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Green Solutions in the Fire Safety Strategy within a Medical Centre

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Abstract

This study investigates the behaviour of the hot gas temperature and associated smoke numerically in case of fire inside a medical centre. Fire Dynamics Simulator (FDS), provided by NIST, has been used to run the simulations for all proposed cases. Different solutions are suggested to reduce the severity of the hot gas temperature and smoke thickness, in case of fire inside the building. Among all investigated solutions, natural ventilation can do the best job. A mechanical fan is also an option, but not as good as a natural vent found at the top of the building. Natural ventilation can offer cheap and clean solutions to improve the safety level and environmental conditions inside the building, which offers an appropriate evacuation process for firefighters and civilians inside the building.

Paper type: Research paper

Keywords: Fire simulation, hot gas temperature, smoke thickness, natural and mechanical ventilation, medical centre.

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Introduction

Powerful computers and well-validated numerical programs have led to a significant expansion in the simulation of different fire scenarios inside modern buildings and large enclosures under a wide range of conditions and assumptions, including different ventilation systems (Nasr *et al.*, 2011; Vilfayeau *et al.*, 2015). Several mathematical models have been solved by well-established fire software and numerical simulators. CFAST (Consolidated Model of Fire Growth and Smoke Transport) is a two-zone fire model simulator for fire inside large enclosures (Peacock *et al.*, 2008). It solves the conservation equations for relatively large control volumes by dividing the compartment into two distinct “zones”, lower and upper ones (Olenick and Carpenter, 2003). The lower zone is the cooler layer and the upper zone is the hot layer. Both layers are assumed to be of uniform temperature and composition. Two-zone fire models are computationally inexpensive, compared to Fire Dynamics Simulator (FDS). Two-zone fire models can take into account building materials, ventilation conditions and room furnishings, but the uniform treatment of the hot layer limits their applicability to large compartments only.

Fire Dynamics Simulator (FDS) (McGrattan *et al.*, 2010) has been widely used for simulation of fire in public compartments and large enclosures, such as supermarkets (Ling and Kan, 2011) and offices (Matheislova *et al.*, 2010). It is a numerical model that solves the Navier-Stokes equation of the low-speed and thermally-driven flow. For a turbulent flow, it applies the Large Eddy Simulation (LES) model. FDS applies a single-step, radiative heat transfer equation for grey gas and mixing-controlled chemical reaction of air, fuel and products (McGrattan *et al.*, 2010). It predicts the temperature of hot gases and smoke of fires in large compartments and also carefully takes into account building materials, ventilation conditions and room furnishings. Modelling parameters related to the assumed mathematical approximations for different structures has been the focus of many studies (McGrattan, 2003; Wen, 2007; and Gourdain *et al.*, 2009). Proper ventilation systems help eliminate hot gases and smoke inside compartments and large enclosures, in case of fire in the place, and introduce cool air instead.

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Thus, cooler air provides a higher level of safety and a better environment for civilians and firefighters in such burning buildings. The effects of ventilation systems in confined and mechanically ventilated fires have been investigated before (Pretrel, 2012; Lassus, 2014, Beji and Merci, 2016; Hostikka *et al.*, 2017). Few studies investigate the effects of natural ventilation systems. Al-Jahmany *et al.*, found that natural ventilation in a multi-storey office building induces significant changes in the pressure and temperature readings of the hot gases in case of fire inside the place (Al-Jahmany *et al.*, 2024).

This study investigates mainly the effect of adding natural ventilation systems to more complex structures, *i.e.* buildings with hidden blocks, stagnant corners and shorter heights. The proposed medical centre has the target structure and meets the required criteria. It provides also a clear picture of adding natural ventilation systems to the building in reducing the temperature of hot gases and getting rid of associated smoke, due to the buoyancy effect, *i.e.*, the chimney effect. Natural ventilation can offer cheap and clean solutions (green solutions) to improve the safety level and environmental conditions inside the burning building. Thus, it offers an appropriate evacuation process for the firefighters and civilians inside the building. It improves also the lighting in the place and goes hand-in-hand with the environmental trend, which reduces the cost of the consumed energy in such places. Mechanical ventilation and water spraying (sprinklers) were also studied to make a fair comparison between the different systems.

1 Materials and Methods:

Improving the safety level within a real medical center, in case of a fire in the building, was the main goal behind this study. Green solutions, such as adding proper ventilation systems, have been suggested. **Figure 1** shows the investigated medical centre with a length of 24m, a width of 16m and a height of 4m. It has two main doors leading to the parking places. Each door has a width of 4m and a height of 3m. At the top of the building, there is a duct with a width of 2m and a height of 2m along the centerline of the building, *i.e.* with a length of 24m. Both natural and mechanical ventilation systems, shown in **Figure 2**, were studied to demonstrate the effect of these systems in reducing the temperature and smoke thickness (visibility) inside the burning building. Only the early growth stage, at the first ten minutes from the beginning of the fire, is calculated, *i.e.* the simulation time is 600s for all assumed cases. Fig. 2 shows the fire source a burning sofa assumed for both investigated cases, natural and mechanical ventilation systems. The ceiling, walls and floors are made of gypsum board 1/2in.

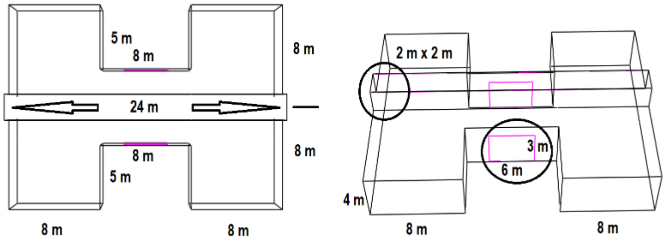

Fig. 1 The medical centre introduced in the current study. It has a length of 24 m, a width of 16m and a height of 4m with two main doors leading to the parking places. A ventilation duct at the top of the building is proposed, it has a width of 2m and a height of 2m along the centre, *i.e.* with a length of 24 m.

2 Results and Discussion

It is assumed that a fire occurred as a result of a burning sofa in the building. The sofa is located at the ground center point of the left block of the building, as shown in Fig. 2. The numerical simulations are investigated and introduced for both assumed cases 1 and 2. Case 1 is for a natural ventilation with an open vent of a width of 2m, and a length of 24m at the top of the building. Case 2 is for a mechanical ventilation (Fan) with an open area of a width of 2m and a height of 2m. The fan has a volumetric flow rate capacity of $10 m^3/s$, to get rid of the hot gases and smoke from the building. As a reference case, the numerical simulation of a fire inside a completely enclosed building with closed doors and no open ventilation openings was presented. The effect of spraying water (Sprinkler) at 4m of height directly above the burning sofa was also calculated to provide a fair comparison. The Sprinkler is switched on directly after the ignition of the fire.

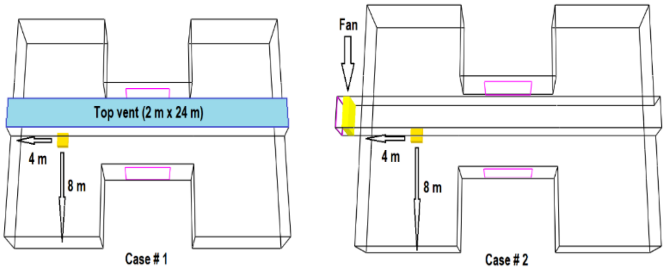

Fig. 2 The location of the burning sofa is assumed to be the same for both investigated cases 1 and 2. Case 1 is for natural ventilation with an open vent of a width of 2m and a length of 24m at the top of the building. Case 2 is for mechanical ventilation (Fan) with an open area of a width of 2m and a height of 2m. The fan has a volumetric flow rate capacity of $10 m^3/s$, to get rid of the hot gases and smoke from the building.

Figure 3 shows the average temperature (AT) of the hot gas inside the building as a function of time (t) for both natural and mechanical ventilation systems. For a completely enclosed building with closed doors and vents, the average temperature inside the building can reach 100°C, after 5min, only. Switching on one single Sprinkler directly after the ignition of the fire with open doors can reduce the average temperature inside the building to 57°C for the same period. Switching on fan mechanical ventilation with an open area of a width of 2m, and a height of 2m can do the same effect, if the fan has a volumetric flow rate capacity of 10m^3/s. The natural ventilation (top vent) with open doors can do the best effect to keep the average temperature inside the building at 20°C, all the time. Ideal green solution for the medical centre in case of fire inside the building. It is cheap, and clean and goes hand-in-hand with the environmental trend. It will offer also better lighting in the place and can save energy, too.

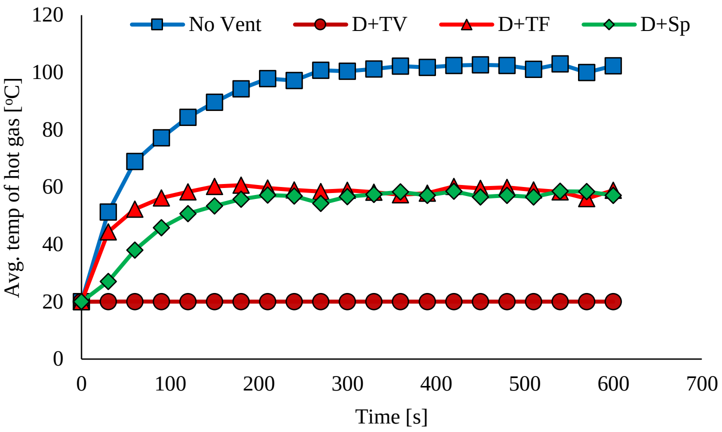

Fig. 3 Average temperature of the hot gas inside the building as a function of time for both natural and mechanical ventilation systems. No vent represents the reference case with a completely enclosed building, closed doors and vents. D+TV represents open natural ventilation -top vent- with open doors. D+TF represents a switched-on mechanical ventilation -top fan- with open doors. D+Sp represents a switched-on Sprinkler with open doors, only.

To get a clear picture, **Figure 4** shows the temperature of the hot gas directly above the sofa, at a height of 4m, as a function of time for both ventilation systems. The temperature of the hot gas will reach 115°C within 10min for the completely enclosed building with closed doors and vents. The natural ventilation (top vent) with open doors still achieves the best effect with a slight increase in temperature from 20-26°C directly above the fire source. The natural ventilation (top vent) can do again a great job even with closed doors, as shown in **Figure 5**. It can keep the average temperature inside the building at 20°C all the time. While the temperature directly above the sofa, at a height of 4 m, will rise from 20-35°C. The effect of natural ventilation with closed doors is still significant in reducing the aggressive behaviour of hot gases inside the building.

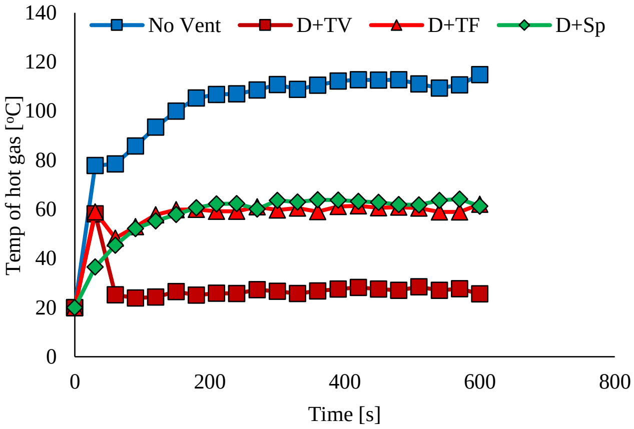

Fig. 4 Temperature of the hot gas above the sofa, at a height of 4m, as a function of time for both natural and mechanical ventilation systems. No vent represents the reference case with a completely enclosed building, closed doors and vents. D+TV represents open natural ventilation -top vent- with open doors. D+TF represents a switched-on mechanical ventilation (top fan) with open doors. D+Sp represents a switched-on Sprinkler with open doors, only.

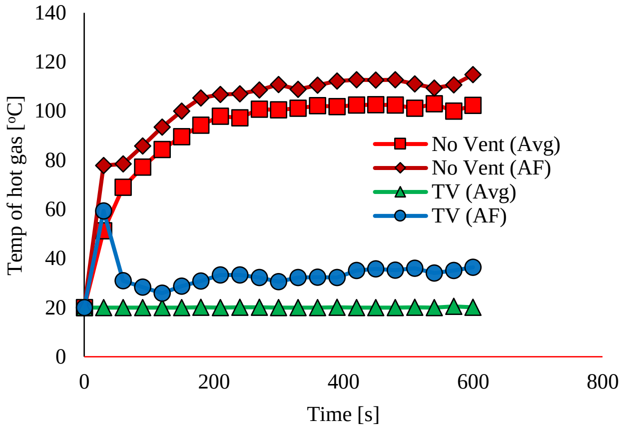

Fig. 5 Average temperature of the hot gas inside the building vs. Temperature directly above the sofa, at a height of 4m, as a function of time for natural ventilation with closed doors.

Figure 6 shows the average smoke thickness (AST) of the hot gas inside the building as a function of time for both natural and mechanical ventilation systems. For completely enclosed buildings with closed doors and vents, the average smoke thickness inside the building can reach 75%/m after 10 min, but it is still increasing with time. A place with a smoke thickness of 100 %/m means that it is a fully smoky place and the visibility is 0 %/m. For such places, the evacuation process will be very difficult and breathing will be almost impossible, without breathing apparatus. People inside have no chance to survive in such places.

Switching on one single Sprinkler directly after the ignition of the fire, with open doors, can reduce the average smoke thickness inside the building to 12%/m after 10min from the ignition point. Water plays the main role in washing the smoky gases and cooling the temperature inside the place. Switching on mechanical ventilation (Fan) can reduce the average smoke thickness inside the building to 18%/m for the same period (Fig. 6). The natural ventilation (top vent) with open doors can do the best effect to keep the average smoke thickness inside the building at 0%/m all the time. An ideal solution for the medical centre in case of fire inside the building. This will significantly improve the safety level inside the building, in case of fire.

Figure 7 shows the smoke thickness (ST) of the hot gas directly above the sofa, at height of 4m, as a function of time for both ventilation systems. The smoke thickness will reach 75 %/m within 10min for the completely enclosed building with closed doors and vents. The natural ventilation (top vent) with open doors still achieves the best effect by keeping the average smoke thickness at 0%/m directly above the fire source.

Figure 8 visually summarizes the discussed results. Smoke thickness is huge inside the completely enclosed building, with closed doors and no vents. Mechanical ventilation can do better job, compared to spraying water. Natural ventilation can do the best job among all investigated techniques, in case of fire in the building, to reduce the hot gas temperature and associated smoke thickness.

Conclusions

This study investigates numerically the behavior of the hot gas temperature and associated smoke in case of fire inside a medical center. Fire Dynamics Simulator (FDS), provided by NIST, has been used to run the simulations for all proposed cases. Different solutions are suggested to reduce the severity of the hot gas temperature and smoke thickness. Among all investigated solutions, natural ventilation can do the best job. However, mechanical fan can do also good job, but not as good as that done by natural vent at the top of the building.

Natural ventilation can effectively get rid of the hot gases and smoke, due to the buoyancy effect (*i.e.* chimney effect) inside the building. Natural ventilation can offer cheap and clean solutions to improve the safety level and environment conditions

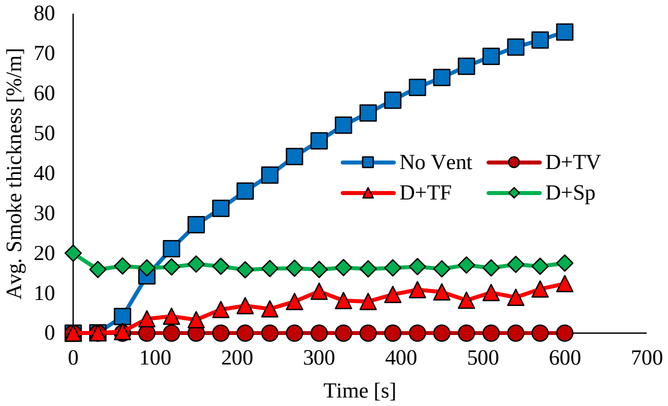

Fig. 6 Average smoke thickness of the hot gas inside the building as a function of time for both natural and mechanical ventilation systems. No vent represents the reference case with a completely enclosed building, closed doors and vents. D+TV represents open natural ventilation (top vent) with open doors. D+TF represents a switched-on mechanical ventilation -top fan- with open doors. D+Sp represents a switched-on Sprinkler with open doors, only.

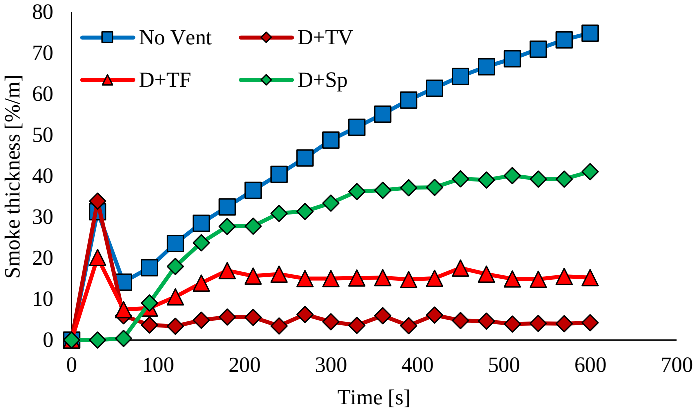

Fig. 7 Smoke thickness (ST) of the hot gas directly above the sofa, at a height of 4m, as a function of time for both natural and mechanical ventilation systems. No vent represents the reference case with a completely enclosed building, closed doors and vents. D+TV represents open natural ventilation -top vent- with open doors. D+TF represents a switched-on mechanical ventilation -top fan- with open doors. D+Sp represents a switched-on Sprinkler with open doors, only.

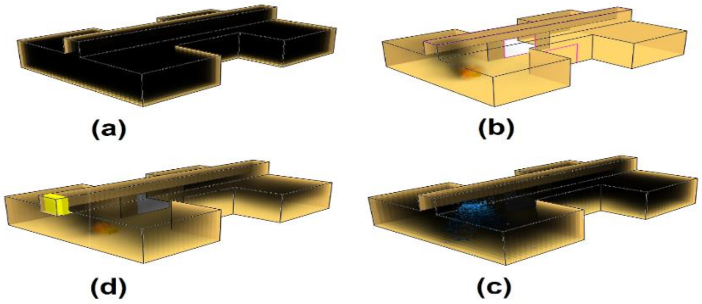

Fig. 8 Smoke inside the building after 10 minutes from the beginning of fire, (a) the building has closed doors and no open vents, (b) the building has only natural ventilation (top vent). (c) the building has only mechanical ventilation (top fan), (a) the building has an activated water sprinkler with open doors only.

inside the building, which offers an appropriate evacuation process for the firefighters and civilians inside the building. It will improve the lighting in the place and go hand-in-hand with the environmental trend, which reduces the cost of the consumed energy of such places.

Nomenclature

AT	=Average temperature	[C]
T	=Temperature	[C]
AST	=Average smoke thickness	[%/m]
ST	=Smoke thickness	[%/m]
t	=time	[s]

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