THE FUNCTIONAL ALGORITHM OF VENTILATION SYSTEMS FOR EVACUATING THE SMOKE AND HOT GASES OUT OF A MULTISTOREY BUILDING ON FIRE

Oleg SUSAN[1], Constantin ȚULEANU[2], Valeriu PANAITESCU[3]

Lucrarea propune un algoritm de desfumare pentru o clădire multietajată, unde se presupune că timpul necesar pentru evacuarea persoanelor poate fi mai mare decât cel acceptat în mod obişnuit. Scopul este de a evita contaminarea serioasă cu fum a casei de scări şi celelalte nivele, precum şi menținerea stratului de fum din zona incendiată la un nivel acceptabil. Originalitatea lucrării constă în combinarea sistemelor de control al fumului prin utilizarea unei presiuni diferențiale între casa scării şi etajul incendiat, aplicarea metodei de presiune diferențială tip „sandwich" între etaje, precum şi utilizarea sistemelor de ventilare normală din clădire în scopul desfumării.

This works offers an algorithm for smoke evacuation out of a multi-storey building inside which it is supposed that the necessary time for people evacuation can be longer than an usually accepted one. The purpose is to avoid a serious smoke contamination of the staircase and of the other floors and also to maintain the smoke layer inside the fire compartment at an acceptable level. The work is original due to the fact that it combines the smoke control systems using a differential pressure between the staircase and the fire floor, applying the method of differential pressure, type „sandwich" between the floors and to use the usual ventilation systems of the building for smoke evacuation.

Keywords: fire, smoke, staircase pressurization, differential pressure

1. Introduction

To protect a multi-storey building against fire situations it is a very important issue, considering all difficulties that may occur when evacuating and saving the people inside, and also those ones involved in fire extinguish due to a high combustion speed and the an important amount of smoke.

The fire compartment ventilation often plays a very important role in fire development. When the amount of input fresh air is more or less equal to the

[1] PhD Student at University POLITEHNICA of Bucharest, Romania and at Technical University of Chişinău, Moldova
[2] Reader, Heat and Gas Supply, Ventilation Department, Technical University of Chişinău, Moldova
[3] Prof., Hydraulics and Hydraulic Machinery Department, University POLITEHNICA of Bucharest, Romania, e-mail: valp@hydrop.pub.ro

necessary amount for combustion, the combustion speed is higher and as a result the evolved heat is higher, having a direct impact on structure thermal loading, accelerating the phenomenon of flashover. When the amount of fresh air is not enough, the rate of burning becomes incomplete initiating a back draft. Another situation can occur when the input air flow and the output air flow inside the fire compartment are not related, so that the smoke layer is too low to safely evacuate the people from the building and the conditions for fire fighting can worsen [1], [7].

Generally, the standard in the current design norms from this domain offers some indications or advices that refer to classic situations, and let the burden on designers' ventilation systems to find adequate solutions. Very often, these engineers are not familiar with all characteristics of a possible fire situation and they are not able to deeply analyse the capacity of smoke evacuation systems in order to insure proper evacuation conditions to protect the goods inside and to ease the fire fighting [13, 14].

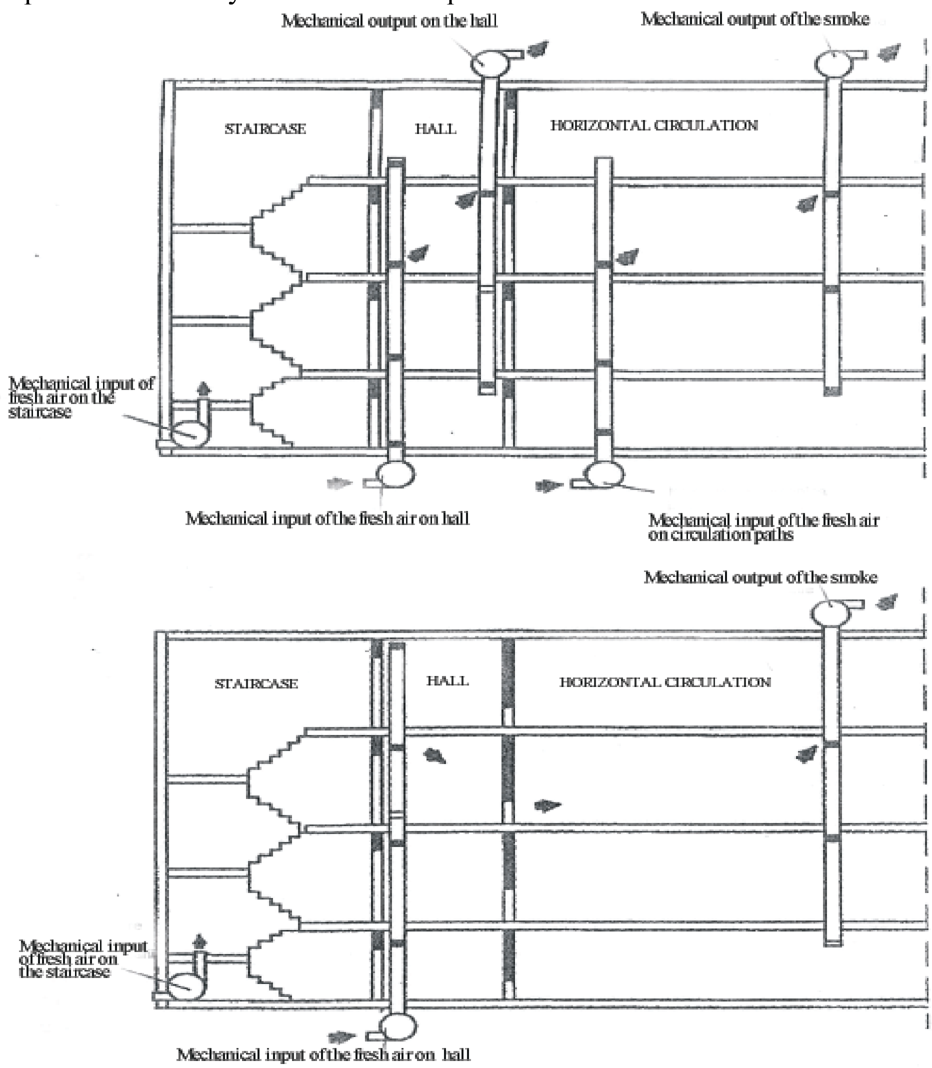
2. Standards of design

The current standard in designing of smoke or hot gases control systems used local or national plan P 188/'99 [2], GP 063/'01 [3] and the recently updates, the European ones EN 12101 part 1, 2, 3, 5, 6 and 10 [4]. Anyway regardless the previous experience and the research along all these years in this domain, it still remains a certain hesitation either technically or in designing when it comes to the question of which way one can ensure people protection and minimize the loss in a fire inside a building.

The compulsoriness of providing such a building with this kind of devices is stipulated in the national standard P 118/'99, which is very indeterminately regarding the building types requesting such devices, as well as in choosing solutions without grounds on principles or calculation in the design of those systems. After choosing reasonable protective methods, which are at the designers' full discretion, for sizing and selecting the level of performance of the smoke and hot gases control systems one can apply to the updated standard [4]. One should notice that in some of the European Communities the fitting out with these devices on some buildings is the responsibility of the designer and also of the fire fighting authorities [6].

3. Solutions for smoke evacuation

The most employed solutions for smoke evacuation in a multi-storey building applied in our country are those recommended in the National Guide of Designing GP 063/'01 [3] and NP 008/'00 [5]. The figs. 1a and 1b represent two of the main solutions using the positive pressure ventilation on staircase as a reasonable protective measure for all kind of building. They are analyzed as it and follows are frequently adopted in our country and all over Europe.



a)

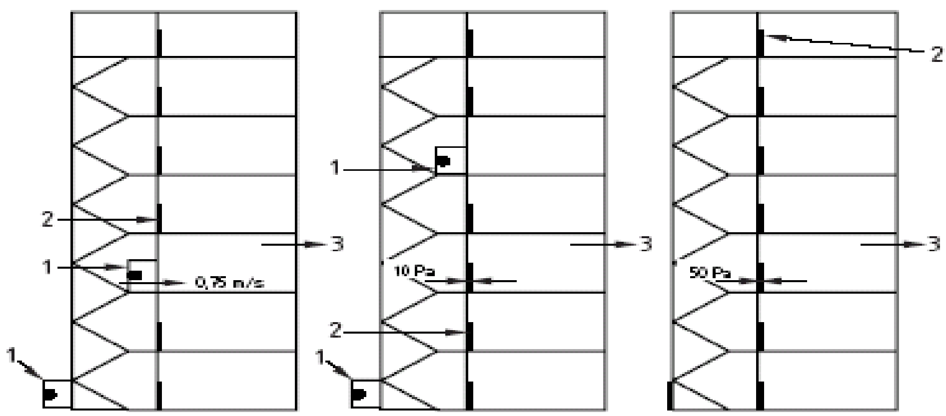
b)

Fig. 1. Principal diagram for two solutions for smoke evacuation

Until we adopt the European Standard SR EN 12101 the 6th and 3rd part, these traditional methods had many errors both in sizing calculation and performances [6]. The European Standard gets to light these errors and presents the design conditions for systems with different pressures for different buildings.

The systems of "D" class are designed for buildings where people can sleep, for instance: hotels, motels and buildings like foster homes. The design standards for "D" class are shown in Fig. 2.

Apart from dimensional calculation of mechanical fans which are supposed to ensure the difference between the pressure inside the building and the pressure inside the fire compartment (for a close door – 50 Pa, for an open door – 10 Pa), there is also necessary some more calculus to ensure that an air speed through the open door is not less than 0, 75 m/s, the force on the latch is not over 100 N, and the vents for releasing the pressure are set to operate at maximum 60 Pa.



Criterion for air flow Criterion for differential pressure (all doors closed) Criterion for differential pressure

Key: 1 – open door, 2 – close door, 3 – path for bringing the air inside

Fig. 2. Design norms for "D" class systems

4. Combined methods to control the smoke and hot gases evacuation

Using the European codes in designing on national level in building work, these codes must be carefully revised and analysed in order to be correctly applied in every particular case and taking into account the complexity of the protected building. Based on this consideration one can talk about multi-storey buildings for tourism, health, commerce where, accordingly to national standards, the existence of at least two fire escape stairs is compulsory; also in most of cases their building are equipped with elevators which can stay functional during a fire if they assist the evacuation from multi-storey buildings or for people that need assistance during the evacuation [2].

Another particular feature of this kind of buildings are the fire fighting using the hose linkage to fire hydrant situated above or below the fire floor. The connection is made along the fire floor stairs.

All these features must be taken into account when is studied the smoke direction, where differential pressure system between the staircase and the floor on fire, may not be enough. For these particular cases the scientific works and research propose the using of a differential pressure system type "sandwich" between the floors [8]. Picture 3 presents a "sandwich" system where the floor on fire is at a low pressure (L) and the two floors above and below the fire are at a higher pressure (H).

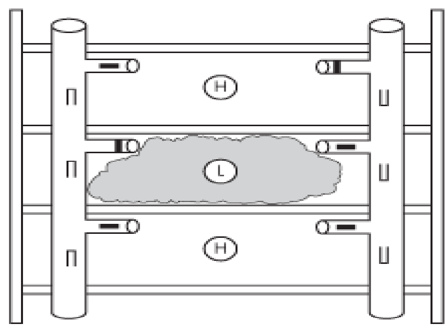


Fig. 3. Functional chart of a protective „sandwich" system

The issue of smoke and hot gases evacuation from the arson floor remains also unsolved, where there are people whose evacuation time can be longer than the usual accepted one, in a regular way, such as hospitals, institutions for people with handicap, malls or supermarkets with extended space, with lot of people, or even hotels that shelter people unfamiliar with the structure of the building. For this kind of situations, the designing goals for smoke and hot gases systems are mainly to protect the escape paths not only for the vertical ones but also for the horizontal ones, including the fire compartment. These goals suppose to maintain a layer of smoke free air at the lower part of the compartment and the control of the air flow through the room whose speed must be lower than 5 m/s to avoid turbulences and thou the combustion to intensity [4], [9].

4.1. Calculus procedures

The calculus methods of the vents smoke and hot gases evacuation systems are available for the moment, and explicitly put in the 5th part of SR EN 12101 standard, for horizontal spaces, offer us the possibility to calculate the dimensions of the vent systems; we can maintain a layer smoke free in the fire compartment, ensuring the proper circumstances for evacuation and fire fighting.

The designer's task to ensure a proper sizing for the vent system and smoke and hot gases evacuation consists in the following calculus steps:

1. To evaluate an area $A_{f,}$, expressed in square meters [m^2], and a perimeter *P,* expressed in meters [m], of a possible hotbed, based on a physical dimension of the fuel or based on the biggest dimension reasonably possible of the fire when the fire fighters apply for the first time a product of fire extinction. For particular cases one can choose the values from the standard [4].

In the calculus methods is used the most unfavourable fire pattern, function of the variation of the liberated heat flux, as well for the safeguard with sprinklers, for the case without sprinklers as such it is presented in the reference standard.

2. To establish the height of the layer of the smoke free air which exists between the evacuation paths, the planking and the basis of the smoke layer, these values of this fresh air height (Y) must be greater than 2,5 m.

The layer of fresh air of a sufficient height under the smoke layer (Y) intents to protect the usage of the horizontal escape routes which are opened from the arson space, facilitating the evacuation of the persons from the arson floor implying this the intervention conditions for the fire fighting forces.

3. The convective heat flow (Q_f) transported by the smoke gases that enters the smoke tank could be evaluated at 0,8 of the emitted heat flow ($q_f \cdot A_f$) established due to the theoretical fire.

The total flux of liberated heat (Q) for a considered fire pattern represents the product between the evaluated surface of the identified hotbed (A_f) and the heat flux liberated by the surface (q_f), expressed in kilowatts per square meters [kW/m^2], the ratio of 0.8 from the total flux liberated by the heat related to the heat flux by convection was evaluated through experimental means. Examples of the calculus methods are presented in the annex from the standard mentioned before.

4. For calculus, one can evaluate only the big fire cores whose $A_f > 0,06$ m^2 meaning that only those which verify the relation $Y \leq 10 \cdot (A_f)^{0,5}$,should be taken into consideration an equation establish by experiments for large areas with flows for emitted heat situated between 200 kW/m^2 and 1800 kW/m^2. For smaller fires it is supposed that they will be extinguished by initial means of fire extinction from the very first stage.

Although some researchers are finalized on the liberated fluxes of heat for a number of individual analyzed materials, this is not relevant for fires in different situation. It is possible that a large range of combustible materials may be involved in any fire. That is why it is not applied a peculiar value to a material, but are used in projection calculus values prescribed for different fire models [4], in function of destination and the projection mode (with or without sprinklers) of the identified space.

5. The mass output of smoke gases that raise in the smoke tank up to a specified height above the fire (M_l), expressed in kilograms per seconds, can be deduced from the following equation:

$$M_l = C_e P Y^{3/2}, \tag{1}$$

where C_e [kg·m$^{5/2}$·s^{-1}] it is a moving coefficient with a value of 0.377 for small rooms such as shops, hotel rooms, office spaces, hospital rooms etc. with ventilation openings towards the commune horizontal circulation ways afferent to the evacuation routes.

6. In order to obtain good results, the designer evaluates the temperature in the smoke layer above the environmental temperature expressed in ^{o}C, using the equation

$$\theta_l = \frac{Q_f}{c \cdot M_l}, \tag{2}$$

where c [kJ·kg·K^{-1}] is the specified heat at a constant pressure.

Depending on the obtained values, the designer can make some adjustments to avoid the situations like the following:

a) The gases temperature in the upper layer $t_e = \theta_l + t_{amb}$ must not exceed 200 ^{o}C, and for the evacuation paths situated under the smoke tank and more over to not exceed 550 ^{o}C, when a flash back becomes possible.

b) The designed temperature from the smoke layer must be situated at least 20 ^{o}C above the environment temperature; when the temperature of the smoke layer is lower than 50 ^{o}C 0,5 m are added to the Y chosen value.

c) The cooling effect of the sprinklers upon the gases inside the smoke tank must be included in the design calculus.

7. The smoke mass, expressed in kilograms per second, that enters in the evacuation slit for smoke is calculated from the equation:

$$M_{slot} = \gamma \cdot \frac{\theta_l^{0,5} \cdot L_s}{T_l} \cdot d_l^{0,5}, \tag{3}$$

where L_s represents the width of the smoke extraction slit, T_l the absolute temperature from the smoke layer, γ a correction coefficient of about 78 if the opening is perfectly joint with the ceiling or 36 if the opening is build in the lowest part of a screen (it's the case for extended areas where the ceiling surface is parted by smoke screens) and d_l representing the height of the smoke layer from the equation

$$d_l = \left(\frac{M_l \cdot T_l}{\gamma \cdot \theta_l^{0,5} \cdot W_l} \right)^{2/3}, \qquad (4)$$

where W_l is the width of the fire compartment.

8. In order to choose the proper fans, the smoke mass can be transformed into volume expressed in [m^3 /s], using the equation:

$$V_{slot} = \frac{M_{slot} \cdot T_l}{\rho_{amb} \cdot T_{amb}} \quad , \qquad (5)$$

where ρ_{amb} [kg/m^3] represents the environment density.

4.2. The ventilation / air-conditioning - smoke evacuation system

In order to combine the three control methods of smoke exposed in this paper, analysed only for smoke evacuation during a fire, there are necessary high costs of investment. The best solution proposed by the authors is to use the vent system of the building for normal climate, which can be designed for smoke evacuation; such a solution is presented in picture 4.

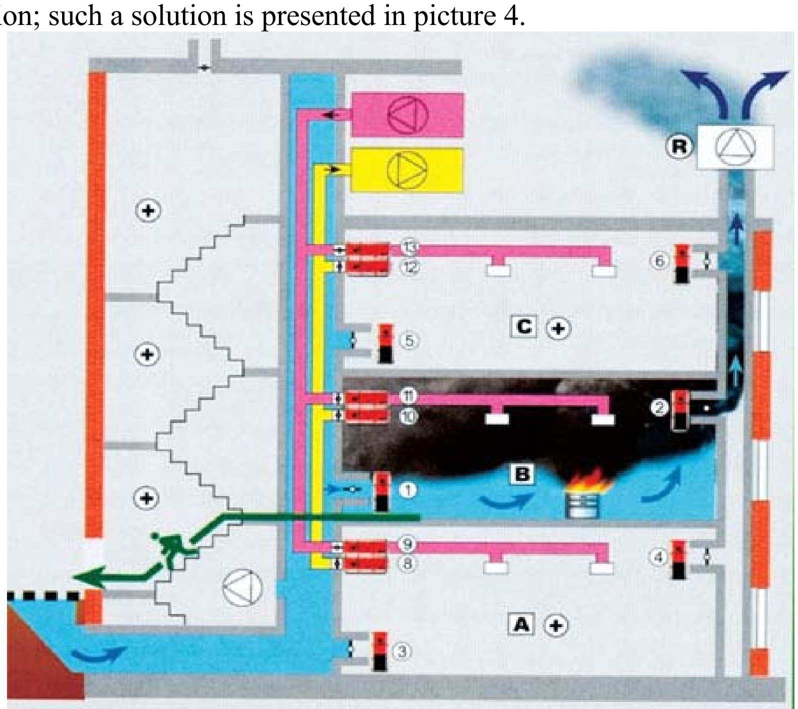


Fig. 4. Combined methods to control the smoke and hot gases

In this figure is presented a ventilation system for smoke evacuation made of a block of fans built in the upper floor of the building, having anti-fire flaps in the ventilation tubes on every floor. In case of a fire at one of the floors, the following: phenomena happens

- *In the smoke evacuation system*: the flap 2 opens and extracts the smoke through the (R) fan, in the some time the flap 1 opens and permits the fresh air to go in. The other flaps 3, 4, 5 and 6 stay closed. The people, quietly, evacuate the floor on fire.
- *In the ventilation system*: the anti-fire flaps 10 and 11 are closed in order to isolate the (B) floor. The other flaps 9 and 13 stay opened and the flaps 8 and 12 close. The inlet vent from the central block continues to function in a special regime and creates an overpressure on the (A) and (C) floors.

6. Conclusion

The above method refers to multi-storey buildings that shelter people unable to evacuate themselves, due either to the special configuration or destination of the building the people need a longer period of time to evacuate. In the same time the fire-fighters for operating can't isolate completely the adjacent floors, not possible a considerable smoke escape on other evacuation paths, except the fire compartment. For such cases the best solution proposed in this work is to combine the normal ventilation system of the building with the smoke evacuation systems, the protection methods known being also applied.

The engineering approaches of such a solution allows us to insure the evacuation for all the people situated in the building with low costs and also to optimize the operations on fire fighting due to the control of the combustion through the system of ventilation and smoke evacuation.

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