Journal of Management & Technology
e-ISSN: 2177-6652

EXPERIMENTAL STUDY OF OVERPRESSURE IN THE PROTECTED ROOM DURING OPERATION OF THE SMOKE EXTRACTION BACKUP SYSTEM IN VARIOUS MODES

ESTUDO EXPERIMENTAL DE SOBREPRESSÃO NA SALA PROTEGIDA DURANTE O FUNCIONAMENTO DO SISTEMA DE BACKUP DE EXTRAÇÃO DE FUMAÇA EM VÁRIOS MODOS

ESTUDIO EXPERIMENTAL DE SOBREPRESIÓN EN EL LOCAL PROTEGIDO DURANTE EL FUNCIONAMIENTO DEL SISTEMA DE RESPALDO DE EXTRACCIÓN DE HUMOS EN VARIOS MODOS

Cite as:
Busakhin, A. & Savenko, G. (2024). Experimental study of overpressure in the protected room during operation of the smoke extraction backup system in various modes. Journal of Management & Technology (Revista Gestão & Tecnologia). Special Edition. v. 24, n. 2, pp: 217-227

Alexey Busakhin
National Research Moscow State University of Civil Engineering, Moscow, Russia
a.v.busakhin@mail.ru

Georgiy Savenko
National Research Moscow State University of Civil Engineering, Moscow, Russia
georgiy.savenko@yandex.ru

Scientific Editor: José Edson Lara
Organization Scientific Committee
Double Blind Review by SEER/OJS
Received on 15/03/2024
Approved on 18/04/2024

ABSTRACT

The purpose of the article was to determine the critical parameter engineers should prioritize during the design of smoke ventilation projects to ensure evacuation safety within protected rooms – specifically, whether overpressure or flow rate (speed) in the opening of the evacuation door is more important. Utilizing a specially designed experimental setup that replicates a building's vestibule-gateway, the research methodically explored the effects of different variables including fan operation, door states, and the presence of overpressure valves on the system's efficacy. Results revealed that door closers significantly impact the force needed for door opening, highlighting a gap in current safety standards. Furthermore, the variability in overpressure valves performance suggested a need for nuanced regulatory guidelines. The study emphasizes the critical role of overpressure valves in maintaining safe evacuation routes and advocates for updated regulatory standards that consider the findings, aiming to enhance the safety and effectiveness of smoke ventilation systems during emergencies

Key words: safety, air balance, smoke ventilation, evacuation

RESUMO

O objetivo do artigo era determinar os parâmetros críticos que os engenheiros deveriam priorizar durante a concepção de projetos de ventilação de fumaça para garantir a segurança da evacuação dentro de salas protegidas – especificamente, se a sobrepressão ou a vazão (velocidade) na abertura da porta de evacuação é mais importante. Utilizando uma configuração experimental especialmente projetada que reproduz o vestíbulo-gateway de um edifício, a pesquisa explorou metodicamente os efeitos de diferentes variáveis, incluindo a operação do ventilador, o estado das portas e a presença de válvulas de sobrepressão na eficácia do sistema. Os resultados revelaram que os fechos de porta têm um impacto significativo na força necessária para a abertura da porta, destacando uma lacuna nos padrões de segurança atuais. Além disso, a variabilidade no desempenho das válvulas de sobrepressão sugeriu a necessidade de diretrizes regulatórias diferenciadas. O estudo enfatiza o papel crítico das válvulas de sobrepressão na manutenção de rotas de evacuação seguras e defende padrões regulatórios atualizados que considerem os resultados, com o objetivo de aumentar a segurança e a eficácia dos sistemas de ventilação de fumaça durante emergências.

Palavras-chave: segurança, equilíbrio do ar, ventilação de fumaça, evacuação

RESUMEN

El propósito del artículo era determinar los parámetros críticos que los ingenieros deben priorizar durante el diseño de proyectos de ventilación de humos para garantizar la seguridad de la evacuación dentro de habitaciones protegidas, específicamente, si la sobrepresión o el caudal (velocidad) en la apertura de la puerta de evacuación es más importante. Utilizando una configuración experimental especialmente diseñada que replica el vestíbulo de un edificio, la investigación exploró metódicamente los efectos de diferentes variables, incluido el funcionamiento del ventilador, el estado de las puertas y la presencia de válvulas de sobrepresión, en la eficacia del sistema. Los resultados revelaron que los cierrapuertas tienen un impacto significativo en la fuerza necesaria para abrir la puerta, lo que pone de relieve una brecha en los estándares de seguridad actuales. Además, la variabilidad en el rendimiento de las válvulas de sobrepresión sugirió la necesidad de directrices regulatorias matizadas. El estudio enfatiza el papel fundamental de las válvulas de sobrepresión en el mantenimiento de rutas de evacuación seguras y aboga por estándares regulatorios actualizados que consideren los hallazgos, con el objetivo de mejorar la seguridad y eficacia de los sistemas de ventilación de humo durante emergencias.

Palabras clave: seguridad, balance de aire, ventilación de humos, evacuación.

1. INTRODUCTION

In recent years, the field of building safety and emergency preparedness has seen significant advancements, yet challenges persist, particularly in the domain of smoke ventilation systems within constructed environments (Perez Arevalo et al. 2022). As urban landscapes continue to evolve (Gorshenin, 2023; Sarvut, 2023) and construction technologies advance, the integration of efficient and reliable smoke ventilation systems has become paramount to ensuring the safety and wellbeing of building occupants during emergencies (Busakhin & Savenko, 2023; McManus et al. 2021;). This urgency is further underscored by the increasing complexity of modern buildings and the diverse nature of hazards they may face, including fire (Martirosyan et al. 2022; Jimenez Ramos et al. 2022).

Despite rigorous regulatory standards and innovative engineering solutions (Erazo Camacho, 2022; Re & Michaux, 2023), practical challenges in the design and implementation of smoke ventilation systems have emerged as recurrent themes, notably in ensuring the safe evacuation of individuals during fire incidents. These challenges are not merely technical but are also entangled with regulatory, environmental (Apergis et al. 2023), and human factors that complicate the straightforward application of existing solutions.

So, the need for this study arose for a number of reasons:

1. Numerous tests of smoke ventilation systems have been carried out, which demonstrate the impossibility of fulfilling a few requirements to ensure the safety of people during evacuation. (Sarvut & Tkachev, 2022)
2. Inconsistency in the issue of providing the required parameters between different construction groups. (Trofimova et al. 2023)
3. The maximum allowable pressure drop on the evacuation door, which does not take into account the force of the installed door closer, which significantly reduces the likelihood of unhindered evacuation of people during a fire. (Anastasios et al. 2022)
4. The absence of a fixed requirement for the use of an overpressure valve in cases where other ways to ensure pressure drops on evacuation doors in protected volumes and premises are impossible (Sergeeva et al. 2023).
5. A significant number of factors affecting the correct operation of smoke extraction backup systems.

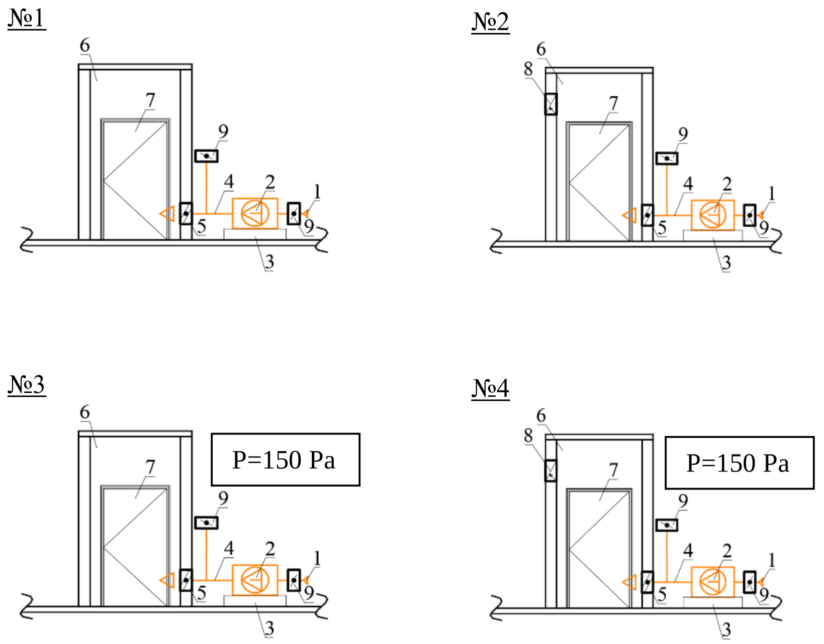
In order to answer the questions posed, we described and demonstrated the actual state of operation of smoke ventilation systems, in particular smoke extraction systems in the vestibule-gateway (hereinafter AV), where the problem of the pressure drop created on the door is most acute, we have made a proposal for scientific cooperation between the NRU MGSU and the leading firms in this study-manufacturers of ventilation engineering equipment LLC "ARCTICA GROUPP" and LLC "AERDIN".

The purpose of the joint work is an experimental study of the emerging parameters during the operation of the smoke extraction backup system in AV. In several stages, discussed between all participants, solutions and algorithms for their implementation were prepared.

The main task was to create a comprehensive stand that simulates the real working conditions of the support system in AV. And through mutual cooperation, this task was completed.

2. METHODS

In this study, an experimental approach was adopted to examine overpressure effects in protected rooms with smoke extraction backup systems operating under varied conditions. The centerpiece of our methodology was a sophisticated experimental setup designed to mimic a building's vestibule-gateway (AV), enabling accurate simulation of smoke evacuation scenarios (Fig. 1). Our tests systematically explored the interplay between fan operation, door state (open or closed), the incorporation of an overpressure valve (OV), and fan pressure settings, aiming to comprehensively understand their impact on system efficacy and evacuation safety.



1.Air intake
2.Axial fan
3.Fan stand
4.Air duct
5.Normally closed fire-fighting valve, wall-mounted
6.Vestibule-gateway
7. The door to the airlock vestibule with a door closer
8. Overpressure valve
9.Air flow control valve

Figure 1. Schematic diagrams of stand No.1,2,3,4

At the stage of consideration of the components required for the layout of the experimental installation, 4 fundamental concepts were derived that need to be considered during the experiment:

1. Consider the operating modes of the fan and the flow rate created by it (spee d in the opening) and pressure in the protected room when closed/an open door, creating a network resistance equal to the equivalent of one fire compartment. There is no overpressure valve (hereinafter referred to as OV).

2. Consider the operating modes of the fan and the flow rate created by it (speed in the opening) and pressure in the protected room when closed/an open door, creating a network resistance equal to the equivalent of one fire compartment (Korotkiy et al. 2023). OV is set to the calculated value of the discharged pressure (from 75 to 150 Pa).
3. Consider the operating modes of the fan and the flow rate created by it (speed in the opening) and pressure in the protected room when closed/an open door, at a given pressure on the fan no more than 150 Pa (via a frequency converter). OV is missing.
4. Consider the operating modes of the fan and the flow rate created by it (speed in the opening) and pressure in the protected room when closed/an open door, at a given pressure on the fan no more than 150 Pa. OV is set to the calculated value of the discharged pressure (from 75 to 150 Pa).

Data collection focused on air flow rates, pressure differentials, and the force required to open the evacuation door under different overpressure conditions, utilizing precise measurement tools for reliability (Neverov et al. 2023). Through analyzing these data, the study identified key operational parameters influencing the performance of smoke extraction systems. The findings are poised to guide recommendations for design and regulatory improvements, emphasizing enhancements in evacuation safety protocols in response to fire emergencies, within a compact and focused examination.

3. RESULTS

It is of paramount importance to determine which dependence characterizes the force of opening the door without an installed door closer. To do this, we turn to the dimension of excess pressure, namely to Pascals. In the international system of accepted SI dimensions, we have the ratio of the applied force F in Newtons to the impact area S in meters squared. Thus, we get, 1 Pa is equal to 1 N of force, per unit area m^2.

Then, if we take the dimensions of the evacuation door 2000 mm high and 1050 mm wide, with the created excess pressure of 150 Pa, the force is equal to:

$$F = P \cdot S = 150 \cdot (2 \cdot 1{,}05) = 315. \quad (1)$$

Within the framework of this study, we are interested in the required force, calculated in kilograms, so that the theoretically obtained value can be tested experimentally on an experimental stand.

The Newton dimension in the SI system is a derived unit. Based on Newton's second law, it is defined as a force that changes in 1 second the velocity of a body weighing 1 kg by 1 m/s in the direction of the force. Then the conversion from Newtons to kilograms, taken as force N, is performed using a constant value of the acceleration of gravity g m/s^2.

$$N = F/\mathrm{g} = 315/9{,}81 = 32{,}11. \qquad (2)$$

The resulting force value does not correlate with empirical data from Table 1, where, with excessive pressure in the protected room of the airlock vestibule, the force to open the door was 19.2 kg (this may interfere with the fulfillment of the requirements, on ensuring the safe evacuation of people during a fire), taking into account the installed door closer. The fixed value of the closer force without the influence of the fan airflow was 4.5 kg, therefore, the magnitude of the force obtained by calculation should be in the range of 14.5-15.0 kg, subject to a small calculation error.

According to this sequence, some representatives of the professional community mistakenly come to the values of the effort to open the door, which causes a number of serious disagreements that affect the right decision.

The derivation of the formula through the entire surface of the door, in this case, is incorrect, since this is equivalent to the piston opening of the door, namely the entire area as a whole.

In fact, during the evacuation period in case of a fire from a building, a person must overcome the moment of the force of opening the door. From the course of school physics, the moment of force is a vector quantity. The direction of the torque vector depends on the direction of the force acting on the axis, hence the moment of force M Newton. The meter is equal to the product of the force acting on the body, F Newtons on the shoulder l in meters (in this case, it is the width of the door B_{AV}). At the moment, the amount of effort to open the door does not appear in the requirements for the design of smoke extraction support systems in the vestibule locks. A clarifying indicator is that it is required to overcome the double moment of force due to the mechanics of the impact on the door handle in relation to the resistance to opening by overpressure in the airlock.

Then the moment of the door opening force is equal to:

$$M = 2 \cdot F \cdot B_{AV} = 2 \cdot 100 \cdot 1{,}05. \quad (3)$$

This method of determining the moment is less accurate, since the shoulder is taken over the entire width of the door leaf.

During evacuation, a person needs to lower the door handles down and overcome the moment of force not from the edge of the doorway, but from the handle.

If we take the distance from the door handle to its edge, in most cases 100 mm, then denoting this value with the letter r, meters, we perform a clarifying iteration:

$$P = 2 \cdot F \cdot (B_{AV} - r) = 2 \cdot 100 \cdot (1{,}05 - 0{,}1). \quad (4)$$

There are three main types of doors in buildings, depending on the location and number of flaps.

Turning the door leaf, relative to the axis of rotation of the hinge, we need to find the movable area. If we consider an open position perpendicular to 90°, relative to its closed position, then the required value is calculated as the square of the width of the door leaf to its height.

The final value of the derived dependence should represent Pa, then the calculated part of the dimension refers to the denominator.

$$\Delta P = 2\frac{F \cdot (B_{AV} - 0{,}1)}{S_{AV} \cdot B_{AV}} = 2\frac{150 \cdot (1{,}05 - 0{,}1)}{2{,}1 \cdot 1{,}05} = 130, Pa. \quad (5)$$

Let's perform a series of experiments for four circuit diagrams and in the considered variants on the stand Fig.2 and get the values of the volume-hour flow rate when the doorway is open. When it is closed, we will estimate the amount of pressure discharged in this variant by the overpressure valve.


Figure 2. Assembled test bench

The main result of the calculations are the empirical data provided, which formed the basis for the development of a series of nomograms to determine the permissible drop on evacuation doors, taking into account a number of external factors.

The values obtained during a series of experiments were required primarily for the formation of this study and the data are summarized in Table 1.

Table 1

Assembled test bench

Parameter	The scheme of the test			
	I	II	III	IV
L·, m^3/h (with the door open)	12 000 (1,85 m/s)	12 000 (1,85 m/s)	2 000 (0,3 m/s)	2 000 (0,3 m/s)
L, m^3/h (with the door closed)	0	7 000	0	2 000
P, Pa (pressure drop on the door)	780	75	150	35
N, kg (applied force to open the door)	>50	11,0	19,2	8,0

The simulated situations during the operation of the fan in the experimental installation clearly demonstrated the principle of operation of the system, and we obtained the indicators that interest us in this study. The obtained values directly affect the existing regulatory requirements and make a number of adjustments, based on the real results of a study conducted under absolutely identical conditions during the evacuation of people and the operation of the smoke extraction backup system in AV.

4 CONCLUSION

Our investigation into the operational parameters of smoke extraction backup systems under various conditions has yielded significant insights with direct implications for current safety standards and evacuation protocols. Through rigorous experimental analysis, we have identified key areas where current regulatory practices fall short in ensuring the safety and efficiency of smoke ventilation systems. Below, we present our main conclusions, each underpinned by empirical data, and offer recommendations for enhancing the design and regulatory oversight of smoke ventilation systems:

1. The evacuation door closer, in fact, has a significant impact on the door opening force, which is not currently taken into account in the current regulatory documentation.
2. The set weighting on the OV, taking into account various network features, can work at a different pressure drop. This is also influenced by the characteristics of the fan, depending on a number of external factors.
3. It is impossible to provide the possibility of opening the evacuation door, except with the help of OV. Picking up the fan at a pressure of no more than 150 Pa does not meet the speed requirement in the opening of the evacuation door.
4. The resulting pressure drop of 150 Pa on the door does not ensure unhindered opening of the evacuation door by various groups of the population (children, women, elderly people).

REFERENCES

Anastasios, K., Despina, P., Nikolas, G., Dimitrios, K. (2022). Evacuation in an Underground Space: A Real-Time Investigation of Occupants' Travel Speed in Clear and Smoked Environments. *Infrastructures*, 7(4), 57. https://doi.org/10.3390/infrastructures7040057

Apergis, N., Kuziboev, B., Abdullaev, I., & Rajabov, A. (2023). Investigating the association among CO2 emissions, renewable and non-renewable energy consumption in uzbekistan: An ARDL approach. *Environmental Science and Pollution Research*, 30(14), 39666-39679. https://doi.org/10.1007/s11356-022-25023-z

Busakhin, A., & Savenko, G. (2023). Example of providing design parameters of smoke ventilation. *Revista Gestão & Tecnologia*, 23, 154-162. doi:https://doi.org/10.20397/2177-6652/2023.v23i0.2603

Erazo Camacho, M. R. (2022). Consumo de energía no renovable y emisión de CO2 en un país en vías de desarrollo. *Universidad Y Sociedad*, 14(S1), 110-115. Retrieved from https://rus.ucf.edu.cu/index.php/rus/article/view/2616

Gorshenin, M. (2023). Symbolic nature of practices of appropriation of urban space as a form of civic activism. *Revista Gestão & Tecnologia*, 23(3), 299-309. https://doi.org/10.20397/2177-6652/2023.v23i3.2721

Jiménez Ramos, A., Puerta Fernández, J. F., Gómez Sarduy, J. R., & Jiménez Santana, Y. (2022). El enfriamiento para menores emisiones de co2 al medio ambiente en extrusión de tuberías plásticas. *Universidad Y Sociedad*, 14(3), 574-588. Retrieved from https://rus.ucf.edu.cu/index.php/rus/article/view/2902

Korotkiy, I., Korotkaya, E., Neverov, E., Korotkikh, P. (2023). Evaluating the energy efficiency and environmental impact of R134a versus R744 refrigerants in refrigeration systems. *International Journal of Heat and Technology*, 41(6), 1461-1467. https://doi.org/10.18280/ijht.410608

Martirosyan, A.V., Ilyushin,Y.V., Afanaseva, O.V. (2022). Development of a Distributed Mathematical Model and Control System for Reducing Pollution Risk in MineralWater Aquifer Systems. *Water*, 14, 151. https://doi.org/10.3390/w14020151

McManus, T.N., Rosa, A., Haddad, A. (2021). Quantifying Air Movement Induced by Natural Forces in an Isolated Structure in the Subsurface Infrastructure. *Infrastructures*, 6(1), 3. https://doi.org/10.3390/infrastructures6010003

Neverov, E.N., Korotkiy, I.A., Korotkih, P.S., Ivanova, L.A. (2023). Development of an energy efficient refrigeration unit using carbon dioxide as a natural refrigerant. *International Journal of Heat and Technology*, 41(5), 1151-1157. https://doi.org/10.18280/ijht.410505

Pérez Arévalo, R., Rivera García, S. B., & Reyes Schade, E. J. (2022). Advantages and challenges of e-learning in architecture: The case of Colombia and El Salvador. *MÓDULO ARQUITECTURA CUC*, 29, 9–38. https://doi.org/10.17981/mod.arq.cuc.29.1.2022.01

Ré, M. G., & Michaux, M. C. (2023). Envelope and thermal behavior. Case study, school building in San Juan, Argentina. *MÓDULO ARQUITECTURA CUC*, 31, 147–166.

Sarvut T.O. (2023). Circumpolar aspect in the development of urban environment organization in Russian cities. *Construction Materials and Products*, 6(5), 8. https://doi.org/10.58224/2618-7183-2023-6-5-8

Sarvut, T. O., & Tkachev V. N. . (2022). Design of outdoor recreational hospital spaces: creating architectural objects in the natural environment. *MÓDULO ARQUITECTURA CUC*, 29, 91–112. https://doi.org/10.17981/mod.arq.cuc.29.1.2022.04

Sergeeva, S., Gladilina, I., Bulochnikova, N., Shichkin, I., Kochetkov, E., Filonova, A. (2023). Impact of Green Fintech Solutions on Achieving ESG Principles. *Revista Gestao & Tecnologia-Journal of Management and Technology*, 23(1), 335-345.

Trofimova, T.E., Rodionovsky, A.N. (2023). Development of public spaces: the impact of metro stations construction on the formation of the structure of the adjacent territory. *Construction Materials and Products*, 6(5), 5. https://doi.org/10.58224/2618-7183-2023-6-5-5