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Estimating the Air Leakage Rate of Smoke Control Doors for Calculations Procedures, Part 2

Abstract

The extent of smoke spread during building fires is critical, as it can adversely affect both evacuation and firefighting intervention. Smoke migration can occur through structural gaps, the potential for which should be minimised. One way to exclude smoke is to pressurise the structure, and an important starting parameter for the design of this is to know the leakage areas. The need for knowledge of the size of structural gaps has been high since the inception of design methods. This article aims to identify the potential for improving the calculation procedures by using the results of measurements on existing smoke control doors in pressurised vestibules. In this section, the author compares the results of two different measurement methods with a series of measurements in a pressurised vestibule. Using computational procedures, the air flow coefficient and leakage area of the single-leaf smoke control doors under investigation are estimated. Suggestions are made for possible improvements to the design methods.

Keywords: smoke control door, leakage area, air flow coefficient, stairwell pressurisation, fire safety design

Introduction

The first part of this article highlighted the risk of uncontrolled spread of smoke and toxic combustion gases from fires in buildings, posing a threat to evacuation and the safety of those fleeing. One concept of evacuation in complex buildings is phased evacuation, whereby the complete evacuation of the building is prolonged over time. In some cases, where there are persons who are unable to use the stairs

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independently, it may be necessary to create temporary protected spaces.[2] One way of doing this may be to provide a separate room with a fire and smoke barrier of a specified performance.[3]

Pressurisation is the technical method of supplying a defined amount of fresh air into the space to be protected (e.g. stairwell, vestibule, etc.) to create a relative overpressure. Air is then flowed out of the pressurised space through gaps in the structure, through door gaps, which keeps out smoke and toxic combustion products.[4] When designing the stairwell pressurisation, the leakage that will occur must be estimated.[5] Since doors play a particularly important role in leakage losses, it is important to know the gap dimensions as accurately as possible.[6]

Even early research was concerned with estimating the amount of air flowing through door gaps at various pressure differentials. The size of the leakage area is an important input parameter both for manual calculations and for computer programmes. One method is the orifice method, where the gaps are considered in the calculations as a numerical value expressed in terms of surface area. In the descriptive equation for doors, the discharge coefficient is typically 0.65 and the flow exponent is 0.5.[7] The air leakage coefficient and gap length can be used to characterise the air flow through the gaps in the openings, which is also a traditional parameter for air leakage through windows and doors in Hungary and in Poland, as well.[8]

In one of Tamura's paper about a computer study of smoke movement, the equivalent flow area for stairwell doors was 0.0185 m^2.[9] Based on air leakage tests on installed doors, Hobson and Stewart estimate the equivalent flow area to be 0.01–0.02 m^2 for single-leaf doors.[10] BS 5588-4 also recommends using a leakage area of 0.01–0.02 m^2 depending on the direction of door opening.[11] This recommended value has been retained in EN 12101-6 and EN 12101-13.[12]

Klote et al. gave flow areas of gaps values for single-leaf doors in tabular form, which can be used in the orifice equation with a flow coefficient of 0.65. For doors 2.13 m high, 0.914 m wide and 44.5 mm thick, the typical value is 0.0073–0.0428 m^2 depending on the thickness of the gaps above and below the door.[13]

The approach in length of the gaps in Hungary is suggested by the Fire Protection Technical Guideline in the field of Protection against Heat and Smoke Spread (TvMI) with an air flow coefficient value of 1.11 and a flow exponent of 0.67.[14] In the literature reviewed in the first part of this article, there is a significant variation with

[2] National Directorate General for Disaster Management 2024: 38–42.
[3] Decree 54/2014 (XII. 5.) of the Ministry of the Interior.
[4] Butcher–Parnell 1979: 109–111; Bérczi–Badonszki 2021: 66–96.
[5] International Code Council and Society of Fire Protection Engineers 2022: 208.
[6] Gross 1991: 171–177.
[7] Martin 1970: A4-3.
[8] Lis–Lis 2021; Baumann 2005: 28–30.
[9] Tamura 1970.
[10] Hobson–Stewart 1972: 47–56.
[11] British Standards Institution 1978: 145; British Standards Institution 2004: 66.
[12] CEN 2005b: 88–91; CEN 2022: 67.
[13] Klote et al. 2012: 119; Klote et al. 2024: 56.
[14] National Directorate General for Disaster Management 2025: 51–52.

air flow coefficient values between 1 and 9 for doors.[15] The problem is that there is little literature data available on the values of air leakage coefficients.[16]

The fire prevention solutions presented in this publication provide an opportunity to prevent or reduce the harmful effects of a possible fire on health.[17] The examination of the harmful effects shows similarities with the consequences of toxic combustion products produced in an industrial environment like chemical warehouses.[18] Additional technical solutions can be fire protection signalling systems, the development of which provides many new solutions in the field of property protection and fire protection.[19] Finally, we can learn important practical lessons for the development of fire protection authority activity when dealing with the policing issues of event order security.[20]

Results

In a recent paper by Mihály et al., the airtightness of single-leaf smoke control doors was investigated by measurements on existing doors.[21] The findings of these measurements and other conclusions that can be drawn from the measurement results are presented below.

Comparison of measurement methods – Blower door and funnel with vane probe

The measurement methods recommended by the harmonised standard for determining the air permeability of buildings include the Blower Door and air permeability measurement using the building's own ventilation system.[22]

Before starting to measure the air permeability of the vestibules and doors with a funnel and a vane probe, the air permeability of the building's own ventilation system was tested to see how it agreed with the measurements made with the Blower Door method. This provides information on how the results of the funnel measurement relate to the measurement results recorded by the Blower Door instrument.

During the tests with the Blower Door, the instrument was installed in a door of the vestibule. For the funnel with vane probe measurements, the Blower Door was removed, the door was closed and the door gaps were taped to ensure conditions were nearly identical. The funnel kit consisted of a measuring funnel with a sealed rim, a flow straightener and a vane probe. The differential pressure was recorded by a tube passed through a gap in the structure under test. A comparison of the measured values is illustrated in Figure 1.

15 Hobson–Stewart 1972: 47–56; Recknagel et al. 2000: 882–891; Várfalvi s. a.; Barna 2015; Gábor–Zöld 1981: 130–131; Liddament 1986: 6.25; ÉSZK 1984: 6–7.

16 Baumann 2011.

17 Almási et al. 2022.

18 Berger et al. 2024.

19 Kátai-Urbán 2023.

20 Kanyó – Vásárhelyi-Nagy 2021.

21 Mihály et al. 2025.

22 CEN 2016: 17–18.

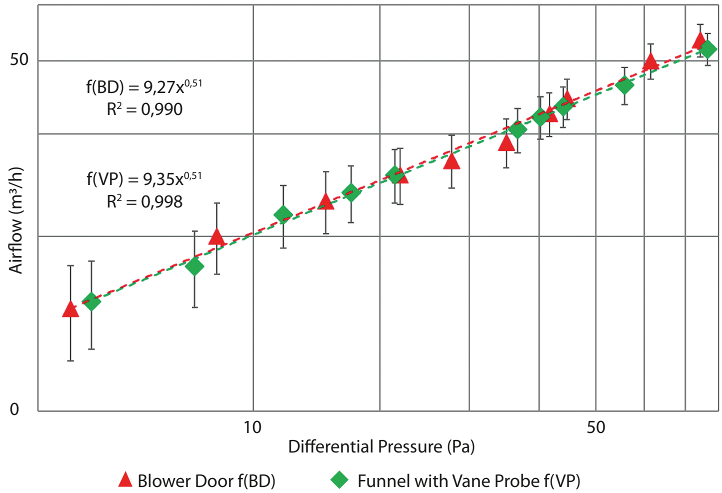

Figure 1: Comparison of measurement results
Source: compiled by the author based on Mihály et al. 2025

Each opening in the building envelope, however, is often described by the power law equation as shown in equation (1).[23]

$$= c \times (\Delta p)^n \qquad (1)$$

where
- Q – is the airflow through opening (m^3/s)
- c – is the flow coefficient ($m^3 s^{-1} Pa^{-n}$)
- n – is the pressure exponent, dimensionless
- Δp – is the pressure difference (Pa)

Applying the energy law equation, the pressure exponent of the two series of measurements was found to be the same, 0.51. This suggests that turbulent flows dominated during the measurements. The value of the flow coefficient is also nearly the same, which suggests good agreement between the two measurements made under identical conditions using two different measurement methods. This indicates that the vestibules' own ventilation system and the funnel kit with vane probe measurement may be adequate for air tightness testing.

Estimation of leakage area

In the first series of measurements, the gaps around the doors opening into the hallway and the doors opening from the hallway were taped. In this case, the amount of air supplied through the disc valve flowed through the structural gaps, assuming that the amount of air leaking through the adhesive tape was negligible.

[23] Owen 2017: 16.15.

The measurements were carried out at a pressure differential of 10–15–25–50–75 Pa. A manually adjustable disc valve is used to adjust the amount of air required to maintain the specified pressure level. The volume of air supplied, the pressure differential produced and the ambient conditions were then recorded.

From the resulting differential pressure and volume flow pairs, the estimated surface area of the structures surrounding the vestibules can be expressed using the recommendation in Annex A of EN 12101-13. In practice, this means all surfaces of wall structures and floors. Table 1 summarises the structural surfaces calculated for each vestibule.

Table 1: Average effective leakage area of structures

Vestibule	**Average effective leakage area of walls + floors (m²)**
6th Floor, Section A	0.001067
6th Floor, Section B	0.001285
5th Floor, Section A	0.001084
5th Floor, Section B	0.001108
4th Floor, Section A	0.001261
4th Floor, Section B	0.001151
3rd Floor, Section A	0.001087
3rd Floor, Section B	0.001145
2nd Floor, Section A	0.001123
2nd Floor, Section B	0.001043
1st Floor, Section B	0.001055
Mean	**0.00113**

Source: compiled by the author based on Mihály *et al. 2025*

The wall area of the examined vestibules was 14.07 m², while the total floor and ceiling area was 5.76 m². By using these values, it is possible to compare how the measured values agree with the values of the leakage areas recommended by EN 12101-13 for walls and floors.[24] According to the standard, the leakage area ratio for stairwell walls is 1.1×10^{-4}, while for floors it is 5.2×10^{-5}. Taking these values into account, using the estimation method proposed in the standard, the estimated wall and floor area of the vestibule can be calculated using formulae (2) and (3).

$$A_{LW} + A_{LF} = (A_{LW}/A_{WALL}) \times A_{WALL} + (A_{LF}/A_{FLOOR}) \times A_{FLOOR} \qquad (2)$$

$$A_{LW} + A_{LF} = 1.1 \times 10^{-4} \times 14.07\,m^2 + 5.2 \times 10^{-5} \times 5.76\,m^2 = 0.00185\,m^2 \qquad (3)$$

where
A_{LW} – is the total wall leakage area (m²)
A_{LF} – is the total floor leakage area (m²)

24 CEN 2022: 70–71.

A_{LW}/A_{WALL} – is the leakage area ratio for walls, dimensionless
A_{LF}/A_{FLOOR} – is the leakage area ratio for floors, dimensionless

From the above calculation, it can be seen that the gap area estimated by the standard is in good agreement with the value calculated from the measurements, and lies between the tight and average ranges.

The measurements were then taken on each door. To do this, the adhesive tape had to be removed from the gaps of the door under test. Air was then supplied to the vestibule, which flowed through the walls, floor and through the gaps of the door under test. Under these conditions, the amount of air to be introduced to maintain the given pressure differential and the ambient data were recorded at a pressure differential of 5–10–15–25–50–75 Pa, set by a manually adjustable disc valve. Using the estimation method of the standard, the amount of air flowing through the door gaps at a given pressure differential could be estimated from the difference between the total air introduced and the air flowing through the walls and floors. From the air volume thus determined, the leakage area of the door could be estimated for a given pressure difference. The results of the measurements taken in each of the vestibules are shown in Table 2.

Table 2: Average effective leakage area of doors

Vestibule	Average effective leakage area of doors	
	into pressurised space (m2)	from pressurised space (m2)
6th Floor, Section A	0.00315	0.00428
6th Floor, Section B	0.00354	0.00367
5th Floor, Section A	0.00331	0.00372
5th Floor, Section B	0.00376	0.00379
4th Floor, Section A	0.00325	0.00346
4th Floor, Section B	0.00391	0.00442
3rd Floor, Section A	0.00326	0.00340
3rd Floor, Section B	0.00358	0.00373
2nd Floor, Section A	0.00378	0.00382
2nd Floor, Section B	0.00523	0.00424
1st Floor, Section B	0.00400	0.00312
Mean	**0.00371**	**0.00379**
	0.00375	

Source: compiled by the author based on MIHÁLY et al. 2025

Based on the measurement results, the air leakage area of the single-leaf smoke control doors was 0.00375 m^2. The values measured showed no significant difference in whether the doors opened into the pressurised vestibule or from the pressurised vestibule. The leakage area of 95.5% of the tested smoke control doors fell within two standard deviations of the mean value.[25]

[25] MIHÁLY et al. 2025.

Estimation of air leakage coefficient

Using the differential pressure and volume flow values from the series of measurements, the gap length of the doors can be used to determine the air leakage coefficient of a given door. The gap factor describes how much air flows through a gap of 1 metre in length of a window or door due to a unit pressure difference.

The volume of air leaking through the doors was determined using the power law equation. For various differential pressures, the amount of air flowing through the structures of the vestibule is known. The volume of air flowing through the door can be estimated as the difference between the volume of air flowing through the door and the structure as a whole and the volume of air flowing through the structure at a given pressure.

The length of the gap was 6.106 m for the door opening into the vestibule and 5.940 m for the door opening from the vestibule. The surface area of the doors was 2.03 m^2 for the door opening into the vestibule and 1.89 m^2 for the door opening from the vestibule.

For all doors, the air leakage coefficient has been determined taking into account the calculation procedure proposed by the TvMI. The calculated values are given in Table 3.

Table 3: Average air leakage coefficient of doors

Vestibule	**Average air leakage coefficient of doors m^3/(hmPa$^{0.67}$)**	
	into pressurised space (CV)	**from pressurised space (VC)**
6th Floor, Section A	0.99	1.39
6th Floor, Section B	1.08	1.15
5th Floor, Section A	1.02	1.18
5th Floor, Section B	1.19	1.22
4th Floor, Section A	0.99	1.09
4th Floor, Section B	1.19	1.38
3rd Floor, Section A	1.00	1.06
3rd Floor, Section B	1.05	1.13
2nd Floor, Section A	1.16	1.21
2nd Floor, Section B	1.57	1.29
1st Floor, Section B	1.18	0.95
Mean	**1.13**	**1.19**
	1.16	

Source: compiled by the author

The results show that there is no significant difference in the value of *c* for doors opening to the vestibule and doors opening from the vestibule. 95.5% of the values are within two standard deviations of the mean value.

Figure 2 shows the calculated value of *c* per door tested. The orange line in Figure 2 shows the average of the calculated values (1.16) and the *c* value proposed by the TvMI (1.11). It can be seen that some of the measured values are above the currently proposed value of 1.11, i.e. there was a slightly higher leakage than the one given in the design formula.

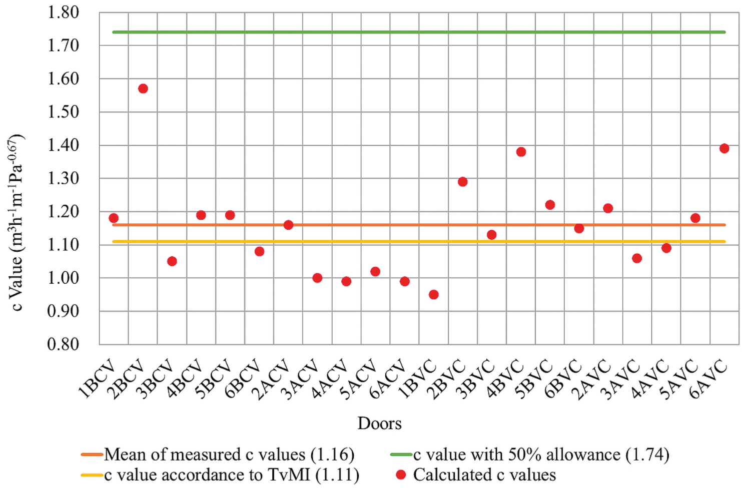

Figure 2: c values according to the TvMI and based on measurement results
Source: compiled by the author

If we increase the measured values of *c* by an uncertainty factor of 50%, we obtain an air leakage coefficient of 1.74 (green line), which covers all measured values with a high degree of confidence.

For the comparability of the calculated values, the air permeability coefficient was determined by taking into account the exponent 2/3. Figure 3 illustrates these values.

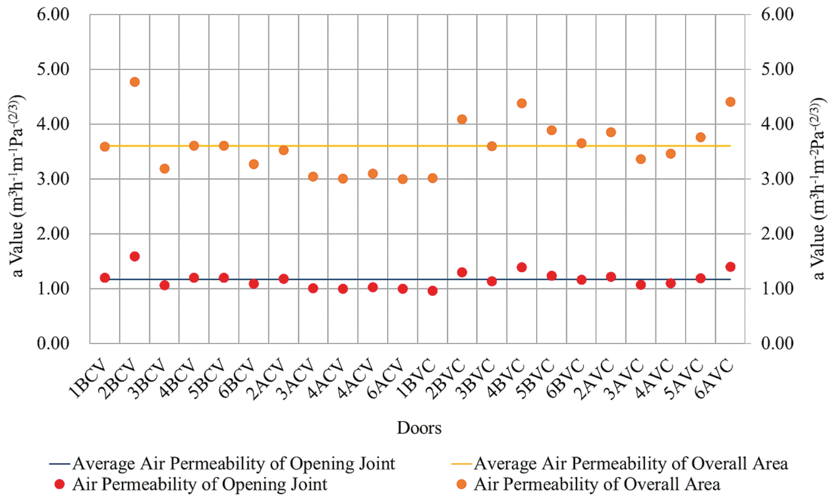

Figure 3: Air leakage coefficients
Source: compiled by the author

On the left axis, the air leakage coefficient is given for the length of opening joint, which is 1.17 $m^3/(hmPa^{2/3})$. On the right axis, the air leakage coefficient is given for the total surface area of the doors, which is 3.6 $m^3/(hm^2Pa^{2/3})$.

Discussion

The initial tests compared the results measured by the Blower Door instrument with the results measured by the funnel with vane probe. In the case of the Blower Door instrument, the supply air was provided by the instrument fan. In the case of the funnel with vane probe, the building's own ventilation system provided the air supply. The comparative measurements showed a good agreement, which confirmed the technical solution proposed by EN ISO 9972 that the building air ventilation system can be used to perform the air permeability measurements. Based on these tests, the results of the funnel type volumetric flow metre were considered usable for further measurements.

Once the amount of air flowing through the vestibule doors at a given pressure was measured, the leakage area of the doors could be calculated. The resulting value of 0.005 m^2 is less than the value recommended by the relevant literature, EN 12101-13, EN 12101-6 and BS 9944. It is half the recommended value of 0.01 m^2 for doors opening into a pressurised space and a quarter of the recommended value of 0.02 m^2 for doors opening from a pressurised space. This value is also lower than the values proposed by Hobson and Stewart. The value of 0.005 m^2 was independent of the direction of the opening of the doors, which is in accordance with the standard for the testing and classification of smoke control doors, which requires that smoke control doors meet the air tightness requirement from all sides, regardless of the direction of opening. The air leakage through the doors at a pressure differential of 25 Pa ranged from 48 to 67 m^3/h, which is well below the 3 $m^3/h/m$ specified by the classification standard for the leakage length at ambient temperature. It is important to note that the test standard ignores leakage under the doors.

The resulting air leakage coefficient value of 1.16 is in good agreement with the current TvMI, but it should be noted that it exceeds the value of 1.11, which suggests that the TvMI value could be corrected or increased by a safety factor. Values in the relevant literature vary widely, ranging from 1 to 9 $m^3/(hmPa^{2/3})$. The air leakage coefficient 1.17, calculated with a factor of 2/3, is in good agreement with the proposed air leakage coefficient of the doors with threshold described by Várfalvi, Gábor–Zöld and Barna.[26] This value is much more favourable than the value between 4 and 9 considered for doors without threshold and lower than the value proposed in ME-04–132–84.[27]

Based on the results obtained, it is urged that the leakage area values recommended in Annex A of EN 12101-13 be added. For single-leaf smoke control doors, regardless of their opening direction, a leakage area of 0.005 m^2 can be considered

26 Várfalvi s. a.; Barna 2015; Gábor–Zöld 1981: 130–131.
27 ÉSZK 1984: 6–7.

up to a maximum perimeter of 6.1 m at a pressure differential of 10–50 Pa at ambient temperature.

For the calculation method used in the TvMI, a minimum increase in *c* is recommended. Based on the measured values, it is recommended to increase the value of the air flow coefficient by a safety factor in the calculations to take into account the uncertainty depending on the quality of the installation.

Given that the tests are carried out on one type of door, it is recommended that several different door designs and geometries be tested in the future. It is necessary to test a wider range of doors, which should include double doors, windows, glazed facades and lift landing doors.

Conclusion

Based on the studies supported by the measurements, the following conclusions can be drawn:

- Based on comparative measurements with the Blower Door instrument, funnel with vane probe measurement with the building's own ventilation system can be a suitable method for measuring air permeability.
- The values proposed by EN 12101-13 for the leakage area for walls and floors were in good agreement with the values measured in the vestibules tested.
- It is proposed to supplement the table of leakage area values for doors in EN 12101-13. For smoke control doors, regardless of whether they open into or out of the pressurised compartment, 0.005 m^2. This value may be taken into account up to a leakage perimeter of 6.1 m, between 10 and 50 Pa and at ambient temperature margins.
- The value of the air leakage coefficient determined by the TvMI showed good agreement with the measured value. However, it is recommended to increase the coefficient by a safety factor to take into account uncertainties due to installation conditions.
- In accordance with the additional classes S_{a3} and S_{a4} defined in EN 13501-2, it is also proposed to amend the test standard to allow for S_{a3} and S_{a4} tests. A corresponding amendment to the EN 15269-20 standard is also proposed.[28]

The results of the tests can be used in the design of air supply systems for pressurised smoke-free staircases and pressurised smoke-free vestibules. The recommendations cover both the estimation methods recommended in Annex A of EN 12101-13 and those recommended by the TvMI. The proposal to amend the test standard may help in the future application of the classification standard.

[28] CEN 2023: 52–53; CEN 2005a; CEN 2021.

References

Almási, Csaba – Cimer, Zsolt – Kátai-Urbán, Lajos – Vass, Gyula (2022): Prevention of Terrorist Attacks during the Transport of Dangerous Goods by Road in Hungary. *American Journal of Research Education and Development,* (2), 2–10.

Barna, Lajos (2015): *Tüzelőberendezések égési levegő ellátása.* Előadás. „A szén-monoxid mérgezések hatékony megelőzése" Országos szakmai konferencia, Budapest, 5 March 2015. Online: www.vedelem.hu/files/UserFiles/File/aktualis/20150403/04.pdf

Baumann, Mihály (2005): Tüzelőberendezések légellátása. *Magyar Installateur,* 15(10–11), 28–30.

Baumann, Mihály (2011): *Épületek légforgalma.* 17th "Building Services, Mechanical and Building Industry Days" International Conference, Debrecen, 13–14 October 2011. Online: www.e-gepesz.hu/files/cikk9422_EUG_Baumann.pdf

Bérczi, László – Badonszki, Csaba (2021): A tűzvédelmi tervezés fő tartópillérei a tűzvédelmi műszaki irányelvek. *Védelem Tudomány,* 6(2), 66–96. Online: https://ojs.mtak.hu/index.php/vedelemtudomany/article/view/13473

Berger, Ádám – Kátai-Urbán, Lajos – Németh, Zsolt – Zsitnyányi, Attila – Kátai-Urbán, Maxim – Cimer, Zsolt (2024): Applicability of Design Methodology for the Remediation Bund of Flammable Dangerous Liquid Storage Tanks. *Fire,* 7(7). Online: https://doi.org/10.3390/fire7070246

British Standards Institution (1978): *BS 5588-4:1978 Fire Precautions in the Design and Construction of Buildings.* Part 4. Code of Practice for Smoke Control in Protected Escape Routes Using Pressurisation. London: British Standards Institution.

British Standards Institution (2004): *BS 5588-4:1998 + A2:2004 Fire Precautions in the Design, Construction and Use of Buildings.* Part 4. Code of Practice for Smoke Control Using Pressure Differentials. London: British Standards Institution.

Butcher, Edward G. – Parnell, Alan C. (1979): *Smoke Control in Fire Safety Design.* London: E. & F. N. Spon Ltd.

CEN (2005a): *EN 1634-3:2005 Fire Resistance Tests for Door and Shutter Assemblies.* Part 3. Smoke Control Doors and Shutters. Brussels: Technical Committee of the European Committee for Standardisation.

CEN (2005b): *EN 12101-6:2005 Smoke and Heat Control Systems.* Part 6. Specification for Pressure Differential Systems. Kits. Brussels: Technical Committee of the European Committee for Standardisation.

CEN (2016): *EN ISO 9972:2016 Thermal Performance of Buildings.* Determination of Air Permeability of Buildings. Fan Pressurization Method (ISO 9972:2015). Brussels: Technical Committee of the European Committee for Standardisation.

CEN (2021): *EN 15269-20:2021 Extended Application of Test Results for Fire Resistance and/or Smoke Control for Door, Shutter and Openable Window Assemblies, Including Their Elements of Building Hardware.* Part 20. Smoke Control for Doors, Shutters, Operable Fabric Curtains and Openable Windows. Brussels: Technical Committee of the European Committee for Standardisation.

CEN (2022): *EN 12101-13:2022 Smoke and Heat Control Systems.* Part 13. Pressure Differential Systems (PDS). Design and Calculation Methods, Installation, Acceptance Testing, Routine Testing and Maintenance. Brussels: Technical Committee of the European Committee for Standardisation.

CEN (2023): *EN 13501-2:2023 Fire Classification of Construction Products and Building Elements.* Part 2. Classification Using Data from Fire Resistance and/or Smoke Control Tests, Excluding Ventilation Services. Brussels: Technical Committee of the European Committee for Standardisation.

ÉSZK (1984): *ME-04–132–84 Füstmentes lépcsőházak követelményei.* Budapest: Építésügyi Szabványosítási Központ.

Gábor, László – Zöld, András (1981): *Energiagazdálkodás az építészetben.* Budapest: Akadémiai Kiadó.

Gross, Daniel (1991): Estimating Air Leakage Through Doors for Smoke Control. *Fire Safety Journal,* 17(2), 171–177. Online: https://doi.org/10.1016/0379-7112(91)90040-6

Hobson, P. J. – Stewart, L. J. (1972): *Pressurisation of Escape Routes in Buildings.* Fire Research Note No. 958. Bracknell: Heating and Ventilating Research Association. Online https://publications.iafss.org/publications/frn/958/-1/view/frn_958.pdf

International Code Council and Society of Fire Protection Engineers (2022): *Fire Safety for Very Tall Buildings. Engineering Guide.* The Society of Fire Protection Engineers Series. Cham: Springer. Online: https://doi.org/10.1007/978-3-030-79014-1

Kátai-Urbán, Maxim (2023): Veszélyes anyagok és áruk tárolásának biztonsága, különös tekintettel a baleseti vízszennyezésre. *Hadmérnök,* 18(1), 29–41. Online: https://doi.org/10.32567/hm.2023.1.3

Kanyó, Ferenc – Vásárhelyi-Nagy, Ildikó (2021): A beavatkozó tűzoltói állomány kompetencia alapú fizikai állapotfelmérése. *Védelem Tudomány,* 6(1), 204–217.

Klote, John H. – Milke, James A. – Turnbull, Paul G. – Kashef, Ahmed – Ferreira, Michael J. (2012): *Handbook of Smoke Control Engineering.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Klote, John H. – Milke, James A. – Turnbull, Paul G. – Kashef, Ahmed – Phillips, Duncan A. – Evans, Douglas H. – Webb, William A. – Roth, Michael J. (2024): *Handbook of Smoke Control Engineering.* Second Edition. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Liddament, Martin W. (1986): *Air Infiltration Calculation Techniques. An Applications Guide.* Coventry: The Air Infiltration and Ventilation Centre. Online: www.aivc.org/resource/air-infiltration-calculation-techniques-applications-guide

Lis, Piotr – Lis, Anna (2021): The Required Amount of Ventilation Air for the Classroom and the Possibility of Air Infiltration through the Windows. *Energies,* 14(22). Online: https://doi.org/10.3390/en14227537

Martin, P. L. ed. (1970): *IHVE Guide. Book A.* London: The Institution of Heating and Ventilating Engineers.

Mihály, István – Bérczi, László – Bognár, Balázs – Kátai-Urbán, Maxim – Tóth, Levente – Kátai-Urbán, Lajos – Vass, Gyula – Varga, Ferenc (2025): Experimental Study to Determine the Leakage Area of Single-Leaf Smoke Control Doors in the Design of Pressure Differential Systems. *Fire,* (8)1. Online: https://doi.org/10.3390/fire8010005

National Directorate General for Disaster Management (2024): *Tűzvédelmi Műszaki Irányelv* [Fire Protection Technical Guideline]. *Kiürítés* [Evacuation]. TvMI 2.6:2024.02.01. Belügyminisztérium, Országos Katasztrófavédelmi Főigazgatóság. Online: www.katasztrofavedelem.hu/application/uploads/documents/2023-12/82903.pdf

National Directorate General for Disaster Management (2025): *Tűzvédelmi Műszaki Irányelv* [Fire Protection Technical Guideline]. *Hő és füst elleni védelem* [Protection against Heat and Smoke Spread]. TvMI 3.6:2025.02.01. Belügyminisztérium, Országos Katasztrófavédelmi Főigazgatóság. Online: www.katasztrofavedelem.hu/application/uploads/documents/2024-12/84963.pdf

Owen, Mark S. ed. (2017): *2017 ASHRAE Handbook. Fundamentals. SI Edition.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Recknagel, Hermann – Sprenger, Eberhard – Schramek, Ernst-Rudolf (2000): *Fűtés- és klímatechnika 2000. I. kötet.* Budapest–Pécs: Dialóg Campus.

Tamura, George T. (1970): *Computer Analysis of Smoke Movement in Tall Buildings.* Research Paper No. 452. Ottawa: National Research Council of Canada, Division of Building Research. Online: https://doi.org/10.4224/40000451

Várfalvi, János [s. a.]: *Ablakszerkezetek légáteresztése.* Online: http://152.66.45.150/EPFIZ/Ablakszerkezetek_legatreresztese.pdf

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54/2014. (XII. 5.) BM rendelet az Országos Tűzvédelmi Szabályzatról [Decree 54/2014 (XII. 5.) of the Ministry of the Interior on the Issuance of the National Fire Protection Regulation]. Online: https://njt.hu/jogszabaly/2014-54-20-0A