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Climate change, fires and their impact on safety

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Abstract. Our planet is warming due to climate change. Along with this, the incidence of fires is increasing. Fires negatively affect the environment. Fire prevention is one of the safety priorities in the Czech Republic and in the world. One aspect of safety is the evacuation of people, animals and potentially property. The paper will present a case study of escape route ventilation.

1. Introduction

Climate change has long been a discussed topic [1]. Climate change is most likely caused by exacerbation of the natural greenhouse effect of the atmosphere by human activity and an excessive increase in anthropogenic greenhouse gas emissions [2]. Climate change brings about a change in conditions either by a direct change in climatic conditions (e.g. an increase in temperature, a change in the distribution of precipitation) or by a change in other conditions related to the climate (e.g. a change in soil moisture, an increase in evaporation). Climate change is also accompanied by extreme phenomena such as high temperatures, drought, torrential rains, floods, cyclones, etc. [2] It is possible to respond to changing climatic conditions with mitigation measures (prevention or slowing down of changes) or adaptation measures (coping with change), but preferably by a combination of these.

There is no doubt that climate change can become manifest in many areas. One of them is the area of safety, especially the area of fire protection. Rising temperatures can cause an increasing number of fires in the outdoor environment (e.g. forests, grasses). A reduction in soil moisture can cause outdoor fires to spread faster. A lower level of the local water supply, which is most often used for extinguishing fires, can make fires more difficult to fight and last longer [3, 4].

However, climate change can also have an impact on the fire safety of buildings. The requirements for ensuring the safety of buildings within the European Union are based, in particular, on the Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC. Fire safety requirements are part of the requirements that buildings must meet. In the event of a fire, these requirements include maintaining the load-bearing capacity of the structure, limiting the spread of fire inside and outside the building, ensuring the evacuation and rescue of people and ensuring the safety of rescue units [6]. Evacuation and rescue of people in case of fire is one of the most important requirements for constructions abroad [7] as well as in the Czech Republic [8, 9].

The development of fires is accompanied by attendant phenomena that fundamentally affect the safety of persons. These are mainly the occurrence of combustion products, reduction of oxygen concentration, the occurrence of flame and the generated heat [10]. These related phenomena also have a negative impact on the environment. The basic factors that affect evacuation include the physical and mental condition of the evacuees, the construction design of the building and the characteristics of its operation [11]. One of the most significant threats to people when evacuating



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buildings is the incidence of smoke. Smoke is a dispersion system of solid particles measuring 10^{-5} to 10^{-7} cm, dispersed in gaseous combustion products. The basic characteristics of smoke in relation to the evacuation of people include its temperature, toxicity and optical density [12, 13].

Evacuating people from buildings in the event of a fire takes place via escape routes, which can be classified into unprotected, partially protected and protected. Protected escape routes can be divided into types A, B or C based on their layout and method of ventilation. Protected escape routes provide protection against the effects of phenomena accompanying fires. Some of the types of protected escape routes can also be used as emergency routes for rescue units [14, 15]

The high level of safety provided by protected escape routes is given by their separation of the fire from other areas of the building and ventilation. Ventilation of protected escape routes can be divided into natural, forced or overpressure [14]. All types of ventilation of protected escape routes have their advantages and disadvantages. The simplest ventilation system is natural ventilation. This is the cheapest way to ventilate protected escape routes. Its disadvantage is its considerable dependence on ambient conditions, especially on temperature, wind direction and speed, which significantly affect the efficiency of this type of ventilation [16].

Changing climatic conditions, which lead to a gradual, albeit slight, increase in the average temperature, may impact the efficiency of the natural ventilation of protected escape routes. The paper presents a case study of natural ventilation of protected escape routes, which demonstrates the possible influence of changing ambient temperature on the efficiency of this type of ventilation.

2. Materials and Methods

Natural ventilation of protected escape routes is based on the principle of the so-called *chimney effect*, which is caused by the difference in air densities inside and outside the building. Assuming lower temperatures in the exterior and higher in the interior of the building $T_e < T_i$, the density of gases on the exterior is higher than in the interior $\rho_e > \rho_i$, and air is sucked into the building through the lower opening or its lower part and expelled outside the building through the upper opening or its upper part. If the temperature in the exterior is higher than in the interior $T_e > T_i$, then the density of gases in the exterior is lower than in the interior $\rho_e < \rho_i$ and the phenomenon is of a *reversed nature* 0.

Natural ventilation of protected escape routes can be ensured by:

- Openable openings on each floor
- Openings in the highest and lowest points
- Ventilation openings 0

The most effective form of natural ventilation is to place the vents at the highest and lowest points. A case study was prepared for this form of ventilation.

2.1. Description of the building for verification of the case study

For the case study, the Fire Dynamics Simulator (FDS) mathematical fire model with the user superstructure Pyrosim version 2021.1.0224 was used. The FDS model is a computational fluid dynamics model developed by NIST (National Institute of Standards and Technology, Maryland, USA 0), which enables the determining of a number of parameters accompanying the development of fire for component “space volumes”. The model uses the Navier-Stokes equations, which are suitable for evaluating flows while taking into account smoke and heat transport. The above fire model uses Smokeview software as a tool for visualizing numerical calculations [19, 0. A calculation network with cell dimensions of 0.25 m x 0.25 m x 0.25 m was used for the calculation. The simulation time in the case study was 4 minutes (safe evacuation time of persons in the type A protected escape route).

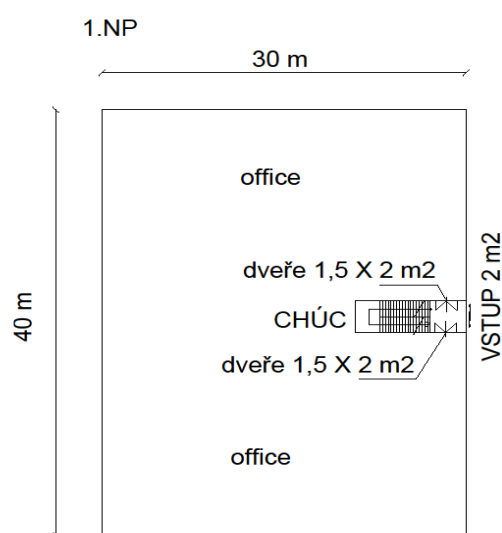
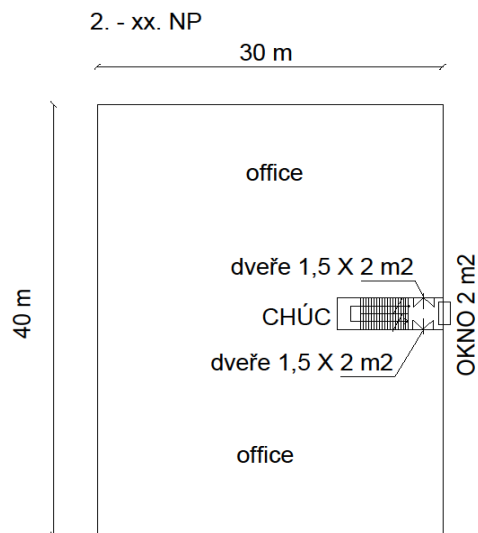
2.2. Input for the case study

The case study was prepared for an administrative building with offices, meeting rooms, storage spaces and restrooms for employees. Further information on the building and the external environment are given in Table 1.

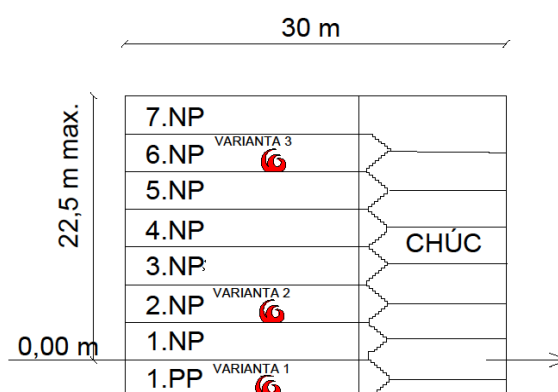
Table 1. Information on the building and external environment.

Characteristic	Selected value
Number of aboveground floors	7
Number of underground floors	1
Fire height of building	22.5 m
Calculated fire load	50 kg.m ⁻²
Interior temperature	20 °C
Exterior temperature	10 °C
Wind speed	0 m.s ⁻¹

Floorplans of individual floors of the building are indicated on Figures 1 and 2.

**Figure 1.** Typical floorplan 1st floor.**Figure 2.** Typical floorplan 2nd – 7th floor.

Building section with the indication of the location of fire foci in the building is shown in Figure 3.

**Figure 3.** Section of a typified building.

Fire engineering methods were used to design fire scenarios and design fires [21, 22]. For the case study, a copier catching fire in the premises adjacent to the protected escape route was chosen, i.e. in an office. The point of origin of the fire in individual simulations was located on the 1st floor, 2nd floor and 6th floor. The fire was detected by an electrical fire alarm and the ventilation of the protected escape route was activated immediately after the fire detection (opening of the door opening in the entrance floor and skylight in the ceiling structure at the highest point of the protected escape route). The door from the floor with the point of origin of the fire was opened (ongoing evacuation of people is expected).

In the case study, the values were the following parameters in the spaces of the protected escape route:

- Temperature in the spaces of the 1st floor, 2nd floor and 3rd floor
- Visibility in the spaces of the 2nd floor, 3rd floor and 4th floor
- Air flow through the ventilation openings (inlet and outlet openings).

In this chapter, partial results of the case study will be presented. This is a situation where the point of origin of the fire was located on the 2nd floor. Similar results were obtained in the other cases (other location of the point of origin of the fire).

The environment of the fire model is shown on Figure 4.

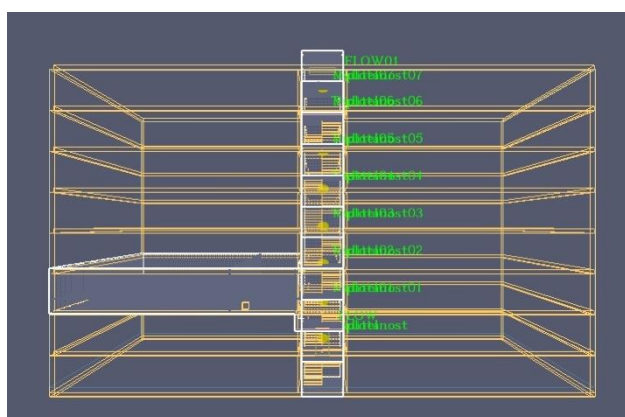
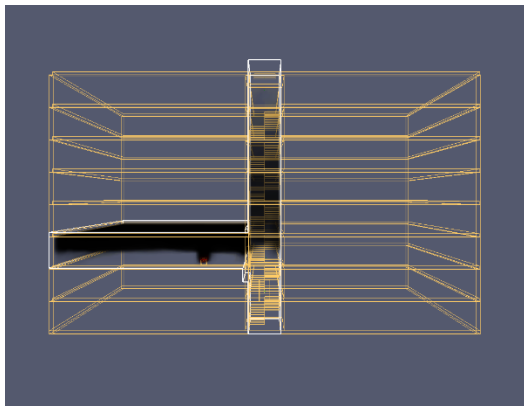
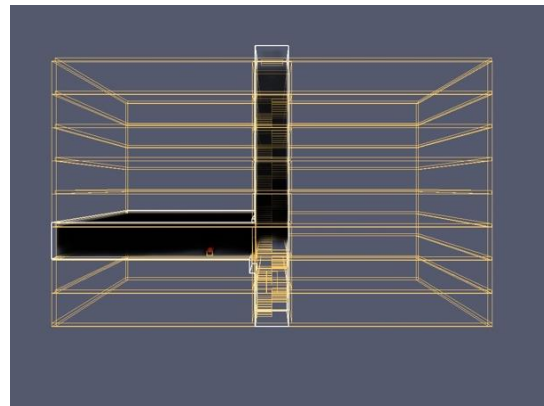


Figure 4. Administrative building in the fire model environment.

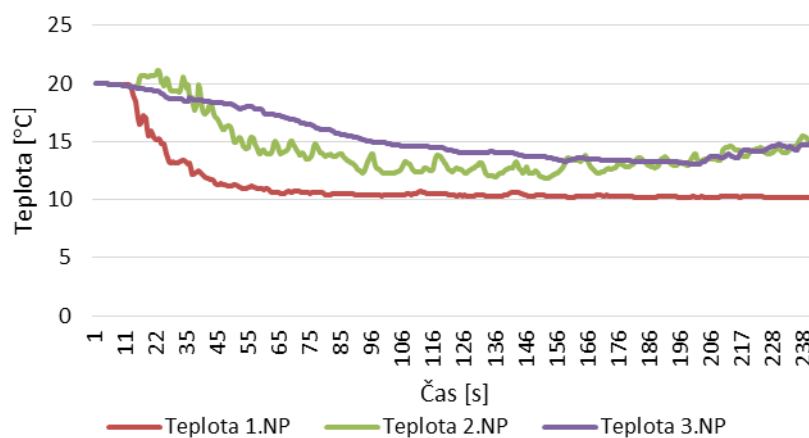
The spreading of smoke from the floors where the fire is developing into the protected for the time intervals 140 s and 240 s, is shown in Figures 5 and 6.

**Figure 5.** Smoke spread in 140 s.**Figure 6.** Smoke spread in 240 s.

From the above illustrations, it is clear that where there will be an open door on the floor where the fire originates, due to the evacuation of persons, the smoke spreads rapidly into the protected escape route.

3.2. Temperature in the spaces of the protected escape route

Temperature in the spaces of the 1st, 2nd and 3rd floor of the protected escape route is shown in Figure 7.

**Figure 7.** Temperature in the spaces of the protected escape route.

The chart shows that on the 2nd floor there was a slight increase in temperature in the initial phase of fire development. Subsequently, the temperature on all floors drops below the inlet temperature of the interior of the building.

3.3. Visibility in the spaces of the protected escape route

Visibility in the spaces of the 2nd, 3rd and 4th floors of the protected escape route is shown in Figure 8.

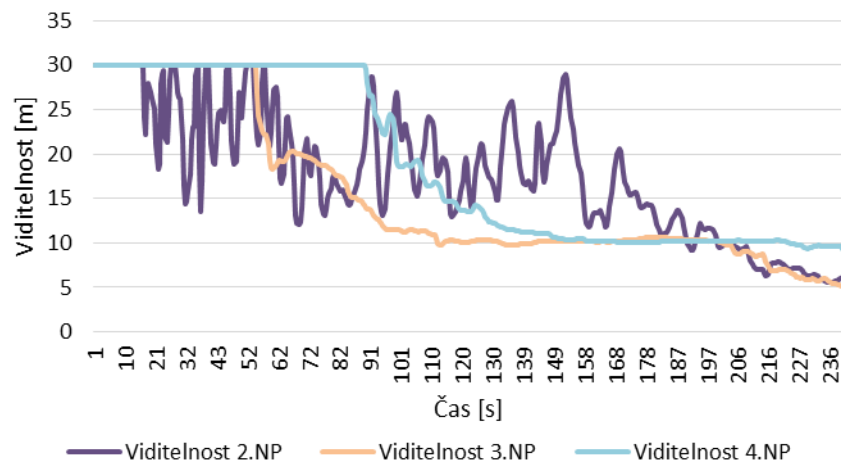


Figure 8. Visibility in the spaces of a protected escape route.

From the chart, we can see that the visibility gradually decreased on all floors. At the end of the simulation, it dropped to 10 m on the 4th floor, and to even lower values on the 2nd and 3rd floors, all the way down to 5 m.

3.4. Air flow through the ventilation openings in the spaces of the protected escape route

Air flow volume through the inlet and outlet openings of the protected escape route is shown on Figure 9.

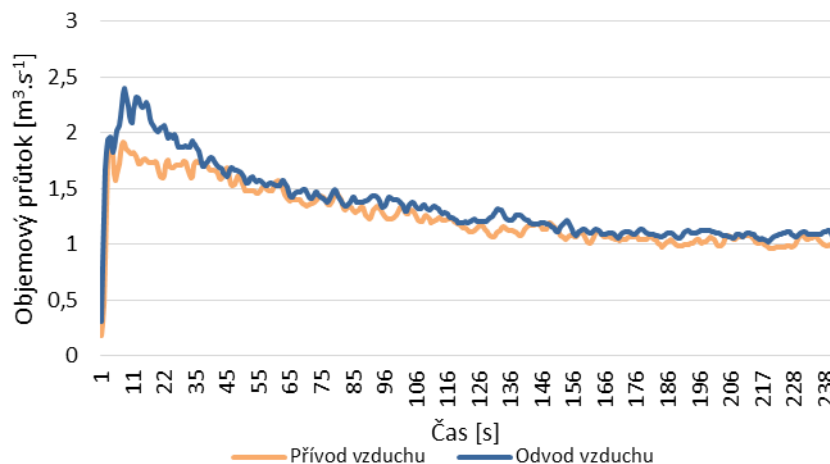


Figure 9. Air flow volume through the inlet and outlet openings.

It is clear from the figure that the air flow volume is highest in the initial phase of fire development. Later it is reduced to a value of 1 to 1.1 m³.s⁻¹. The air flow volume in the discharge opening is higher than in the inlet opening.

4. Discussion

The presented case study, where the temperatures inside the building are higher (20 °C) and lower outside (10 °C), simulates the conditions in the winter, when natural ventilation reaches its highest efficiency. It is evident from Figure 7 that on the 2nd floor there was a slight increase in temperature in the initial phase of fire development and only subsequently does it decrease. The temperature on the 1st floor dropped to 10 °C, which corresponds to the temperature outside. By the end of the simulation, temperatures on the 2nd floor and 3rd floor stabilized at 15°C. The original assumption of an increase in

temperature in the protected escape route area due to the development of fire was not confirmed. The temperature dropped due to the intake of cooler air from the outside.

We can see from Figure 8 that the visibility gradually decreased on all floors. At the end of the simulation, it dropped to 10 m on the 4th floor, and to even lower values on the 2nd and 3rd floors, all the way down to 5 m. By default, the evacuation of persons can be assumed to be safe if the visibility for people unfamiliar with the route is at least 10 m, and 3 to 5 m for people who are familiar with the route [23, 24]. The results of the case study show that the environment for evacuation could be considered safe if there were only people familiar with the environment, e.g. employees, in the building. If there were visitors in the building, the evacuation conditions would be unsatisfactory.

It can be seen from Figure 9 that the air flow volume is highest in the initial phase of fire development. Later, it is reduced to a value of 1 to 1.1 m³.s⁻¹, while the volume flow in the discharge opening is higher than in the inflow opening. The decrease in the air flow volume occurs due to the decrease in the indoor temperature compared to the initial value of 20 °C. As the interior temperature decreases, the difference between the interior and exterior temperatures also decreases, thereby reducing the pressure differences and consequently also reducing the air volume flows. At the same time, it is necessary to draw attention to the fact that the air volume flow of approximately 1 m³.s⁻¹ is not able to provide 10 times the air exchange in the protected escape route per hour, which is the standard required value for forced ventilation of this type of protected escape route.

The case study shows that the natural ventilation system is very sensitive to changes in outdoor conditions. In this context, it is clear that climate change, leading to an increase in average temperature, may affect the natural ventilation systems of protected escape routes. However, since the year-on-year increase in temperatures is in the order of decimal fractions of one degree Celsius, it can be assumed that the impact on the natural ventilation of protected escape routes will not be significant. It is other influences (for example, wind) that will become manifest.

5. Conclusion

Climate change has a major impact on various areas of life, including the people's safety. Rising temperatures, which can increase the frequency and development of open-air fires, along with declining water resources for firefighting are among its many impacts. At the same time, the fires themselves, which are accompanied by the formation of combustion products, have a negative effect on the environment and ultimately contribute to the emergence of negative climate change. One of the basic requirements for buildings is to ensure safe evacuation of people in case of fire. This includes evacuation via protected escape routes, which must be ventilated. One form of ventilation is natural ventilation. Changing climatic conditions, which lead to a gradual increase in the average temperature, may affect the efficiency of the natural ventilation of protected escape routes. The paper presents a case study of natural ventilation of protected escape routes performed by the FDS fire model. The results of the study show that the fire ventilation system is sensitive to temperature differences between the interior and exterior of buildings. Temperature changes caused by climate change can therefore affect the efficiency of natural ventilation of protected escape routes. However, due to the relatively low temperature increases, the impact of climate change on the ventilation of protected escape routes will not be significant.

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