Hinged doors opening-force in pressurized stairwells

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Abstract

The ability to evacuate buildings is one of the most important pillars of safety. Internal stairwells providing vertical access must be designed to protect against smoke spread while ensuring escape routes. One commonly used method of smoke extraction is to create positive pressure in the stairwell, also known as pressurization. In many cases, doors leading to such stairwells are equipped with escape-supporting locking devices, the primary purpose of which is to ensure easy opening. These panic bar doors ensure that the locking mechanism can be released even in an emergency. However, when using pressurization, the torque generated by the pressure difference between the two sides of the door must also be overcome in order to open the hinged door.

The study investigates the opening force of doors in pressurized stairwells, considering different opening solutions and pressure values. In addition to mechanical tests, it also evaluates the role of building materials, with particular regard to the rigidity of the door leaf, the behavior of seals, and the material and design of the connection between the frame and the wall.

The results show that optimizing door opening force is not only a structural issue, but also a matter of material selection. The author proposes a labeling system that supports the proper design of doors used in pressurized environments based on the materials and structural details used.

Keywords: pressurization, door opening force, escape routes, panic bar, pressurized stairwell

Kulcsszavak: túlnyomásos, ajtónyitási erő, menekülési útvonalak, pánikvasalat, túlnyomásos lépcsőház

1. Introduction

Combustible substances often have dangerous chemical properties [1] which, in the event of an emergency situation, together with toxic combustion products spreading in the event of a major building of industrial fire, can further endanger the human health and the environment [2].

Pressurized smoke-free stairwells reduce the entry of smoke and toxic combustion gases into smoke-free spaces when doors are closed by means of overpressure created by the introduced air, without obstructing access to the stairwell. In this case, flows are mainly through small cross-sectional gaps and cracks [3]. One of the most important aspects of pressurized ventilation systems is how they can affect door opening forces [4]. If the relative overpressure in the stairwell is too high, the force required to open doors leading to the stairwell increases, which can be an obstacle for people escaping to the stairwell [5]. In mechanical systems, care must be taken to ensure that door opening forces are complied with [6]. This can be achieved by regulating the speed of the fans and by using devices to dissipate excess pressure. Frequency converters are often used to regulate the amount of air supplied by the fan(s), which are primarily controlled by pressure transmitters.

It is generally accepted that traditional masonry structures can withstand pressures of 500 Pa, while lightweight structures, such as assembled plasterboard partitions, can only withstand pressures of 250 Pa. Certain types of structures may have even lower limits [7]. The material and structural characteristics of door systems – including door leaf rigidity, the behavior of the sealing materials under pressure, the airtightness performance of the sealing profiles, and the structural interaction between the door frame and the surrounding wall – all play a critical role in determining the amount of force required to open the door.

The harmonized European standard for the design of pressure differential systems is EN 12101-13. According to this standard, systems must be designed so that the force required to open the door does not exceed 100 N at all levels and on all doors in escape routes [8]. According to NFPA 92, which focuses on the design of smoke control systems, the maximum force required to open a door must not exceed the value specified in NFPA 101 or in state or local codes and regulations [9]. According to NFPA 101, the pressure difference between door openings must not exceed the value at which door leaves can be opened with a force greater than 133 N. According to the IBC, if a door must be fire rated, the force required to be set in motion the door shall not exceed 133 N [10].

According to standard AS/NZS 1668.1:1998, regardless of whether the exits are under pressure or not, the maximum force required to open doors must not exceed 110 N, thus ensuring that the exits can be used in all cases [11].

According to TRVB 112 S, the pressure difference caused by the overpressure ventilation system must not affect the opening of doors and the reliable closing of door closers, therefore appropriate measures must be taken to ensure that the force required to open the door does not exceed 100 N [12]. According to VDMA 24188, the maximum pressure difference must be limited so that the door opening force measured at the door handle does not exceed 100 N, so that the doors remain openable for weaker persons and so that they do not give the impression to people escaping that the door is locked [13].

In Hungary, most fire protection designers and experts prefer the solutions proposed in the fire protection technical guidelines [14]. Fire protection technical standards can be applied in various ways in relation to fire protection design, installation and use [15-17]. According to fire protection technical guidelines in field of protection against heat and smoke spread, the openability of doors in pressurized stairwells or vestibules is ensured if the force required to open them does not exceed 100 N in normal cases. In special cases (e.g., accessibility), this value may be lower [18].

The EN 179 standard tests the force required to operate lever handles and push bars [19]. The force required to operate panic bars is specified in standard EN 1125. When using a panic bar, the force required to open the lock mechanism of an unloaded door must not exceed 80 N [20]. Doors in pressurized smoke-free stairwells are typically equipped with self-closing devices. The requirements for self-closing door closers are specified in standard EN 1154, among others [21].

Overall, it can be concluded that various standards and technical guidelines generally recommend a maximum door opening force of around 100-130 N. In the case of accessibility designs, this value may be significantly lower. The harmonized European standards for emergency exit devices operated by a lever handle or push pad, furthermore horizontal bar, for use on escape routes, examines the force required to operate the lock mechanism when testing the force required to open the door. The harmonized European standard for controlled door closer devices refers to the weight and width of the door mechanism operated by the door closer according to different classes.

2. Material and methods

Two types of force measuring instruments were used during the measurements (*Fig. 1*). One of them is a calibrated digital push/pull force gauge with peak-hold function. The measuring range of the instrument was 1 kN, with a resolution of 0.5 N and an accuracy of 0.5% of the measuring range. The other instrument is a spring force gauge with a measuring range of 0-156 N with a maximum indicator. At least three opening force measurements were performed at each measurement point. In order to ensure that successive measurements were taken at exactly the same point, a red marker was affixed to the axis of force.

Fig. 1 Measurement of opening force at marked measuring points using a digital and spring force gauge
1. ábra Ajtónyitási erő mérése a megjelölt mérési pontokon digitális és rugós erőmérővel

2.1 Method and tools for measuring opening force

Comparative measurements were performed on a test door to check the reliability of the spring force gauge. In the first test, the fan in the pressurized smoke-free stairwell was switched off. In the second case, the fan was in operation. During the test, the pressure difference between the two sides of the door was measured with a calibrated differential pressure gauge. The door tested had a fire resistance rating of 90 minutes and was equipped with a self-closing mechanism in accordance with EN 1154. The door was 1080 mm wide and 2142 mm high, with the handle 90 mm from the latch, and a total weight about 145 kg. The distance between the hinge and the edge of the door leaf was 15 mm. The door was installed in a 20 cm thick reinforced concrete wall, and the gaps between the frame and the wall opening were filled with fire-retardant foam. The door was bordered by ceramic cladding at the bottom, and the slabs were made of 28 cm thick reinforced concrete.

When a hinged door opening into a positive pressure area is opened, the total torque acting around the hinge at the moment of opening can be described by the following equation [22].

$$M_r + A\cdot\Delta p\cdot\left(\frac{W}{2}\right) - F\cdot(W-d) = 0 \qquad (1)$$

Where
F is the total door-opening force (N)
M_r is the moment of door closer and other friction (Nm)
W is the door width (m)
A is the door area (m^2)
Δ_p is the pressure difference across door (Pa)
d is the offset (the distance that the door-opening force is offset from the latch side of the door) (m)

Based on *Equation (1)*, we can infer that the force required to open the door must cover the opening torque of the door closer, the resultant force on the door leaf by the overpressure, the resultant of which acts at the center of the door leaf, and the torque resulting from other losses (e.g., friction).

2.2 Single-leaf door with lever handle and panic bar.

If the number of occupants of the area, their knowledge of the premises or other factors affecting their evacuation so warrant, emergency exit or panic locks may be required on doors leading to pressurized spaces. If the door opens into a pressurized area, such as a pressurized smoke-free stairwell, it is important to consider where and how much force is required to open the door when operating the handle or panic bar. *Fig. 2* illustrates the significant differences between the use of a handle and a bar.

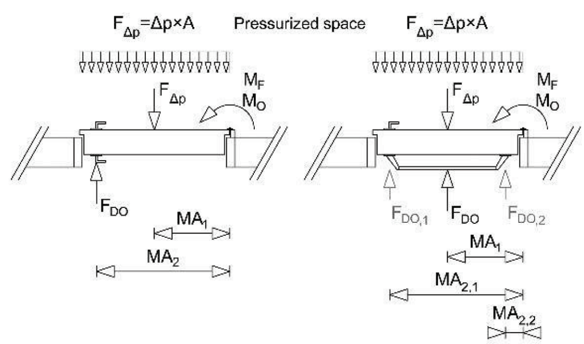

Fig. 2 Door opening into a pressurized space; effect of the opening mechanism on the opening force
2. ábra Túlnyomásos térbe nyíló ajtó; a nyitószerkezet hatása a nyitási erőre

The distributed force resulting from the overpressure of magnitude Δ_p acts on the surface area A of the door leaf. The resulting force is $F_{\Delta p}$, which exerts a torque against the opening with a force arm M_{A1}. When a handle is used, F_{DO} is the force required to open the door, which acts with force M_{A2} against the opening torque M_O, the friction torque M_F and the torque resulting from overpressure.

When using a panic bar, if it is fixed at two points on the door leaf, the force required to open the door acts at two points. In this case, the opening force F_{DO} is balanced by the reaction forces $F_{DO,1}$ and $F_{DO,2}$ (which are shown as action forces in the figure for illustrative purposes). The $F_{DO,1}$ force is associated with the $MA_{2,1}$ force arm, while the $F_{DO,2}$ force is associated with the $MA_{2,2}$ force arm. It follows that in the latter case, the door opening mechanism is more reliable, but due to the method of force transmission, the force required to open the door is more sensitive to the pressure difference between the two sides of the door. The force required to open the door increases as it approaches the hinge.

3. Results and discussion

3.1 Measurements with digital force gauge and spring force gauge

Two series of measurements were performed. In the first series, the overpressure ventilation was not in operation, and there was an approximate pressure difference of 0 Pa between the two sides of the closed door. In the second series, the overpressure ventilation was in operation, resulting in an average overpressure of 56.6 Pa opposite the opening. The results of the measurements are shown in *Table 1.*

Fan	Measured opening force with digital force gauge (N)			Measured opening force with spring force gauge (N)		
OFF	35,5	36,5	35,5	39	40	40
ON	91,5	90,5	91,0	90	90	90

Table 1 Comparative measurements with spring and digital force gauges, with and without differential pressure.
1. táblázat Összehasonlító mérések rugós és digitális erőmérővel, nyomáskülönbséggel és anélkül

The values measured with the simple spring-loaded device showed good agreement with the measurement results of the calibrated digital gauge. The hand-held device was suitable for measuring the opening force with the fan switched on and off. The door opening force did not exceed 100 N even at an overpressure of more than 50 Pa.

3.2 Opening force measurement on double-leaf panic bar doors

In the next test, a door fitted with a panic bar that met the EN 1125 standard was tested. The panic bar covered 80% of the door width. During the standard test, the force required for operation is tested in the middle and at both ends of the bar. The door tested was 1350 mm wide and 2062 mm high. The panic bar transferred the force to the door leaf at a distance of 80 and 1270 mm from the hinge. The door leaf weighed approximately 180 kg and equipped with EN 1154 door closer device. A mark indicating the opening mechanism was located in the center of the door tested. The force required for opening was therefore measured in the center of the bar and at both edges (*Table 2*). The smoke extraction system was not in operation during the measurements.

Position	Measured opening force (N)			Mean (N)	Calculated opening torque (Nm)
Left side	34,0	34,0	36,0	34,7	38,12
Middle	57,0	58,0	59,0	58,0	39,15
Right side	208	207	210	208,3	40,46

Table 2 Opening force measured at different points on the panic bar and calculated opening torque
2. táblázat A pánikvasalat különböző pontjain mért nyitási erő és a számított nyitónyomaték

The measurement results clearly show that the force required to open the door is significantly influenced by where the force is applied on the panic bar. Even with a door closer, the force required to open the door remained below 80 N in the middle of the panic bar and at the end closest to the latch when the pressurization system was not in operation.

In the following case, the pressurized smoke-free stairwell supply fan was operating and created a pressure difference of approximately 48 Pa between the two sides of the door leaf. The opening force was then measured again (*Table 3*), but only in the middle of the bar and at the end near the latch, as opening would have required a disproportionately large force near the hinge.

Position	Measured opening force (N)			Mean (N)	Calculated opening torque (Nm)
Left side	122,5	120,0	121,5	121,3	141,56
Middle	200,5	201,0	204,5	202,0	136,35
Right side	-	-	-	-	-

Table 3 Opening force measured at different points on the panic bar and calculated opening torque during operation of the stairwell pressurization system
3. táblázat A pánikvasalat különböző pontjain mért nyitási erő és számított nyitónyomaték a lépcsőházi túlnyomásos rendszer működése közben

The measurement results clearly show that, while ensuring an overpressure of around 50 Pa in the stairwell, it was not possible to ensure the force required to open the door (maximum 100 N) even in the area closer to the panic bar latch.

In the case of double-leaf doors, if the design is symmetrical, the force exerted on the second leaf is even more unfavorable, regardless of whether the pressurization system is in operation or not. In this case, depending on the design of the rebate, the surface area exposed to overpressure is greater at the moment of opening, and the opening torque of the first leaf must also be overcome (*Fig. 3*).

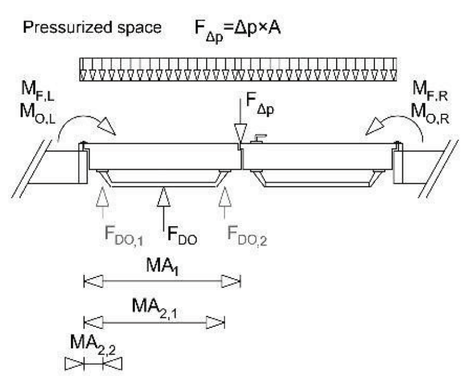

Fig. 3 Force required to open a double-leaf door opening into a pressurized space, measured at the center of the second door leaf.
3. ábra Túlnyomásos térbe nyíló kétszárnyú ajtó nyitásához szükséges erő, a második ajtószárny közepén mérve

Based on calculations and measurements, it can be concluded that in the case of doors equipped with panic bars, the force required to open the door was lowest on the side of the bar latch on the first opening leaf. EN 179 and EN 1125 recommend that the opening mechanism be marked directly above or on the operating mechanism. The door forms part of a smoke-free stairwell with positive pressure, therefore, unlike the general use of panic locks, additional markings may be necessary to ensure safe operation. The author illustrates the recommended method of marking in *Fig. 3*.

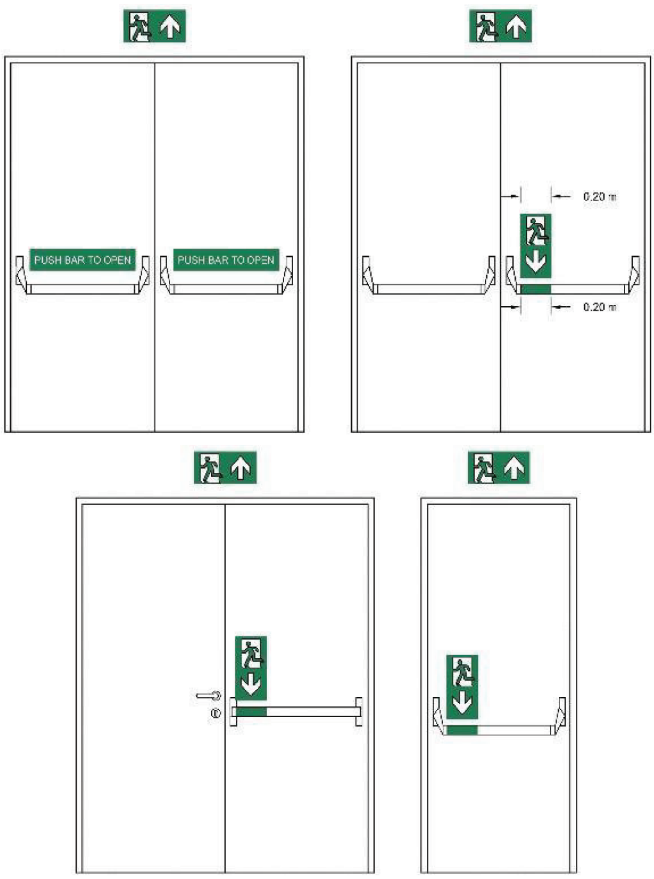

Fig. 4 Mark the opening mechanism of doors opening into pressurized spaces at the point where the opening force is lowest, using pictograms and labeling.
4. ábra Túlnyomásos térbe nyíló ajtók nyitószerkezetének megjelölése piktogramokkal és feliratokkal azon a ponton, ahol a nyitási erő a legalacsonyabb

The first door in *Fig. 4* shows the standard marking for panic bar doors. Since in this case both the operating mechanism and the markings are symmetrical, it is not possible to determine clearly at which point the minimum opening force must be applied. On the other doors, the part of the operating mechanism where the least force is required to open the door is marked in green. For better visibility, the markings recommended by ISO 7010 have also been added to the doors above this part. It is important to note that the opening mechanism of panic locks is safer than other designs. Doors opening into pressurized smoke-free stairwells are considered special applications, where the use of the markings described above is recommended to increase opening safety.

3.3 Discussion

Various international standards typically recommend between 100 N and 133 N as the maximum force required to open doors in general [8-13, 18]. Some standards differ between doors that must be fire rated [10]. In pressurized stairwells, the force required to open the door may ultimately limit the maximum pressure difference between the two sides of the door leaf.

Since stairwells are typically evacuation routes, in some cases, an easily openable locking mechanism is required, for which test standards examine the force required to release the locking mechanism. In these tests, the door leaf is not under positive pressure in the direction of opening [19, 20].

The results of measurements taken with the spring-loaded gauge showed good agreement with the values measured with the calibrated digital gauge.

Tests on doors with handles showed that even with an overpressure of more than 50 Pa, the force required to open the door did not exceed 100 N. This was due to the favorable force distribution and the dimensions of the door leaf.

During the test, the force required to open the single-leaf door fitted with a panic bar was less than 80 N at the center of the bar and at the end of the bar closer to the lock, without any pressure difference, which is in good agreement with EN 1125. The opening torque value complied with class 3 of EN 1154 [21].

When the stairwell pressurization system was in operation and there was an average pressure difference of 48 Pa between the two sides of the door leaf, the force required to open the tested door increased significantly. Approximately 200 N was measured in the middle of the panic bar. At the end of the bar closer to the latch, the force was approximately 120 N, which still complies with certain regulations.

In addition to the design of the locking mechanism, differences in opening force can also be attributed to material and structural factors. These include, for example, the stiffness and deformation behavior of the door leaf (depending on the core material and manufacturing method), the compressibility and aging properties of the sealing rings, and the stiffness of the connection between the frame and the wall. The structural compliance of the deformation caused by overpressure can also influence the uniformity of the seal and load transfer, which in turn affects the force required to overcome static friction and air resistance.

The results of the research showed that if the door opening mechanism is symmetrically positioned on the door leaf and the door opens into a pressurized stairwell, the part of the opening mechanism on which the opening force acts has a significant influence on the force required to open the door. Based on this, recommendations can be made for the designation of opening mechanisms for doors opening into pressurized stairwells in certain cases.

A further research direction could be the interpretation of the scientific problem examined in this article in terms of its application in pressurized rooms installed in chemical industry establishents and chemical warehouses, such as in industrial buildings serving the operation of facilities or emergency management [23].

4. Conclusions

Based on the research carried out in this study, the following final conclusions can be drawn:

1. A digital or spring-loaded force gauge can be used to measure the force required to open the door.
2. By positioning the locking mechanism correctly and limiting the size of the door leaf, the force required to open the door can be limited to below the specified values.
3. In the case of doors equipped with panic bars, depending on the design of the panic bar, the force required to open the door may be greater in the middle of the symmetrically designed bar if the door opens into an pressurized stairwell.
4. In the case of doors equipped with panic bars, the force required to open the door on the side of the bar closest to the latch was found to be lower based on measurements.
5. It is recommended that, in the case of doors opening into stairwells with positive pressure, where justified by the design of the door and the locking mechanism, the section of the panic bar requiring the least force to open be marked.
6. The recommended method of marking is to mark part of the bar with a color and to use a marking composed of the symbols of ISO 7010, which does not conflict with the marking recommended in the annex to EN 1125.
7. Materials and structural factors – such as door leaf stiffness, mechanical behavior of seals, and door frame-wall connection stiffness – can influence opening force, especially under pressurized conditions. These factors, along with hardware design and pressure control, should be considered critical design criteria.

Conflicts of interest

There is no conflict of interest

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