

7.1 Numerical Simulation of Fire Dynamics

Numerical simulation techniques have grown in importance during the last decades due to improved computer capabilities. This general trend was also followed by refined numerical fire simulation techniques.

For the protection of historic buildings, fire simulation can be applied in following types of analyses:

- **Risk assessment.** Experts use simulations for analyzing fire risk of building parts. The effects of the fire and smoke spread can be simulated and fire protection concepts studied. The results may be used by fire insurances and as input data for evacuation simulations.
- **Fire safety certification.** With simulations alternative fire safety concepts may be studied, developed, or improved. In most cases the particular characteristics of the building make it very difficult to comply with fire protection regulations. In these cases, alternative solutions must be found within a performance-based approach for fire safety certification.
- **Post-fire analysis.** When a fire has occurred, fire simulations can be applied to analyze the possible causes of the fire and for identifying the liabilities. These aspects are fundamental for insurances and court authorities.

At present, numerical fire simulation methods can compute the following fire-related quantities relevant to fire protection of historic buildings:

- **Fire spread.** The fire ignition, the propagation of smoke, and the spread of fire to other parts of the room and of the building.
- **Air temperatures.** The air temperatures are a criterion for safe evacuation of people and for the fire brigade intervention.
- **Surface temperatures.** The temperature of the surfaces in proximity of the fire has an influence on flashover, on the material destruction, and on the structure load capability. Sprinkler activation can also be predicted.
- **Heat radiation intensity.** The local radiative heat flux is a criterion for safe evacuation of people and for the fire brigade intervention.
- **Smoke concentration in the air.** The local smoke and toxic gases concentration in the air is a criterion for safe evacuation of people and for the fire brigade intervention. An example is shown in Figure XY.
- **Visibility.** The local visibility in the contaminated air. This is fundamental for analyzing the ability for people to escape from the involved area and for the fire brigade to identify and access the fire location.
- **Material damage.** The loss of property and the degree of material destruction during the fire propagation.
- **Smoke deposition.** The smoke deposition on surfaces (e.g. walls or furniture). This issue is important for the assessment of the damage.
- **Moisture concentration.** The local concentration of moisture in the air can be computed. This issue is important for the estimation of the damage when sprinklers or water mist systems are used.

- **Efficiency of fire suppression measures.** The effect of fire suppression measures such as sprinklers, water mist, hypoxic air systems, and nitrogen systems can be computed, analyzed, and improved.
- **Efficiency of smoke extraction ventilation.** The effect of natural or mechanical ventilation systems can be computed, analyzed and improved.

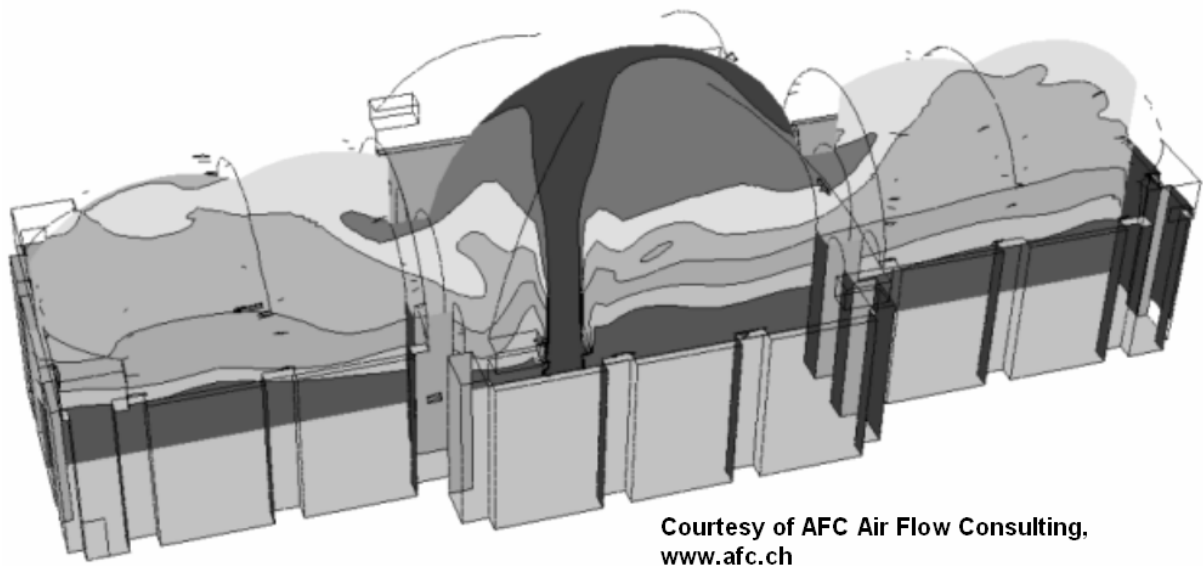


Figure XY Simulated fire inside of the exposition hall of the 19th-century Swiss National Museum: Smoke distribution in a vertical plane.

There are currently two fire simulation techniques with different advantages and disadvantages:

- **Zonal Models.** Zonal Models are based on analytical and/or empirical equations that are applied to large volumes. Each volume is divided into two zones, an upper smoke layer and a lower air (smoke-free) layer. Typically, every room in a building is taken as a volume (two zones). Therefore, a typical computation does normally not exceed 20 volumes in total.
- **CFD.** In Computational Fluid Dynamics (CFD) a room is divided in many thousands of volumes. The exact physical equations involved in a fire are applied to each of these volumes. With the current computer capabilities, a CFD fire simulation does commonly not exceed 1 million volumes.

The following table summarizes the relationship between the fire related quantities, the type of analysis and the simulation technique. Some fire related quantities are of interest for only one or two types of analysis (denoted by “X”). Certain fire related quantities can only be computed by CFD (denoted by “X”).

Fire related quantity	Damage	Type of analysis			Simulation technique	
		Risk assesment	Fire safety certification	Post-fire analysis	CFD	Zonal Models
Fire spread	Material	X	-	X	X	X
Air temperatures	People	X	X	X	X	X
Surface temperatures	People Material	X	X	X	X	X
Heat radiation intensity	People Material	X	X	X	X	X
Smoke concentration	People	X	X	X	X	X
Visibility	People	-	X	-	X	-
Material damage	Material	X	-	X	X	-
Smoke deposition	Material	-	X	X	X	-
Moisture concentration	Material	-	X	-	X	X
Efficiency of fire suppression measures	Material	-	X	X	X	X
Efficiency of smoke extraction ventilation	People Material	-	X	X	X	X

Due to the higher number of volumes to be solved, a CFD computation uses more computational resources and needs more computation time than a Zonal Model. On the other hand, Zonal Models are too inaccurate when the geometrical characteristics of the building are complex. Currently, a detailed and systematic analysis of the geometrical limits of Zonal Models is missing. However, such an analysis is needed in order to define the applicability limits of Zonal Models.

The following table describes roughly the different approaches to be used, depending on the geometrical characteristics of the historic building and the physical characteristics of the problem. More details can be found in the document “standardfires.pdf”.

Geometry	Multiple reactions	Approach	Use of computational resources (CPU and RAM)
Simple	Needed	Zonal Model	Low
Complex	Not needed	CFD with additional scalar	Medium
Complex	Needed	CFD with multi-reactions	High – Very High

Guidelines for the problem setup, for the implemented models, and for the fire heat release rate must be formulated for both simulation techniques. The document “standardfires.pdf” provides guidelines for the definition of the *fire heat release rate* in historic buildings.

The following checklist should be consulted when a numerical fire simulation study of a historic building has to be carried out:

- **User expertise.** The engineer who performs the CFD analysis must have an in-depth understanding of both the simulation techniques and fire dynamics. CFD consultants must provide previous reference projects and demonstrate relevant simulation experience.
- **Simulation code.** The code employed should ideally be validated for application to fire dynamics.
- **Computational domain.** The domain must be three-dimensional. The level of geometric detail represented inside the domain should include anything that might significantly affect the flow, for instance potential obstacles, heat sources other than the fire, and so on. Ensure that geometric simplifications are justified and unlikely to significantly affect the flow.
- **Computational grid (CFD).** The disposition of grid cells and their size should be based on an understanding of the key flow phenomena and preferably experience from a similar case.
- **Time dependent simulation.** The simulations should be time dependent. Select an appropriate time step consistent with the physics of the flow and the geometry.
- **Fire model.** Whichever approach is used to model the fire, the resulting plume and flaming region temperatures should be checked to ensure they are representative.
- **Smoke and temperature.** The temperature field should not be used as a means to illustrate smoke movement, since unlike smoke mass, temperature is not a conserved variable. For example, heat exchange on walls and thermal radiation affect temperature but not smoke concentration.
- **Visibility.** Any prediction of visibility through smoke should be treated with great caution: Presentations of visibility based on iso-surfaces of smoke concentration can be misleading. The line-of-sight integration approach is more soundly based and is recommended.

Other details on guidelines for fire simulations with CFD can be found in N. Gobeau, H.S. Ledin and Dr C.J. Lea, "Guidance for HSE Inspectors: Smoke movement in complex enclosed spaces - Assessment of Computational Fluid Dynamics", Health and Safety Laboratory, 2002.