# Fire safety and fire dynamics of a school room simulated in FDS computer program

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*Abstract* – **Fire safety and fire dynamics are very important in these days. Building constructions and planning must be up to the requirements of different laws in force and instructions. They are in result of the scientific exploitation and human experience for ages. This paper present such treatment of a real building case in a Bulgarian high school located near to the Technical university in Sofia. A fire arise out of the chemical laboratory which is located in the underground floor of the school. A PYROSIM (FDS) program is used to simulate the fire dynamics-fire arise, flame and smoke movement and the even self-extinguish. The reason for this result is the usage of a new woodwork which helps the fire to be extinguished because the room is run out of oxygen if the door and windows are closed. The temperature on the premises is under the level of breaking the glass, which would lead to oxygen income. The result helps to predict the situation of fire calamity and the time for evacuation. This method may be used in different buildings with different sizes and different building plans..**

*Keywords* – **Thermal impact, Fire dynamics, Fire safety, PYROSIM, School building.**

## I. Dangerous fire factors

In case of fire, there are enough hazards that force people to leave the room, often taking the decision independently and spontaneously.

It is known that in most cases the time for which dangerous fire factors acquire critical meanings (so-called critical evacuation time) is less than the time required for the arrival of fire departments.

Smoke is a mixture of combustion products and particulate matter with the air. The composition of the smoke depends on the composition of the burning substances and the combustion conditions. When burning organic materials (wood, straw, paper, gas, etc.) in the composition of the smoke may be carbon monoxide, water vapors, carbon dioxide and soot. In the thermal decomposition and burning of plastics, rubber, synthetic fibers and others in the composition of the smoke is found nitric oxide, hydrogen chloride, hydrogen sulphide, sulfur dioxide, phosgene, silicic acid and other toxic substances. The concentration of these products in smoke depends on the intensity of the gas exchange and the quantity of these products that are separated from the 1 m2 burning area. In the case of internal fires due to incomplete combustion, the amount of these products is greater than in the case of fires in the open, where full combustion occurs. The smoke density is determined by the amount of solid particles in unit volume and is measured in gr / m3. Density (smoke rate) can be regulated by gas exchange. The high density complicates the orientation and actions of the fire departments in the extinguishing of the fires. Products of incomplete combustion (carbon, carbon monoxide, etc.), which are in the composition of smoke mixed with air, can create not only combustible but also explosive mixtures. The high concentration of combustion products in the smoke composition reduces the percentage of oxygen. At 14-16% of oxygen in the air there is oxygen starvation, and at 9% there is a danger to life. (Under normal conditions, the amount of oxygen contained in the air is 21% by volume.), The density and the toxicity of the smoke depend on the properties of the burning material and on the conditions in which the combustion process takes place. The volume of products that are released during combustion of the burner is called smoke formation.

Combustion of organic substances and materials (wood, paper, gasoline, etc.) in the composition of the smoke contains carbon monoxide, carbon dioxide, water vapor and soot. In thermal decomposition and combustion of plastics, synthetic rubber, synthetic fibers, etc. in the composition of the smoke is found: nitrogen oxide, hydrogen chloride, hydrogen sulphide, sulfur oxides, sialic acid and other toxic substances.

The concentration of these products in smoke depends on the smoke intensity and the quantity of these products, which is separated from one m2 of combustion area. In internal fires, due to incomplete combustion, the amount of these products is greater than in the case of open fires where the combustion of the substances is complete.

Smoke concentration is the amount of combustion products contained in a unit of the room volume (gr/m$^3$, gr/l or in volume percentages).

The high concentration of internal combustion products and the combustion process are the reason for reducing the percentage of oxygen.

Heat load is the thermal energy expressed in SI units, which is released by the burning of all materials in a given space, including the lining of the walls, partitions, floors and ceilings.

The self-evacuating process of heat transfer in a space with a non-uniform temperature field is called heat exchange.

Many heat transfer processes are accompanied by bulk transfer. The cooperative process of heat and mass exchange is called heat exchange. The sum of the instantaneous temperature values at all points of the considered space / body (coordinates x, y, z) at time t is called the temperature field.

Each temperature can be expressed either in degrees Celsius [°C] or in Kelvin [K], since in the Celsius and Kelvin

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rocks the linear dimensions corresponding to one degree are the same.

The temperature field can be characterized by isothermal surfaces - a geometric location of points with the same temperature at a given time. Isothermal surfaces corresponding to different temperatures cannot cross. They are either closed or ending on the surface of the body. When crossing a plane (for example, in a drawing), isothermal surfaces leave traces in the form of families of curves - isotherms.

The fire is a collection of time-consuming processes. The dynamics of the phenomenon and the impacts on structures in case of fire are described by the non-stationary heat exchange equations.

The density of the heat flow is proportional to the temperature gradient. The energy transfer is always from a higher location to a place with a lower temperature and continues until equilibrium is reached [1].

In the case of a fire, a process of non-stationary heat transfer from a moving environment (gas) to a solid medium (building structure) through a separating surface is realized. Temperature influence on a structure for each point of fire development in a building is quantified by the density of the heat flow to the surface of the elements (the amount of heat passing per unit of time over a unit of area of an isothermal surface.

Temperature mode is the change in the average volume temperature over time [1]. Normalized temperature modes represent either a steadily increasing time function (continuous fuel delivery, eg standard fire) or an increase followed by a constant stretch (hydrocarbon and external fire curve). There is still no international technical consensus on the issue of harmonizing the conditions for thermal radiation in the implementation of standardized temperature regimes. In the conditions of a free (non-extinguishing) fire in buildings, the temperature rises, after reaching the maximum for a short time, it holds approximately a constant value, followed by a drop due to the burning of the fire load. The standard temperature curve adopted for international scale (ISO 834) (for Bulgaria BDS 6316-81) simulates the period of active combustion of fire in a room containing solid combustible materials with a calorific value Hu = 20,9 [MJ / kg] and a mass burning rate equal to $13.9.10^{-3}$ [kg / ($m^2$.s)]. The idea of a standard fire curve arises in 1903, the computation formula was proposed by Briton S.N. Ingberg in 1928, in 1961 was adopted by ISO. Mathematical models for the determination of temperature regime of fire in buildings provide the possibility to predict the change of the dangerous factors of the real object phenomenon and the transition from a comparative assessment of the fire hazard of the building materials / structures (based on the standard fire) to its forecasting of the actual operating conditions .
Attempts for a mathematical description of fire behavior date back to 1737 and continue to this day due to the complexity of the physico-chemical processes accompanying the phenomenon.
Knowledge of fire regulations in premises is the basis for solving issues related to the fire resistance of building structures, providing evacuation, expert assessment of buildings, etc. Integral analysis of the fire by experimentally determined aggregate characteristics provides sufficient accuracy for building practice. Differential analysis of the phenomenon is more detailed but requires the application of equations of the solid environment mechanics (including the rheological law of Stokes), the Fourier heat law, the laws of diffusion and radiation transmission in the gaseous environment, etc. The system of equations describing the change in density, pressure, temperature and composition of the gaseous medium in time / space is complex / difficult to solve [2].

The normative fire load is the sum of the temporary (burning content of the temporary load in buildings) and constant (the combustible content of the building elements, including linings / coatings) [2].

In the norms of Switzerland, Great Britain, Sweden, France, etc., as well as in the European Union Construction Design Guide, the classification of the thermal potential [MJ/$m^2$] of the normative temporary fire load, determined according to the functional purpose of premises.

## II. Dynamics of the Internal Fire Phenomenon in Non-Hermetic Buildings

The development of the fire involves spreading the burning process on the fire load and changing the parameters of the phenomenon in space and time. A good picture of the free development of a fire in a room is as follows. After combustion occurs at a point in the volume of the room, flame propagation on the surface of a burning material causes a sequence of continuous flames of the gases / vapors released from the material. In the initial period the dimensions of the area of the fire are small and the combustion develops at the expense of the air in the local volume.

After heating the surface of the enclosing structures begins to radiate heat. The floor temperature increases from the thermal conductivity. The ceiling and the walls are heated by the convective gas streams, a convective gas jet is formed above the hearth. Gas exchange between the combustion zone and the air from the room volume is established. The area and the thermal impact of the fire are increasing.

On combustion, the substances emit a volume of gas larger than the volume of air required to burn per unit mass. The pressure in the room increases, the glazing is heated and destroyed (at an average temperature of 480 - 580 ° C). The airflow increases sharply, air exchange is established with the outside environment or adjacent premises, the fire parameters are intensified.

The development of the fire accelerates to a certain limit, then ceases due either to the exhaustion of the fuel or to the insufficient speed of the exhaust air.

In the period of active combustion, 70 - 80% of the fire load is absorbed and the maximum gas temperature is reached.

An important role in studying gas exchange processes is the knowledge of the fluid dynamics.

In case of a fire, it is necessary to consider a number of additional factors that affect the gas exchange: the weight of the burned material, the rate of change of the room temperature, etc. It is also known that in small sections of the inlet and inlet openings, and at a high rate of increase in room temperature, overpressure may occur in relation to the outside air. These features must be known because of their great practical significance.

## III. Computer Modelling of Fire

PyroSim - is the user interface of Fire Dynamics Simulator (FDS) software [3]. FDS model can predict the spread of smoke, temperature, carbon monoxide and other hazards during a fire. The results of the simulation are used to ensure the safety of the buildings in the design, to determine the safety of existing buildings, to reconstruct fires in the investigations, and to assist in the training of firefighters.

Fire processes are very complex and complex phenomena consisting of combustion, radiation, strong turbulence, processes, and is related to physical and chemical processes as well as phase transformations.

Contemporary requirements for the occurrence and development of fires are based on numerical simulations. They allow, using minimal means, to anticipate the course of the fire, resp. Smoke formation on the building volume, the increase of the combustion during the fire, including eventually the development.

The use of computer modeling of fires and precise fire protection analyzes has become increasingly applicable in recent years, with prognostic capabilities covering a wide range of applications. In general, basic algebraic ratios can be included in modeling and simulation of fire to determine model zone parameters and computational fluid dynamics (field models) that are used to predict or report different fire-fighting phenomena within established set of boundary conditions.

In recent years, computer fire simulation has been used as the economically cheapest method to study the processes of fire development and their visualization. This approach is particularly applicable in the case of fires in tunnels, car parks and buildings, because full-scale ground fire experiments in these structures can cause serious damage to the material and technical base. Nowadays, the development of the fire environment allows for a relatively good knowledge of fluid and gas dynamics.

Existing software tools provided by CFD simulators also allow them to visualize their development. The use of (fluid mechanics) of theoretical CFD and its practical knowledge has a wide application in aerodynamics, fluid dynamics, combustion engineering and other areas. CFDs have been applied over the last decades. In these models, the field of fire is divided into separate fire zones, so each of these current processes is self-contained. The theoretical basis of these methods consists of the laws of mass and energy conservation. The whole space is divided into two spatially homogeneous zones: the warm upper volume containing heat and smoke, and the lower part significantly less affected by heat and smoke. For each zone, mass and energy balances are implemented with additional models describing other physical processes such as the development of fire through doors, windows and other technological openings, radiation and convective heat transfer and solid fuel pyrolysis.

Computational Hydrodynamic (CFD) models were introduced in the 1990s and have reached significant development and relatively widespread use in various areas of human activity. The rapid growth of computational calculation resources has led to the development of CFD based field models by solving the Reynolds equations, an average format of the Novae-Stokes equations. The use of CFD models is allowed to describe fires in complex geometries involving a wide variety of physical phenomena related to the development of the fire.

In the FDS model, low-speed, thermal-driven equations are solved. FDS solves the numerical form of the Nova-Stockx equations, suitable smoke and heat spreaders in a fire. The equations in the FDS are presented as a set of so-called private differential equations with appropriate simplifications and approximations.

Basic equations of mass, time and energy conservation of Newtonian gas are equations relating to the dynamics of the gas mixture.

This class of equations and their variations are Anderson's, which represent a set of private differential equations consisting of six equations with six unknowns, all of which are functions of three spatial dimensions and time: the density, the three components of velocity, temperature and pressure. Full calculation can be simultaneously considered as a Direct Numerical Simulation in which sputtering members are calculated directly or with the help of Large Eddy Simulation (LES) in which large-scale swirling movements are computed directly and at the same time modeling network scattering processes. The numeric algorithm is shaped so that LES becomes DNS when the network is cleared. Most FDS applications are LES.

The FDS version accepts that the pressure may vary from volume to volume. In the case of a given volume inside the computing sphere, it is isolated from the other volumes, except for a fluid leak, for example from ventilation ducts, it is referred to as "zone pressure" and assigned a given origin pressure.

## IV. Description of the Program PyroSim

PyroSim - is the user interface of Fire Dynamics Simulator (FDS) software [3]. The FDS model can predict the spread of smoke, temperature, and other hazards during a fire. The results of the simulation are used to ensure the safety of the buildings in the design, to determine the safety of existing buildings, to reconstruct fires in the investigations, and to assist in the training of firefighters.

FDS - a powerful fire simulation tool developed by the National Institute of Standards and Technology (NIST). The program allows you to enter interactive input data and validate the source file format for FDS.

PyroSim provides convenient tools for creating geometry in 2D and 3D mode, such as diagonal walls, to facilitate drawing, object grouping, flexible display setup, and copy and change objects. You can import DXF files with 3D faces or 2D lines, from which you can then create 3D objects in PyroSim.

PyroSim includes tools for creating and validating multiple networks. Networks allow parallel processing of information to speed up the solution.

## V. Object and conditions of research

The numerical simulation was made in a training corpus in the building of the Professional high school of Telecommunications (Fig.1). The building consists of a basement and four floors. At both ends of the building there are internal staircase cells from the basement to the 4th floor.

Fig. 1. Photo picture of the building

The purpose of the present work is to attempt numerical modeling and to show the spread of smoke and indoor pollution by displaying areas with critical emission, smoke and fire parameters. The source of smoke and debris generation is burning objects in learning rooms. The first step towards the solution of the task is to construct a geometric model of the room (Fig.2).

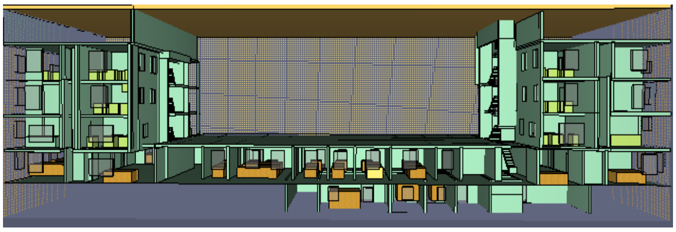

Fig. 2. Geometric model of the building

Room (school room) is selected in the basement of the building with dimensions: 9m long and 7m wide or total area 63m$^2$. According to Regulation 1971 STPNBP, the heat load for study rooms is 72 kW.h/m$^2$. We take heat load of 80 kWh/m$^2$, being increased by 10% of the normative.

## VI. Results and analysis

According to the heat load given above, the fire has a power of 12600 kW. The fire occurs quickly and in the first minutes it covers the entire room. Subsequently, it reduces its intensity, which can be explained by the rapid combustion of combustible materials and the reduced amount of oxidant.

The smoke in the first minutes through the corresponding slits between the room in which the fire and the surrounding area arose, emerges out of the fireplace. It almost fills the basement floor, covers a part of the first floor and reaches the staircase, leaves the first floor through the open outside door. This indicates that a possible evacuation of the residents on the ground floor should take place in the first 5-10 minutes. When the outer door is closed, the smoke will fill the entire ground floor and will "rise" on the staircase, which will complicate the situation during evacuation and the actions of the fire service.

The fire rate in the room (kW), depending on the time in (min), is given in Fig. 3. In the first five minutes (3 minutes), the fire reaches its maximum power, corresponding to the full range of combustion materials in the room. Here is a section with characteristic turbulent combustion and average power about half the maximum. After 19-20 min. there is a gradual attenuation. This is due to a lack of combustible material and an oxidant ($O_2$) in the room.

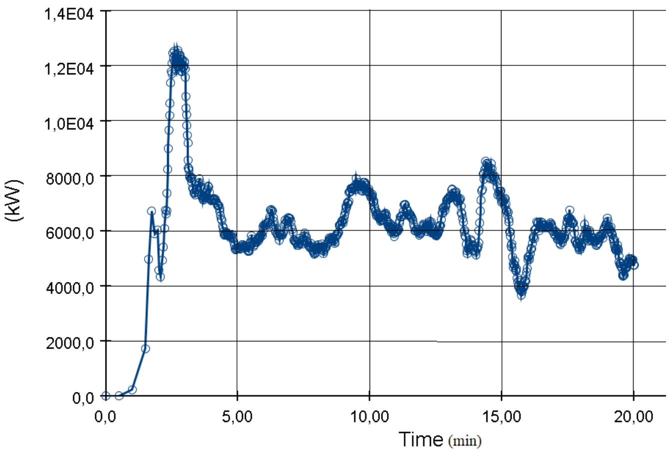


Fig. 3. The fire rate in the room in time domain

## VII. Conclusion

This article shows an opportunity with the methods of computational fluid mechanics to investigate the development of a fire occurring and developing in a limited space- in this case a study corpus of the Professional high school of Telecommunications.

The FDS program allows for fairly accurate results on the development of fire, smoke, heat exchange with the environment, and provision for measures to limit the occurrence and spread of fire and smoke. This also allows the evacuation routes to be identified with great precision. This is possible if the smoke movement is shown.

The simulation done refers to a specific actual site that was provided with information about the building's layout.

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