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RESULTS OF THE SIMULATION OF THE FLAME THERMAL RADIATION PROPAGATION THROUGH ROOM OPENINGS

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Abstract. *A still unsolved problem of fire transfer through room openings, especially by heat radiation and convection, as well as general lack of the literature dealing with the simulation methods, numerical experiments and calculations of spatial-temporal distribution of temperature field, imposes the need for its solution. To all this we can add data from practice pointing to the fact that fires in the buildings, in most cases, develop and spread through inner and outer openings. For this reason, in the world at large and in our country, fire models and software tools develop and get improved, namely, those that will lead to the results concerning propagation of thermal radiation through room openings in real time; they are to give adequate help in solving the given problem. Its solution, though, comprises making of an adequate mathematical model of the flame thermal propagation by radiation and convection as well as the choice and application of numerical techniques for solving the given problem in addition to the choice of an optimal software for calculation and a graphic display of the calculation results. The paper gives the results of the simulation of the flame thermal radiation propagation through room openings by using the program Fire Dynamics: Simulator (FDS).*

Key Words: *Thermal Radiation, Fire Model, Software, Simulation*

1. INTRODUCTION

The rapid growth of computing power and the corresponding maturing of the Computational Fluid Dynamics (CFD), have both led to the development of CFD-based "field" models applied to fire research. The use of CFD models has allowed the description of fires in complex geometries and the incorporation of a wide variety of physical phenomena. Virtually all this work is based on the conceptual framework provided by the Reynolds-averaged form of the Navier-Stokes equations (RANS), in particular the *k-ε* turbulence model pioneered by Patankar and Spalding [2]. However, these models have a fundamental limitation for fire applications – the averaging procedure at the root of the model equations. The application of Large Eddy Simulation

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(LES) techniques to fire aims at extracting greater temporal and spatial fidelity from simulations of fire is performed with more certainty. The phrase LES refers to the description of turbulent mixing of the gaseous fuel and combustion products with the local atmosphere surrounding the fire. The simplified equations, developed by Rehm and Baum [1, 2, 9], have been widely adopted by the larger combustion research community, where they are referred to as the "low Mach number" combustion equations. The low Mach number equations are solved numerically by dividing the physical space where fire is to be simulated into a large number of rectangular cells. Within each cell the gas velocity, temperature, etc., are assumed to be uniform; changing only with time. The accuracy with which the fire dynamics can be simulated depends on the number of cells that can be incorporated into the simulation. This number is ultimately limited by the computing power available.

2. FIRE DYNAMICS SIMULATOR

FDS computes temperature, density, pressure, velocity and chemical composition within each numerical grid cell at each discrete time step. There are typically hundreds of thousands to several million grid cells and thousands to hundreds of thousands of time steps. Typical output quantities for the gas phase include: gas temperature, gas velocity, gas species concentration (water vapor, CO_2, CO, N_2), smoke concentration and visibility estimates, heat release rate per unit volume, mixture fraction (or air/fuel ratio), gas density, water droplet mass per unit volume. On solid surfaces, FDS predicts additional quantities associated with the energy balance between gas and solid phase, including: surface and interior temperature, heat flux, both radiating and convective, burning rate, water droplet mass per unit area. Global quantities recorded by the program include: Total Heat Release Rate (HRR), sprinkler and detector activation times, mass and energy fluxes through openings or solids. ***Fire Dynamics Simulator*** includes further submodels: hydrodynamic model, combustion model and radiation model.

In **hydrodynamic model** FDS solves numerically a form of the Navier-Stokes equations appropriate for low-speed, heat-driven flow with an emphasis on smoke and heat transport from fires. The core algorithm is an explicit predictor-corrector scheme, of second order accuracy in space and time. Turbulence is treated by means of the Smagorinsky form of Large Eddy Simulation (LES). It is possible to perform a Direct Numerical Simulation (DNS) if the underlying numerical grid is fine enough. LES is the default mode of operation. For most applications, FDS uses a **mixture fraction combustion model**. The mixture fraction is a conserved scalar quantity that is defined as the fraction of gas at a given point in the flow field that originated as fuel. The model assumes that combustion is mixing-controlled, and that the reaction of fuel and oxygen is infinitely fast. The mass fractions of all of the major reactants and products can be derived from the mixture fraction by means of "state relations," empirical expressions arrived at by a combination of simplified analysis and measurement. **Radiating model** analyzes radiation transport equation for a non-scattering gray gas. The radiation equation is solved by using a technique similar to a finite volume method for convective transport, thus the name given to it is the Finite Volume Method (FVM). For calculation absorption coefficients $\boldsymbol{\kappa}$, as a function of mixture fraction and temperature applied narrow-band model **RadCal** is combined with FDS. Water droplets can absorb thermal radiation [8]; this is important for the cases involving mist sprinklers.

All the solid surfaces are assigned thermal boundary conditions plus information about the burning behavior of the material. Usually, the material properties are stored in a database and accessed by name. Heat and mass transfer to and from solid surfaces is usually handled with empirical correlations, although it is possible to compute directly the heat and mass transfer when performing a Direct Numerical Simulation (DNS).

Usage FDS is limited to low speed fluid (Mach number is lesser from 0.3), what is pronounced at transport heat and smoke from fire. This supposition determines that model cannot be used to scenery which gripe speed fluid adjacent speed sound, such as explosion, dense fluid through start and detonation. In the cases where the model provides speed fluid and temperature, precision ranges from 5 ÷ 20 % in relation to experimental exploration, depending on numerical grid resolution.

3. Model Input Data

Input parameters required by FDS contain information about the numerical grid, ambient environment, building geometry, source ignition location, heat release rate of source ignition, thermal properties of a wall, ceiling, floor and furniture, opening size, etc.

Test room used in all the calculations consists of two levels with same base dimension 5.2x4.6x2.4m. Opening on under level has dimension a=1.6m (width) and b=1.2m

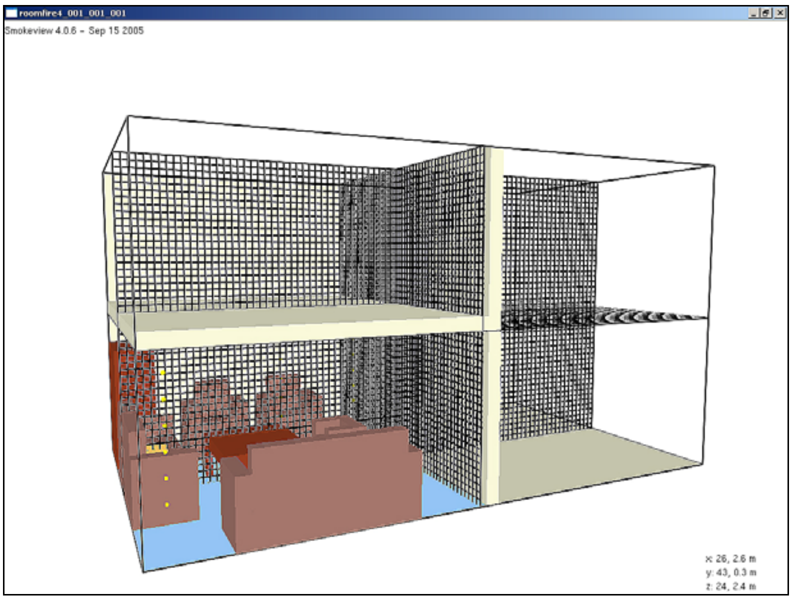


Fig. 1 Appearance Pensive Test Premise with Opening and Numerical Grid for Computation

(height). Window under border is at 0.9 m from a floor. Space around the test room is represented as outer space without a wind. Total assumed space (test room and space ahead of opening) is split by a numerical grid in 214656 calculated cells, where every cell cube dimensions are 0.1 x 0.1 x 0.1m. This particular numerical grid is selected to get more accurate results; its accordance with the previous data about computation validation and reliability depends upon dimensions (fineness of the) numerical grid. Room ceiling, walls, and walls considered as simulation necessaries are all coated with gypseous panels. Inside room geared by fire are placed two couches, two chairs and children chairs, all made from upholster pillow. There are also wooden stuff (table and pine-cupboard) and vinyl-carpet. Data about used materials and furniture dimensions are given in Tables 1 and 2.

Table 1 Thermal Properties of Used Materials

Material	Thickness (m)	Density (kg/m^3)	Conductvity (W/mK)	Temp. Ignition (°C)	Heat Evapor. (kJ/kg)	Burn Rate (kg/m^2s)
Gypseous panel	0.013	1440	0.48	400	-	-
Carpet	0.006	750	0.16	290	2000	0.05
Pine	0.028	450	-	360	500	-
Upholster pillows (cotton)	-	40	-	280	1500	0.03

Table 2 Furniture Dimension and Form-materials

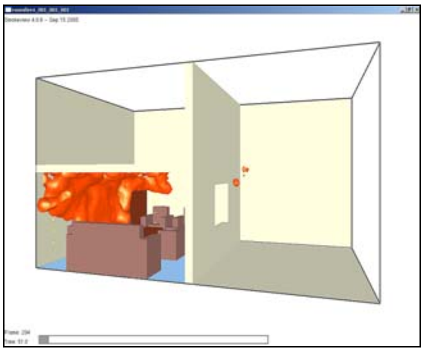
Object	Material	Dimension (m)
Board	Pine	1.5 x 1.2 x 0.2 (thick.)
Couch (2 pieces)	Upholster pillows	2.8 x 0.8 x 1.2
Chair (2 pieces)	Upholster pillows	0.8 x 1.0 x 1.2
Children chair	Upholster pillows	0.8 x 0.6 x 0.8
Cupboard	Pine	1.3 x 0.6 x 1.9
Carpet	Vinyl	5.2 x 4.6 x 2.4

For fire initialization is used ignition source on one of couches, size 0.6 x 0.6m, heat release rate of 360 kW.

4. SIMULATION RESULTS

Results for opening dimension a>b (1.6 x 1.2 m)

Fire development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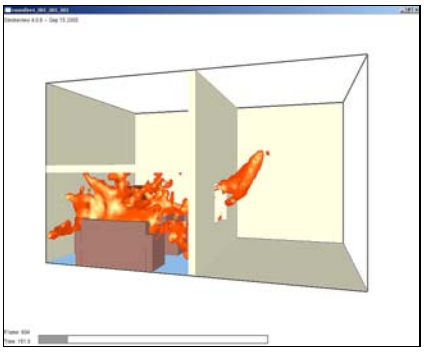
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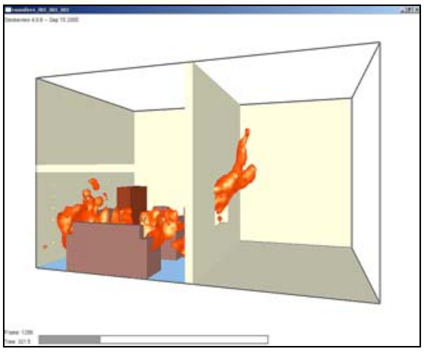
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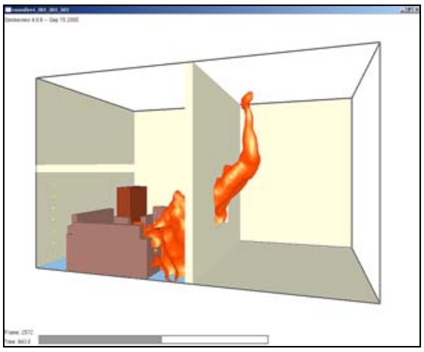
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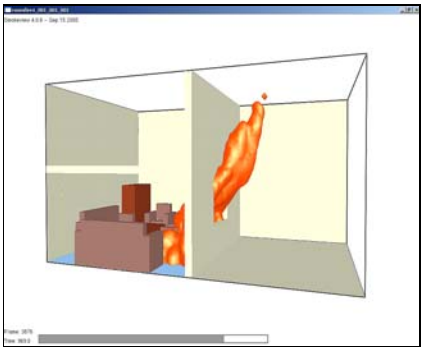
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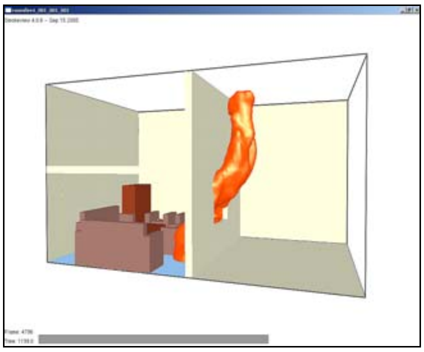
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Fig. 2 Review of Fire Development from 51 to 1200 seconds since Ignition

Temperature schedule for axis aperture (x=2.6m)

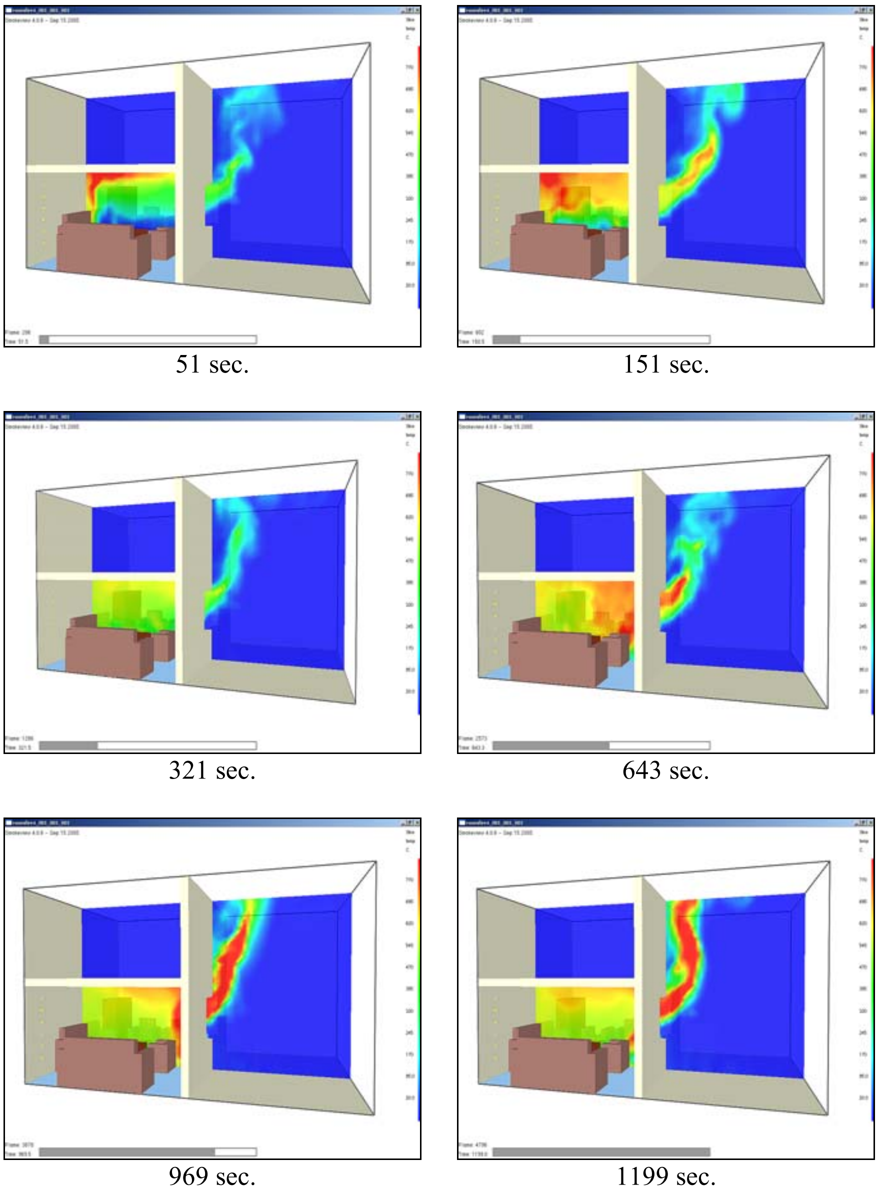

Fig. 3 Temperature Schedule at Axes Opening from 51 to 1199 Seconds since Ignition

Heat release rate and burning rate

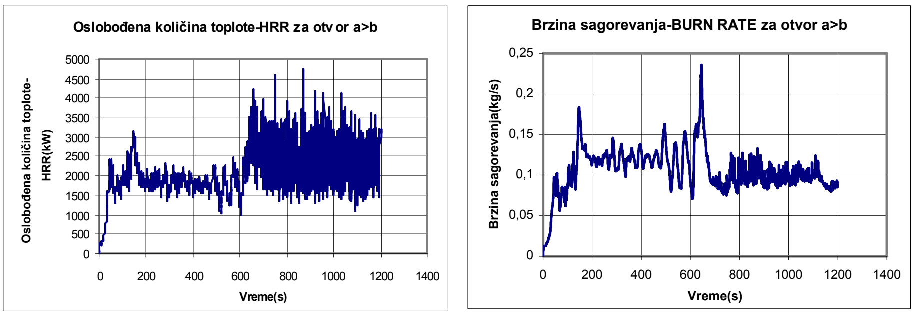

Fig. 4 Heat Release Rate and Burning Rate for Room with Opening 1.6 x 1.2 m

5. CONCLUSION

In this fire simulation (Fig. 2) fire has kept on burning during the entire 20 minutes simulation. The maximum registered temperature (Fig. 3) in- and out- of room (through opening), has reached 770°C, and flame geometry has taken on the full assumed height (to 4.8 m). Flashover (the moment when complete room volume is geared with flame) is set in 150 seconds after the beginning of simulation. Regarding temperature's dependence on heaight, we have concluded that the topmost amount is registered aloft of room ceiling, as for altitude from 1.8 ÷ 3.6 m relative to object front, what is accordance with flame geometry, i.e., its outcurvation through existing opening, as motion of fire front from broom initial ignition toward opening, i.e. toward unoccupied-free from fuel stuff and oxygen source, as necessary parameters for combustion. Fire transfer from furniture parts geared with fire on parts that are not geared or are in the "smouldering " phase, followed by the front fire transfer toward aperture and the arrival of a "flashover ", have all caused a variable diagram derivation for heat release rate and burning rate (Fig. 4), i.e., "sawtooth signal ", unlike the simple representation of the ignition and only one material of a piece of furniture tested when the diagram has a regular shape; both are often found in practice.

Based on the available literature which comes as a result of experimental exploration, we have come to the conclusion that the results of our simulation are in accordance with the results of practical experiments (5 to 15%). The causes of possible differences does not only spring from an imperfect model but also from proper selection and stuff attribute incorporating spatial-temporal disposition of considered components, solid geometry, ability to get actual and credible information about materials used in simulation, outer condition, properly selected grid for computation, computer facility and the like.

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REZULTATI SIMULACIJE PROSTIRANJA TOPLOTNOG ZRAČENJA PLAMENA KROZ OTVORE PROSTORIJE

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Nerešen problem prenošenja požara kroz otvore prostorije, posebno toplotnim zračenjem i konvekcijom, kao i potpuni nedostatak literature koja obrađuje metode simulacije, numeričke eksperimenate i proračune prostorno-vremenske raspodele temperaturnog polja, nameće potrebu da se ovaj problem rešava. Svemu ovome moraju se dodati i podaci iz prakse koji ukazuju na to da se požari u zgradama u najvećem broju slučajeva razvijaju i prenose kroz unutrašnje ili spoljašnje otvore. Iz ovog razloga u svetu i kod nas razvijaju se i usavršavaju požarni modeli i softverski alati koji će dovesti do rezultata za raspodelu toplotnog zračenja kroz otvore prostorije u realnom vremenu i pružiti adekvatnu pomoć u rešavanju datog problema. Rešavanje ovog problema obuhvata: izradu adekvatnog matematičkog modela prenošenja toplote zračenjem i konvekcijom, izbor i primenu numeričkih tehnika za rešavanje postavljenog problema i izbor optimalnog softvera za proračunavanje i grafički prikaz rezultata proračuna. U radu su dati rezultati simulacije prostiranja toplotnog zračenja plamena kroz otvor prostorije primenom programa Fire Dynamics Simulator (FDS).

Ključne reči: *toplotno zračenje, požarni model, softver, simulacija*