with dwellings. About 50% of the residential buildings were built or renovated between 1946 and 2000, approximately 25% before 1946 and 25% after 2000. Relevant data about the number of the non-residential buildings are not available.

On average, 51.000 building permits are issued yearly for new construction or renovation of buildings. The permits for the residential buildings represent approximately 2/3 of the total number; permits for the non-residential buildings represent the remaining 1/3. Among the permits for the residential buildings, about 50% represent new construction and 50% renovations. Among the permits for the non-residential buildings, the share of new construction is about 40%.

The average number of single-family houses and multi-family residential buildings commissioned yearly is approximately 16.500. About 6% of these buildings are rated energy performance class A. The yearly average of the commissioned new non-residential buildings is approximately 1.500.

2 Building airtightness

2.1 Introduction

The Czech Republic is situated at the boundary of the oceanic and continental climate zones. The winters are relatively long with low temperatures. Therefore, the buildings must be heated and their envelope structures are subject to potential structural damage caused by the heat, air and moisture transfer. In case of residential buildings, heating has always been considered the most important part of the total energy consumption. For these reasons, the thermal performance of buildings has systematically been addressed in the building regulations since the 2nd half of the 20th century. In the last decades, building airtightness has been recognized as one of the key factors influencing both the thermal performance and the energy consumption of buildings and the airtightness requirements have been progressively implemented into the building regulations.

All the requirements concerning the thermal performance of buildings have progressively been included in the national technical standard ČSN 73 0540-2. This standard, for example, sets the limit values of thermal transmittance or requires the control of the interstitial condensation, summer overheating risk etc. It also includes the requirements concerning the building airtightness. The requirements for the energy consumption in buildings are defined in the Ordinance 264/2020 Coll. which is the local implementation of the EPBD. This ordinance namely sets the indicators of energy performance, defines the calculation method of the energy consumption as well as the form and content of the energy certificate. However, the building airtightness is not directly addressed in this legal document.

Although the standard ČSN 73 0540-2 had included the requirements concerning the airtightness of windows for a long time before, the requirements concerning the airtightness of the building envelope as a whole were only introduced in 2002. The amendment of 2002 reflected the new needs of the building industry transformation after the political changes in 1989. This transformation process involved e.g., a diversification of construction modes and a growing concern about the energy conservation. However, the airtightness requirements of ČSN 73 0540-2 have not been legally binding until now, therefore the check of compliance is still not mandatory.

In 2009, the ministry of environment launched an energy performance programme (New Green Savings - NGS). This programme, still running, offers state subsidies for construction of new passive houses and refurbishments aimed at significant reduction of energy consumption in the existing buildings (the programme is funded by revenues from the sale of the European Union Allowance). In order to facilitate the programme administration, several documents (guidelines and preliminary standards) were released. Among other topics, they include special building airtightness requirements set in the programme and further specifications of standard airtightness testing procedures (ČSN EN 13829 and ČSN EN ISO 9972 later on). Compliance with these airtightness requirements must be justified in order to obtain the financial support.

The popularity of the NGS energy performance programme has significantly raised awareness about the building airtightness among all the stakeholders, and in particular among the building industry professionals. The airtightness testing has progressively become more frequent in other sectors than low energy building construction. At the same time (2009), the local airtightness testers founded a professional network Association Blower Door CZ with main objectives to spread the knowledge, to support the development of technical and legal regulations and to supervise the competence of the members (hereafter the Association Blower Door CZ is referred to as A.BD_CZ which is its commonly used acronym).

Recently, the Association of manufacturers of wooden houses (ADMD) in cooperation with the Timber Research and Development Institute have developed a quality certification scheme for construction companies producing timber structure buildings. Systematic airtightness testing is mandatory in the context of this certification scheme. The buildings tested should meet the requirements according to the standard ČSN 73 0540-2.

At present, several changes in building regulations concerning the building airtightness are in progress. The standard ČSN 73 0540-2 is being revised, including the building airtightness requirements. The new technical standard ČSN 73 0515 is being prepared. Its purpose will be to provide detailed guidelines for practical use of the testing standard ČSN EN ISO 9972. At the occasion of amendment of the building code under way, discussion was raised whether the justification of compliance with the airtightness requirements according to the standard ČSN 73 0540-2 would be mandatory at least for selected categories of buildings. None of these amended documents has been approved at the time of this publication's writing.

2.2 Airtightness indicator

As explained in the section 2.3.1, the Czech regulations contain different requirements related to the building airtightness. Concerning the airtightness of the building envelope as a whole, the air change rate at 50 Pa, n_{50} [h^{-1}] is the indicator used universally in the technical standards and legal documents. The n_{50} value is calculated as a quotient of the air leakage rate q_{50} [m^3/h] and the buildings internal volume V [m^3], both of them determined according to the standard ČSN EN ISO 9972.

It means that since the introduction of the standard ČSN EN ISO 9972 in 2016, the internal volume should be calculated using the overall internal dimensions regardless of the purpose of the test. This new situation has complicated the granting of the financial support from the NGS programme based on the assessment of an airtightness test result. Since the n_{50} values are lower if the internal volume is calculated from the overall internal dimensions, the applicants for the financial support after 2016 would benefit from more favourable conditions than those who applied before 2016 when the internal volume was calculated using the internal dimensions. Hence, for the reasons of continuity and fair distribution of the subsidies, the administrator of the NGS energy performance programme requires the internal dimensions to be used for calculation of the internal volume V, as it was prescribed in the older testing standard ČSN EN 13829.

This deviation from the rules of the ČSN EN ISO 9972 standard complicates the comparison of the test results obtained in the context of the NGS programme with the results of the tests carried out for different purposes. Therefore, the system of dimensions used for the calculation of the internal volume should always be specified in the test report.

2.3 Requirements and drivers

2.3.1 Building airtightness requirements in the regulation

The technical standard ČSN 73 0540-2 (see the section 2.1) deals with different topics related to the building airtightness, the air permeability of the building envelope being only one of them:

- air permeability of joints in curtain walls
- air permeability of gaps in the other structures of the building envelope
- protection of the thermal insulation layers against the impact of wind
- air permeability of rooms equipped with a system of mechanical ventilation or cooling
- air permeability of the building envelope

The air permeability of the joints between the operable and fixed parts of the curtain walls should meet the specifications of the classes LP1 and LP 2 (Table 1). The air permeability classes LP1 and LP2 mentioned in the standard ČSN 73 0540-2 correspond to the classes A1 and A2 according to the standard ČSN EN 12152.

Table 1: Required classes of the air permeability of the curtain walls

Joint between the operable and fixed parts of a curtain wall	Required class of air permeability	
	Building with natural or combined ventilation	Building with mechanical ventilation
Curtain wall	LP1	LP2

The air permeability class of the joints in the curtain wall is determined by means of laboratory testing according to ČSN EN 12153.

The standard ČSN 73 0540-2 does not specify any quantitative criteria for airtightness of the structural joints. It only states that the external structures of the building envelope should not present any joints or gaps allowing air leakage except for joints of operable parts of windows, doors curtain walls etc. All the joints between the building elements must be executed permanently airtight, according to the state of the art. The standard does not specify any method for justification of compliance with this requirement.

Obviously, it is ambiguous to observe this requirement. If the requirements concerning the air permeability of the building envelope as a whole admit a limited air leakage (see below), consequently, the existence of some leakage paths must be admitted as well. It is not clear how to assess whether a specific leakage path (joint or gap) was executed according to the state of the art or not. A generally approved rule states that a particular leakage path can be considered to be airtight if the measured air leakage rate through it is lower than the uncertainty of the measuring method used.

However, the in-situ measurement of the air flow rate through the particular leakage paths is a difficult task and no standardised methods are available for this purpose.

The aim of the required protection of the thermal insulation is to limit the convective heat transfer through porous thermal insulation materials if their external surface is directly exposed to wind. Therefore, the standard requires that the thermal insulation layer must be effectively protected against the impact of wind (penetration of cold air). The requirement applies for thermal insulation layers installed at the external face of the building structures as well as for layers installed inside a ventilated air gap (e.g., in case of a cavity wall). The requirement is supposed to be fulfilled if the external surface of the thermal insulation layer is covered with a continuous layer of plaster, impermeable plastic foil or rigid boards (e.g., OSB or plywood).

The air permeability of the rooms equipped with a system of mechanical ventilation or cooling should be reduced as much as the infiltration air change rate n [h^{-1}] induced by the natural driving forces is lower than 0.05 h^{-1}. The infiltration air change rate n should be calculated at design phase for the winter design conditions. The standard does not specify the calculation method.

In the standard ČSN 73 0540-2, the requirement of the building envelope airtightness is expressed in terms of the air change rate at 50 Pa, n_{50}. The limit values are defined as function of the building ventilation system and target energy performance (Table 2). These limit values are not legally binding (see section 2.1), thus the term "recommended" is used to reference the limit values.

Table 2: Recommended values of the air change rate at 50 Pa, $n_{50,N}$ according to ČSN 73 0540-2

Ventilation system	Recommended value of the air change rate $n_{50,N}$ [h^{-1}]	
	Level I	Level II
Natural or combined ventilation	4.5	3.0
Mechanical ventilation	1.5	1.2
Mechanical ventilation with heat recovery	1.0	0.8
Mechanical ventilation wit heat recovery in buildings with a very low energy use for heating (passive houses)	0.6	0.4

Since the standard does not specify for which categories of buildings the limit values apply, it is assumed that they are generally valid for all buildings including refurbishments. The values at level I are supposed to represent the state of the art and should be always fulfilled. The level II values are supposed to be the target values representing the best practice.

It is a well-known fact that small buildings have to achieve a better air permeability of the building envelope q_{E50} [$m^3/(m^2 \cdot h)$] than large buildings in order to fulfil the same limit value of the air change rate n_{50}. Considering the relation between the air change rate n_{50} and the building envelope air permeability q_{E50}, this effect can be understood easily:

$$n_{50} = (A_E/V) \cdot q_{E50}$$

where:
A_E is the envelope area of the building in m^2
V is the internal volume of the building in m^3

Note that, in general, the area-to-volume ratio A_E/V decreases with the size of the building. Figure 1 provides a practical example.

Especially very large buildings can fulfil strict limit values of n_{50} even with inadequate airtightness of the building envelope corresponding to high values of the building envelope air permeability q_{E50} in $m^3/(m^2 \cdot h)$. Consequently, keeping a constant limit value of the air change rate n_{50} regardless the size and geometry of the building may not be a suitable approach to limit the heat losses, risk of structural damage and other negative impacts of an excessive air leakage. In order to avoid this shortcoming in the existing method for assessment of the building envelope airtightness, the amendment under way of the standard ČSN 73 0540-2 would propose a new approach taking into account the size and the geometry of the building. The air change rate n_{50} would be maintained as the airtightness indicator, however the assessment of the large buildings would be based, in fact, on the specific leakage rate per the envelope area, $q_{E,50}$ [$m^3/(h \cdot m^2)$].

Single-family house

A_E = 300 m²; V = 290 m³
A_E/V = 1.03 m²/m³
Air change rate limit value:
$n_{50,N}$ = 1.0 h⁻¹
Corresponding air permeability:
q_{E50} = 0.97 m³/(m²·h)

Multi-family residential building

A_E = 1 500 m²; V = 2 600 m³
A_E/V = 0.58 m²/m³
Air change rate limit value:
$n_{50,N}$ = 1.0 h⁻¹
Corresponding air permeability:
q_{E50} = 1.73 m³/(m²·h)

Office building

A_E = 8 800 m²; V = 50 500 m³
A_E/V = 0.17 m²/m³
Air change rate limit value:
$n_{50,N}$ = 1.0 h⁻¹
Corresponding air permeability:
q_{E50} = 5.74 m³/(m²·h)

Figure 1: The relationship between a constant air change rate limit value and the corresponding building envelope air permeability for buildings of a different size – an example.

The air change rate at 50 Pa, n_{50} [h⁻¹], should not be higher than the required value $n_{50,RQ}$ [h⁻¹]:

$$n_{50} \leq n_{50,RQ}$$

The required value $n_{50,RQ}$ is determined individually for each building assessed in function of its geometrical characteristics:

$$n_{50,RQ} = (A_E/V) \cdot q_{E50,RQ}$$

where $q_{E50,RQ}$ is the required value of the specific leakage rate per the building envelope area across the building envelope at 50 Pa in m³/(h·m²)

For smaller buildings with the internal volume V no greater than 1500 m³ it would be allowed to take the area-to-volume ratio A_E/V equal to 1. The required values of the specific leakage rate, $q_{E50,RQ}$, are given in Table 3.

Table 3: The limit values of the specific leakage rate q_{E50} proposed in the amendment of ČSN 73 0540-2

Ventilation system	specific leakage rate [m³/(m²·h)]	
	Required values $q_{E50,RQ}$	Recommended values $q_{E50,REC}$
Natural or combined ventilation	3.0	2.0
Mechanical ventilation	1.5	1.2
Mechanical ventilation wit heat recovery	1.0	0.8
Mechanical ventilation with heat recovery in buildings with a very low energy use for heating (passive houses)	0.6	0.4

Compliance with the limit values mentioned in the standard ČSN 73 0540-2 would be mandatory, if it was required by another regulation or by an agreement of the contracting parties. It is assumed that in the future a superordinate legal document will make the justification of compliance mandatory. In order to allow for a mandatory check of compliance in the future, the limit values are termed "required" in the amendment. The discussion has already started about the possibility to bind the mandatory compliance check with a planned amendment of ordinances implementing the building code, at least for selected categories of buildings.

The recommended values $q_{E50,REC}$ are supposed to be the target values representing the best practice. The comments in the text of the amendment remind that it is advisable to achieve stricter recommended values with regard to potential decrease of airtightness over time due to aging of the air barrier system.

Unlike the envelope airtightness (n_{50} value), the other airtightness requirements of the standard ČSN 73 0540-2 would remain almost unchanged. The amendment has not been approved at the time of this publication's writing; thus the possibility of mandatory compliance check remains undecided.

Apart from the technical standard ČSN 73 0540-2, special building airtightness requirements are included in two preliminary standards TNI 73 0329 and TNI 73 0330. These preliminary standards provide a classification scheme for low energy and passive single-family and multi-family residential houses respectively. Their main purpose is to provide an approved definition of a low-energy or a passive house and clearly set their target performance if these labels have to be referenced in legal documents, terms of a subsidy programme or commercial contracts. The requirements according to these preliminary standards are summarised in Table 4. These requirements are not in contradiction to those according to the standard ČSN 73 0540-2.

Table 4: Required values of the air change rate at 50 Pa, $n_{50,N}$ according to TNI 73 0329 and TNI 73 0330

Building category	Required value of the air change rate $n_{50,N}$ [h^{-1}]	
	Single-family building	Multi-family residential building
Passive house	0.6	0.6
Low-energy building	1.5	1.5

Special building airtightness requirements prescribed in the energy performance programme New Green Savings are presented in the section 2.3.2.

2.3.2 Incentive for building airtightness

At present, the New Green Savings (NGS, see section 2.1) is the most impactful long-term energy performance programme administrated in the Czech Republic. Its aim is to reduce the energy consumption in the residential sector by reinvesting the revenues of the European allowance units into the construction of energy efficient buildings. The programme offers financial subsidies for the construction of new passive houses, the refurbishment of existing buildings providing significant energy savings and for the execution of selected particular energy saving measures (e.g., installation of a solar heating system or ventilation system with heat recovery). The categories of financial support where compliance with some building airtightness requirements is prescribed are listed in Table 5 together with the corresponding limit values. In these categories, compliance with the airtightness requirements must be justified in order to obtain the financial support.

Table 5: Required values of the air change rate at 50 Pa, $n_{50,N}$ in the New Green Savings energy performance programme

Category of the financial support	Required value of the air change rate $n_{50,N}$ [h^{-1}]	
	Single-family building	Multi-family residential building
Construction of new passive houses (mandatory installation of a ventilation system with heat recovery)	0.6	0.6
Construction of new buildings with very low energy demand (mandatory installation of a ventilation system with heat recovery)	1.0	--- 1)
Installation of ventilation system with heat recovery in existing buildings	2.5	--- 2)
1) financial support is not provided for this category 2) financial support is provided but the airtightness requirement is not set		

2.3.3 Building airtightness justifications

Compliance with the building airtightness requirements set in ČSN 73 0540-2 (see Table 2) should be justified by means of testing according to the standard ČSN EN ISO 9972 (the latest version of ČSN 73 0540-2 of 2011 mentions ČSN EN 13829, replaced with ČSN EN ISO 9972 in 2016). The standard ČSN 73 0540-2 does not specify further details about the testing, in particular the measured extent, time of measurement and mainly the building preparation method. The standard ČSN 73 0540-2 does not require any proof of qualification for airtightness testing. The justification of compliance with requirements according to ČSN 73 0540-2 is not mandatory as explained above.

The amendment of the standard ČSN 73 0540-2 under way would require the justification of compliance by means of testing according to the standards ČSN EN ISO 9972, method 3 and ČSN 73 0515. ČSN 73 0515 is a purpose-made technical standard currently in preparation which would specify detailed guidelines for testing procedures of ČSN EN ISO 9972 including detailed specification of the method 3 (the rules of building preparation). Section 2.5.2 gives further details about the standard ČSN 73 0515.

Compliance with the building airtightness requirements set in TNI 73 0329 and 73 0330 (see Table 4) should be justified by means of testing according to the standard ČSN EN ISO 9972. The preliminary standards do not give further details. The preliminary standard TNI 73 0330 dealing with the multi-family residential buildings allows for testing by separate parts e.g., apartments or groups of apartments (see section 2.5.2).

In the context of the NGS energy performance programme, compliance with requirements should be justified by systematic testing of each building. Multi-family residential buildings can be tested by parts using the method given in the TNI 73 0330. The tests have to be carried out according to the standard ČSN EN ISO 9972. A special document prescribes detailed guidelines for testing in this context (see section 2.5.2). The programme administrator does not require any proof of qualification for airtightness testing.

The manufacturers of the wooden houses involved in the certification scheme of the association ADMD (see section 2.1) have to test a specified portion of their production on a regular basis. The terms of the certification scheme define sampling rules for this purpose. The tests must be carried out by an accredited laboratory according to the standard ČSN EN ISO 9972.

2.3.4 Sanctions

As mentioned above, the airtightness requirements according to the standard ČSN 73 0540-2 are not legally binding, therefore the authorities do not check the compliance and there are no sanctions applied if a building does

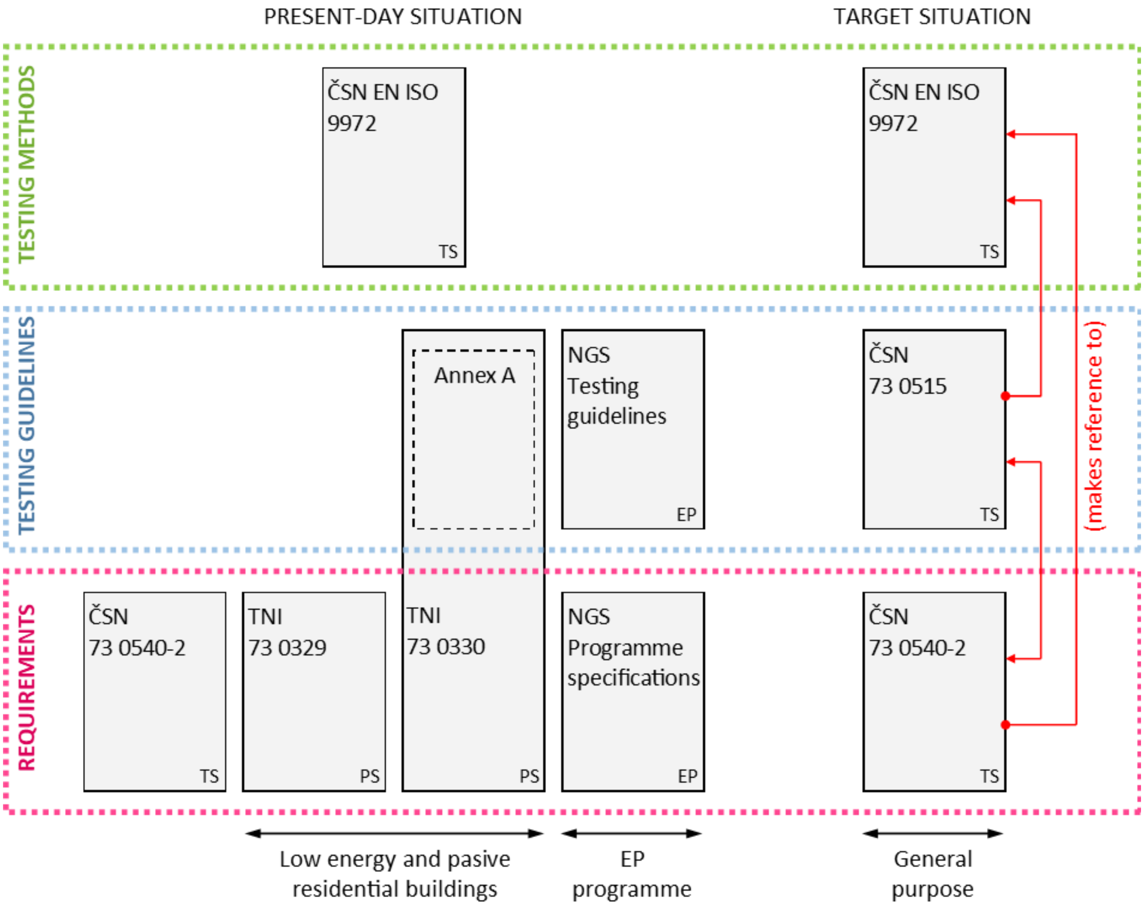

Figure 2: Overview of the documents mentioned in the text specifying limit values, testing guidelines or testing methods of building airtightness. The marks in the right lower corner designate the type of document: TS stands for technical standard; PS stands for preliminary standard and EP stands for document of the energy performance programme.

not comply. It means that the building can be commissioned and operated with no restrictions unless some particular sanctions are imposed by e.g., a contractual agreement.

If a test is carried out for the purpose of building classification according to the preliminary standards TNI 73 0329 or TNI 73 0330 and the test result does not fulfil the required values (see Table 4), the consequence is that the building cannot be labelled a low-energy or passive house according to TNI 73 0329 or TNI 73 0330.

In the context of the NGS energy performance programme a non-fulfilment of the building airtightness requirements results into the refusal of the financial subsidy (even though the building would comply with all the other required performance criteria). The building can still be commissioned.

2.4 Building airtightness in the energy performance calculation

2.4.1 Calculation

Detailed specifications concerning the assessment of the energy efficiency of buildings are given in the Ordinance 264/2020 Coll. This ordinance requires the system of the Czech technical standards (including the adopted international standards) to be used for the determination of the energy consumption. The standardised calculation methods referenced in the Ordinance take the building airtightness into account using the air change rate at 50 Pa, n_{50} [h^{-1}] as the building airtightness indicator.

The energy need for heating should be calculated according to the standard ČSN EN ISO 52016-1. The ventilation and infiltration air flow rates required for the calculation of the energy need should be determined according to the standard ČSN EN 16798-7. The air flow rates calculation is based on iterative solution of the simplified mass balance equations for the ventilated zone. The infiltration air flow rate is calculated out of a known n_{50} value, or estimated with n_{50} values at level I according to ČSN 73 0540-2.

2.4.2 Default values

The Ordinance 264/2020 Coll. does not impose any default n_{50} values to be used in the calculation of the energy consumption. No further guidance at this point is given in the referenced documents, except for a comment to the building airtightness requirements in the standard ČSN 73 0540-2 (see section 2.3.1). It states that the recommended n_{50} values at level I according to ČSN 73 0540-2 (see Table 2) can be used as an estimate of the final building airtightness for the purpose of energy consumption calculation (e.g., in the design phase) unless the measured n_{50} value is available. This is the common practice among the building energy advisors, since the energy consumption is usually calculated at the design phase, before the building construction starts and the airtightness could be measured. The present regulations do not set any default values penalising the energy consumption calculation results in order to stimulate a systematic airtightness testing.

Besides the modification of the airtightness requirements, the revised standard ČSN 73 0540-2 would also specify the default n_{50} values for the energy performance calculations in different context (energy performance certificate, energy performance optimisation in the design process, assessment of energy savings by means of alternative retrofitting measures). A set of penalising default values is foreseen for energy performance calculations in situation if the measured n_{50} value is not available. In such case, the energy performance can be recalculated later (after the airtightness test) using the measured n_{50} value. This approach is expected to rise awareness and motivation for systematic airtightness testing.

2.5 Building airtightness test protocol

2.5.1 Qualification of airtightness testers

The justification of compliance is not mandatory; therefore the state authorities do not require any proof of competence for airtightness testing. Since 2010, the Association Blower Door CZ (A.BD_CZ, local airtightness testers network, see section 2.1) has developed its own competent testers scheme based on a comparative measurement (round-robin test). The technicians involved have to test the same building under conditions of reproducibility. The reliability of their test results is assessed by means of statistical methods (ČSN ISO 5725).

At the same occasion, the integrity of the equipment and the calibration dates are checked as well as the ability of the technicians to follow correctly the procedures according to the standard ČSN EN ISO 9972. This proof of competence is mandatory for the members of the A.BD_CZ and has to be repeated every two years. At present, 15 of 21 A.BD_CZ members fulfil the conditions of this competent tester's scheme. It is assumed that the A.BD_CZ members (21) represent about 40 % to 50 % of all the testers operating in the Czech Republic.

Five laboratories hold the accreditation for building airtightness testing issued by the national accreditation body (the Czech accreditation institute, ČIA) according to the standard ČSN EN ISO/IEC 17025. In order to obtain the accreditation, the laboratories have to justify their competence to the accreditation body. For this purpose, the laboratories use the service of the A.BD_CZ (the technicians of the laboratories follow the qualification scheme described in the previous paragraph). The accreditation is needed for testing in the context of the certification scheme of the Association of manufacturers of wooden houses (see section 2.1).

In 2021, the A.BD_CZ started a new qualification scheme called authorisation for building airtightness testing. It is based on the same principles as the previous scheme, but besides the practical examination (the comparative measurement), the proof of the competence includes also theoretical examination consisting of the test of knowledge, the test of the building volume calculation and the oral examination. The authorised technician obtains a certificate valid for 6 years. Every 2 years, the authorised technician has to pass the practical examination and report his activities. After 6 years, he has to pass both theoretical and practical examination in order to extend the validity of the certificate. As a part of the scheme, the A.BD_CZ has prepared an educational programme as a support for the applicants for the authorisation. The participation to this educational programme is open to anybody interested in the topic.

2.5.2 National guidelines

The standard ČSN EN ISO 9972 itself does not include any national annex specifying further guidelines for airtightness testing in the Czech Republic. However, at present there are 2 external documents specifying such guidelines.

The annex to the preliminary standard TNI 73 0330 specifies the method for testing of the multi-family residential buildings. According to the annex, one of the following procedures can be chosen:

- the building is tested as a whole including the non-residential zones (e.g., commercial rooms on the 1st floor)
- only the residential part of the building is tested excluding the non-residential zones
- the building is tested by separate parts e.g., apartments or groups of apartments

The annex provides a sampling method for selection of the parts of the building to be tested separately as well as a method for assessment of the test results. The apartments or groups of apartments to be tested should represent at least 25% of the internal volume and all the types of construction constituting the building envelope should be represented in this sample. A major part of the envelope of apartments in the sample should face the external environment. A single n_{50} value representing an estimate of the building airtightness is calculated out of the test results obtained for the individual parts tested. Then, this value can be compared to the limit value which is defined for the whole building. The annex allows for the use of the so-called guard zone techniques in order to eliminate the internal air leakage between the adjacent zones during the test of a separate part of the building. Although the preliminary standard TNI 73 0330 deals with the classification of passive and low-energy buildings, this method can be used in other contexts and for other categories of large buildings if they have to be tested by separate parts.

In the context of the energy performance programme New Green Savings, an airtightness test has to be carried out according to the special guidelines issued by the programme administrator. These guidelines mainly specify:

- requirements on equipment
- time of measurement (requirements on the state of the building)

- measured extent
- building preparation (detailed specification of the method 3 according to ČSN EN ISO 9972)
- position of the measuring device (rules for selection of the appropriate opening)
- pressure difference sequence (determination of the lowest, the highest and the intermediate pressure differences)
- control of the regression line (rules for eventual rejection of outlying data points)
- calculation of the reference values (the internal volume in particular)
- content and form of the test report

In the case of the multi-family residential buildings, the guidelines allow for the testing by separate parts according to the annex to TNI 73 0330 (see above). For an easier processing of the applications for subsidies, the use of a common template for the airtightness test report is prescribed (a spreadsheet available from the programme webpage).

Based on a suggestion of the A.BD_CZ, the Czech Standardisation Agency decided to prepare a stand-alone standard ČSN 73 0515 providing complex and detailed guidelines for airtightness testing according to ČSN EN ISO 9972. The reason behind is that the ongoing revision of the airtightness requirements of the standard 73 0540-2 (see section 2.3.1) presents a good opportunity to harmonize the new airtightness requirements with the well elaborated guidelines for testing in order to establish both of them as generally valid. Then, the requirements, testing method and testing guidelines included in the technical standards could be referenced in legal documents, energy performance programmes, commercial and any other contracts.

The new standard ČSN 73 0515 would gather, revise, update and extend the rules spread over the guidelines for the NGS programme and the annex to TNI 73 0330. Besides the clarifications and comments concerning the testing procedures of the standard ČSN EN ISO 9972, it would also offer some practical recommendations for testing in special conditions (e.g., windy weather, high buildings, airtight buildings, etc.).

At present, the fan pressurization method is the sole building airtightness testing method referenced in the regulations. Neither the existing regulation, nor the documents being prepared expect the use of alternative methods for airtightness testing.

2.5.3 Requirements on measuring devices

According to the guidelines for airtightness testing in the context of the NGS programme (see section 2.5.2), only a commercial equipment intended for the air permeability testing of buildings can be used (the aim is to avoid the use of improvised equipment). The equipment must fulfil the specifications of the standard ČSN EN ISO 9972. The pressure measuring devices have to be calibrated yearly. Calibration of the other measuring devices is not required (air flow rate measuring system, thermometers). Exceptionally, in situations where it can be justified, the guidelines admit the use of a ventilation system for airtightness testing of large buildings.

The technicians involved in the A.BD_CZ qualification scheme must prove that their equipment:

- does not present any defects which might influence its functionality
- is calibrated on a regular basis
- provides reliable airtightness test results

Based on previous experience, the A.BD_CZ believes that the accuracy of a test result requires a perfect function of the whole set of measuring equipment components, including the software. Therefore, in addition to the usual check of calibration of separate measuring devices, the A.BD_CZ insists on verification of a correct function of the measuring device (typically a blower door) as a whole. A measuring device is considered as working correctly if it provides test results within the reproducibility limits. This is assessed by means of the comparative measurement (see section 2.5.1). The technical state (integrity) of the equipment is checked on the same occasion. The terms of the qualification scheme require the calibration of the pressure measuring devices to be repeated every 2 years and the calibration of the thermometers every 4 years.

The new standard ČSN 73 0515 would provide further specifications regarding the equipment. In principle, the standard would adopt the approach of the A.BD_CZ qualification scheme.

2.6 Building airtightness tests performed

2.6.1 Tested buildings

The limited availability of statistical data about the tested buildings (see section 2.6.2) complicates the determination of the percentage of the buildings tested. The time evolution of the number of the buildings tested cannot be evaluated. The figures mentioned in this section do not represent the results of a thorough statistical analysis, but rough estimates of the author.

The 21 A.BD_CZ members perform approximately 1.800 tests per year. It can be expected that the total number of the airtightness tests carried out in the Czech Republic does not exceed the double of this figure, i.e., 3.600 tests per year. The large majority (very likely more than 80%) are the tests of the residential buildings (single-family houses and multi-family residential buildings). Some of the reported numbers are repeated tests of the same building. Based on these rough data and on the average number of residential buildings finished yearly in the Czech Republic (approx. 16.500 according to the Czech statistical office), it can be expected that no more than 15% of the residential buildings are tested. The share of the tested buildings in the non-residential sector cannot be estimated but very likely it would be lower than in the residential sector.

It is interesting to compare the number of the finished residential buildings of the energy performance class A (about 1.000 buildings per year according to the Czech statistical office) with the number of the tests performed (3.600). Very likely, a significant part of the residential buildings of class A are tested.

2.6.2 Database

Since its foundation in 2009, the A.BD_CZ tries to build up a database of the airtightness tests carried out by the members. The initial intention was to collect all the test results (all types of buildings) together with complementary information on the building envelope structure and the air barrier system. This goal has not been achieved despite the contribution to the database being mandatory for the A.BD_CZ members. The submission of the database records requires to fill in manually a special form (spreadsheet) which is generally perceived as a burden and the members are not motivated to do it. The database increases by approx. 100 records per year which represents less than 6% of the total amount of tests performed by the A.BD_CZ members. Therefore, the database grows very slowly and loses the representativeness. At present day, the database contains 795 records. The data are not analysed.

The administrator of the energy performance programme New Green Savings collects complex information about the subsidised buildings including the airtightness test results. However, these data are not open to public. The author of this report is not aware of any publication presenting the analyses of these data.

2.6.3 Evolution of the airtightness level

No relevant information based on statistical data is available about the evolution of the airtightness level over time. However, the A.BD_CZ members report unanimously that since the introduction of the NGS programme, the number of buildings tested has increased and the airtightness level of the tested buildings has improved significantly. This energy performance programme which sets the airtightness requirements and offers a financial support for energy efficient and airtight buildings has undoubtedly acted as a driver and has contributed to a general improvement of the building airtightness level.

2.7 Guidelines to build airtight

Except for the ČSN 74 6077 there is no technical standard providing guidelines to build airtight. The standard ČSN 74 6077 dealing with installation of windows and doors recommends several technical solutions for an airtight design of the window-to-wall interface.

The very basic principles of airtight design are mentioned in numerous articles and publications focused on low-energy and passive houses. More detailed guidelines can be found in two books listed in section 2.9 Key documents. The monograph on the building airtightness (Novák, 2008) contains one chapter focused on the principles of airtight design. Among other information, it offers exemplary (model) solutions for typical interfaces between building elements and penetrations (structural details) illustrated with schemes. The second book (Hazucha, 2016) is a catalogue of structural details for passive houses. It contains a selection of technical solutions focused on elimination of the thermal bridge effect which proved their feasibility and performance in real construction practice. The technical solution is documented by means of detailed drawings, 3D schemes, photographs from the building site and comments. Where relevant, this description provides also detailed guidelines how to achieve the airtightness of the particular construction detail.

Several manufacturers provide guidelines to airtight design and construction specific to their products. This is especially the case of the manufacturers of foils, bonding tapes and thermal insulation. Recently, several manufacturers of wooden or masonry construction systems have published this kind of guidelines as well.

2.8 Conclusion

During the last 2 decades, excessive air leakage has been recognised as an important factor with a negative impact primarily on the energy efficiency of buildings and on the hygrothermal performance of building envelope structures. Building airtightness requirements were integrated into the technical standard specifying general requirements on the thermal performance of buildings. Nevertheless, the justification of compliance by means of systematic airtightness testing has never become mandatory, mostly due to the concerns about an increase of administrative burden, increase of costs, complications of the construction process (learning process, reparations after a failed test, etc.) and unreadiness of the market to a sudden change (lack of the skilled workmanship and the qualified testers and designers).

The state's energy performance programme providing financial support for construction of energy efficient and airtight buildings has considerably increased the awareness about the building airtightness and has stimulated a progress in knowledge and skills of the building professionals. On one hand, the success of the energy performance programme proved that the building market can deal with the new challenging situation such as mandatory airtightness testing with no major problems, at least in a particular segment of the building industry. On the other hand, the lessons learned have clearly pointed out a need of a solid regulative framework for the implementation of the systematic mandatory airtightness testing:

- correctly defined requirements
- detailed guidelines for the testing
- detailed procedures for the compliance check
- detailed rules for the control of the testers qualification including a system of supervision aimed at avoiding frauds and illegal practice

Nowadays, a significant effort is being made to collect the requirements and testing guidelines spread over different documents, revise and update their content and integrate them into the system of the Czech technical standards. The results of this attempt would provide a unified regulative framework ready for a general use. With this aim, the requirements of the standard ČSN 73 0540-2 are revised and linked to the new standard ČSN 73 0515 providing detailed testing guidelines and, alongside, a more complex competent tester scheme has been prepared.

An effort is needed to convince the state authorities that it is advisable to stimulate improvements of the building airtightness in a large scale in order to achieve the targets of energy efficiency and sustainability in the building sector. The experience from the energy performance programme shows that mandatory justification of compliance with requirements by means of systematic testing is an efficient and feasible approach. If this option was chosen, it would seem reasonable to implement the mandatory testing of different building types progressively. A preceding information campaign and educational programmes for all the concerned building professionals seems to be highly advisable in order to avoid the long process of learning of one's own mistakes.

2.9 Key documents

Official webpage of the Czech statistical office: https://www.czso.cz/csu/czso/home

ČSN 73 0540-2 Thermal protection of buildings – Part 2: Requirements, únmz, 2011 (In Czech)

ČSN 73 0540-2 Thermal protection of buildings – Part 2: Requirements, amendment of the standard, not approved yet (In Czech)

Ordinance 264/2020 Coll. Of energy efficiency of buildings (In Czech)

ČSN EN ISO 9972 Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method, únmz, 2017

Official webpage of the energy performance programme New Green Savings: https://novazelenausporam.cz/

Web presentation of the Association Blower Door CZ (In Czech): http://www.asociaceblowerdoor.cz/

ČSN EN 12152 Curtain walling - Air permeability - Performance requirements and classification, ČNI, 2002

ČSN EN 12153 Curtain walling – Air permeability – Test method, ČNI, 2001

TNI 73 0329 Simplified numerical assessment and classification of residential buildings with low energy need for heating – Single-family houses, únmz 2010 (In Czech)

TNI 73 0330 Simplified numerical assessment and classification of residential buildings with low energy need for heating – Multi-family residential buildings, únmz 2010 (In Czech)

ČSN EN ISO 52016-1 Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 1: Calculation procedures, únmz, 2019

ČSN EN 16798-7 Energy performance of buildings – Ventilation for buildings – Part 7: Calculation methods for the determination of air flow rates in buildings including infiltration (Modules M5-5), únmz, 2021

ČSN 73 0515 Thermal performance of buildings – Determination of air permeability of buildings – Guidelines for application of testing methods according to ČSN EN ISO 9972, in preparation, the proposal of the standard not approved yet (In Czech)

ČSN 74 6077 Windows and external pedestrian doorsets – Requirements for installation, únmz, 2018 (In Czech)

Novák, J., Airtightness of building envelopes, Grada Publishing, 2008, ISBN 978-80-247-1953-5 (In Czech)

Hazucha, J., Structural details for passive and zero-energy houses, Recommendations for design and construction, Grada Publishing, 2016, ISBN 978-80-247-4551-0 (In Czech)

3 Ductwork airtightness

3.1 Introduction

Ductwork airtightness is becoming increasingly important with the growing demands for energy efficiency of building energy systems and reduction of energy consumption in buildings. However, there is currently no assessment methodology in place in the Czech Republic to take into account duct airtightness. Consideration of duct airtightness in terms of certification is when a building is rated, for example, for LEED certification. However, this certification is neither mandatory in the Czech Republic nor conditional for subsidy programmes.

The significance of duct leakage is important in terms of operation, capital costs and energy consumed in buildings. If a building has a designed airflow to individual zones or rooms and the required airflows are not reached at the outlets during commissioning, the air handling unit needs to be operated at higher airflows than would be required with perfectly tight ductwork. If there are high losses within the ductwork, the flow may not be assured even at high fan speeds. In conventional buildings, this effect is mainly accompanied by increased energy consumption for the operation of the air handling equipment and also by acoustic noise, both from the air handling unit not operating at the design point, but also due to acoustic manifestations within the ductwork during various types of leakage and also due to increased air velocity.

The importance of duct leakage becomes more important with the requirements for the treatment of the indoor environment, especially through highly filtered air, for example for clean plants where filter devices are fouled more quickly with increased flow rates.

Test procedures and measurement methods are defined in several standards. All of them are of European origin. Duct leakage tests for components (products) are described in ČSN EN 15727 (11/2010), the implementing standards are ČSN EN 1507 (10/2006) for rectangular ducts and ČSN EN 12237 (11/2003) for circular cross-sections. The determination of the surface area of the ducts is defined in ČSN EN 14239 (09/2004). A leakage test is defined for air terminal elements and dampers in ČSN EN 1751 (05/2014). Where non-metallic ducts are used in air handling systems, the requirements are specified in ČSN EN 13180 (07/2002) for flexible ducts and ČSN EN 13403 (12/2003) for ducts made of insulation boards. The main standard that specifies test procedures and measurement methods for the inspection of installed ventilation and air conditioning equipment is ČSN EN 12599 (06/2013).

3.2 Airtightness indicator

The calculated factor for the classification of the airtightness of the duct is referred to as the **air leakage factor *f***. This value is determined at given pressure difference from measured air flow rate through the leaks of the tested duct and the area of the tested pipe (according to ČSN EN 14239).

The pressure difference during testing is maintained alternatively as underpressure or overpressure at 200, 400 or 1000 Pa. Selected pressure should respect average operational pressure in the duct system.

3.3 Requirements and drivers

3.3.1 Ductwork airtightness requirements in the regulation

Air distribution systems and air conditioning systems are so-called "specified products" (orig. stanovený výrobek) within the meaning of Act No. 22/1997 Coll. on technical requirements for products and on amendments and supplements to certain acts. They are also subject to Government Regulation No. 163/2002 Coll. as amended, laying down technical requirements for selected construction products. For this reason, products must be assessed for conformity with the standards and issued with a 'declaration of conformity' before being placed on the market.

Another important requirement is the subsequent declaration of the product used on the building. The required standards have been defined in the introductory chapter and the classification of air leakage is defined according to the type of duct. The classes according to the standards are shown in the tables below for rectangular and circular cross-sections, also for ducts made of insulating materials and for flexible pipes.

For classification, the value of f_{max}, based on the difference between the pressure in the pipe at the test and the ambient pressure, is determined. The classification is carried out according to the tables below.

To meet the classification, the value of f shall be less than f_{max} for each test at a pressure equal to or less than the design working pressure. The requirement shall be met for both positive and negative pressures. Table 6 and Table 7 show values for two typical duct types: with a circular and a rectangular section.

Table 6: Airtightness classes for circular sheet metal ducts (ČSN EN 12237)

Airtightness class	Static pressure limit (Pa)		Air leakage limit f_{max} ($m^3 \cdot s^{-1} \cdot m^{-2}$)
	Positive	Negative	
A	500	500	$0.027 \cdot p^{0.65} \cdot 10^{-3}$
B	1000	750	$0.009 \cdot p^{0.65} \cdot 10^{-3}$
C	2000	750	$0.003 \cdot p^{0.65} \cdot 10^{-3}$
D (for special applications)	2000	750	$0.001 \cdot p^{0.65} \cdot 10^{-3}$

Table 7: Airtightness classes for sheet metal air ducts with rectangular section (ČSN EN 1507)

Airtightness class	Static pressure limit (Pa)				Air leakage limit f_{max} ($m^3 \cdot s^{-1} \cdot m^{-2}$)
	Neg.	Positive (at pressure class)			
		1	2	3	
A	200	400			$0.027 \cdot p^{0.65} \cdot 10^{-3}$
B	500	400	1000	2000	$0.009 \cdot p^{0.65} \cdot 10^{-3}$
C	750	400	1000	2000	$0.003 \cdot p^{0.65} \cdot 10^{-3}$
D (for special applic.)	750	400	1000	2000	$0.001 \cdot p^{0.65} \cdot 10^{-3}$

3.3.2 Incentive for Ductwork airtightness

None are required, only in optional building certification such as LEED, BREEM, etc.

3.3.3 Ductwork airtightness justifications

As there are no limit requirements, the measurement of the airtightness of the ductwork is only a recommended test when commissioning the system. The procedure is specified in accordance with ČSN EN 12599, whereby the airtightness measurement can be carried out during the installation stage of the duct system. Once a sufficiently large section of the duct system has been installed, all openings shall be plugged and measurements shall be taken according to the above procedures in ČSN EN 12237, ČSN EN 1507 and ČSN EN 14239.

3.3.4 Sanctions

Penalties for poor installation of piping with significant leaks can only be determined in the relationship between the contractor and the purchaser of the work.

If the product does not have a valid declaration of conformity in accordance with the relevant standards, the manufacturer may be subject to financial penalties for marketing an unsuitable product.

3.4 Ductwork airtightness in the energy performance calculation

In the Czech Republic, building permits and the installation of technical systems in existing buildings require compliance with the energy performance of the building according to the implementing laws and regulations based on the European Directive 2010/31/EU.

The airtightness of the ducting is not included in the energy performance calculation. This is mainly a calculation for the designed condition; the airtightness of the ducts is mainly a matter of the actual installation on site. The calculation mainly includes the heat recovery efficiency and SFP of the air handling equipment from the design documentation.

3.5 Ductwork airtightness test protocol

3.5.1 Qualification of ductwork airtightness testers

The national accreditation body of the Czech Republic is the Czech Institute for Accreditation, o.p.s. (CIA), on the basis of a mandate from the Ministry of Industry and Trade and notification to the European Commission in accordance with the above-mentioned legislation.

Mandatory ducts certification follows one of two schemes due to specific material. They relate to product, not real installation:

- Certification scheme NV No. 163/2002 Coll., § 6 (1) 5); SZÚ-1a:2020.00 (based on scheme 1a of ISO/IEC 17067, based on testing and inspection)
- Certification scheme NV No. 176/2008 Coll., § 5 (2), (3) (a), 6; Directive 2006/42/EC, Art. 12 (2) and (3a), Art. 13 (2); SZÚ-1a:2020.00 (based on Scheme 1a of ISO/IEC 17067, based on testing and inspection)

Distinction between schemes:

- For standard EN 1507 and 12237 applies certification scheme NV No. 163/2002 Sb. – metal ducts.
- For standard EN 13403 applies certification scheme NV No. 163/2002 Sb. – non-metallic ducts made of insulation boards.
- For standard EN 13180 applies certification scheme NV No. 176/2008 Sb. – flexible ducts.

There are 2 accredited laboratories that can do the certifications for all standards

No certification scheme for installed ductwork exists in Czech Republic therefore, there are no qualification requirements for testers.

3.5.2 National guidelines

Regarding products, previously mentioned standards are available. General national guidelines for practical installation are not available. Each producer provides guidelines for his products.

The procedure in EN 12599 can be used as a non-binding guide. Once a sufficiently large section of the duct system has been installed, all openings are closed. A ventilator, connected to the sealed duct system via a measuring device, creates a test pressure differential (overpressure or negative pressure). It is recommended to set the test pressure for the supply air duct at 200 Pa, 400 Pa or 1000 Pa, as close as possible to the average operating pressure of the system. The test pressure for the air discharge ducts shall be set at 200 Pa, 400 Pa, or 750 Pa. In the case of large sections, the pressure value may not be reached, the standard EN 12599 gives a recalculation of the specified leakages.

3.5.3 Requirements on measuring devices

Basic requirements for device's measuring range and uncertainty of measurement are provided in EN 12599.

3.6 Ductwork airtightness tests performed

3.6.1 Tested ductwork

There is no data available but the number of tested ductworks is probably very limited for special installations e. g. in industry, laboratories, clean spaces, etc.

3.6.2 Database

A general database doesn't exist. On the market there are only a few companies offering additional ductwork sealing, which run their own non-public databases.

3.6.3 Evolution of the ductwork airtightness level

As mentioned before some businesses offer solutions for sealing ductworks. It may suggest rising interest from the market, mainly building owners and facility agencies. But no deeper investigation to describe real situation is presently known to the authors.

3.7 Guidelines to build airtight ductwork

There are no guidelines to build airtight ductwork. Every producer provides his product with installation description.

3.8 Conclusion

Despite the importance of the airtightness of air ducts, there are no general guidelines nor national regulations. In the future, it would be appropriate to develop general recommendations and/or requirements and ensure that those carrying out practical installations are better informed. State regulation would not be beneficial in view of the large number of regulations already in place. It is expected that the specific requirements and their fulfilment will govern the relationship between the supplier and the purchaser of the duct system.

In the Czech Republic there are standards and associated airtightness tests and certifications for the placing on the market of individual air duct products. However, these do not consider the actual installation. The only and very brief guide for on-site measurement is provided by standard EN 12599.

3.9 Key documents

Act No. 22/1997 Coll. on technical requirements for products and on amendments and supplements to certain acts (In Czech).

Government Regulation No. 163/2002 Coll. specifying technical requirements for selected construction products (In Czech).

ČSN EN 1507 (2006) Ventilation for buildings - Sheet metal air ducts with rectangular section - Requirements for strength and leakage

ČSN EN 12237 (2003) Ventilation for buildings - Ductwork - Strength and leakage of circular sheet metal ducts

ČSN EN 12599 (2013) Ventilation for buildings - Test procedures and measurement methods to hand over air conditioning and ventilation systems

ČSN EN 13180 (2002) Ventilation for buildings - Ductwork - Dimensions and mechanical requirements for flexible ducts

ČSN EN 13403 (2003) Ventilation for buildings - Non-metallic ducts - Ductwork made from insulation ductboards

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

The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.