Simulating and Predicting Escape Routes for Ventilation Network of Duong Huy Coal Company using Ventsim DESIGN Software

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In underground coal mining, the ventilation task plays an important role because it ensures enough fresh air for workers and decrease negative effects of deleterious gases released from coal seam as well as blasting explosions. Furthermore, when coal mines go deeper, the ventilation task is more and more important. In order to guarantee good ventilation performance, we should apply a simulation software. In this article, we present the application of Ventsim DESIGN software for ventilation network of Duong Huy Coal company as well as prediction of escape routes in urgent cases. The simulation results demonstrate that the software offers good performance, stable operation as well as the suitable escape routes in urgent cases.

Keywords: *ventilation network, Ventsim DESIGN, escape routes, Duong Huy coal company, vinacomin*

1. Introduction

Ventsim DESIGN is the world's best-selling mine ventilation software, used and trusted by over 1500 mines, universities, consultants, government and research organizations. It is an underground mine ventilation simulation software package designed to model and simulate ventilation, airflows, pressures, heat, gases, financials, radon, fire and many other types of ventilation data from a model of tunnels and shafts [1, 2]. It includes two versions named Ventsim DESIGN Advanced and Ventsim DESIGN Premium. The first has some characteristics as follows:

- Compressible Flows: Compressible airflows effects at depth are modelled
- Thermodynamic environmental simulation:
  — Heating and Cooling – includes heat or refrigeration options in network analysis;
  — Rock Thermal Input – predicts heat and moisture emanated from rock strata;
  — Diesel Equipment – predicts heat and humidity generated by diesel equipment;
  — Natural ventilation – uses thermodynamics to simulate natural ventilation effects.
- Dynamic blasting: Blasting fume animated dynamic spread time and clearance time dispersion.
- Diesel Particulate Simulation: Utilizes diesel engine sources to estimate DPM levels throughout the mine.
- Dynamic Heat and Gas Distribution: Individual heat and gas time based simulation and spread through model with graphing.

While the later includes all features of Ventsim Advanced as well as Fire Simulation, VentLOG ventilation survey record software, LiveView remote data connection and display module AND the brand new Duct Calculator and has the following features [1]:

- All features of Ventsim Advanced
- Dynamic Heat and Gas programmable events: Heat, air or gas changes can be introduced at pre-programmed dynamic intervals.
- Radon Simulation: Predict worker exposure levels based on radon emission rates from different areas, and the length of time the gas is allowed to remain in the mine atmosphere based on your ventilation design.
- Escape Routes: Find the shortest path to a refuge bay or surface from any point in the mine.
- VentLOG: Software package to record survey data, export to plans and overlay on Ventsim models.
- LiveView to connect to external data and display and simulate real time data.
- Fire Simulation to predict fire heat, gases and flow direction
- Duct Calculator

Ventsim DESIGN is used in many scientific articles for simulating the ventilation network for tunnels as well as underground mines. The authors in [3] proposed to link real-time information generated by underground mine ventilation airflow monitoring sensors into a network simulation program to undertake network simulations and allow interpretation of key system data. Most mine ventilation engineers are involved in ventilation planning and design in some capacity. Ventilation modelling software used by a competent experienced ventilation engineer is extremely presented in [4]. The Redeemer Gold Mine is a sub-level caving gold operation located in Western Australia. The underground mining commenced in 1989 and followed a slightly subvertical ore body to the depth of approximately. The authors in [5] evaluated mine ventilation for Agnew Gold mine expansion using Ventsim. In Vietnam, there are several mine ventilation sim-

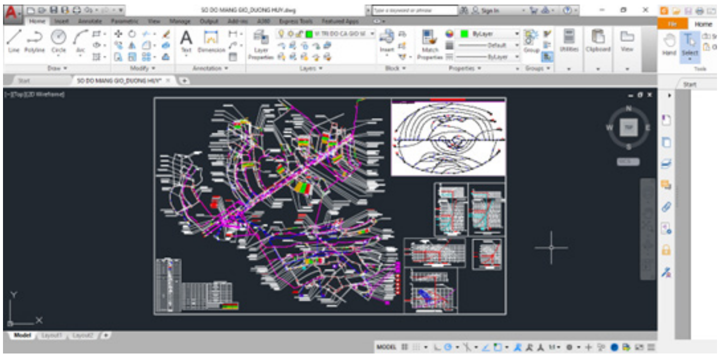


Fig. 1. The diagram of the mine ventilation network in AutoCAD
Rys. 1. Schemat sieci wentylacyjnej w programie AUTO CAD

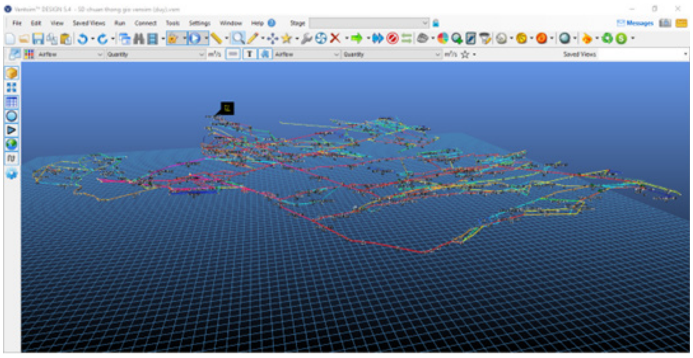


Fig. 2. The diagram of the mine ventilation network in Ventsim DESIGN
Rys. 2. Schemat sieci wentylacyjnej w programie Ventsim Design

ulation softwares as Ventsim, Kazemaru, VentGraph used for simulating underground Coal mine ventilation network [6]. Some Coal mines in Quang Ninh province begin using Ventsim DESIGN for simulating their mine ventilations. Duong Huy coal mine is one of those. In this article, we present the simulation results in using Ventsim DESIGN to simulate the ventilation network for this company.

The rest of the article is structured as follows: Section 2 describes the related works. The simulation of Duong Huy coal company's ventilation network and prediction of escape routes in urgent cases are presented in section 3. Section 4 offers some conclusions as well as the future work.

2. Related works

2.1. Steps of mine ventilation simulation in Ventsim DESIGN

In order to simulate the mine ventilation in Ventsim DESIGN, we execute as follows:

- Step 1: Draw the ventilation network in AutoCAD software, and then save it to .dxf/.dwg file
- Step 2: Import the AutoCAD file into Ventsim DESIGN
- Step 3: Import data for the ventilation in Ventsim DESIGN
- Step 4: Check for the validity of the ventilation as direction, the junction among airways. In order to do this, Fix flow for airways which we will install the fans equal to the total flows of whole mine
- Step 5: Simulate the ventilation
  - — Remove the fixed flow at step 4
  - — Install the fan at the airway
  - — Run simulation of airflows
  - — Check flows at airways which consume fresh air. If they do not ensure enough fresh air, we have to adjust the ventilation network as using local fan to increase flow, obstruct for reducing flow… Besides we also check the velocity of airways. If they exceed the threshold value, we have to decrease them.
- Step 6: Check the whole mine ventilation, focus on the flows, velocities, pressures, working mode of the fans.

2.2. Ventilation network characteristics of Duong Huy Coal mine

The ventilation network of Duong Huy coal mine is quite complicated and typical for underground coal mine in Vietnam. At present, the mine is exploring form level -100 to +38. The mine includes three mining areas called "Trung tam", "Nam", "Dong Bac". All the areas have 10 longwalls, 34 the prepared tunnel faces, where "Trung tam" area is exploiting seams 8, 10, 11; area "Nam" is mining seam 9 whereas area "Dong Bac" is exploiting seams 11, 12, 14. According to [7, 8], the total output of the mine in 2020 is 2,130,000 tons/year. The total length of digged tunnels is 22,730 m. For the ventilation task, the total flow of whole the mine (Qm) is manually counted according to the following equation [9]:

$$Q_m = 1.1\times(k_{sl}\times\Sigma Q_{kt}+\Sigma Q_{cb}+\Sigma Q_{ht}+\Sigma Q_{rg});\ \mathrm{m^3/s} \qquad (1)$$

In which:

1.1: The coefficient refers to the uneven distribution of wind in wind currents.

k_{sl}: Coefficients to account for the increase in output of the longwall (normally k_{sl} = 1.1).

ΣQ_{rg}: Total leakage flow in mine, m^3/s.

Tab. 1. Quantity of fan used in simulation
Tab. 1. Ilość wentylatorów użytych w symulacji

Fan name	Role	Quantity
2K56No30	Main fan	2
2K56No24	Main fan	2
2K60-44-No16	Main fan	2
BD-II-4No12/2*45	Local fan	1
FBDCZ-II-4-No 12/2*45	Local fan	1
BD-II-6-No 12/2*30	Local fan	1
FBD6/2*15	Local fan	18
FBDY6/2*22	Local fan	2
FBDY6.3/2*30	Local fan	3
FBDY6.7/2*37	Local fan	2
JBT 52-2	Local fan	4
YBT 42-2	Local fan	5

Fig. 3. The locations of 6 main fan stations in mine ventilation network
Rys. 3. Lokalizacja sześciu głównych stacji wentylatorowych w sieci wentylacyjnej

ΣQ_{lc}: Total flow required for the longwall face, m³/s.
ΣQ_{cb}: Total flow needed for the roadway heading or heading, m³/s.
ΣQ_{ht}: Total flow required for the stations, m³/s.

The value of Qm is manually calculted equal to 304 m³/s.

Total ventilation pressure of mine (hm) is counted using Equation (2) [9]:

$$h_m = \Sigma h_{ms} + \Sigma h_{cb},\ mmH_2O \qquad (2)$$

where:
Σh_{ms}: The total hypotension is caused by the frictional resistance of the segments that follow each other in airflow, calculated from the beginning to the endpoint. The pressure of tunnel i (hms) is calculated according to formula (3).

$$h_{ms} = \alpha_i \frac{L_i \times P_i}{S_i^3} \times Q_i^2;\ mmH_2O \qquad (3)$$

In which:
α_i: The aerodynamic resistance coefficient in tunnel i on the airflow, kGS²/m⁴;
L_i, P_i, S_i: Length, circumference, the cross-section of the tunnel i;
Q_i: The amount of wind going through tunnel i, m³/s.
Σh_{cb}: The total hypotension due to local resistance calculated by an airflow. In fact, it is often taken from 10 to 25% of Σh_{ms}.

The value of h_m is manually calculted equal to 1994.68 Pa.

The velocity of airflow at tunnel i (vi) is computed according to equation (4):

$$v_i = \frac{Q_i}{S_i};\ m/s \qquad (4)$$

Where: Q_i, S_i are flow and area of tunnel i, respectively.

3. Simulating the ventilation network in Ventsim DESIGN

3.1. Simulation of the ventilation network

In order to simulate the mine ventilation of Duong Huy coal mine, we implement according to the steps in subsection 2.1. The diagram of the mine ventilation in AutoCAD is presented in Figure 1.

And then, we import this diagram into Ventsim DESIGN. Next, we put data for all the airways of the mine ventilation network. The mine ventilation diagram is shown in Figure 2.

When simulate the ventilation network of Duong Huy coal mine, we use several types of fans currently used in the mine shown in Table 1 [8].

The locations of 6 main fan stations are represented in Figure 3.

All the fans use exhaust ventilation method.

Summary of key simulation results of the mine ventilation network is shown in Figure 4. The mine ventilation network in-

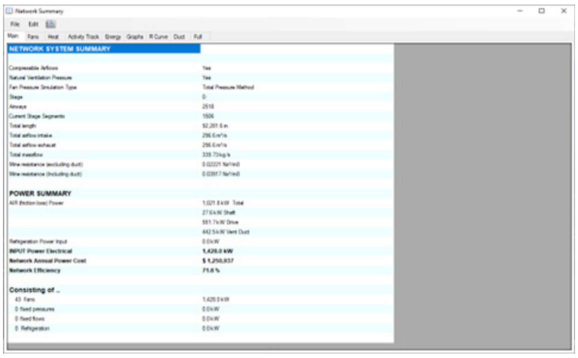


Fig. 4. Summary of main simulation results of mine ventilation network
Rys. 4. Podsumowanie wyników symulacji sieci wentylacyjnej

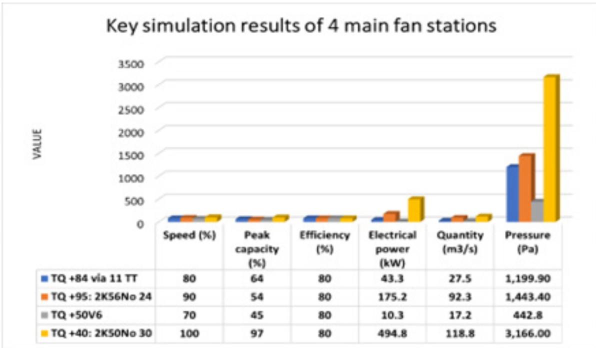


Fig. 5. Simulation results of main fan station
Rys. 5. Wyniki symulacji stacji wentylatorów głównych

cludes 2518 airways, total length of 92,281.6 m, total airflow is 296.6 m^3/s; mine resistance (including duct) is 0.03917 Ns^2/m^8.

Figure 4 shows the main simulation results of 4 main fans used in the mine ventilation. Summary of the main factors is presented in Figure 4. The simulation results show that fan named "TQ +40: 2K50No30" has the best performance with the peak capacity is 97% while the remaining fans having this factor from 45 to 64 %. This means the TQ +50V6 has the worst performance with the peak capacity is 45%. These fans will be efficient used in the future when the mine is deploying the expansion of mining area. The mine will go deeper.

The calculation results of some important factors according to manual method and using Ventim DESIGN as shown in Table 2. It is clear that the difference between two methods is not significant. This means we can efficiently apply the software to simulation of the ventilation network of Duong Huy coal mine.

3.2. Prediction of the escape routes

This feaure is to offer the best/shorted path form the position of the breakdown (due to fire, tunnel collapse, water flooring, gas explosion, etc.) to the safe location (entrance/exit surface, refuge bay, etc.) with the shorted of moving time. According to [5], some urgent situations can be shown as:

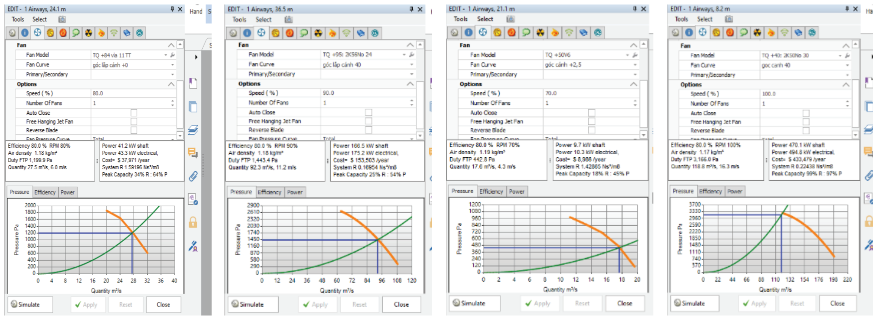
- Mine fires or explosions where some escape routes or parts thereof may be flushed with fire or pernicious gases;
- Blockage of an escape route through mine collapse or flooding;
- Some parts of a mine may not have planned or formed fully escape routes into all areas of the mine.

In Ventsim DESIGN, Dijkstra's algorithm [10] is developed to find out the safest and fastest path solutions. The mine ventilation is seen as a direction-oriented graph where node (junction) is the top of the graph, airway is the edge of the graph. The weighting of the connections between nodes needs be estimated. Relevant considerations for graph weighting include [5]:

- The speed and safety of escaping personnel include the walking slope or gradient of the path;
- Can the path can be driven, walked or climbed (with a ladderway)?
- The presence of blockages or non-route controls like inaccessible regulators or walls;
- The presence of smoke, gas, fire or impassable water within a pathway;
- What about if the roadway is entrance or return?
- The presence of mask stations or rescue bays in those roadways.

The speed and walk time of workers are computed according to Naismith's method [11, 12]. The method is based on a horizontal walking pace of 4.5 km/h with an inclined penalty of an extra hour travel per 1000 m vertical distance. Because of reduced visibility, a further walking speed penalty of 40% is recommended for travelling in adverse conditions such as smoke or gas. The speed (Sw) and walk time (Tw) of workers are counted according to Equations 5 and 6.

$$S_w = \frac{TD}{\frac{TD}{4.5}+H}\times(1-E);\ \text{km/h} \qquad (5)$$



a) b) c) d)

Fig. 6. Main simulation results of 4 of 6 main fans used in the mine ventilation. Names of fan stations: a) TQ +88 via 11TT; b) TQ +95: 2K56No 24; c) TQ +50V6; d) TQ +50 2K50No 30

Rys. 6. Główne wyniki symulacji dla 4 z 6 głównych wentylatorów Oznaczenia wentylatorów a) TQ +88 via 11TT; b) TQ +95: 2K56No 24; c) TQ +50V6; d) TQ +50 2K50No 30

Tab. 2. The calculation results of some important factors according to manual method and using Ventsim DESIGN software

Tab. 2. Wyniki obliczeń najważniejszych czynników metodą ręczną i z wykorzystaniem Ventsim DESIGN software

Method of calculation	Quantity of the mine (m^3/s)	Pressure of the mine (Pa)
Manual	304	1994.67
Ventsim DESIGN	296.6	1958.68
Difference	**±2.4%**	**±1.8%**

Tab. 3. Parameters used for simulating the escape routes in urgent cases

Tab. 3. Parametry wykorzystane w symulacji dróg ucieczki w warunkach niebezpiecznych

Scenario	Airway with breakdown	Positions of refuge bays	Number index of Entry/Exit branches
1	SSC cho N-8-1 V8 KN	DV+45 V7 Khu Nam; XV-100 Khu BI	509, 511, 596, 1126, 1275, 1280, 1306, 1310, 1312, 1358, 1359, 1388, 2061
2	TKD lap gia cho DB-11-3B V11 DB		

$$T_w = \frac{S_w}{L};\ \mathrm{h} \qquad (6)$$

Where:
TD: Total distance (km);
L: Leng of pathway (km);
H: Vertical height up only (km);
E: Environmental penalty factor (0% = clear, 40% = smoke).

For this case study, we assume some positions which usually happen the breakdowns in practice. Then we use function of escape routes in the software for finding out the path to the safe location. In this simulation scenario, we suppose the breakdown positions as described in Table 3.

After simulation with the function of escape routes in the software, the simulation results of scenario 1 are indicated in Figure 8.

The selected path from the breakdown position (SSC cho N-8-1 V8 KN) to the surfaces is Exit Branch which has number index equal to 1306, with the total time is 59 minutes, including 40 minutes of walking time, and 19 minutes of climbing time. The total distance is 2,400.5 m. The total time of pathways to two refuge bays are 1 hour 21 minutes and 1 hour 25 minutes, consisting of time walking and time climbing. It's clear that, the selected path is the best pathway in this case. Figure 9 shows the selected path for the first scenario. The selected path is highlighted while the other airways hidden.

In the second scenario as shown in Figure 10, the selected path is the way to the Entry branch named "Ngam TG -100/+160" with 41 minutes of walking time only. The total distance is 2,073.9 m. The total time of pathways to two refuge bays "XV-100 khu BI" and "DV+45 V7 Khu Nam" are 14 minutes and 16 minutes walking time only, respectively. Hence, the best pathway in this scenario is the way to the refuge bay "DV+45 V7 Khu Nam". Figure 11 shows the selected path for the second scenario. The selected path is highlighted while the other airways hidden.

The simulation of urgent situations will show the best path to the safe location. This will protect the workers when having disasters. The simulation of urgent situations will show the best path to the safe location. This will protect the workers when having disasters.

4. Conclusion

In this article, we assess the performance of application of Ventsim DESGN software to the mine ventilation network of Duong Huy coal mine. The simulation results show that the software operates stably, exactly, lively. The mine ventilation network of Duong Huy Coal mine is quite complicated and typical for underground coal mines in Vietnam. So the successful development of the ventilation simulation will create many chances in applying the Ventsim DESIGN software to other underground Coal mines in Vietnam. In the future, we will study to simulate heat, contaminant, fire for the mine ventilation network of Duong Huy Coal mine.

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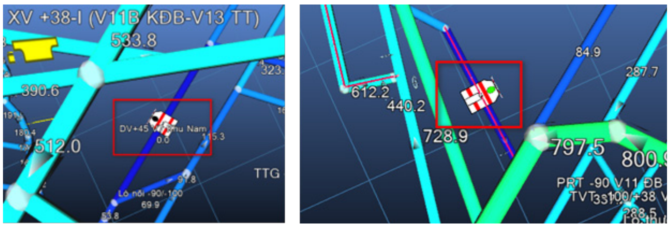

Fig. 7. Positions of the Refuge Bays
Rys. 7. Lokalizacja komór ucieczkowych

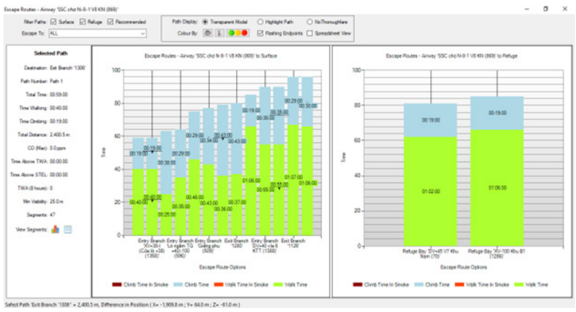

Fig. 8. Simulation result of the escape routes function for scenario 1
Rys. 8. Symulacja dróg ucieczkowych według scenariusza 1

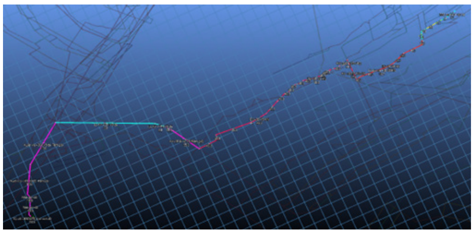

Fig. 9. The selected path is prominently displayed while the other remaining airways hidden in scenario 1
Rys. 9. Wybrana droga ucieczkowa jest wyraźnie widoczna, podczas gdy pozostałe drogi są opisane w scenariuszu 1

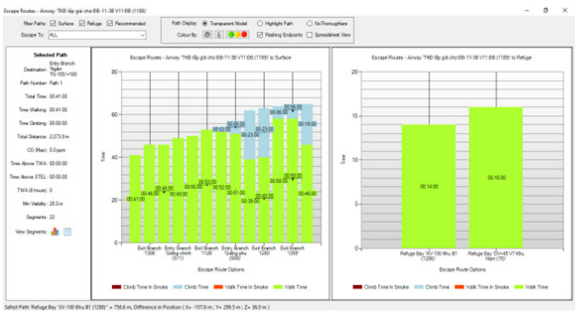

Fig. 10. Simulation result of the escape routes function for scenario 2
Rys. 10. Symulacja dróg ucieczkowych według scenariusza 2

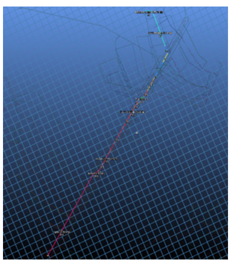

Fig. 11. The selected path is prominently displayed while the other remainning airways hidden in scenario 2
Rys. 11. Wybrana droga ucieczkowa jest wyraźnie widoczna, podczas gdy pozostałe drogi są opisane w scenariuszu 2

work as well as coordinated in using the Ventsim DESIGN software to simulate the whole ventilation network with realistic data of the mine.

Conflicts of Interest

The authors declare no conflict of interest.

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Symulacja i przewidywanie dróg ewakuacyjnych dla Sieci Wentylacyjnej Spółki Węglowej Duong Huy przy użyciu oprogramowania VENTSIM DESIGN

W podziemnym górnictwie węgla wentylacja odgrywa ważną rolę, ponieważ zapewnia wystarczającą ilość świeżego powietrza dla pracowników i zmniejsza negatywne skutki uwalniania się szkodliwych gazów z pokładów węgla oraz możliwość wystąpienia wybuchów. Ponadto, gdy eksploatacja sięga głębiej, zadanie wentylacji jest coraz ważniejsze. W celu zagwarantowania dobrej wydajności wentylacji do obliczeń sieci wentylacyjnej stosuje się oprogramowanie symulacyjne. W artykule przedstawiono zastosowanie oprogramowania Ventsim DESIGN dla obliczenia sieci wentylacyjnej kopalni Duong Huy oraz przewidywania dróg ewakuacyjnych w nagłych przypadkach.

Wyniki symulacji pokazują, że program dobrze wylicza wydajność sieci , warunki stabilnej pracy oraz odpowiednie drogi ewakuacyjne w nagłych przypadkach.

Słowa kluczowe: *sieć wentylacyjna, Ventsim DESIGN, drogi ewakuacyjne, spółka węglowa Duong Huy, Vinacomin*