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Trends in building and ductwork airtightness in Germany

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1 General introduction

The objective of this paper is to give an overview of building airtightness and airtightness of ductwork in Germany.

Before that, general information on the building stock and the construction market in Germany is provided.

The German Energy Agency (dena) shares the following information on the building market in its 2023 report.

Residential and non-residential building stock in 2021

There were around 19.4 million residential buildings in Germany. Of these, 12.9 million were single-family homes, 3.2 million were two-family homes and 3.3 million were multifamily homes.

From 2011 to 2021, about 100,000 residential buildings were built per year.

There are approximately 2 million non-residential buildings that are Building Energy Act -relevant. This figure is based on a statistical evaluation from 2019.

The past years, about 11,000 non-residential (heated) buildings were built per year.

In total, therefore, the building stock amounts to 21 million buildings, which differ in terms of use, heat demand, energy consumption, and so on.

Number of residential units in 2021

There is a total stock of 43.1 million units. Between 2017 and 2021, approximately 250,000 units per year were built. This number will decrease significantly due to the effects of the Ukraine war in the following years.

2 Building airtightness

2.1 *Introduction*

There are various reasons for airtight constructions in Germany of heated and / or conditioned buildings [1, 2]: thermal protection, moisture protection, noise protection, fire protection, controlled ventilation, comfort, and better indoor air quality.

Throughout all building periods, people have tried to keep the air permeability of the building envelope as low as possible. In wooden block buildings, for example, occupants stuffed joints and cracks with moss or clay to prevent unpleasant drafts [2].

Studies at the beginning of the 20th century showed that the unavoidable leaks from windows and doors caused considerable heat loss. In addition, the importance of the plaster for the airtight design of the masonry was recognized. Air permeabilities less than 1 m³/(h.m²) were achieved, and even less than 0.1 m³/(h.m²) for plasters with cement or painted surfaces.

"Airtight" today principally means that the entire building envelope is as airtight as a masonry, plastered wall [3].

The term air permeability of building components was already mentioned in the standard DIN 4108 - Thermal Performance in Building Construction [2] from 1952: The thermal performance of a room depends on the thermal resistance of the enclosing building components (walls, ceilings), the air permeability of these components (joints, gaps, etc.), especially those that seal the room from the outside air, and the heat storage.

Concerning the air permeability, the standard describes in detail: Walls and ceilings, especially if they are plastered, are generally only slightly permeable to air, so that heat loss through heat transfer is low. On the other hand, large amounts of heat are lost through leaks in windows and doors; therefore, all joints should be well sealed. This also applies in particular to the joints between the window frame and the masonry and to the joints in large-scale building components (slab walls). Also, the importance of ventilation is mentioned: In the case of extremely tightly closing windows, e.g. with rubber seals, it is advisable to provide for easy ventilation by means of ventilation flaps or similar [2].

One main driver for changes was the so-called energy crisis 1973. It is a key year also for the development of airtightness. After the "energy crisis", the focus was on reducing transmission and ventilation heat losses. Not only windows were sealed, but also exterior walls and roofs were better insulated [3,6].

The first Thermal Protection Directive (WSVO) from 1977 then defines general requirements for limiting heat loss in the case of leakage [4,5]:

- The joint permeability coefficients of exterior windows and french doors of heated rooms shall not exceed specified values.
- The other joints in the heat-transferring building envelope must be permanently sealed in an airtight manner in accordance with the state of the art.

The first specific requirements for the airtightness of the building envelope “the air change rate n_{50}” were defined in the standard DIN V 4108-7 Thermal Insulation and Energy Performance in Buildings from 1996 [8].

Based on that standard, the legislator was able to adopt these values in the Thermal Saving Directive (WSVO) from 1998 [7].

The following Energy Saving Regulations (EnEV) of 2002, 2004 and 2009 adopted the same limit values.

The Energy Saving Regulation (EnEV) [8] from 2014 added a new indicator “the air permeability” for buildings with an internal volume greater than 1500 m³.

The current Building Energy Law [9] from 2020, on the one hand, sets requirements for the quality of the implementation of the air barrier and, on the other hand, it provides the two different indicators “net air change rate n_{L50}” and “air permeability q_{E50}” for testing the airtightness of buildings.

2.2 Airtightness indicator

The airtightness indicators that are used in the German Buildings Energy Act [9,11]] are:

- the net air change rate n_{L50} (1/h)
- and the air permeability q_{E50} (m³/(h.m²))

The reference building pressure difference is for both 50 Pa.

Net Air Change Rate n_{L50}

$$n_{L50} = q_{50} / V_L$$

q_{50}: air leakage rate at 50 Pa in m³/h

V_L: internal volume excluding all internal and external walls and ceilings acc. to DIN EN ISO 9972:2018-12 (L = Luft this means “air”) in m³

Air Permeability q_{E50}

For buildings with a heated or cooled internal volume of more than 1,500 m³, the air permeability is used.

$$q_{E50} = q_{50} / A_E$$

q_{50}: air leakage rate at 50 Pa in m³/h

A_E: building envelope area acc. to ISO 9975:2015 in m²

While the n_{L50} is usually automatically low in large buildings due to the low surface-to-volume ratio, the air permeability can be used to assess the quality of the airtight envelope even in large buildings.

The air permeability measurement is performed according to DIN EN ISO 9972: 2018-12 with the German national annex. The building preparation is carried out according to method 3 of this standard.

2.3 Requirements and drivers

2.3.1 Building airtightness requirements in the regulation

The Building Energy Act [9,11] set requirements for the quality of the air barrier and honors compliance with limit values if an air permeability test is performed.

(1) In general, a building must be constructed in such a way that the heat-transferring building envelope, including the joints, is sealed in accordance with the recognized rules of technology.

(2) If the airtightness of a new building is checked according to DIN EN ISO 9972:2018-12 Annex NA, the measured net air change rate may be considered in the annual primary energy demand. When checking the airtightness, the measurements shall be carried out with both pressurization and depressurization. The maximum values specified shall be complied with for both cases.

The net air change rate measured at a reference pressure difference of 50 Pascals shall not exceed:

- $n_{L50} \leq 1.5\ h^{-1}$ for buildings with ventilation system
- $n_{L50} \leq 3\ h^{-1}$ for buildings without ventilation system

The smaller limit value of the air change rate is extremely relevant for the function of ventilation systems. The air should flow through the planned supply and exhaust apertures of the system, and this requires a defined tightness of the building envelope.

This rule honors the performance of an airtightness test by taking into account the airtightness proven by the measurement when determining the annual primary energy demand and by allowing a reduced air exchange rate compared to the flat-rate values according to the DIN regulations to be applied for the calculation.

Buildings with an internal volume > 1500 m³

- $q_{E50} \leq 2.5$ m³/hm² for buildings with ventilation system
- $q_{E50} \leq 4.5$ m³/hm² for buildings without ventilation system

History of the indicators

In 1996, the first specific requirements for the airtightness of the building envelope were defined in the standard DIN V 4108-7 Thermal Insulation and Energy Performance in Buildings [8]:

- air change rate $n_{50} \leq 1\ h^{-1}$ for buildings with mechanical ventilation systems
- Air change rate $\leq 3\ h^{-1}$ for buildings without ventilation system.

Based on this information, the legislator was able to adopt these values in the Thermal Saving Directive (WSVO) from 1998 [7] with one change: air change rate should be $n_{50} \leq 1.5\ h^{-1}$ instead of $1\ h^{-1}$ for buildings with mechanical ventilation systems due to “construction tolerances”.

The Thermal Saving Directive offers the option of applying reduced ventilation heat losses in the energy calculation of a new building if a measurement is carried out and the limit values are complied with. If the test is specified in the verification, it must also be carried out after completion of the building envelope.

The Energy Saving Regulations (EnEV) of 2002, 2004 and 2009 adopted the same limit values.

The Energy Saving Regulation (EnEV) [8] from 2014 added limits for air permeability for buildings with an internal volume greater than 1500 m³, to minimize large individual leakage in big and compact buildings with favorable surface-to-volume ratios.

- Air permeability $q_{50} \leq 2.5$ m³/(h.m²) for buildings with mechanical ventilation systems
- Air permeability $q_{50} \leq 4.5$ m³/(h.m²) with ventilation by opening windows.

The current German Buildings Energy Act [9,11] has adopted these limit values. However, in comparison to the Energy Saving Directive, in which the building envelope was prepared according to method B (DIN EN 13829), fewer temporary sealings may be applied today. The preparation is carried out according to method 3 of DIN EN ISO 9972:2018-2.

Noticeable is that for new buildings the airtightness test is not mandatory, but it is required to establish a durable airtight building envelope, and current jurisprudence does not consider compliance with limit values as the absence of a defect.

DIN 4108-2 Thermal protection and energy economy in buildings – Part 2: Minimum requirements to thermal insulation defines values for construction joints and functional joints:

- The air permeability of component joints derived from measurement results must be less than 0.1 $m^3/(m.h\ (daPa^{2/3}))$.
- The functional joints of windows and balcony doors must be at least class 2 (in buildings up to two full floors) or class 3 (for buildings with more than two full floors) according to DIN EN 12207. For external doors, the air permeability of the functional joint must be at least Class 2 according to DIN EN 12207.

2.3.2 Incentive for Building airtightness

Programs that provide or require a good building airtightness are:

Kreditanstalt für Wiederaufbau (KFW)

The Kreditanstalt für Wiederaufbau, or KfW for short, supports occupied new buildings and renovations with various programs. All of these measures are linked to certain boundary conditions. Certain KfW efficiency house programs require airtightness testing. For all measures funded by KfW regarding the building envelope an "airtightness concept" (schematic of the air barrier in the test object) is required.

Passive Houses requirements

Air tightness shall not exceed 0.6 air changes per hour at a reference pressure of 50 Pascal (n_{50}) and shall be verified by on-site air permeability measurement (depressurization and pressurization).

DGNB (German Sustainable Building Council)

The aim of the DGNB is, among other things, to minimize the energy required for the room conditioning of buildings, while at the same time ensuring a high thermal comfort and to avoid structural damage. The DGNB prescribes various limit values depending on the building type and its use.

Single federal states also promote airtightness.

2.3.3 Building airtightness justifications

An air permeability test must be performed and the limit value must be complied with, if a measurement is applied in the energy calculation according to the German Buildings Energy Act [9,11] (formerly ENEV 2014 [10]).

Passive houses must all be measured and comply with the limit value.

2.3.4 Sanctions

If a limit value for air tightness according to the Building Energy Act is not complied with, an improvement of the air barrier is necessary.

If the limit value for airtightness is not complied with in the case of subsidy programs and an improvement is not possible, then the subsidy is forfeited.

2.4 Building airtightness in the energy performance calculation

2.4.1 Calculation

Determination of the infiltration air change in the EP calculation is done according to DIN V 18599:

Infiltration air change is determined as a function of building tightness as a daily average.

Values for building airtightness are the measured air change rate at 50 Pa pressure difference (n_{50}/n_{L50} value) and the air permeability of the building envelope area at 50 Pa pressure difference (q_{50}/q_{E50} value). As the standard has not been revised old terms are still used.

For EP calculation q_{50}/q_{E50} value is converted into a n_{50}/n_{L50} value.

$$n_{50} = \frac{q_{50} \cdot A_E}{V}$$

With:

n_{50} air change rate at 50 Pa pressure difference

q_{50} leakage rate per building envelope area at 50 Pa pressure difference

A_E building envelope area

V internal volume

Default values are set for untested buildings.

When using fan-assisted ventilation with unbalanced supply and exhaust airflow rates, infiltration increases or decreases due to the pressure difference caused by the ventilation system.

- Without mechanical ventilation (no ventilation system or ventilation system switched off, during weekend or vacation periods), determine the average daily infiltration air change according to equation:
  $n_{inf} = n_{50}\ e_{wind}$
- With mechanical ventilation, the average daily infiltration air change increases or decreases according to the equation:

$$n_{inf} = n_{50} \cdot e_{wind} \left(1 + f_{V,mech} \cdot \frac{t_{V,mech}}{24\ h}\right)$$

With:

n_{50} air change rate at 50 Pa pressure difference

- after air permeability test: measured value,
- without air permeability test or intended leakage test: standard values, specified according to table

e_{wind} wind protection coefficient, standard value is: $e_{wind} = 0.07$

(corresponds to wind protection coefficient according to DIN EN ISO 13790 in case of semi-exposed location, more than one facade exposed to the wind);

$t_{V,mech}$ daily operating time of the ventilation system (see DIN V 18599-10);

$f_{V,mech}$ factor for evaluating the increased or decreased infiltration caused by the mechanical ventilation system according to equations (61) to (63) of DIN V 18599 - 2.

2.4.2 Default values

The classification of the building airtightness of the building zone is specified in tables 1 and 2:

Table 1: n_{50}- Design values (standard values for untested buildings, $V \leq 1500\ m^3$)

Categories for the general estimation of the building tightness	Design values n_{50} (1/h)
I	a) 3; b) 1.5
II	4
III	6
IV	10

Table 2: q_{50}- Design values (standard values for untested buildings, $V>1500\ m^3$)

Categories for the general estimation of the building tightness	Design values q_{50} (m^3/m^2h)
I	a) 3; b) 2
II	6
III	9
IV	15

- Category I: Compliance with the building airtightness requirement according to DIN 4108-7:2001-08, chapter 4.4 (i.e. airtightness test is performed after completion);
  a) Buildings without ventilation and air-conditioning system,
  b) Buildings with ventilation and air-conditioning systems (also residential ventilation systems);
- Category II: buildings or parts of buildings to be constructed, for which no airtightness test is provided for
- Category III: cases not corresponding to Categories I, II or IV;
- Category IV: presence of obvious leaks, such as open joints in the air barrier of the heat-transferring building envelope.

If the classification into above categories cannot be made in a clearly qualified manner, an airtightness test must be performed to determine the n_{50} value.

Refurbished buildings that are not tested for airtightness must be calculated with Category III or IV.

2.5 Building airtightness test protocol

2.5.1 Qualification of Airtightness testers

The German Association for Air Tightness in Construction e. V.: Fachverband Luftdichtheit im Bauwesen e. V. (FLiB e. V.) offers a qualification / certification program for air tightness testers[1].

Testers can measure all types of buildings with this certification: apartments, single family houses, multifamily houses, large buildings, etc.

The certification is recommended from the FLiB e. V. Some funding programs, including those from single states, require qualification.

Approximately 500 testers have been qualified (about 40% FLiB members and 60% others). The certification was introduced in 2002 and the number of certified testers has grown slowly but steadily since then.

Many of the testers work as energy consultants, building physicists or building surveyors. Few perform air tightness tests exclusively.

2.5.2 National guidelines

Germany has a national guideline for performing airtightness tests: the DIN EN ISO 9972:2018-12 with the German national annex.

It contains, among other things:

- a description of how to calculate the internal volume V_L and the net air change rate n_{L50}
- a detailed checklist for building preparation according to procedure 3 of this standard.
- requires a depressurisation and a pressurization test
- requires that a building pressure of 50 Pa be achieved in each multipoint test and limits the pressure drop within the building to 10% of the induced building pressure differential.
- a description of a weighted calculation of the air leakage flow
- a description of the calculation of the uncertainties of the measurement as well as the total uncertainty of the derived quantities
- Furthermore, it gives instructions for the random measurement of arcade apartments, section-by-section measurement as well as guard-zone measurements

The Fachverband für Luftdichtheit im Bauwesen FLiB e. V. (www.flib.de) offers additional assistance such as requirements for the test report according to DIN EN ISO 9972 with a sample test report including checklists for the building preparation and the test report.

FLiB-Info sheets provide brief information on various topics related to measurement: overview of reference quantities and their calculation, derived quantities, liability risks, description of leakages: primary and secondary, etc.[2]

In addition, the association offers regular online seminars for further education and refresher courses on the standard and the Building Energy Act.

Others

In addition to verification testing for the Building Energy Act, there are other applications around building airtightness:

- Leak detection at 50 Pa negative pressure during the construction phase, for locating primary leaks to fix these leaks quickly and easily before covering the air barrier.
- Investigations with single-point measurements in existing buildings prior to renovation to determine the actual condition as a basis for improvements.
- Building inspection in existing buildings, for example, in the case of drafts or moisture damage in roof or exterior wall constructions due to ingress of indoor air humidity via leaks in the air barrier.

2.5.3 Requirements on measuring devices

The FLiB e. V. recommends to have the differential pressure gauge checked or calibrated every 2 years and the air flow measuring device every 4 years.

[1] https://flib-ev.de/messdienstleister.php

[2] https://flib-ev.de/publikationen.php

2.6 *Building airtightness Tests performed*

2.6.1 *Tested buildings*

In Germany, no statistics are currently available on air permeability tests.

2.6.2 *Database*

Currently, no data is collected on air permeability tests. Therefore, no data is available on the evolution of the airtightness level.

2.7 *Guidelines to build airtight*

The most important standard with information on airtight construction is DIN 4108-7 [12], which generally describes the necessity and design of an airtightness concept for a building. In addition, it gives recommendations on limit values depending on the ventilation concept, provides information on sufficiently airtight building materials and presents examples of the most common connection points / joints of the airtightness level (e.g. transition from a vapor barrier in the roof to the interior plaster of the exterior wall, socket connection to the exterior wall).

The German Association for Airtightness in Building (FLiB e.V.) provides information on the airtightness concept with requirements, principal sketches, sample details and a guideline for creating an air tightness concept as well as implementation instructions on the website[3].

Other standards set requirements for the air tightness of building components:

DIN 4108-2 [13] specifies limit values for the joint permeability between building components. It also specifies classes of air permeability for functional joints in windows and French windows as well as exterior doors in accordance with DIN EN 12207 [14].

DIN EN 12152 [15] specifies requirements for air permeability and classification of fixed and openable parts of curtain walls, which are subject to positive and negative static air pressure.

DIN EN 12426 [15] specifies the classification for resistance to air permeability for industrial, commercial and garage doors and gates in the closed state when tested according to EN 12427.

DIN 18015-5 [16] provides information on airtightness of electrical installations in residential buildings.

The FLiB book Building Airtightness Volume 1 [17] is the standard work on building airtightness. 12 authors report on the following topics: Reasons for airtightness of the building envelope, Changing requirements - airtightness in the past and today, Measuring the air permeability of the building envelope, Bonding - materials and processing, Ventilation in airtight (residential) buildings and the airtightness of the building envelope in public and private building law.

In the FLiB book Building Airtightness, Volume 2 [18], the following topics are described by 13 authors: Guide to airtightness concept; Basics for bonding practice - advice for installers; Implementation of airtightness in the renovation of old buildings; Air exchange through leaks and openings; Measurement practice: measurement of large buildings; Durability of building airtightness - field measurements; The work contract dispute about airtightness.

FLiB Research Report - Leakage Assessment [2]: In order to cover the topic of assessing leakage in the building envelope, researchers evaluated existing material, created a leakage system, interviewed measurement service providers and experts, documented practical cases, and conducted simulations for leakage assessment. In addition, the research report contains external expert contributions. These highlight air leakage and its evaluation from the viewpoints of ventilation technology, the entry of odours, window and exterior door technology, fire and noise protection, and from a legal perspective.

2.8 *Conclusion*

Over the last three decades, the air tightness of the building envelope has established itself as an important component for energy-saving buildings in Germany.

Standards around the topic have emerged and been further developed, such as DIN EN ISO

[3] https://luftdicht.info/fach-informationen_ldk.php

9972:2018 with the German national annex and DIN 4108-7 with guidance on the airtightness concept, materials, and designs. The early regulations (Thermal Protection Directive and later Energy Saving Directive) and today the Building Energy Act refer to these standards and their requirements for building airtightness.

Over the years, this development has led to a higher visibility and acceptance of building airtightness, as evidenced by a large number of air permeability measurements, especially in new buildings. For old buildings that are to be renovated, however, more educational work is still required.

In order to promote the importance of airtightness, particularly with regard to issues such as saving energy and protecting the building envelope from moisture damage caused by leaks, the German Association for Airtightness in the Buildings (Fachverband Luftdichtheit im Bauwesen) was founded at the beginning of the 2000s. To this day, the FLiB e. V. is also and especially committed to the further development and implementation of standards and laws for building airtightness.

The upcoming Building Energy Act, which will probably come into force in 2023, will focus on heating systems. Changes to building airtightness are unlikely to be implemented.

In the next years, it will be important to focus more on the renovation of existing buildings. Regulations and subsidies for thermal insulation and the connection to the airtightness of the building envelope are urgently needed here.

2.9 *Key documents*

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[12] 4108-7 (January2011) Thermal insulation and energy economy in buildings - Part 7: Air tightness of buildings - Requirements, recommendations and examples for planning and performance. s.l.: Beuth, 2011.

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[14] DIN EN 12207 (March 2017) Windows and doors - Air permeability - Classification; German version. Beuth, 2017

[15] DIN EN 12152 (December 2023) Curtain walling- Air permeability - Performance requirements and classification; Beuth, 2023

[16] DIN 18015-5 (July 2015) Electrical installations in residential buildings - Part 5: Airtight electrical installations free from thermal bridges, Beuth, 2015

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3 Ductwork airtightness

3.1 *Introduction*

The requirements for the tightness of air ducts and air duct systems are based on the requirements for the planning, construction and operation of ventilation and air-conditioning systems under hygienic and energy aspects.

In the Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products (89/106/EEC) [1], Section 6 of Annex I – Energy saving and thermal insulation – requires that systems for heating, cooling and ventilation must be designed and installed in such a way that energy consumption in the use phase is kept low. This includes, among other things, the blanket requirement for the tightness of air ducts and air duct components. Directive 89/106/EEC was published in the Official Journal No. L 040 of 11.02.1989.

EPBD (Energy Performance of Buildings) [2], as amended in 2002, refers to Directive 89/106/EEC of December 21, 1988.

A specification of the general requirements in the European regulations was legally binding in Germany with EnEG 1980 [3] and EnEV 2002, which was a part of the German economic administrative law. The full implementation of EPBD 2002 took place with EnEV 2007 [4].

The requirements for energy efficiency at European level were initially essentially based on reducing dependence on energy imports, such as oil or natural gas, from non-European countries.

The requirements for air tightness of air ducts have been regulated since 1994 in technical regulations for the production of rectangular air ducts (DIN EN 1507) [5] and since 1996 for round ones (DIN EN 12237) [6].

DIN 1946-2 (January 1994) [7] requires exhaust air ducts[4] that are operated with positive pressure in relation to the environment to be tight in accordance with DIN V 24194-2 [8] so that an outflow (exfiltration) of polluted air can be reliably prevented.

Further, requirements for the tightness of air ducts on the hygiene requirements for ventilation and air-conditioning systems for planning, construction, operation and maintenance are set out in VDI 6022 Sheet 1 (January 2018) [9].

VDI 6022 references DIN EN 16798-3 (November 2017) [10]. VDI 6022 is legally binding via the Ordinance on Workplaces (Workplace Ordinance – ArbStättV) [11] in the amended version of March 27, 2024 and the Workplace Guideline ASR A3.6 Ventilation (Technical regulation for workplaces) [12]. The ArbStättV and ASR A3.6 require state of the art and intended operation for ventilation and air-conditioning system. VDI 6022 Sheet 1 describes the state of the art.

AMEV Recommendation No. 166 – Air Handling Units (July 2023) [13] must be observed by the technical personnel responsible for the operation of air handling units in buildings of state and municipal administrations for new construction, conversion and expansion measures as well as renovation and maintenance measures (building maintenance).

In this set of rules, air ducts are required to have low energy demand, high tightness, low pressure and heat losses, and favorable hygienic conditions in order to reduce the cost of operating air handling systems.

For public construction projects, the VOB [14] (German construction contract procedures) must be observed and, because it is part of the contract for work and services, is agreed upon in a legally binding manner. Already in DIN 18379 (April 2010) [15] of VOB Part C (General Technical Terms of Contract for Construction Work (ATV)), information on the required pressure rating and the tightness class of air duct systems must be provided for the execution. Furthermore, there is a general

[4] According to European standards, exhaust ducts are those located between the fan and the outdoor exhaust. Extract ducts are between the ATD and the fan.

requirement that all connections of the air ducts must be airtight and stable in accordance with the operating conditions. The leak test of air-carrying system parts is required as a secondary service or special service.

3.2 *Airtightness indicator*

With EnEV 2007 [4], requirements for energy efficiency of cooling and air-conditioning systems were set for the case of construction or renewal. This regulation, as well as the amended versions, does not contain a classification for the tightness of air ducts. However, it does require for air conditioning systems with more than 12 kW nominal cooling capacity for cooling demand and for air handling units (AHU) with a design air flow rate of ≥ 4,000 m^3/h that the electrical power for the fan systems does not exceed the limit value of category SFP 4 (SFP: Specific Fan Power) according to DIN EN 13779 (May 2005) [16].

The P_{SFP} value is the electrical power required to convey the total air volume flow - i.e. the nominal air volume flow and the leakage air volume flow.

The leakage air volume flow is thus included in the pressure loss calculation for the fan design/the design of the air duct system with regard to the cross-section.

Because the limit value of class SFP 4 must be complied with in a legally binding manner, either a tight air duct system must be installed or the energy requirement for the additional leakage air volume flow to be conveyed must be compensated for by other energy-saving measures on the air handling unit.

DIN EN 13779, which is referenced in EnEV 2007, requires that supply air ducts be sufficiently airtight to prevent supply air losses and recommends limiting the proportion of leakage air volume flow to < 2 % of the total air volume flow to be conveyed, which corresponds to tightness class B according to DIN EN 12237 (July 2003) [5] and DIN EN 1507 (July 2006) [6].

DIN EN 13779 (September 2007) has been replaced by DIN EN 16798-3 (November 2017) [10]. The number of categories for classification of the P_{SFP}-value was extended from four categories to seven. DIN EN 16798-3 (November 2017) is referenced in the current Building Energy Act (GEG) [17] and category 4 is still required for the maximum permissible electrical power of fan systems.

The GEG, which came into force on 01 November 2020, replaced the last applicable EnEV 2016. The GEG has now come into force in the amended version of 16 October 2023 on 01 January 2024. In the GEG, DIN EN 16798-3 (November 2017) is referenced for the energy efficiency requirements of ventilation and air conditioning systems. In this set of regulations, at least tightness class B (ATC 4) is required and C (ATC 3) is recommended.

AMEV Recommendation No. 166 – Air Handling Units (July 2023) explicitly does not require any tightness classes for air ducts. With regard to tightness classes for air ducts, the regulations make general reference to DIN EN 16798-3 and VDI 3803 Part 1 [18].

3.3 *Requirements and drivers*

3.3.1 *Ductwork airtightness requirements in the regulation*

In DIN EN 13779 (May 2005), there were five categories for the P_{SFP}-value (Table 3). According to category SFP 4, the maximum permissible electrical power per fan system was limited to < 2,000 $W/(m^3/s)$.

Table 3: Classification of specific fan power P_{SFP} according to DIN EN 13779 (May 2005)

Category	$P_{SFP} \cdot \left[W / (m^3/s) \right]$
SFP 1	< 500
SFP 2	500 - 750
SFP 3	750 - 1.250
SFP 4	1.250 - 2.000
SFP 5	> 2.000

Furthermore, in DIN EN 13779 (September 2007), tightness class B was required as a minimum requirement and C was recommended. The classification for the air tightness of the air duct and the limit values of the air leakage rate are shown in Table 5 (highlighted in red).

In DIN EN 16798-3 (November 2017), the successor to DIN EN 13779 in the September 2007 version, the P_{SFP}-value per fan system for category SFP 4 was adopted unchanged (Table 4).

Table 4: Classification of specific fan power P_{SFP} according to DIN EN 16798-3 (November 2007)

Category	$P_{SFP} \cdot \left[W / \left(m^3/s \right) \right]$
SFP 0	< 300
SFP 1	≤ 500
SFP 2	≤ 750
SFP 3	≤ 1.250
SFP 4	≤ 2.000
SFP 5	≤ 3.000
SFP 6	≤ 4.500
SFP 7	> 4.500

As a minimum requirement, DIN EN 16798-3 (November 2017) calls for tightness class ATC 4 (B) and recommends ATC 3 (C). The classification for the air tightness of the air duct and the limit values of the air leakage rate are shown in Table 5.

Table 5: Air tightness classes of the air duct and limit values of the air leakage rate in the current version of DIN EN 1507 (July 2003), DIN EN 12237 (July 2006) and DIN EN 16798-3 (November 2017)

Air tightness classes of the air duct according to DIN EN 1507 and DIN EN 12237	Air tightness classes of the air duct according to DIN EN 16798-3	Air leakage rate limit f_{max} $\left[\frac{m^3/s}{m^2} \right]$
Corresponds to DIN EN 13779 (September 2007) ~> withdrawn	ATC 7	non classified
	ATC 6	$0.0675 * p_{test}^{0.65} * 10^{-3}$
A	ATC 5	$0.027 * p_{test}^{0.65} * 10^{-3}$
B	ATC 4	$0.009 * p_{test}^{0.65} * 10^{-3}$
C	ATC 3	$0.003 * p_{test}^{0.65} * 10^{-3}$
D	ATC 2 [1)]	$0.001 * p_{test}^{0.65} * 10^{-3}$
	ATC 1 [1)]	$0.00033 * p_{test}^{0.65} * 10^{-3}$

[1)] Air duct for special requirment

P_{test} [Pa] Test pressure – design pressure differential of the air duct system or air duct subsystem under test

Air leakage rate is an air volume flow due to air leakage, which is related to one square meter of air duct surface.

The leakage air volume flow must be conveyed by the fan system in addition to the nominal air volume flow required for use.

Figure 1 shows the leakage of air ducts as a function of the test pressure for classification according to DIN EN 16798-3 (November 2017).

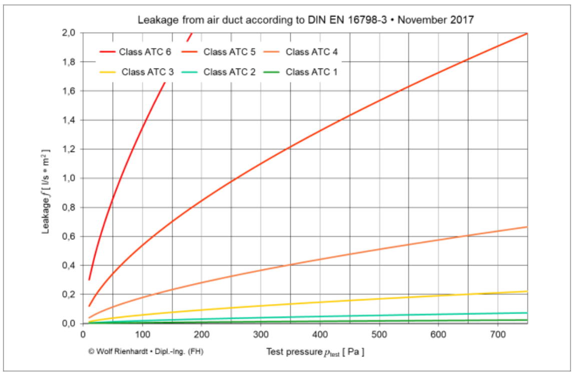

Figure 1: Leakage of air ducts as a function of test pressure for classification according to DIN EN 16798-3 (November 2017).

In VDI 6022 sheet 1 (January 2018), tightness class C is recommended in table 1 for offices, hotels, restaurants, schools, theaters, residential buildings, shopping areas, exhibition buildings, sports facilities, general areas in hospitals and general work areas in industry. For laboratories, treatment areas in hospitals, other rooms with increased requirements for indoor air quality, tightness class D is recommended.

3.3.2 Incentive for Ductwork airtightness

According to the information sheet of the Federal Office of Economics and Export Control (BAFA) on the eligible measures and services within the framework of the Federal Promotion for Efficient Buildings (BEG) (version 9.0 of January 2024) [19], measures to improve energy efficiency are promoted for indoor air and air conditioning systems in residential and non-residential buildings. With regard to the tightness of air ducts, this includes the material and professional installation.

The guideline for federal funding for efficient buildings – non-residential buildings (BEG NWG) [20] requires pneumatic balancing and proof of the tightness of the air duct system. A verification procedure is not explicitly required, rather it is sufficient in terms of the subsidized measure that the implementation is checked by the energy efficiency expert and the determination is documented.

For a promotion of energy and resource efficiency in the economy (EEW) [21], a guideline was published in the Federal Gazette for Economy and Climate Protection as of August 26, 2024. Eligible for funding in Module 4 for industrial and commercial facilities and processes are exclusively investment measures that contribute in particular to increasing the energy and/or resource efficiency of facilities for heat supply, cooling and ventilation, provided that these facilities are clearly and predominantly used for processes for the manufacture, further processing or refinement of products. The amount of funding depends essentially on the CO_2 savings potential.

3.3.3 Ductwork airtightness justifications

An energy efficiency expert must be involved in the application for funding under the federal funding program for energy-efficient buildings (BEG) and in monitoring the project. After completion of the project, the energy efficiency expert quantifies and confirms compliance with the minimum technical requirements and the savings in primary and final energy as well as CO_2.

The volume flows of ventilation systems must be pneumatically balanced and the tightness of the air duct system must be verified. Further requirements for the tightness test of the air duct system are not imposed by the funding guidelines.

If air duct systems are erected under a construction contract, which is a special type of contract for work and services, acceptance is mandatory. The acceptance includes the inspection of the contractual performance – i.e., for air duct systems, the agreed leakage class as the target condition. Reliable proof can only be provided by means of a leakage test – if necessary, exemplary for an air duct subsystem – in conjunction with a test report (inspection report for functional measurement based on DIN EN 12599 (January 2013)).

3.3.4 Sanctions

Section 108 of Part 8 in the GEG (08 August 2020 – last amended 20 July 2022) contains provisions on fines in the event that the requirements in this Act are violated. The fines range from EUR 5,000 to EUR 50,000.

Explicitly, the leak tightness of air duct systems in air handling units (AHU) is not listed as a fact in § 108 in GEG. As already explained in section 3.3 and section 3.3.1, the energy requirement for the additional leakage air volume flow to be conveyed is recorded via the SFP-value and a legally binding limit value must be complied with for this.

If the requirement for tightness of an air duct system, for the construction or improvement of which it was claimed a subsidy according to the federal subsidy for energy-efficient buildings (BEG), is not fulfilled, the subsidies are reclaimed on the basis of the Administrative Procedure Act (VwVfG) § 48 [22].

3.4 Ductwork airtightness in the energy performance calculation

3.4.1 Calculation

Calculations of the energy consumption of air handling systems are often made for nominal operation, which is based on a utilization profile. The design of the air handling unit for nominal operation includes the legally binding owed or contractually agreed leakage air flow rate, which is a function of the leakage class. Thus, the calculation of energy consumption also includes the proportional energy consumption caused by the leakage air volume flow.

3.4.2 Default values

The national series of standards DIN V 18599 provides a procedure for determining the energy performance of existing and new residential and non-residential buildings. Part 3 of this series of preliminary standards (DIN V 18599-3 (September 2018) [23], in conjunction with DIN V 18599-7 (September 2018) [24], describes a procedure for determining the useful energy demand for thermal air conditioning and the final energy demand for air conveying in air handling units (AHUs) with an outdoor air component.

The calculation method is based on characteristic values in connection with a variant matrix for the arrangement of components and the process control. Due to the number of variants and complex calculation algorithms, no standard value can be named at this point.

According to these regulations, air leakage is not taken into account when determining the useful energy requirement for thermal air treatment and the final energy requirement for air conveyance in air handling systems with an outside air component, provided that the supply air temperature is only slightly above (heating air < 10 K) or slightly below (cooling air < -10 K) the room temperature.

If the temperature difference between the supply air temperature and the room temperature is > 10 K or > -10 K, the air leakage must be calculated and documented according to the state of the art.

The state of the art for air leakage is described in DIN EN 16798-3 (November 2017) and at least tightness class ATC 4 (B) is required.

From a hygienic point of view, the state of the art is described in VDI 6022 Sheet 1 (January 2018) and at least tightness class ATC 3 (C) is required.

These requirements for the tightness class for state-of-the-art air duct systems must also be observed for the design (sizing).

3.5 *Ductwork airtightness test protocol*

3.5.1 *Qualification of ductwork Airtightness testers*

Until now, there is no qualification system for persons performing leakage testing.

Because leakage testing is a functional measurement that is part of the inspection as part of the maintenance of air handling units, it is mandatory to have expertise in accordance with DIN EN 12599 (January 2013) and VDI 6022 Sheet 4 (August 2012) [25].

Because the tightness of air duct systems agreed upon at the time of construction must be maintained over the entire service life of the air handling unit (AHU) – inspection (determination of the actual condition) and maintenance (restoration of the target condition), legally binding regulations, such as the Building Energy Act (GEG), require maintenance and the necessary expertise.

3.5.2 *National guidelines*

The testing of air duct systems in air handling units must be carried out in accordance with DIN EN 12599 (January 2013) [26]. The detailing of the procedure in DIN EN 12599 is low. For example, this set of rules does not specify any requirements for the permissible uncertainty for determining the air duct surface or the permissible deviation for the actual value of the test pressure from the setpoint value.

For the test pressure, the average value of the air pressure in the air duct system for the nominal operation of the air handling unit is to be used. The regulations contain recommendations for the test overpressure and test underpressure.

In HFL 2002 (June 2022) [27] for square air ducts and in HFL 3002 (June 2022) [28] for round air ducts, recommendations are published by the Manufacturers' Association for Air Ducts (HFL) on when to perform a leakage test on air ducts as well as on the procedure. According to this code, a minimum surface area of 10 m^2 is required for the air duct subsystem to be tested. HFL 2002 (June 2022) and HFL 3002 (June 2022) refer to DIN EN 12599 (January 2013).

Furthermore, the limit values for the leakage air rate depending on the pressure class according to DIN EN 1507 (July 2006) as well as DIN EN 12237 (July 2003) and for the leakage air rate depending on the tightness class according to DIN EN 16798-3 (November 2017) are listed in these HFL regulations.

3.5.3 *Requirements on measuring devices*

According to DIN EN 12599 (January 2013), the measuring equipment for determining the leakage air volume flow must be selected taking into account the overall measurement uncertainty. Calibrated measuring equipment must be used for the measurements.

3.6 *Ductwork airtightness Tests performed*

3.6.1 *Tested Ductwork*

At present, there are no statistical figures available from the Federal Statistical Office (federal authority in the portfolio of the Federal Ministry of the Interior) on the number of air duct systems in air handling units that have been tested for leaks.

3.6.2 *Database*

At present, there are no static numerical values available at the Federal Statistical Office (federal authority in the portfolio of the Federal Ministry of the Interior) about the level of air ducts in RLT systems with regard to tightness and, in this context, about persons who carry out the leakage tests on air ducts.

3.6.3 *Evolution of the ductwork airtightness level*

At present, there are no statistical figures available from the Federal Statistical Office (federal authority in the portfolio of the Federal Ministry of the Interior) on the development of the air tightness level of air duct systems.

3.7 *Guidelines to build airtight ductwork*

At the professional association for building services engineering (FGK), a guide to the best practices for the construction of tight air ducts (Good Practice Guide Air Ducts) is currently being prepared in Working Group 10 (Air Ducts).

Installation recommendations for square seamed air duct (HFL 4000 (June 2022) [29]) and round seamed air duct (spiral duct) (HFL 4001 (June 2022) [30]) have been published by the Air Duct Manufacturers Association (HFL).

3.8 *Conclusion*

The requirements for the tightness of air ducts/air duct systems and the limitation of energy consumption by air handling units (AHU) in technical and legally binding regulations have become increasingly stringent in recent years. What has been insufficient so far is consistent follow-up for implementation in the planning, construction and operation of air handling units.

The original draft bill for the GEG contained requirements for recording the energy consumption of the users and the load-oriented distribution of energy costs to the users in the case of communal air handling units – in other words, the metrological recording of energy consumption as the basis for energy consumption billing.

Furthermore, users should be provided with information on data relevant for estimating, comparing and controlling energy consumption and operating costs of HVAC systems.

This was not included in the final version of the GEG of 08 August 2020 in this way.

In the current GEG in the version dated 08 August 2020 (BGBl. I p. 1228), which was amended by Article 1 of the Act of 16 October 2023 (BGBl. 2023 I no. 280), the Federal Government is authorized to issue a statutory instrument regulating the recording of energy consumption and the distribution of operating costs according to the energy consumption of the users for central HVAC Systems. As of October 2024, no such statutory instrument has been issued.

The publication of the revised DIN EN 16798-3 and DIN EN 12599 is expected in early 2025.

3.9 *Key documents*

[1] Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products (89/106/EEC)

[2] Directive 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings

[3] Law for the Saving of Energy in Buildings (Energy Saving Law – EnEG) of July 22, 1976 (BGBl I p. 1873), amended by the First Law for the Amendment of the Energy Saving Law of June 20, 1980 (BGBl I p. 701)

[4] Ordinance on energy-saving thermal insulation and energy-saving systems engineering for buildings (Energy Saving Ordinance – EnEV) of July 24, 2007

[5] DIN EN 1507 (withdrawn October 1994) Ventilation for buildings – Air ducts – Rectangular sheet metal air ducts; strength and tightness; requirements and testing

[6] DIN EN 12237 (February 1996 - withdrawn) Ventilation for buildings – Air ducts – Circular sheet metal air ducts; strength and tightness; requirements and testing

[7] DIN 1946-2 (January 1994 – withdrawn) Room ventilation – Health requirements (VDI ventilation rules)

[8] DIN V 24194-2 (November 1985 – withdrawn) Duct components for ventilation systems; tightness; tightness classes of air duct systems

[9] VDI 6022 Part 1 (January 2018) Ventilation, indoor air quality – Hygiene requirements for ventilation and air-conditioning systems and units (VDI Ventilation Code of Practice)

[10] DIN EN 16798-3 (November 2017) Energy performance of buildings – Ventilation for buildings – Part 3: For non-residential buildings – Performance requirements for ventilation and room-conditioning systems (Module M5 - 1, M5 - 4)

[11] Workplace Ordinance of August 12, 2004 (BGBl. I page 2179), as last amended by Article 10 of the Act of March 27, 2024 (BGBl. I no. 109)

[12] ASR A3.6 (January 2021) Ventilation – last amended GMBl 2018 p. 474

[13] Air handling units – Recommendation No. 166 AMEV (July 2023) Guidance on the design, construction and operation of ventilation and air conditioning systems for public buildings

[14] -Construction Tendering and contract regulations for construction Work (VOB)– Part A (DIN 1960 (September 2019)): General conditions for the award of construction contracts

– Part B (DIN 1961 (September 2016)): General conditions for the execution of construction work

– Part C (Oktober 2023): General technical contract conditions for construction work (collection of technical DIN standards)

[15] DIN 18379 (April 2010) Contract Regulations for the Award of Public Works Contracts (VOB) – Part C: General Technical Terms of Contract for Construction Work (ATV) – Ventilation and air-conditioning systems

The valid copy is from September 2019.

[16] DIN EN 13779 (September 2007 – withdrawn) Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning system

[17] Law on Unification of Energy Saving Law for Buildings and Amendment of Other Laws of 08.August. 2020 – Article 1 – Act on Energy Saving and the Use of Renewable Energy for Heating and Cooling in Buildings (Building Energy Act (GEG)) which was last amended on 20 July 2023

[18] VDI 3803 Part 1 (May 2020) Air-conditioning – Structural and technical principles – Central air conditioning systems (VDI Ventilation Code of Practice)

[19] Federal funding for efficient buildings – Fact sheet on eligible measures and services (version 9.0 – valid from 01.01.2024). URL https://www.bafa.de/SharedDocs/Downloads/DE/Energie/beg_infoblatt_foerderfaehige_kosten.html

[20] Federal Ministry of Economics and Climate Protection – Guideline for Federal Funding for Efficient Buildings – Non-Residential Buildings (BEG NWG) (December 2022) published in the Federal Gazette (December 30, 2022)

[21] Federal Ministry of Economics and Climate Protection (August 26, 2024)) Announcement of the Guideline on Federal Funding for Energy and Resource Efficiency in Business – Funding Competition.

[22] Administrative Procedures Act (VwVfG) (Execution of May 25, 1976) in the version of January 23, 2003 (BGBl. I p. 102), as last amended by Article 2 of the Act of July 15, 2024 (BGBl. 2024 I no. 236)

[23] DIN V 18599-3 (September 2018) Energy performance of buildings – Calculation of useful, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting – Part 3: Useful energy demand for energetic air conditioning

[24] DIN V 18599-7 (September 2018) Energy performance of buildings – Calculation of useful, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting – Part 7: Final energy demand of ventilation and air-conditioning systems for non-residential buildings.

[25] VDI 6022 Sheet 4 (August 2012) Ventilation and indoor-air quality – Qualification of personnel for hygiene checkings, hygiene inspections, and assessment of indoor-air quality

[26] DIN EN 12599 (January 2013) Ventilation for buildings – Test procedures and measurement methods to hand over air conditioning and ventilation systems

[27] HFL 2002 (Manufacturers association for air duct e. V.) (June, 2022) Air tightness angular air ducts

[28] HFL 3002 (Manufacturers association for air duct e. V.) (June, 2022) Air tightness round air ducts.

[29] HFL 4000 (Manufacturers association for air duct e. V.) (June 2022) Installation recommendation angular air ducts folded

[30] HFL 4001 (Manufacturers association for air ducting e. V.) (June 2022) Installation recommendation round air ducts folded - spiral duct

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