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ASSESSING THE IMPACT OF POSITIVE PRESSURE VENTILATION ON THE BUILDING FIRE – A CASE STUDY

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ABSTRACT: Closed-space fires often occur in Hungary, so it is necessary to examine the effects of fires on building structures, taking into account Hungarian architectural features. Fires inside the buildings are characterized by intense heat development and smoke generation that can cause permanent damage to the building structures. Heat and smoke extraction during fire extinguishing is based usually on natural ventilation. Not only being a non-effective process also makes it more difficult to accomplish firefighting tasks. Experiments in this research have been conducted with mobile positive pressure ventilation (PPV) in order to increase the efficiency of the firefighting process and to reduce the adverse effects of fires. The tests have been carried out in unused buildings, providing real conditions. Practical application has been examined in order to reduce the harmful effects of closed-space fires and to provide guidance for professional use. This research based on observations and experiments contributes to enhancing fire safety.

Keywords: Building structures, Closed-space fires, Fire loads, Positive pressure ventilation

1. INTRODUCTION

Increasing the fire protection of building structures, a better understanding of the combustion process, scientific examination of the negative effects of fires on building structures is an important issue even nowadays. Many of the world's scientific centers and laboratories deal with this topic. Despite careful planning and effective fire prevention, fires can occur in buildings of any function posing a threat to the people, the stored materials, building structures and the environment. Reducing the adverse effects of fires and promoting firefighting is, therefore, an important task.

Firefighters are exposed to many dangers within a burning building. The heat radiating from hot flue gases accumulated under the ceiling helps to spread the fire, while the high temperatures threaten trapped occupants, the building structure and the firefighters. Smoke obscures exit and access routes, greatly delaying escape and firefighting. Therefore, it is vital to divert damaging heat and resulting fumes and ensure proper ventilation.

Ventilation efficiency can be increased by using positive pressure ventilation. This paper evaluates new types of fans, with effective air flow rates higher than previously-used fans as they are installed and tested to determine their proper use. The methodology for installation of PPVs is considered especially for residential buildings since the majority of closed-space fires occur there. An average dwelling fire is considered with relevant building characteristics for Hungary.

In case of fire protection efforts should be made to reduce environmental damages or to apply methods or materials that are not harmful or are less harmful to the environment.

2. CORRELATION BETWEEN BUILDING CHARACTERISTICS &VENTILATION

In order to reduce the detrimental effects of intensive heat on building structures, natural ventilation is mostly used for heat and smoke extraction [1].

During a fire, in addition to the use of windows, the most efficient way to divert hot flue gases from a building flooded with smoke is to create at least one opening at the highest part of the building, thus relying on the physical phenomenon of the upward flow of hot flue gases.

It has to be emphasized in case of natural ventilation that the efficiency of these systems depends heavily on the conditions of the area affected by the fire and on the weather conditions in the location of the fire. These factors should be taken into account since the planning of the ventilation always implicates the possibility of a faulty decision [2].

The essence of natural ventilation is that hot flue gases filling the enclosed spaces flow out through openings higher than the line of pressure equalization, and the outflow air is replaced by cold air through openings underneath the pressure equalization line [3].

The most efficient heat and smoke diversion are the openings installed on the ceiling of the room. However, openings are mainly located on the side wall of the room, ventilation occurs less effectively.

The efficiency of natural ventilation is greatly influenced by the following factors:

- factors concerning building structure:
  - size, the location of openings,
  - the height of the room,
  - the distance between flue gases and openings,
  - obstacles in the airflow path,
- factors concerning weather:
  - the humidity of the air,
  - external and internal temperature difference,
  - wind direction [4].

Built-in mechanical smoke extraction systems can offer sufficient ventilation; however, implementation is not feasible in most buildings, especially in case of residential buildings and family houses. The emphasis is placed on the development of mobile devices to achieve serious benefits in smoke extraction and fresh air supply. The efficiency of ventilation can be further enhanced with mobile fans, which have been tested for practical applications during the presented experiments.

3. DESCRIPTION OF EXPERIMENTS

According to our knowledge, if fresh air is brought into the fire, combustion and the spread of fire is increased. With proper heat and smoke extraction the spread of the fire slows down, the extinguishing becomes easier. PPV provides the solution to improve the efficiency of the process not only diverting the heat and smoke but creating of a directed, orderly flow [5]. Several attempts have been made to apply PPVs in the United States, taking into account the factors relevant to that area.

Those tests provide the basis for our experiments [6]. A fan installed at the entrance to the building (inflow opening) creates a higher pressure in the closed space than the outside atmospheric pressure. The overpressure ranges between 4-5 mbar on average in the room needing ventilation.

The differential pressure causes an air flow between the inflow and outflow openings passing through the burning room forcing the hot air, toxic gases and other resulting combustion products to leave the building together with the air flow. Hot air, smoke, and combustion gases are replaced by cool air helping to maintain primary and secondary escape routes, thus revealing people in trouble, as well as supporting the detection of fire nest and assisting firefighting [7].

3.1 Location of the experiments

The site of the experiment was a two-story brick residential building with brick main walls and partition walls, slabs made of reinforced concrete beams and concrete lining, and plastered concrete flooring. The inner height was 2.75 m. The expected (lowest) temperature was 10 ºC in the experimental rooms (38 m2, 105 m2). Tests were carried out by the units of the professional fire department.

3.2 Preparation of tests

Required measuring instruments:

- Temperature meters: TECPEL Thermometer, RS-232 Thermology;
- Flue gas analyzer: TESTO 325-1 M;
- Pressure gauge: DIG. BAROMETER DM-120;
- Water meter used: Hydrometer NA 80;
- Wind speed meter: ANEMO-DEUTA;
- Remote temperature sensor: Raynger MX2;
- Stoppers.

Other necessary tools, materials:

- Airborne turbo fan manufactured by LEADER GmbH, type MT 260 of 60,000 m3 / h;
- Smoke generator: ANTARI Z-3000;
- Thermal camera: MSA EVOLUTION 5000;
- Combustible material (pallet, mattress, wood);
- Stick with lighter.

Before executing the combustion experiments, it was necessary to determine the optimal positioning distance of the fan from opening inflow with the help of a smoke generator and air flow velocity monitor, taking into account the change in the air pressure in the ventilated room.

Standard unit fire flames were used and parameters of the fire were continuously measured and recorded during the development and extinction of the fire in both cases: using standard extinguishing method and applying the PPVs. Accordingly, the change in the temperature of the burning room (0.3 to 2.6 m in height), the change in the volume percentage of the oxygen (O_2) to the carbon monoxide (CO) (at 0.3 m height) was recorded as a function of time. The number of extinguishing materials used for the two different firefighting methods was also measured and recorded.

In addition, the effect of PPV on the spread of fire had to be monitored.

3.3 First experiment

The essence of the two-stage experiment is to determine the following parameters of the turbo ventilator: the degree of tilt and the optimal positioning distance from the inlet opening (door). So the airflow rate was continuously measured at the shutter of the outflow opening (window). The locations for the turbo ventilator were:

- 3 m from the inlet opening,
- in the inlet opening,
- at different distances between these two locations.

Table 1 Measurement results of airflow speed and air pressure change

	t (sec)	v (m/s)	p (mbar)
Ventilator 1.2 m from inflow opening	00:00	0.0	35.00
	00:30	2.5	8.00
	01:00	3.0	7.00
	01:30	2.5	9.00
	02:00	3.0	8.00
	02:30	3.0	6.00
Ventilator in inflow opening	00:00	0.0	17.00
	00:30	1.0	6.00
	01:00	1.5	8.00
	01:30	1.0	6.00
	02:00	1.5	7.00
	02:30	1.5	6.00
Ventilator 3.0 m from inflow opening	00:00	0.0	14.00
	00:30	1.5	6.00
	01:00	2.0	5.00
	01:30	1.5	6.00
	02:00	2.0	6.00
	02:30	2.0	5.00

The results of the measurements are given in Table 1. During the analysis, it was found that the highest flow velocity (3.0 m/s) was measured in the case of a fully tilted turbo ventilator (20º) spaced 1.2 m away from the inlet, the results are shown in Figure 1.

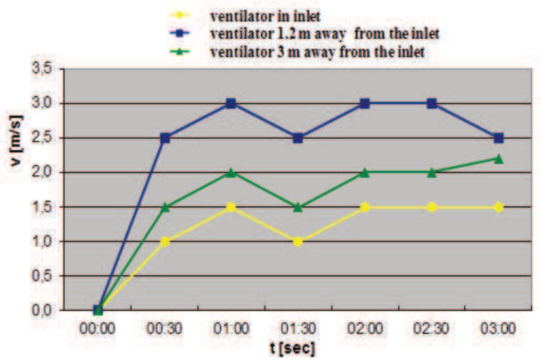

Fig.1 Change in airflow velocity at outflow opening based on the position of the ventilator

The change in air pressure in the examined room was also measured (Table 1). It was found that 9 mbar was the highest air pressure measured between the door line and the 3 m placement distance at a distance of 1.2 m (after opening the shutter of the outflow opening). The result is presented in Figure 2.

The results of this measurements helped to determine the optimum positioning distance of the fan for later measurements. In addition to the fire ignition experiment, ventilation was also examined using cold smoke produced by a smoke generator. Complete ventilation took place within a short time. This experiment supports and proves the assumption that the use of the fan in smoke-saturated rooms significantly improves the visibility conditions even in the first minute. This helps to orient the incoming firefighters, allows detection of the fire nest, and offers the quickest access to trapped occupants.

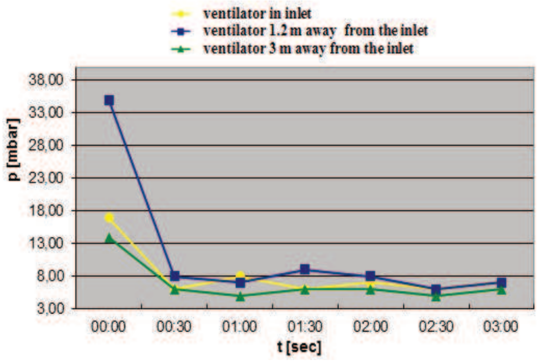

Fig.2 Overpressure changes in the ventilated room depending on the placement of the fan

In subsequent experiments, heat and smoke generation was ensured by unit fires. In all cases, the same amount of wood and mattress was used for unit fires. The ignition temperature was assured by a gasoline ignition rod. In order to achieve the expected realistic measurement results, the extinguishing of the unit fires was carried out according to the same methodology. In order to be able to compare the results the same persons carried out the firefighting, recorded the intervention procedures, and documented results of the experiments.

3.4 Second experiment

In this experiment, the turbo ventilator was not used. The extinguishing of the unit fire was achieved using a conventional method using only one water jet "C" to ensure comparability. The unit fire quickly filled the experimental room with smoke.

The maximum temperature reached 262°C at a height of 2.6 m after a 2-minute pre-heating. In order to reduce the fire loads on the building structures, the temperature was not allowed to rise, the window was opened and intrusion started through the door. Of course, it should be taken into account that the relatively rapid approach of fire nest was due to the prior knowledge of heat conductor since it is harder to orient and find a fire in dense, smoke-filled rooms in an unknown area.

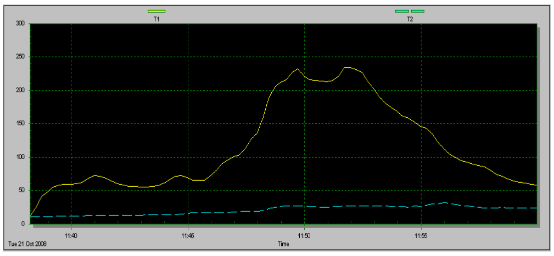

Fig.3 Changes in temperature in case of firefighting with the conventional method

The saturation of the smoke, however, did not change despite the open window, and even the visual conditions decreased to a minimum (from 1.5 to 0.5 meters) due to the generated smoke and steam. After extinguishing the fire, the temperature of the room was still 180ºC at a height of 2.6 m, while at 0.3 m it remained well below 50ºC. The smoke from the room began to disperse very slowly. Significant improvement in visual acuity and temperature decrease below 50ºC at 2.6 m required more than 10 minutes after extinguishing.

3.5 Third experiment

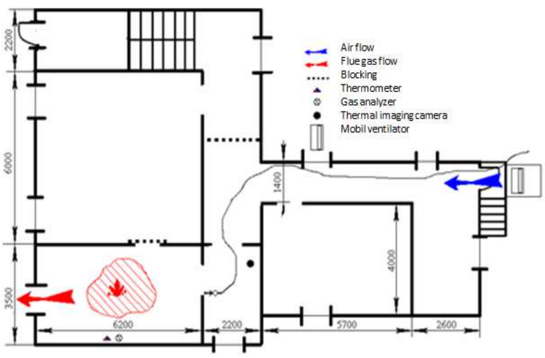

Fig.4 Layout of the building and the intervention

The circumstances were the same as in the second experiment. After the unit fire ignition and pre-heating, as the ambient temperature reached 220ºC, the window and front door of the room were opened and turbo fan was started. Intrusion began after 10 seconds as shown in Figure 4.

The visibility improved rapidly because of the use of the PPVs, smoke and heat flowed out the window. The firefighters immediately found the relatively clear fire nest and began fire extinguishing. The temperature of the room decreased drastically from 220°C to 70°C after the fan was started (Figure 5).

Better orientation and much lower temperatures made it easier and safer for the intervention, reducing the fire load on building structures.

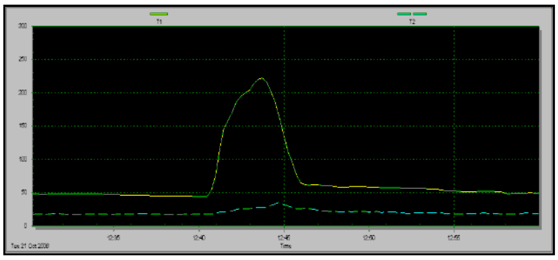

Fig.5 Fire extinguishing using PPV

4. EVALUATION OF RESULTS

Based on the airflow rate and air pressure measurement used in the first experiment, the optimum positioning distance of the turbo fan can be established on the site, which has been proved during subsequent experiments. It can be concluded that with the use of PPVs, the approach of the fire nests, i.e. the start of firefighting proved to be faster than with the use of the conventional method, thus reducing the fire load on building structures. The advantage of using PPV is clearly shown based on the temperature variation measured in case of the two types of extinguishing method to eliminate unity fires (Figure 6).

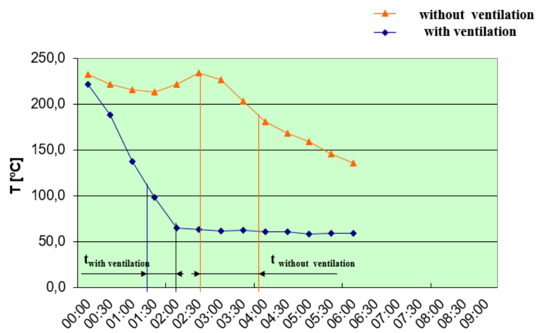

Fig.6 Measurement results comparing temperature change and fire extinction time

It can also be stated that firefighting with the use of PPV can be accomplished faster and more safely thanks to better visibility and lower temperature (t without ventilation > t with ventilation).

Figures 7 and 8 show the measured temperature at 0.3 m, the results volume of oxygen (O_2) and the carbon monoxide (CO) concentration meter. It can be stated that with the use of PPV if the trapped person remains near the floor, his physiological functions are not impaired.

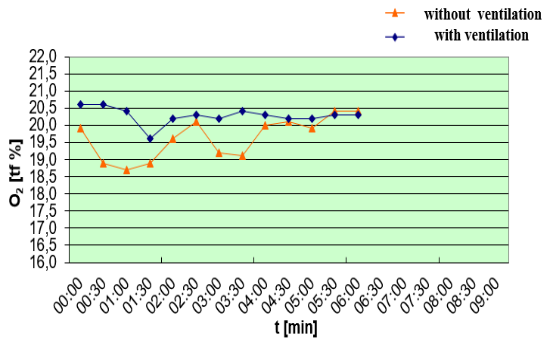

Fig.7 Comparison of the change in the volume percentage of oxygen

The temperature remained well below 50°C, ensuring that the oxygen content of the air was minimum 15 volume%. Although the concentration of carbon monoxide exceeded the permissible value, the trapped person would survive 1-2 hours depending on the health of the individual. Based both on the volume percentage of the oxygen (O_2) and on carbon monoxide (CO) concentration, it can be clearly stated that physiologically more favorable condition is provided by ventilation.

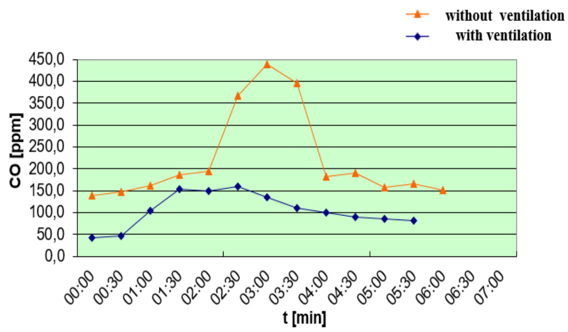

Fig.8 Comparison of the change in the volume percentage of carbon monoxide

Table 2 The time of extinguishing and the amount of fire water used

Firefighting method	Water pump operation time (sec)	Used extinguishing water (liter)
Conventional extinguishing method	265	146
Firefighting with PPV	130	58

Analyzing the data it can be clearly determined that the use of PPV facilitates firefighting, with approximately 50% less time and approximately 60% less extinguishing water than in case of conventional extinction method was needed for successful firefighting. The use of PPV greatly reduces the fire load on building structures as well as any secondary damage. These experiments also proved that proper use of PPV reduces the internal temperature, thereby inhibiting the formation of harmful combustion gases.

5. CONCLUSION

Most of the closed-air fires occur in residential buildings. In order to save lives of the trapped people, to reduce the fire load on building structures, and to protect the utilities from fire damage, it is particularly important to have effective fire-fighting, and for this, it is essential to have proper ventilation. During this research, several experiments have been carried out to demonstrate the efficiency of using PPVs parallel to conventional extinguishing methods in enclosed areas.

The conditions for the practical application of mobile fans were also tested, providing guidance for the professional use. Experiments and experience gained so far clearly demonstrate that mobile ventilation can reduce the adverse effects of fires under appropriate conditions and increase the efficiency of firefighting interventions. This research can contribute to the practical application of mobile ventilation.

6. ACKNOWLEDGEMENTS

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