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For Fire Security Scenarios**

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FIRE AND SMOKE SIMULATION SOFTWARE FOR FIRE SECURITY SCENARIOS

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ABSTRACT

Current software systems address modelling and simulation of fire in various environments and conditions. They allow you to test various fire scenarios and model their course and consequences. They are able to detect the possible risks and circumstances that can lead to the damage and to prevent or limit the consequences of potential future fires. Based on fire tests and experiments, new tools and means have been developed to gather the necessary information on fires. Such a means is computer fire simulation. They are based on empirical and scientific knowledge and are comparable to real fire experiments. The great advantage of fire simulations is the non-destructiveness of materials and greater flexibility of use. The complexity of spatial geometry, the mathematical difficulty of solving differential equations, and the demands on computer performance, often include the complexities of fire modelling, but simulation currently allows fairly accurate prediction of the spread of fire and has become an important part of improving fire safety. Fundamental programs such as FDS, Smokeview and Smartfire are introduced as well as flood simulator developed in Czech Republic.

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INTRODUCTION

Fire is a problem for every community from ancient times. Fires causes human fatalities, major injuries, consequently health problems, they also destroy properties or entire quarters, towns, cities, and entire ecosystems, as well. For sufficient prevention, it is essential to have as much knowledge as possible about fires. We need to know their behaviour in the room and in the open air. When we understand the spread of the fire, we will be able to limit its consequences as well. Fire is often used as a weapon against enemies both in offensive and defensive purpose of use.

Current software systems address modelling and simulation of fire in various environments and conditions. They allow you to test various fire scenarios and model their course and consequences. They are able to detect the possible risks and circumstances that can lead to the damage and to prevent or limit the consequences of potential future fires.

Methods for obtaining fire information can be divided into three groups:¹

- Observation of fires that have occurred in the past.
- Performing fire tests and laboratory experiments.
- Computer simulation of fire.

Fire propagation can be tested on the same object for only a few selected scenarios. After completing the experiment, the corrupted object must be repaired or replaced by a copy. In addition, a part of the instrumentation (for measuring fire parameters) is usually destroyed in a fire test. In spite of these non-benefits, large-scale fire tests and laboratory experiments are essential sources of knowledge on and spread of fires and are the basis upon which new, modern means of combating fire and acquiring knowledge of fires could arise.

In terms of financial and time requirements, small-dimensional tests of fire-technical properties of interior materials are very suitable. This issue is dealt with by the Faculty of Safety Engineering of the University of Zilina. The results of this approach have been published by Vráblová² and Müllerová³, observing the specific conditions of the dimensionless

¹ R. D. Peacock, *Characteristics of fire scenarios in which sub-lethal effects of smoke are important*, "Fire technology", 2004, Vol. 40, No. 1, p. 132.

² L. Vráblová, *Modelovanie rizikových situácií v trénažéri na nelineárne formy požiarov*, Dizertačná práca, FBI, Žilinská univerzita 2015, p. 50–75.

³ J. Müllerová, R. Michalovič, *The effect of different fuel types on the flashover phenomena in 3D model fire experiment*, "SGEM 2016: ecology, economics, education and legislation", Albena, Bulgaria. Volume II. – Sofia: STEF92 Technology, 2016. p. 815.

groups defined by Veloo⁴ and experimentally verified by Perricone⁵, Wang⁶ and others.

Another important source of input data for exact computer simulations are fire exams of a real-time room equipped by Nelson et al.⁷, in China Wu et al.⁸ who watched the theatre fire or Weisenpacher⁹ simulating intentionally ignited cars.

Using a computer simulation to test different fire scenarios and model the fires in different conditions and when changing conditions. With computer simulations, we are able to discover the circumstances that make fire behaviour change diametrically. Computer modelling and fire simulation has a great impact on the everyday life of every citizen, even though he does not even know it. Simulation programs and tools are used in the field of top engineering. Whether we start designing a single storey house or reaching huge halls and meeting thousands of people, think of the possibility of fire and especially its effects, which can complicate the evacuation or cause death.

At present, computing technology offers the opportunity to simulate and model a variety of extraordinary events using software support. Computational methodology is a part of a fire design to solve the reliability of structures. It is mainly about whether the structure is load-bearing and whether this load is retained for longer than is necessary to ensure reliability. Problems with fire design solutions are currently being addressed by programs that can model fire.

SMARTFIRE

SMARTFIRE is a modern CFD simulation environment developed at the University of Greenwich (USA). Unlike other CFD programs capa-

⁴ P. S. Veloo, *Scale modeling of the transient behavior of heat flux in enclosure fires*,. Masters of Science. Maryland : University of Maryland, 2006. p. 70.

⁵ J.A. Perricone, *Scale Modeling Of The Transient behavior of wood crib fires in enclosure*, Thesis, Master of Science, University of Maryland, College Park 2005. p. 190.

⁶ M. Wang, *Scale modeling of structural behavior in fire*, Doctor of Philosophy. Maryland: University of Maryland, 2006. p. 125.

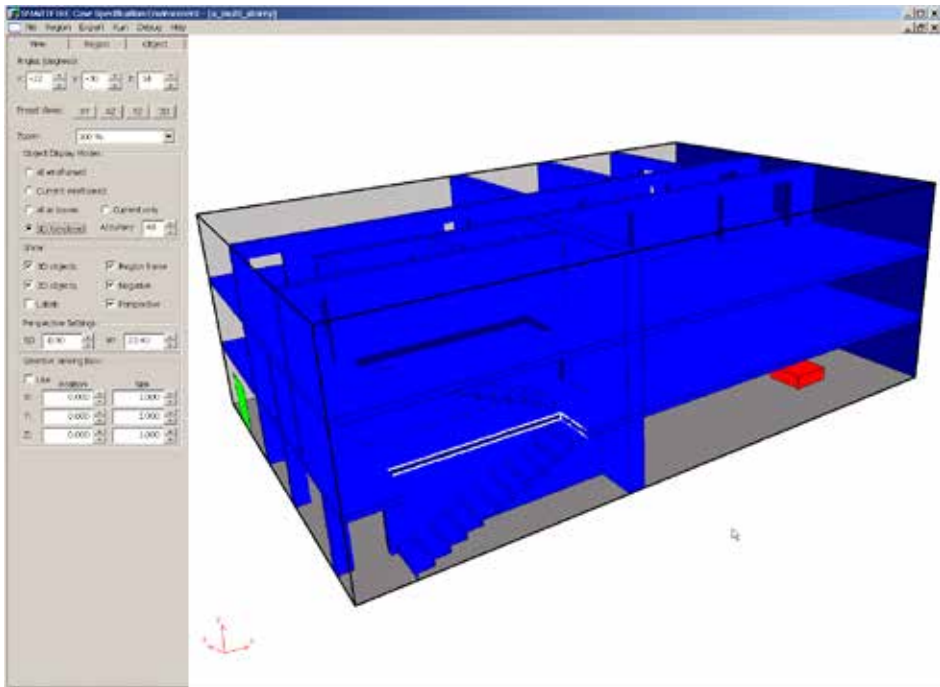
⁷ N.P. Bryner et al., *Technical Study of the Sofa Super Store Fire*, South Carolina, June 18, 2007, Volume I, NIST 2008.

⁸ G.H. Wu, X. Han, M.Y Wang, Q. Liu, *Simulation Analysis of Smoke Distribution Features for a Theater Fire*, "Int. Symp. on Innovations and Sustainability of Structures in Civil Engineering", Vol. 1 and 2, Shanghai 2008, p. 1155.

⁹ P. Weisenpacher, J. Glasa, L. Halada, *Parallel simulation of automobile interior fire and its spread onto other vehicles*, "Int. Congress on Fire Computer Modeling", Santander 2012, p. 333.

ble of simulating fire simulation, SMARTFIRE was specially designed as a simulation tool for firefighting engineers. It is based on over twenty years of exploration and modeling with CFD. This program provides a whole range of features that can be used for a quick and sophisticated fire analysis. The analysis is based on a unique feature, a quick problem specification that allows you to provide simple and effective responses to the solution.

FIG. 1. VIEWING OBJECT SIMULATION IN 3D SMARTFIRE

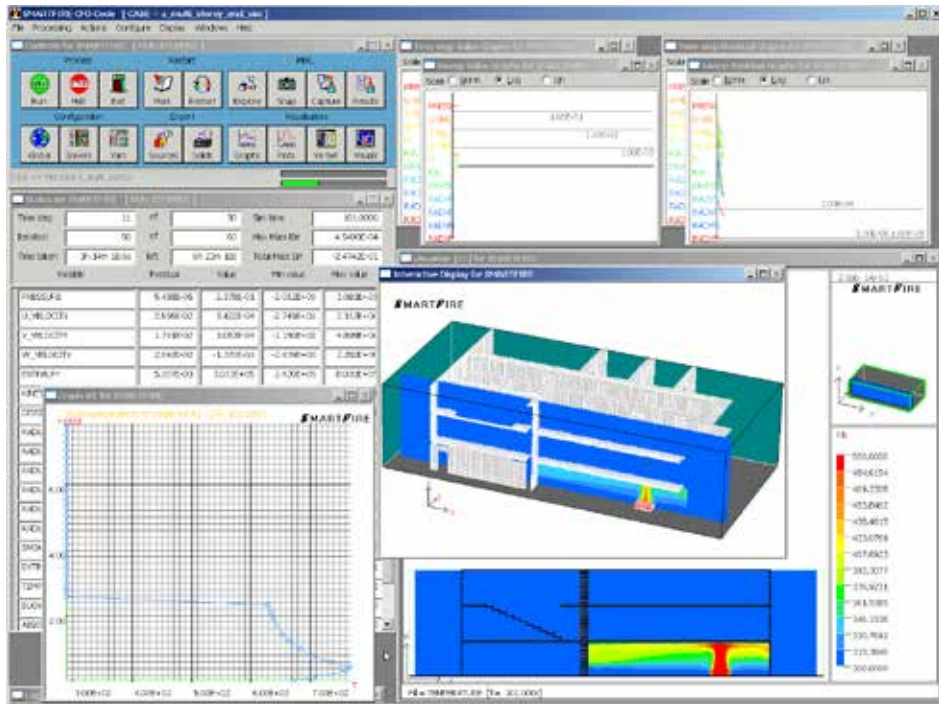


Benefits of SMARTFIRE:

- The program can be used on various computer platforms using 32 or 64-bit Microsoft Windows XP, XP Pro, Vista, 7.8.
- Uses proven CFD technology combined with advanced exploration capabilities to provide accurate simulations across a wide range of fire scenarios.
- Defines the old data processing concept and uses state-of-the-art CFD Engine technology to ensure that the entire modelling process is more efficient and results are more comprehensible.

- The SMARTFIRE environment is constantly evolving with many new capabilities to improve and enhance the level of analysis and modelling.
- It allows to solve and simulate both temporary and steady fire conditions, for example in steady or natural ventilation, to determine heat transfer size, to measure the toxicity of combustion gases and combustion products, and others.

FIG. 2. VIEWING BASIC OUTPUTS AND 2D VISUALIZATIONS

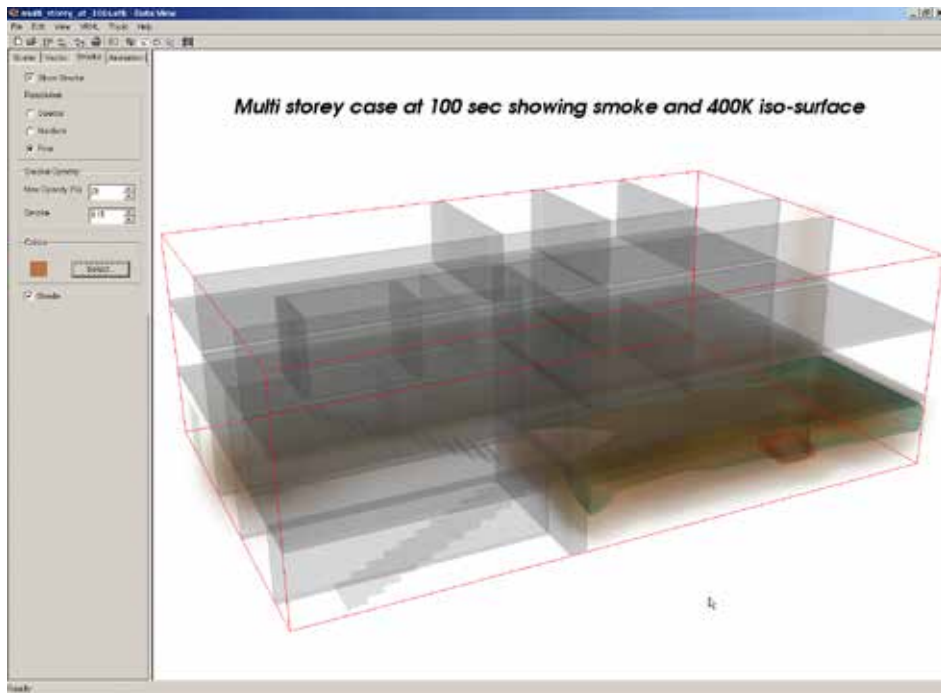


The SMARTFIRE simulation program provides a 3D view of the environment in which model scenarios are built. The program has a collection of configurable primitive objects that can be added to calculations to build a building, room, objects such as furniture, heat exchangers or fuel sources, ventilation, and other items that are important for data acquisition and monitoring. The user interface is very simple and beginners can be able to correctly create complex scenarios. The system uses reasonable result values and also provides extensive configuration options to pre-set control over most aspects of simulation. Once the scenario has been completely designed, the user can run a system to create a CFD simulation.

SMARTFIRE is based on numerical algorithms that are designed to be further upgraded and upgraded. The numeric part of the program includes a number of interactions and tools, along with the ability to create 2D slides of visualization, graphing and output control, and more.

This program allows the processing results to be displayed in graphical form to be varied according to time steps. This method is mainly used to observe the formation and spread of smoke in a designated object. According to the following time intervals, smoke behaviour can be used in the EXODUS program, which, in combination with the SMARTFIRE program, is used to simulate the evacuation of persons from a fire-affected object¹⁰.

FIG. 3. VIEW SMOKE BEHAVIOUR IN AN OBJECT



The SMARTFIRE system is now an important tool for fire engineers in the field of fire safety solutions for buildings and buildings. With its basic functions, it is possible to monitor the behaviour of fire and smoke in an object with changing parameters. Its advantage is its use with other pro-

¹⁰ J. Müllerová, M. Orinčák, I. Coneva, *Efficiency of gas stable fire extinguishers*, "Interdisciplinarity in Theory and Practice", No. 9 (2016), online, p. 144.

grams dealing with evacuation of people (ELVAC) and similar programs. The program is available in multiple versions, with the main goal of creating a version that will best analyse and model the behaviour of each type of fire.

FIRE DYNAMICS SIMULATOR (FDS)

FDS Models are designed to predict smoke, temperature, carbon monoxide and other fires produced by fires. The results of these simulations are used to ensure the safety of buildings before commencing construction, evaluate the security capabilities of existing buildings, participate in the reconstruction of fireplaces during the investigation, and assist in the training of firefighters. FDS is one of the most used fire simulation simulators developed by NIST. FDS simulates fire scenarios by calculating quasi-steady dynamics and is optimized for low-speed and heat-driven flows. This approach is very flexible and can be used from stove fire to oil storage tanks. It also models situations where there is no fire, but ventilation is checked in buildings. FDS and the Smokeview viewer are closely associated with PyroSim¹¹.

In the FDS system, it therefore solves numerically the Navier-Stokes equations for low-speed fire-induced flows with emphasis on the transmission of smoke and heat from fire. Spatial partial derivations are approximated by the 2nd order finite differences and the variables (describing the gas flow) are updated over time using an explicit 2nd order prediction-proof correction scheme on a three-dimensional orthogonal grid. Gas flow during fire at low speeds remains laminar and obstructs the obstacle. From a certain speed, beliefs, Turbulent flows. Turbulences are modeled using the Smagorine method of LES (Large Eddy Simulation), which is pre-set in the FDS. This method is based on the modeling of large vortices, with the effects of small turbulences being represented in a different way. If the basic numerical grid is very dense, it is possible to model turbulence using the Direct Numerical Simulation (DNS) method [70]. DNS puts high demands on the computing capacity of the computer, because the computing network needs to cover even the smallest creed.

FDS does not simulate streams with near-speed velocities such as blasts, detonations and others.

¹¹ G.P. Forney, *Smokeview (Version 6), a Tool for Visualizing Fire Dynamics Simulation Data, Volume I: User's Guide*. NIST Special Publication 1017-1, NIST, Gaithersburg, Maryland, May 2013.

INCINERATION

Combustion consists of two phases:

- pyrolysis.
- burning – oxidation.

Pyrolysis is the decomposition of the material into flammable and non-combustible components produced by heat. Oxidation is the exothermic reaction of released flammable gases with oxygen. In this reaction, a large amount of heat and light is emitted in the form of a flame. In the input file, it is necessary to define an initiation source of fire by specifying the heat release rate (HRR) on a defined area or specifying the thermophysical properties of the fuel undergoing pyrolysis.

In the latter case, the combustion model assumes that with a sufficient concentration of combustible gases and oxygen react when in contact, it is not necessary to define the initialization source of the fire. FDS knows how to work with different types of flammable substances. The gaseous phase of the combustion is implemented in three ways. For most FDS applications, the combustion model uses the concept of the mass fraction of mixtures. It is a constant scalar quantity, which is defined as the proportion of gases coming from fuel pyrolysis at a given point of the flow field.

The mass fractions of most reactants and products can be derived from the weight fraction of mixtures by laboratory analyzes and measurements. Fuel and oxygen reaction is not necessarily immediate and complete in fires, so FDS offers the use of several optional schemes designed to predict flame prolongation in a space free of oxygen¹².

In the FDS, a default two-parameter fractional model is a simplified form of chemical equations. The first parameter is the mass fraction of non-fired fuel, the second parameter is the mass fraction of the burned fuel. The assumption that the reaction rate between fuel and oxygen is infinitely small irrespective of the temperature at which it occurs is particularly suitable for large-size fires with sufficient oxygen access.

The second type of model is a three-parameter model that simulates a two-step chemical reaction. The first part of the reaction is fuel oxidation to produce carbon monoxide, the second part is the oxidation of carbon monoxide to carbon dioxide.

¹² K. McGrattan, B. Klein, S. Hostikka, J. Floyd, *Fire Dynamics Simulator (Version5) User's guide*. NIST-Special publication, 2007, p. 136.

The parameters are:

- non-combustible fuel,
- the weight of the spent fuel in the first part of the reaction,
- the weight of the spent fuel in the second part of the reaction.

The third type is a finite-rate method where all components of flammable gases released during a fire are defined and monitored individually. This method is much more demanding than the mass fraction method. The model type is determined by the specified parameters and materials that are burned in the simulations, and depending on whether the LES or DNS method used to resolve the turbulence is used.

RADIATION

It is modeled by the solution of the RTE (Radiation Transport Equation) for gray gas, in some cases the broadband model is used to obtain better spectral accuracy. The radiation equation is solved using a finite volume method for convective heat dissipation, requiring approximately 20% of the total calculation time. Absorption coefficients of gaseous carbon black are calculated using the RadCal narrow-band model.

HEAT, SMOKE AND FIRE DETECTORS

In FDS, devices for measuring fire parameters, such as radiant heat, wall temperatures, bodies or gases at room or sectional points, gas concentrations (e.g. CO, CO₂, O₂), visibility, etc. can also be included in the simulation. The activation of fire extinguishing systems and heat or smoke detectors is modeled by simple relationships for thermal inertia of atomizers and heat detectors and delay of transmission of smoke detectors.

Sprinklers are modeled using Lagrange particles, which represent a representation of water droplets emitted from sprayers. It is also necessary to specify the output parameters in the input file, since it is not possible to retrieve the information once the fire computation and simulation has been completed unless it has been specified at the beginning. Thus, the FDS only stores information to the user of defined fire parameters

The output parameters of the gas phase are:

- temperature,
- flow rate,
- gas concentration (CO, O₂, N₂, water vapor),
- smoke density,

- visibility,
- pressure
- Heat Index per unit of volume,
- mass fractions,
- weight of water droplets per unit volume.

FLOOD SIMULATORS

The role of flood simulations is to prioritize the possible range of floods in urbanized areas or coastal areas. In addition to floods due to the sudden increase in water level, they can also simulate the ditch breakage, tsunami waves. These simulators are advantageous for coordinating units and evacuation methods. Practitioners can more accurately visualize the course of the floods and thus learn how to make better use of time.

FIG. 4. FLOOD SIMULATOR



3D FLOOD SIMULATOR

Specific simulation enables the training of tactical activities of components of an integrated rescue system. It is a continuation of the training course. The solution includes the use of 3D modelling of real conditions, which, in combination with the game elements, creates an attractive and effective system for training tactical activities related to flood issues.

Simulator allows you to adjust the water level in the area. Thanks to the use of precise height maps, the flooded area exactly corresponds to the actual spill of the water flow in the given area. In order to respond

to the information on the level of flood activity of the area, it is possible to set different parameters to the water plates located along the water flow.

Another important part of the simulator is necessary for training tactical activities related to the flood situation, namely evacuation. The simulator allows you to select the location (s) from which it will evacuate and specify other specific parameters necessary for its execution (means, evacuation logic, etc.).

FIG. 5. FLOOD SIMULATION



A more realistic process of training or visualization of the impact of floods in the area is possible to adjust the height of the water level. In default system settings, this setting is done with the plus and minus buttons, and this is done by changing the height of the water flow by a factor of centimeters. The change of level is immediately reflected in the visualization of the water in the country and in the deduction of the water-borne substances placed after it. Based on this visualization, it is then possible to adjust the value of the level of flood activity corresponding to the respective water level as actually. Thanks to this feature, it is possible to develop specific and unique scenarios that allow systematization of training.

The 3D flood simulator has two complementary parts, and these are: What to do, Flood and Support Web Publishing Connecting the simulator, publishing and the support site is the opportunity to find addition-

al information on the topic of flood protection through thematic keys that are stored on the web and visible through the publication, as well as through the simulator.

BASIC PROGRAM FEATURES:

– Changing environment and weather

The ability to set these parameters makes it possible to adapt the training conditions to the needs of the user while at the same time the training approaches the real conditions required to solve the real situation.

The time can be set within a 24-hour cycle. The individual clocks correspond approximately to the position of the sun or moon, which is also the light conditions. Changing the time is possible in the edit panel.

Cloudiness is set in percent, indicating visibility through cloudiness. However, in this case, the percentage is adjusted to real conditions in the environment, so that 100% does not mean darkness but the highest possible adjustable cloudiness.

– Water flow control

The simulator allows for a clear adjustment of the water flow, respectively. Water level. The change of level is immediately reflected in the water flow visualization in the country but also in the water table located on the flow. Based on this visualization, it is then possible to modify the value of the level of flood activity corresponding to the respective water level as well as in the action. Thanks to this feature, it is possible to recognize specific and unique scenarios that allow systematization of training.

Plumbing plates serve to visualize the actual height of the water level in the terrain and its dependence on the set level of flood activity. The associated level of water activity to the level of the water level when the level of the flood activity (SPA) occurs on the level of the water level, on the water table and on the terrain.

The board panel also contains additional information, Coordinates, description, location, possibility to move over the appropriate board in the tee. At the same time, it is possible to display more watermarks so that it is possible to observe the actual water level on all boards at the same time.

– Inserting and moving dynamic objects.

– Static objects.

Benefits:

- Usable by the IRS components for prevention, floods and land reclamation.
- A small demand for personal computer performance.
- Network multiplayer.
- Repeatability of exercise, changing conditions, etc.
- No installation required – just copy to PC.

There are other softwares for support of prevention phase during the preparation for security scenarios. Some special tools enable to make a simultaneous team training in a real-time. Very important are also evacuation softwares which are useful in many kinds of accidents or risk events because the people security should be the most protected value.

CONCLUSION

Simulation programs designed for use in building fire safety can provide a very useful insight into the security of buildings and objects. In order to be able to use these programs in practice, they need to be legally binding, but they are lacking in Slovak legislation. The legal definition made it possible to directly use the generated simulations as a basis for drawing up a fire safety plan for buildings, while at the same time helping to select the right fire simulation program.

Slovak legal laws and standards are aimed at preparing the fire safety of buildings on the basis of technical standards and regulations. This method is sophisticated and functional, and in general it can be said that it is a debtor for almost all situations. The aim of using simulation programs is not a substitute for the current fire protection design, but rather, in certain cases, to supplement or verify the protection against fire. Some situations require a specific approach to addressing fire safety.

Public areas, spaces and buildings such as airport halls are very challenging in this respect, and developing a simulation in a computer simulation program could solve this problem. The basic precondition for correct and accurate simulation that provides relevant information is to select the right program. It is necessary to focus on the most important factors that need to be taken into account in the simulation. It is also necessary to take into account the extent to which detailed results are to be obtained and, accordingly, to adjust the selection of the program.

However simulation programs are very specific and are focused on specific factors and others simply simplify or take into account relatively few, it is not possible to select one universal program that could be used in every simulation.

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