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RESEARCH ARTICLE

The Impact of Design Solutions for Smoke Ventilation during Commissioning: Organizing A Smoke Removal System in an Inter-Apartment Corridor

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ABSTRACT

The study aims to address the issues of smoke ventilation systems in inter-apartment corridors, considering global research, regulatory frameworks, and Russian technical legislation. It focuses on technical solutions based on the Code of Rules 7.13130.2013 (with amendments) and compares them with international standards like BS EN 12101.6-2005. The study highlights key regulatory requirements for modern buildings, including ensuring proper operation of exhaust and supply smoke ventilation systems. Additionally, it stresses the need for coordination among construction participants and regulatory bodies to guarantee safety. This research forms a foundation for future work on smoke protection systems.

INTRODUCTION

The problems of the operation of smoke ventilation systems in buildings are discussed all over the world. In particular, many researchers consider a complex of systems operating in an inter-apartment corridor. Methods to achieve the main goal, namely, to ensure safe evacuation from the fire floor, use variable methods. For a number of space-planning solutions, a system based on BS 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» (BS EN 12101.13-2022, 2022). For other cases, in particular for objects with a significant area of premises adjacent to the corridor, but located in a single-story building within the same volume, the requirements may be more appropriate BS9991:2015 « Fire safety in the design, management and use of residential buildings» (BS 9991:2015, 2015). One of the special cases is the installation of a smoke hatch in the ceiling space of a corridor or an automatically opening transom, described in BS EN 12101.2-2017 «Smoke and heat control systems - Specification for natural smoke and heat exhaust ventilators» (EN 12101.2-2017, 2017). Methods of ensuring safe evacuation in tunnels generally have their own specifics, which the authors from China of the article write about in more detail (Ding et al., 2023).

The successful use of technical solutions and methods for determining operating parameters for some cases is quite possible for others located in other countries. This may be due to climatic conditions, logistical opportunities for each specific region, the cost of facilities under construction and their engineering equipment, and many others. That is why, for the authors of this article, it is important to consider the problems of the operation of smoke ventilation systems in the inter-apartment corridor in the context of global research and regulatory documentation, in the legal field of the requirements of the current technical regulatory legislation of Russia, so that the constant exchange of knowledge and experience between colleagues around the world can reduce the number of victims during a fire due to technical solutions in the field of smoke protection systems ventilation.

1 METHODOLOGY

In this case, the scenario of working out technical solutions based on the fundamental document in the design of smoke ventilation systems for the entire territory of the country is considered on Code of Rules 7.13130.2013 (2013) "Heating, ventilation and air conditioning. Fire safety requirements" from Amendment No. 1,2 (Code of Rules 7.13130.2009, 2009). In many ways, the requirements and approaches are similar to the document BS EN 12101.6-2005 «Smoke and heat control systems. Part 6: Specification for pressure differential systems — Kits» (BS EN 12101.6-2005, 2005)). A detailed overview of the documentation used around the world is provided in the materials of the article by colleagues from Indonesia (Alianto et al., 2022). For most modern buildings in the Russian Federation, clause 7.2(a) applies, stating:

7.2 Smoke removal in case of fire by exhaust smoke ventilation systems should be provided:

<u>a) from corridors and halls of residential, public, administrative and multifunctional buildings with a height of more than 28 m.</u>

Taking into account this requirement, we are also obliged to ensure clause 7.14 (k):

7.14 The supply of outdoor air in case of fire by supply smoke ventilation systems should be provided:

<u>k) to the lower parts of the premises (including corridors) protected by exhaust smoke ventilation systems - to compensate for the volume of smoke removed.</u>

In fact, at this stage, for the corridor of a residential, public, administrative, household and multifunctional building, we need to ensure the operation of the exhaust smoke ventilation system (hereinafter referred to as ESVS) and a smoke extraction compensation system, referred to as a supply smoke ventilation system (hereinafter referred to as the SSVS).

To determine the operating parameters of the ESVS and the SSVS, you can use one of the existing methods (within the framework of this article, comparing methodological differences is not a priority goal and aspects of choosing certain dependencies are omitted), which specify the sequence of calculation. The basis for calculating the parameters of the ESVS corridor is clause 7.4 (a) and the final paragraph, in which the following is written:

7.4 Combustion products removed by exhaust smoke ventilation should be calculated depending on the heat output power of the fire, heat loss through the enclosing building structures of premises and ventilation ducts, the temperature of the removed combustion products, outdoor air parameters, the condition (positions) of door and window openings, geometric dimensions:

a) for each corridor with a length of not more than 60 m - in accordance with subparagraphs "a"-"d" of paragraph 7.2.

With the combined action of supply and exhaust smoke ventilation systems, a negative imbalance in the protected room is allowed no more than 30%. In this case, the pressure drop at the closed doors of the evacuation exits should not exceed 150 Pa. A positive imbalance is not allowed.

Similarly, the basis for calculating the parameters of the SSVS is clause 7.14 (d):

7.15 The outdoor air flow rate for supply smoke ventilation should be calculated provided that an overpressure of at least 20 Pa is provided:

d) the air consumption supplied to the common corridors of rooms from which combustion products are directly removed must be calculated on condition that a mass balance is ensured with the maximum consumption of the combustion products to be removed from one room, taking into account air leaks through closed doors of all rooms (except one burning one).

The totality of the two points considered is summarized in the following complex:

- it is required to ensure a mass balance between the consumption of ESVS and SSVS;

- the permissible difference in consumption should not exceed 30% (on the floor of the fire);

- the pressure drop on the evacuation door of the corridor should not exceed 150 Pa.

In principle, the scheme of operation of the corridor smoke ventilation system, taking into account the described requirements, is shown in Fig.1.

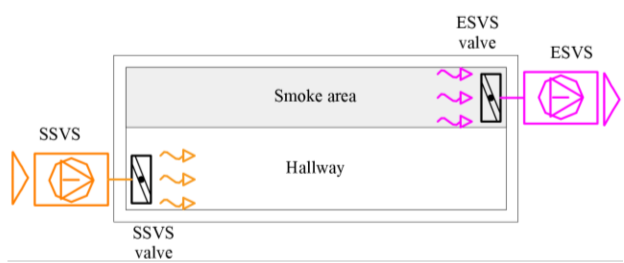

Figure 1: The scheme of operation smoke ventilation in the corridor

Then, having fulfilled all these requirements, the project receives a positive expert opinion, is checked by a technical specialist on the part of the customer, is coordinated by the technical support department and goes to work in the hands of installation organizations. After installing the systems, the organization, consisting of a work crew, foreman, site manager, etc., receives a satisfactory conclusion from the supervision of the author, technical supervision, operation service and passes the systems to the commissioning organization for verification. Let's take an example of what happens in this case:

- the most typical smoke removal consumption for typical solutions on the floor of a potential fire in a residential building is 18 000 m^3/h;

- with different configurations of stair and elevator nodes and the length of the corridor, the temperature of the combustion products does not exceed 400 °C (the density of the combustion products is calculated by formula 1);

$$\rho_{cp} = \frac{353}{T_{cp}} = \frac{353}{t_{cp} + 273} = \frac{353}{400 + 273} \approx 0{,}52 \text{ kg/m}^3. \tag{1}$$

- it follows from this that the mass consumption of smoke extraction is 2.6 kg/s, as well as the required consumption of the compensation system (calculated by formula 2);

$$G_{ESVS} = G_{SSVS} = \rho_{cp} \cdot \frac{L_{ESVS}}{3600} = 0{,}52 \cdot \frac{18\,000}{3600} \approx 2{,}6 \text{ kg/s}. \tag{2}$$

- under the condition of the worst case scenario for the SSVS, namely the cold period, it is necessary to take the air density for the temperature of a cold five-day period according to parameter A, temperature is -26 °C Code of Rules 131.13330.2020 "Building climatology" from Amendment No. 1,2 (Code of Rules 131.13330.2020, 2021) (the density of outdoor air is calculated by formula 3);

$$\rho_{os} = \frac{353}{T_{os}} = \frac{353}{t_{os} + 273} = \frac{353}{-26 + 273} \approx 1{,}43 \text{ g/m}^3. \tag{3}$$

- therefore, the flow rate of the compensation feed is 6 550 m³/h with 100% compensation, and 4 600 m³/h with an acceptable imbalance of 30% (calculated by formula 4.5).

$$\text{if } \frac{G_{ESVS}}{G_{SSVS}} = 1 <=> L_{SSVS} = \frac{3600 \cdot G_{SSVS}}{t_{os}} = \frac{3600 \cdot 2{,}6}{1{,}43} \approx 6\,550 \text{ m}^3/\text{h}; \tag{4}$$

$$\text{if } \frac{G_{ESVS}}{G_{SSVS}} = 0{,}7 <=> L_{SSVS} = \frac{3600 \cdot G_{SSVS}}{t_{os}} = \frac{3600 \cdot (0{,}7 \cdot 2{,}6)}{1{,}43} \approx 4\,550 \text{ m}^3/\text{h}. \tag{5}$$

The project has been completed, installation has been completed, the input control of the equipment has been successfully performed, the deviation of costs from the design values according to Code of Rules 73.13330.2016 "Internal sanitary engineering systems of buildings" from Amendment No. 1 (Code of Rules 73.13330.2016, 2017) does not exceed the permissible 10% and all relevant requirements have been met. Commissioning should be carried out in accordance with GOST 53330-2009 "Smoke protection of buildings and structures. methods of acceptance and periodic tests" (GOST 53330-2009, 2009). In simplified terms, the procedure for setting up ESVS and SSVS systems in the corridor is as follows:

- select the floors on which measurements will be made (usually lower, middle, upper) and open the door to a room with a potential fire source;

- flow measurement is performed on the valve of the ESVS system (with the window open so that air movement is possible with conditional compensation);

- flow measurement is performed on the valve of the SSVS system (with the window closed);

- if the costs correspond to the design data, both systems are started and the pressure drop on the evacuation door from the corridor is checked (the data are summarized in table 1.)

As many might have guessed, it is not possible to get a pressure drop on the door of no more than 150 Pa with a difference in volume costs of 3-4 times. The reflection of such issues and the study of various regimes in other conditions can be found in the materials, developed by colleagues from Poland (Zapała & Szumski, 2012).

Since the operation of these systems, in fact, is the sequential operation of two fans installed on the "corridor" network, their characteristics, therefore, are shifted in accordance with the operation of each fan.

2 RESULTS

Table 1. Fan operation parameters depending on changing indicators

Flow rate at the smoke extraction valve on the floor of a potential fire, m^3/h	Flow rate at the compensation valve on the floor of a potential fire, m^3/h	Formed pressure drop on the escape door, Pa
17 540	5 980	790

Since the operation of these systems, in fact, is the sequential operation of two fans installed on the "corridor" network, their characteristics, therefore, are shifted in accordance with the operation of each fan.There is a misconception regarding the effect of the density of the moving medium on the performance of the fan. In order to answer this question in advance, let us refer to the materials of Appendix A of GOST 10616-2015 "Radial and axial fans. Dimensions and test parameters" (GOST 10616-2015, 2015), summarized in Table 1.It follows that the density of the moving medium affects the pressure and power at which the fan will operate in a given mode. The selected fans can be axial, radial, executed according to various schemes, but despite this, a more powerful fan in terms of performance will "self-balance" the network in relation to a less powerful one. Thus, the ESVS fan will reach the power limit point in order to compensate for the lack of SSVS consumption, and the compensation fan will either "scroll" due to the inability to provide the engine with the set mode, or "break" over the edge of the characteristic. In the first and second cases, for the smoke removal fan, this will only become an additional resistance, which, when overcome by increasing the operating currents, a relatively stable mode will be formed, in which the flow rate on the smoke removal valve will drop significantly, and the compensation flow rate will increase by close to the magnitude of the drop. The data is summarized in table 2. This issue is especially relevant for high-rise construction, in particular for residential, public and administrative buildings. The assessment of the evacuation regime for each specific facility must be carried out in accordance with all factors that potentially worsen the evacuation conditions. The materials of the article show the numerical method and its experimental verification (Ivanov & Chow, 2023). In addition, the data are correlated with the case in question at one of the studied objects.

Table 2. Fan operation parameters depending on changing indicators

$P_v{}' = P_v\left(\frac{n'}{n}\right)^2\left(\frac{D'}{D}\right)^2\left(\frac{\rho'}{\rho}\right);$	P_v – total fan pressure, Pa
$P_{sv}{}' = P_{sv}\left(\frac{n'}{n}\right)^2\left(\frac{D'}{D}\right)^2\left(\frac{\rho'}{\rho}\right);$	P_{sv} – static pressure of the fan, Pa
$P_{dv}{}' = P_{dv}\left(\frac{n'}{n}\right)^2\left(\frac{D'}{D}\right)^2\left(\frac{\rho'}{\rho}\right);$	P_{dv} – dynamic fan pressure, Pa
$Q' = Q\left(\frac{n'}{n}\right)\left(\frac{D'}{D}\right)^3;$	Q – fan capacity, m^3/h
$N' = N\left(\frac{n'}{n}\right)^3\left(\frac{D'}{D}\right)^5\left(\frac{\rho'}{\rho}\right);$	N – power consumed by the fan, kW
$\eta' = \eta;$	η – full fan efficiency
$\eta_s' = \eta_s.$	η_s – static efficiency of the fan

This inevitably leads to two negative consequences:

- the formed discharge creates a pressure drop in the corridor significantly greater than 150 Pa, which does not allow opening the evacuation door and passing the test;

- low smoke extraction consumption will lead to a decrease in the height of the smoke-free zone, and as a result, deterioration of evacuation conditions.

Proportionally, the flow is equalized, including that there are the following ways of air intake into the corridor:

- looseness of apartment doors;

- leaky devices for inspections, passage of pipes, air ducts, etc. through ceilings;

- the hinges of the evacuation doors were installed incorrectly (gaps appear).

But all these elements have significant resistance to overcome by the fan, as well as a small area of air passage, which is why, even with all possible violations of the installation of systems and structures, the balance of costs is unattainable.

The logical question is, why not ensure a volume balance? All according to the same paragraph of the last paragraph 7.4 – a positive balance is not allowed. Since the provision of mass balance has been approved. The requirement of this paragraph, when explained by VNIIPO specialists, is justified by the inadmissibility of maintaining a fire and its "inflating" by supplying additional air. Consider Article 81 of Federal Law No. 123 "Technical Regulations on Fire Safety Requirements" (Federal Law of the Russian Federation, 2021), paragraph 3, which says:

3. Fire protection systems for buildings and structures must ensure that people can be evacuated to a safe area before the maximum permissible values of fire hazards occur.

Colleagues from Germany, who presented the results in one of their articles, investigated the same problem (Eidmann et al., 2006). Then, following the paragraph of the Federal Law, in the initial period of fire development, in the presence of a volumetric balance, the temperature in the corridor does not yet have time to heat the air to significant density changes, the ESVS system removes heated air, the ESVSV system supplies warm or cold air for compensation. There is no discharge preventing safe evacuation and the necessary balance of the mass of the transported gas-air mixture is observed. When the temperature begins to heat up, the entire described regime changes, but at this moment the maximum permissible values of fire hazards (temperature, combustion products, structural failure) occur and ensuring a mass balance in this case is not a requirement required for execution. Commissioning organizations at temperatures with normal conditions have the opportunity to do their part on engineering systems, and the problem is being solved. Many experts agree with this approach, but the Ministry of Emergency Situations does not agree. It is quite fair to point out that in this mode, the air goes to the development of the fire source. Only there is a nuance that is not linked at the moment:

- if there is a fire in the room and the door is open to the corridor, then the entire compensation expense goes to maintaining and developing the fire source, both during and after evacuation;

- if there is a fire in the room and the door is closed to the corridor, then the systems operate in normal air and with a volume balance, anyone has the opportunity to open the door (provided that a window is open in a room with a hearth or glass has flown out);

- if there is a fire in the room and the door is closed to the corridor, without oxygen access to the source of the hearth, then the fire "suffocates" and goes out.

Thus, regardless of the selected balance, mass or volume, the compensation system will "inflate" the fire source and keep it burning, but the influence of the selected balance directly affects the possibility of ensuring the opening of the door.

The following statements follow from this:

1. Compliance with the regulatory requirements of one of the parties to the construction does not always ensure that the requirements of the other party can be fulfilled. Coordination of the project is an important, but not the main task, the main thing is the implementation of all solutions together with other participants in the construction process and ensuring a comfortable and safe stay for users of the building.

2. The development and coordination of regulatory requirements should take place jointly with all departments and parties involved in the implementation of security measures at the facility. The end user is always a human being, the work should be aimed at ensuring the requirements that guarantee the operation of all systems under any conditions.

3. There are norms for the time of arrival of fire departments at the facility, methods for calculating the evacuation time, and in order to avoid additional destructive consequences caused by the supply of air to compensate for smoke removal, it is time to consider a variable shutdown of the system after successful evacuation from the facility, without waiting for its complete combustion.

3 CONCLUSION

Within the framework of this study, results have been achieved showing the correlation between the requirements of regulatory documentation and their empirical embodiments in the joint operation of smoke ventilation systems in an inter-apartment corridor. Global practices in this area show solutions that help solve this problem in their region, but do not allow using these methods in other countries for a number of related reasons. This stage of the study will allow us to continue working in this direction and show solutions for other areas of smoke protection of the building, in conjunction with the requirements of regulatory documents, in order to avoid disagreements at all stages of construction.

REFERENCES

Alianto B, Nasruddin N, Nugroho YS, 2022. High-rise building fire safety using mechanical ventilation and stairwell pressurization: A review. Journal of Building Engineering, 50: 104224.

BS 9991:2015. Fire safety in the design, management and use of residential buildings. October 31, 2015.

BS 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. June 30, 2022.

BS EN 12101.6-2005. Smoke and heat control systems - Part 6: Specification for pressure differential systems — Kits. November 1, 2005.

Code of Rules 131.13330.2020. Construction Climatology with Amendments No. 1, 2. June 25, 2021. [Electronic resource]: website of the legal system Consortium Codex: https://docs.cntd.ru/.

Code of Rules 7.13130.2009. Heating, ventilation and air conditioning. Fire safety requirements. March 25, 2009. [Electronic resource]: website of the legal system Consultant Plus: https://www.consultant.ru/.

Code of Rules 73.13330.2016. Internal sanitary and technical systems of buildings with Amendment No. 1. March 1, 2017. [Electronic resource]: website of the legal system Consortium Codex: https://docs.cntd.ru/.

Ding Y, Mei J, Zhang J, Li X, Lu K, Li C, 2023. Study of temperature distribution and smoke movement by mobile ventilation during emergency rescue in tunnel fires. Thermal Science and Engineering Progress, 46: 102254.

Eidmann J, Rahn B, Albers KJ, 2006. Rauchausbreitung während der Initialbrandphase. Brandschutz, 46–49.

EN 12101.2-2017. Smoke and heat control systems - Specification for natural smoke and heat exhaust ventilators. April 30, 2017.

Federal Law of the Russian Federation. Technical Regulations on Fire Safety Requirements. April 30, 2021 No. 123. [Electronic resource]: website of the legal system Consultant Plus: https://www.consultant.ru/.

GOST 10616-2015. Radial and axial fans. Dimensions and test parameters. December 10, 2015. [Electronic resource]: website of the legal system Consortium Codex: https://docs.cntd.ru/.

GOST 53330-2009. Smoke protection of buildings and structures. Methods of acceptance and periodic tests. February 18, 2009. [Electronic resource]: website of the legal system Consortium Codex: https://docs.cntd.ru/.

Ivanov ML, Chow WK, 2023. Experimental and numerical evacuation study in tall office building. Journal of Building Engineering, 76: 107103.

Zapała R, Szumski M, 2012. Kalibracja instalacji różnicowania ciśnienia. Wybrane problemy w kontekście prowadzenia prób odbiorowych. Chłodnictwo i klimatyzacja, 3: 38-40.