ADJUSTMENT OF MINING VENTILATION SOFTWARE FOR CIVIL OBJECTS

Zahari Dinchev[1], Nadezhda Kostadinova[1], Elena Vlasseva[1]

[1]University of Mining and Geology "St. Ivan Rilski", 1700 Sofia
e-mail: dinchev@mgu.bg; nadezhda.kost@gmail.com; elena.vlaseva@mgu.bg

ABSTRACT Due to its complexity and branched structure the ventilation system of underground mining objects is modeled using specialized software products. This paper presents application of two of the most commonly used by the ventilation specialist programs - MfirePro + and Ventsim. Similarities and differences in data input, graphical presentation creation, setting of ventilation facilities and modeling of different modes are analyzed. On the basis of ventilation characteristics of mining objects, an analogy of the ventilation paths for emergency ventilation of a high building is developed. Emergency ventilation is performed by three fans - two supply and one exhaust fans. Air flows are regulated in order to meet safety rescue requirements. Aerodynamic resistances reflect in-situ measurements, but additionally some approximations for pressure drops and air leakage are undertaken. Numerical model and solutions of building emergency ventilation, obtained with MfirePro + and Ventsim, are presented.

Keywords: emergency ventilation, modeling, mining ventilation software

АДАПТИРАНЕ НА МИНЕН ВЕНТИЛАЦИОНЕН СОФТУЕР КЪМ ГРАЖДАНСКИ ОБЕКТИ

Захари Динчев[1], Надежда Костадинова[1], Елена Власева[1]
[1]Минно-геоложки университет "Св. Иван Рилски
e-mail: dinchev@mgu.bg; nadezhda.kost@gmail.com; elena.vlaseva@mgu.bg

РЕЗЮМЕ. Вентилационната система на подземните минни обекти поради своята сложна, разклонена структура се моделира със специализирани софтуерни продукти. Статията представя възможностите на двете най-използвани сред вентилационните специалисти специализирани програми – MfirePro+ и Ventsim. Разгледани са приликите и разликите при въвеждането на данни, създаването на графичен вид на системата, задаване на вентилационни съоръжения и моделиране на различни режими. На основата на вентилационните характеристики на минните обекти е разработена аналогия на вентилационните пътища при аварийна вентилация на висока сграда. Аварийната вентилация се осъществява с три вентилатора – два работещи на нагнетателен режим и един на смукателен. Движението на въздуха се регулира за постигане на изискванията за безопасна евакуация. Аеродинамичните съпротивления са определени с измервания и с допълнителни апроксимационни зависимости. Представен е численият модел на вентилацията на сградата, получен с програмни системи MfirePro+ и Ventsim.

Ключови думи: аварийна вентилация, моделиране, минен вентилационен софтуер

Introduction

Underground mines as ventilation objects are branched structures with several entrances and exits, developed with levels in depth. Analysis of interaction of ventilation air flows, their distribution, pressure drops and operational modes of regulators and fans is a complex research task, solved successfully with implementation of specialized software products. These programs can find additional applications in other underground objects such as: tunnels – rail- and road (Vlasseva, 2015), underground parking places and garages, metro. There are numerous varieties in type and purposes of underground objects and although there are many similarities with underground mines, some specific features should be taken in consideration. Authors search for possible expansion of application areas of specialized mine ventilation software programs to aspiration systems, industrial ventilation installations with complex topology.

This paper presents emergency ventilation model of a high building, presented as a ventilation object with specialized ventilation programs VnetPc, MineFirePro+ VentSim. Numerical model creation of this object and also operation of emergency ventilation, reflecting fire regulation codes (PSTN, BS EN 12101-6:2005) are discussed in details.

Ventilation systems presentation

Ventilation systems are presented as a network of ventilation paths (branches), where air moves and places where air flows mix (nodes). Important part of their description are regulation devices – passive (producing pressure loses) and active – fans (supply and exhaust) generating pressure. Most common views of ventilation networks representation are graphical or/and tabular. In both variants all parts of the ventilation object, where air flows (branches), should be described. Each branch has a specially evaluated aerodynamic resistance R_i.

At a design stage of the project R is calculated by known expressions (Stefanov, 1992), while for objects in operation it can be measured. Aerodynamic resistance depends on geometrical as well as aerodynamic factors. These factors are taken into account for modeling ventilation paths in a high building further in this paper. For one linear section (ventilation branch) the resistance law is valid:

$$W = R.Q^2 \qquad (1)$$

where

R - is aerodynamic resistance [$N.s^2/m^8$];

W - is pressure loss [Pa];

Q - is volumetric flow rate [m^3/s];

Aerodynamic resistance can incorporate friction factor, length, perimeter, area, local loses, pressure drop.

Distribution of ventilation flows in the whole ventilation system obeys two basic network laws - mass conservation in nodes and mechanical energy conservation in independent contours.

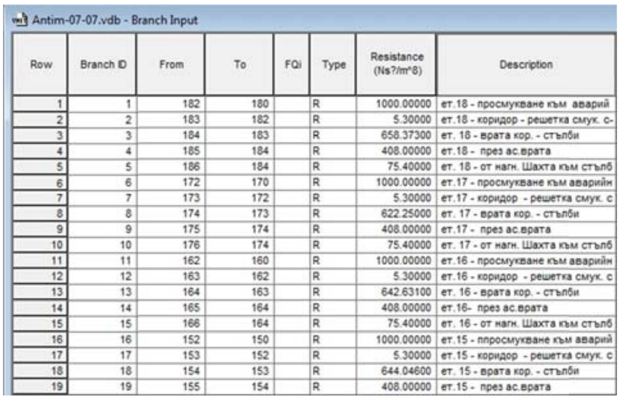
Two main approaches in network modeling are applied – incompressible and/or compressible flows. More often stationary problems are solved – no change of parameters in time. But increasing complexity of networks and phenomena occurring there impose additional studies such as: analysis of emergency situations and their reflection on normal ventilation, transition of the system into emergency mode (Vlasseva, 2017). Specialized ventilation software programs can be utilized in modeling of incompressible, thermodynamic and emergency modes. Two of the most applied programs in the world, available for the authors of this paper are:

- Programs of Mine Ventilation Services Inc. - VnetPC (incompressible mode, passive network) and MineFire Pro (transient distribution of fire gases and heat),
- Program of Australian company Chasm Consulting - VentSimTM advance version.

Implementation of two independently developed software products makes possible to compare the results obtained as well as to model various physical phenomena, which are available in one or other program.

Specialized mine ventilation software

Both programs (VentSim and MineFire) incorporate methods described in books such as Subsurface Ventilation and Environmental Engineering by Malcolm J. McPherson (2009). This means, that results obtained by both programs are comparable. The reason for application of two different programs is that both of them have advantages in one or other direction. For instance, VnetPC and MFire Pro+ are text oriented, while VentSim is graphically oriented. Topology of network in VnetPC- MFire Pro+ is uploaded into spread sheet view (Fig. 1). Graphical output is generated after coordinates of nodes are input in a special spread sheet.


Antim-07-07.vdb - Branch Input

Row	Branch ID	From	To	FQi	Type	Resistance (Ns?/m^8)	Description
1	1	182	180		R	1000.00000	ет.18 - просмукване към аварий
2	2	183	182		R	5.30000	ет.18 - коридор - решетка смук. с-
3	3	184	183		R	658.37300	ет. 18 - врата кор. - стълби
4	4	185	184		R	408.00000	ет.18 - през ас.врата
5	5	186	184		R	75.40000	ет. 18 - от нагн. Шахта към стълб
6	6	172	170		R	1000.00000	ет.17 - просмукване към аварийн
7	7	173	172		R	5.30000	ет.17 - коридор - решетка смук. с
8	8	174	173		R	622.25000	ет. 17 - врата кор. - стълби
9	9	175	174		R	408.00000	ет.17 - през ас.врата
10	10	176	174		R	75.40000	ет. 17 - от нагн. Шахта към стълб
11	11	162	160		R	1000.00000	ет.16 - просмукване към аварийн
12	12	163	162		R	5.30000	ет.16 - коридор - решетка смук. с
13	13	164	163		R	642.63100	ет. 16 - врата кор. - стълби
14	14	165	164		R	408.00000	ет.16- през ас.врата
15	15	166	164		R	75.40000	ет. 16 - от нагн. Шахта към стълб
16	16	152	150		R	1000.00000	ет.15 - ппросмукване към аварий
17	17	153	152		R	5.30000	ет.15 - коридор - решетка смук. с
18	18	154	153		R	644.04600	ет. 15 - врата кор. - стълби
19	19	155	154		R	408.00000	ет.15 - през ас.врата

Fig. 1

VentSim operate in the opposite way – all branches are introduced either with direct drawing, or by coordinates input (Fig.2). Both programs may import DXF, Autocad DWG, Microstation DGN, Datamine files, which is really useful in the whole process of mine design. Surely, some additional predesign for ventilation purposes is needed after such data transfer. VentSim can even convert a file, prepared by MineFire, for modeling into its environment.

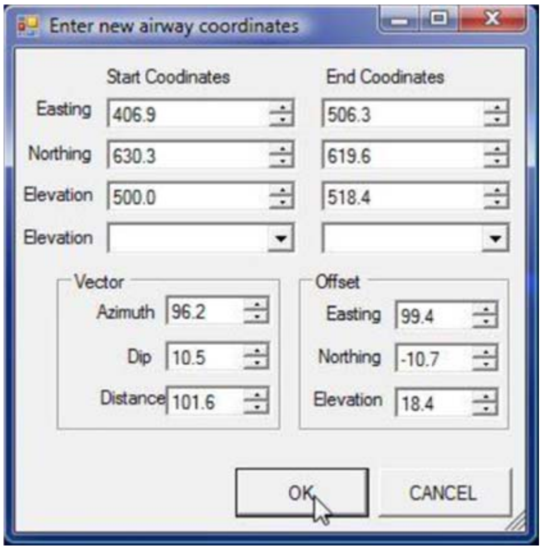


Fig. 2

Both programs have as an outcome airflows distribution along all branches, give fans and regulations regimes. In VentSim some useful for practice problems can be modeled: thermodynamic, diesel particulates, dynamic contaminants, gas, heat and DPM (Fig. 3).

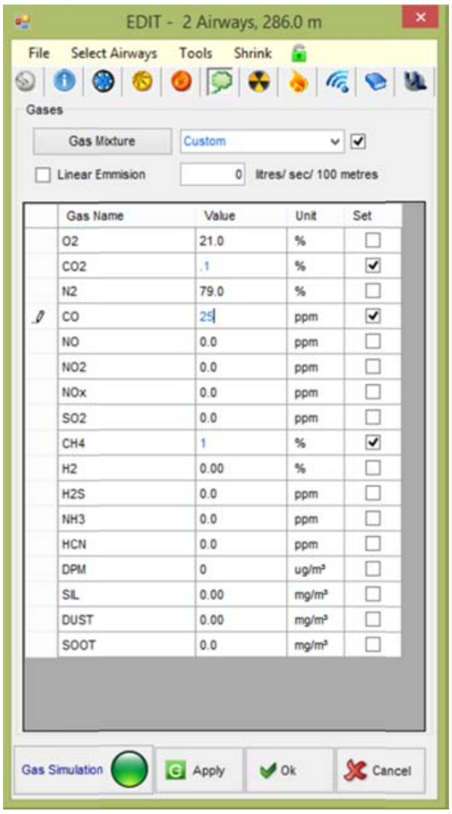


Fig. 3

Heat might come from point sources (such as electric motors), linear sources (such as conveyors), diesel engines, auto-compression of air, refrigeration and spot cooling. A very important feature is taking into account changing densities due to depth and temperature effects, natural ventilation, and moisture from sources such as dust suppression sprays, condensation from over saturated air. It is obvious that all these phenomena exist in other ventilation objects which are more civil oriented. VentSim has well developed visualization in many directions, including real time data from sensors (fig. 4).

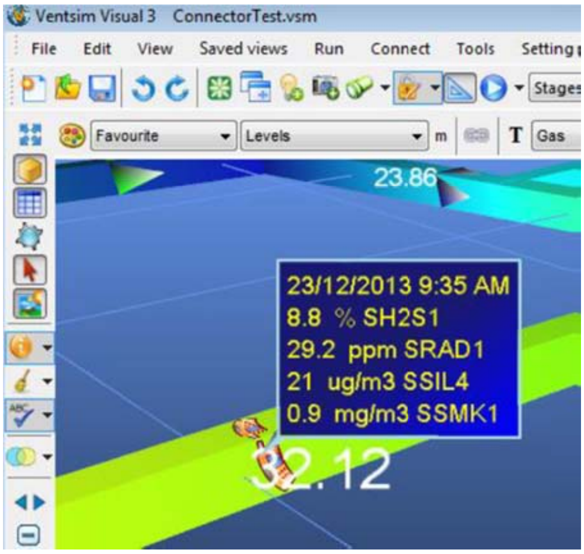


Fig. 4

MineFire Pro+ simulates a system's response to dynamic transient state phenomena such as fire with variable in time parameters, varying outside temperatures, changing ventilation control structures, or development of new mine workings. These features continue the process of full scale modeling of one ventilation system.

Requirements for high building emergency ventilation

Emergency ventilation of a high building should be designed so that to ensure safe evacuation of occupants from any floor through a staircase. It is assumed that fire has started somewhere in the work places. The aim of emergency ventilation is to create fresh air flow towards rescued people (overpressure in a staircase) and to extract fumes from the corridor (Fig. 5a and 5b).

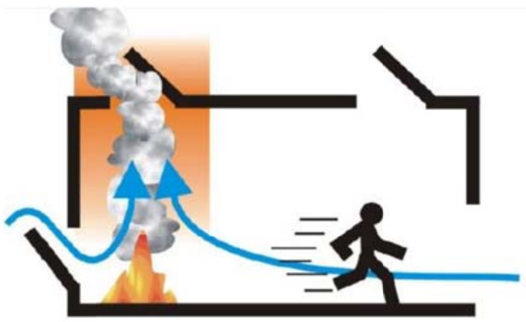


Fig. 5a

Evacuation takes place through the staircases. That means, that no combustible materials should be there as well as the air should remain clean from combustion products during the whole evacuation period.

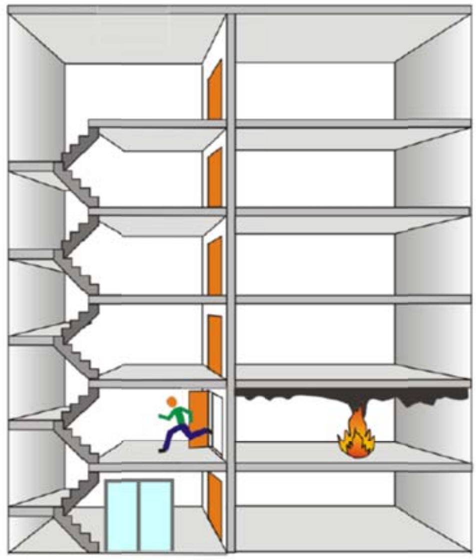


Fig. 5b

Fire safety regulations stated that:

- The staircase is isolated from a corridor with airtight, non combustible, smoke tight, self closing doors. The smoke tightness is secured through the door construction. The gaps should be no bigger than 2 mm with the doorcase, and no bigger than 4 mm with the floor (BS EN 12101, PSTN).
- The minimal pressure difference (overpressure) across a closed door and operating emergency ventilation between the staircase and the corridor shall be not less than 20 Pa.

Ventilation Object

The ventilation object, discussed in this paper, is an 18th floor administrative building. Fig. 6 presents the scheme of each floor of the building. Offices are located along a corridor. It is supposed that fire can occur somewhere there. In case of fire people should leave through the corridor door towards the staircase.

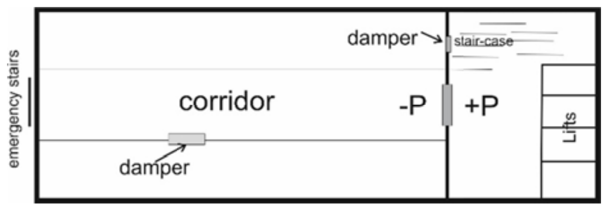


Fig. 6

Smoke extraction is achieved by extracting smoke through an exhaust fan located on the roof. It exhausts fumes from the corridor through a damper, sized 1225 x 225 mm, vertically mounted on the wall, connected to the exhaust fan through a pipeline.

The intake of fresh air is performed via two supply fans:

- Fan V1 supplies air in four lift shafts, creating overpressure to the staircase place; lifts are stopped at the first floor. Air leaks through lift doors and mixes with supply air from fan V2;

- Fan V2 supplies fresh air in staircase platforms through a pipeline and louvers (dampers) sized 425 x 225 mm, each one with 11 lamellas. Air supply is distributed between floors, which presumes different open area of louvers.

In order to fulfill emergency ventilation requirements the amount between supply and extraction flows should be as follows:

$$Q_{extraction} = (1.25 \div 1.4) Q_{supply} \quad (2)$$

A fire scenario, which is closer to the real rescue situation, is the following: the lifts are located on the first floor, all corridor doors are closed, the three fans operate – two supply fresh air in the staircase and in lift shafts, one exhausts from the corridor, all doors at entrance hall are opened.

In-situ measurements

Full scale measurements are published in Michaylov, 2008 and in Project 1856, 2005. Fans' performance, pressure difference (over pressure between potential fire zone and escape route) and other data, required by fire regulations are presented there. In brief, measurements show the following:

Fans:

- fan V1 supplies 13.715 m^3/s fresh air ;
- fan V2 supplies 8.213 m^3/s fresh air;
- fan V3 exhausts 30.69 m3/s fumes and air.

Pressure differences through doors

Fig. 7 presents the results from the measurement of overpressure between the corridor and the staircase. Data show that pressure difference for all floors between rescue section (staircase) and fire place (corridor) is greater than 20 Pa, varying from 55 Pa for 18th floor to 24 Pa for 2nd floor. Requirements of fire regulations are fulfilled.

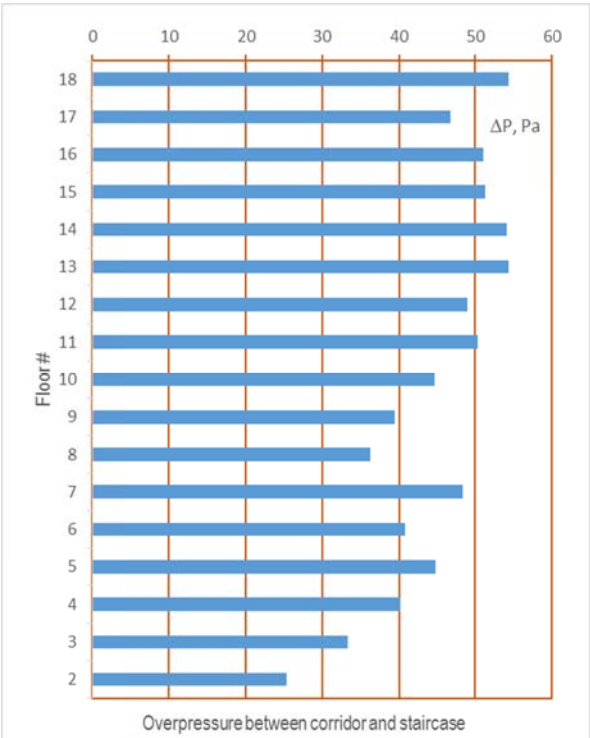


Fig. 7

Emergency ventilation model

Air flow movement is accomplished with the following equipment:

- supply air through lift shaft and air leakage through lift doors;
- supply air through shaft into staircase via air dampers;
- leakage through doors between staircase and corridor;
- exhaust air through shaft via air dampers.

In order to make an adequate model of emergency ventilation air resistances representing air leakage through doors and air supply through dampers, need special attention.

Air leakage through doors

Interesting results for air leakage through doors are presented in (Gross D., 1981 and Gross D., W., Haberman, 1989). Relationship between air flow through small gaps around closed doors and pressure difference between two sides of the door follows the general expression:

$$Q = k\,A\left(\Delta P\right)^n \quad (2)$$

where: Q is volume flow rate of air, m^3/s;

k is a flow factor incorporating the discharge coefficient (Cd,) of the leakage openings;

A is an equivalent area of opening or passage, m^2;

ΔP is pressure difference, Pa;

n is exponent which can vary between 0,5 and 1,0.

When the above variables are expressed in SI units $k = 0{,}827$ *and* $n = 0{,}625$.

Calculation of the area of the opening and further hydraulic diameter of the gab is important in order to ensure type of flow through the closed door. Doors in our ventilation object are 2.05 x 0.92 m. Gaps are 4 mm from the floor and 2 mm from the sides of the door. Then the hydraulic diameter is:

$$D_h = 4\frac{A}{\Pi} = 4\frac{(0.92*0.004+5.02*0.002)}{5.94} = 0.0092 \quad (4)$$

where: Π is perimeter of the gab, m

In order to evaluate resistance R for all branches of a network, representing leakage through doors, Reynolds number should be known. It is expressed in a well-known form, by using of gap flow rate and hydraulic diameter:

$$\mathrm{Re} = \frac{uD_h}{\nu} = \frac{\frac{Q}{LD_h}D_h}{\nu} = \frac{Q}{L\nu} \quad (5)$$

Fig. 8 shows Reynolds numbers vs Q. It is seen that the flow through closed doors is laminar. Using that data, aerodynamic resistance R is calculated (Fig. 9). Depending on measured data for ΔP at each floor, corresponding R is input into the program MineFire.

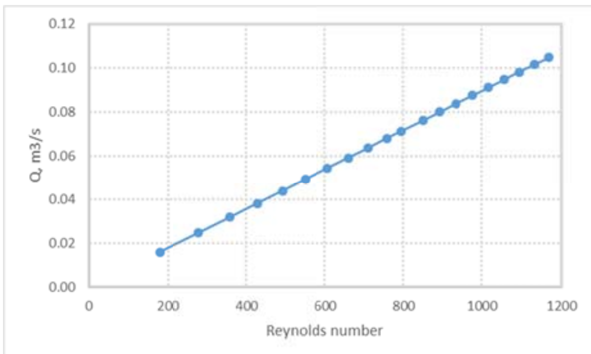


Fig. 8

Air supply through dampers

Air supply dampers, sized 425x225 mm, are with 11 lamellas and with area of 0.08 m2 when fully opened (100%). During measurements lamellas were regulated as follows:

- 1st to 4nd floor – 4 closes lamellas, i.e. 64% open;
- 5th to 8th floor – 3 closed lamellas, i.e. 73% open;
- 9th to 11th floor – 2 lamellas closed, i.e. 82 % open;
- 12th to 18th floor – 100% open.

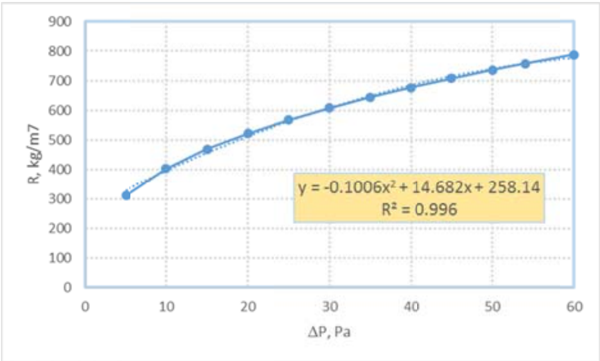


Fig. 9

Assuming regular distribution of air flow through the supply shaft and taking into account reduced area of the dampers at the corresponding floors, air resistances was evaluated. They vary from 149.27 kg/m^7 for 1-4 floors, to 75.4 for 12-18th floors.

The same approach was applied to exhaust shaft and dampers. Their regulation follows percentage of open area same as supply case. Air resistances' of the dampers in the corridors vary from 17.7 to 5.3 kg/m^7.

Numerical model of emergency ventilation

Numerical model of emergency ventilation include all paths, where air moves. Air supply and exhaust for each floor is presented by four similar air branches:

- leakage through lifts doors;
- leakage through corridor doors;
- air supply through dampers;
- air exhaust through fire dampers in the corridor.

In summary – four air branches should be described for each floor. Additionally, three shafts are presented – two supply and one exhaust. They are separated between floors with supply/exhaust dampers and loft doors. Regulation of flows throughout the building is made via adequate air resistances through doors and dampers. In general the ventilation of the building is presented in numerical view with 116 nodes (where air flows interact) and 149 branches (where air flows move through nodes). Initially, a numerical model was created for MFirePro+. Its graphical view is shown on Fig 10. The same model was transferred to Ventsim (Fig. 11). As stated above, it is easier to input a complex ventilation system into MFire Pro+, but Ventsim provides more opportunities for simulation and graphical presentation. Bearing in mind that both programs share the same mathematical models (McPherson, 2009), results are convertible and comparable. The goals of emergency ventilation are fulfilled:

- air is supplied through staircase and lift shafts;
- dampers are regulated so as to supply/exhaust air into required amounts;
- all directions of air flows are according to the purposes of emergency ventilation, i.e. towards rescued people;
- the programs also show fans regimes.

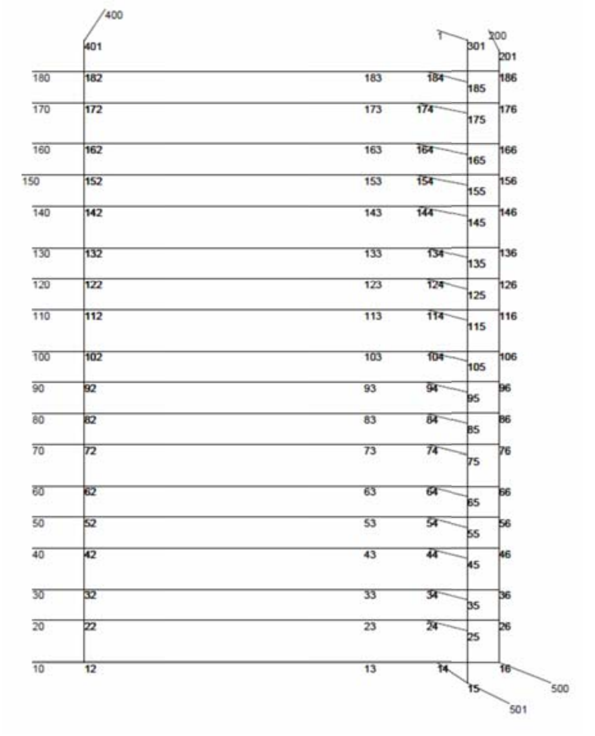


Fig. 10

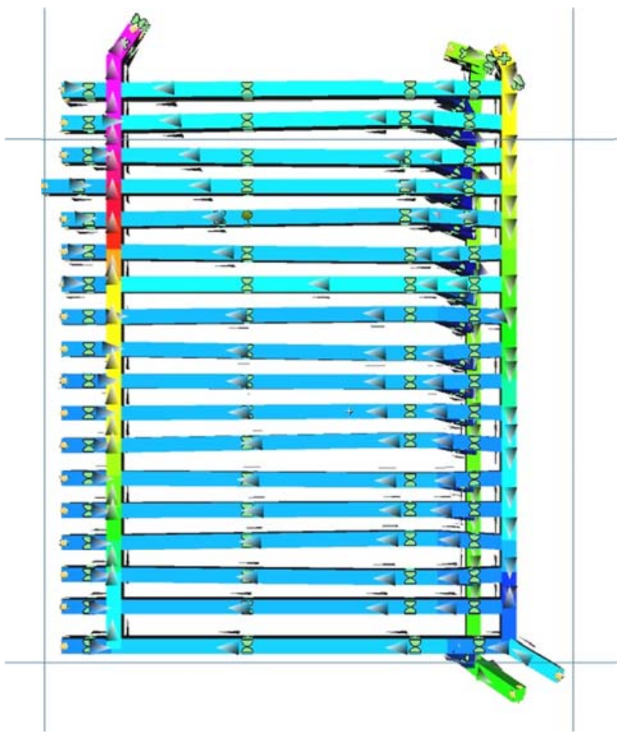


Fig. 11

Fig. 12 presents air reduction through supply shafts:

- starting from 8 m^3/s for the 18th floor for lift shafts and reaching 4 m^3/s at the 1st floor;
- starting from 13 m^3/s for the 18th floor for staircase shaft and reaching 1 m^3/s at the 1st floor.

Fig. 13 presents air extraction rate starting from 1st floor with 1 m^3/s and reaching 32 m^3/s at the 18th floor.

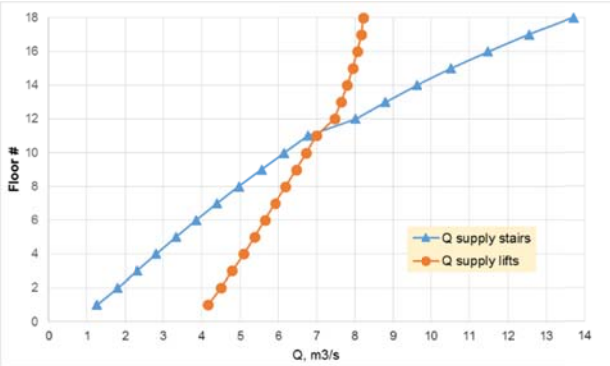


Fig. 12

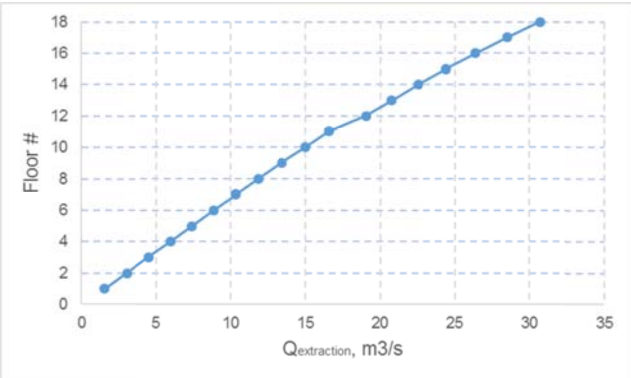


Fig. 13

Fig. 14 shows staircase duct supply fan's operation attributes, generated by VentSim software.

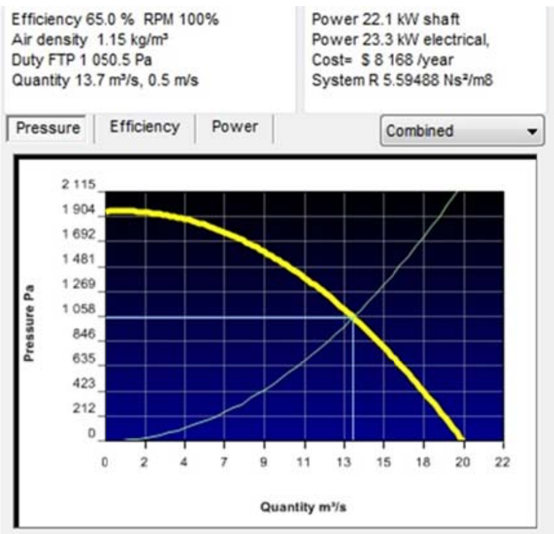


Fig. 14

Conclusion

In the process of transferring high building emergency ventilation system into numerical model a need for additional measurements arose. Pressure difference between air flow in shafts and ambient atmosphere in the staircase is an important parameter, needed to settle air resistance of the dampers. Lack of these values brings about the need for special research on the relationship between velocity through dampers and pressure difference. From the other side, impossibility to measure air leakage through doors also forced some research on air resistance of closed door with air leakage. Additional research in these directions is inevitable.

Application of specialized mine ventilation software towards civil objects gives positive results in several areas:

- better understanding of required air distribution throughout the ventilation system;
- regulation on the model and direct application on real object;
- all possible fire and other accidents modelling, serving as a plan for rescue operation.

Further research and transformation of different civil ventilation objects like underground garages, aspiration systems with several inputs and outputs, road and railway tunnels are appropriate objects for modelling with full scale analyses of thermo-dynamical and air-dynamical phenomena.

Refferences

Michaylov M., Z. Dinchev, El. Vlasseva, 2008, Avarijna ventilatsiya na visoki sgradi, Nauchno-tehnicheski sbornik “Pozharna i avarijna bezopasnost”, br.17, Sofia, str. 80 – 93

Dog. 1856, 2005, Depresionna snimka v ANTIM TOWER za opredelyane na depresiyata mezhdu stalbishtnoto otdelenie i koridorite na sgradata, Arhiv na NSI na MGU

BS EN 12101-6:2005, Smoke and heat control systems —Part 6: Specification for pressure differential systems; Part 3 Smoke and heat control systems: Specification for powered smoke and heat exhaust ventilators.

Naredba 2. Protivopozharni stroitelno-tehnicheski normi (PSTN). Dv. br. 33/19.04.94.

AS/NZS 1668 The use of ventilation and air conditioning in buildings.

Vlaseva El., Ventilacija na transportni tuneli, Izd. kasta “Sv. Ivan Rilski“, Sofia, 2015, str. 96, ISBN 978-954-353-286-5

Vlaseva El., Matematichesko modelirane v minnata ventilatsiya, Izd. kashta “Sv. Ivan Rilski“, Sofia, 2017, 236 str., ISBN 978-954-353-235-1

Gross D., 1981, A Review of Measurements, Calculations and Specifications of Air Leakage Through Interior Door Assemblies, NBS Publications 81-2214

Gross D., W., Haberman, 1989, Analysis and Prediction of Air leakage through Door Assemblies, Fire Safety Science – Proc. of the Second International Symposium, pp. 169-178

HSE Safety Guidelines SG-FS-0-0-2, CERN Safety Code E.

McPherson M., (2009), Subsurface Ventilation and Environmental Engineering, Mine Ventilation Services, Inc., ISBN

Ventsim™ User Guide

MineFire Pro+ A Simulator for Underground Fires, USER'S MANUAL & TUTORIAL, Mine Ventilation Services, Inc., www.mvsengineering.com

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