Smoke simulation in enclosed spaces

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2018

Project Objectives

- The formulation and solution of the equations of computational fluid dynamics for smoke simulation
- Creation and use of a program for simulating the burning of household objects
- Solution of use cases for two buildings and evacuation analysis
- Production of a 3D video of smoke.

Introduction

Smoke is the collection of liquid and solid particulates and gases that are produced by the burning of materials and is the number 1 cause of death in house fires.

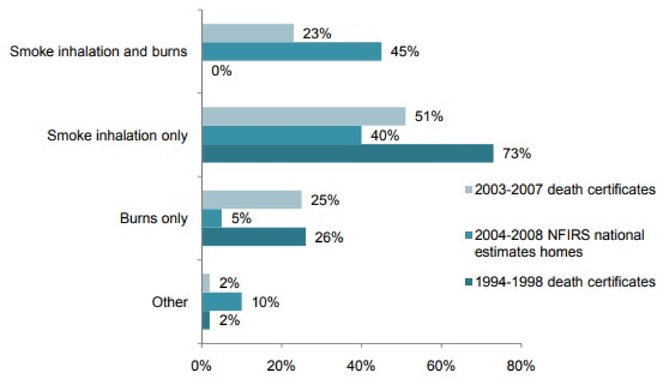


Figure: Causes of death in house fires [1]

Harmful Effects of Smoke

The ways that smoke hampers movement and causes so much damage are four.

1. **Oxygen deficiency**
2. **Distribution of poisonous gases**
3. **High Temperature**
4. **Visibility reduction**

Optical density of smoke

Lack of visibility is the criterion used for the evacuation analysis

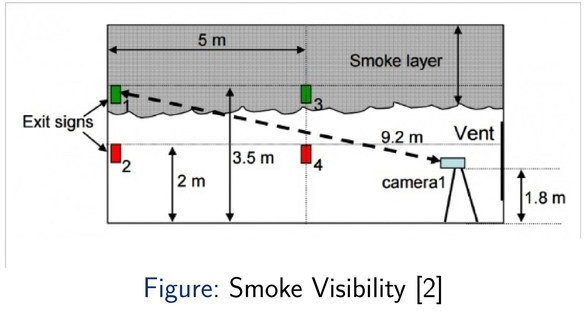


Figure: Smoke Visibility [2]

The intensity of light passing through smoke of optical density D, for length L, is equal to

$$I = I_0 10^{-DL} \tag{1}$$

For density $D = 0.1$ the visibility drop is $1dB/m$. To calculate D for real objects the following formula is used.

$$D = \frac{m_c \sigma_m}{A U_z \Delta t} \tag{2}$$

where
$\mathbf{m_c}$ is the combustible mass,
$\sigma_\mathbf{m}$ the smoke production per mass unit
$\mathbf{A}$ the surface of the object, and
$\mathbf{U_z}$ the velocity of smoke

Solution

Carbon dioxide gas is used to emulate the movement of smoke, by solving the CFD equations, in a hexahedral mesh. An upper limit of smoke density is then matched to the 100% of CO2

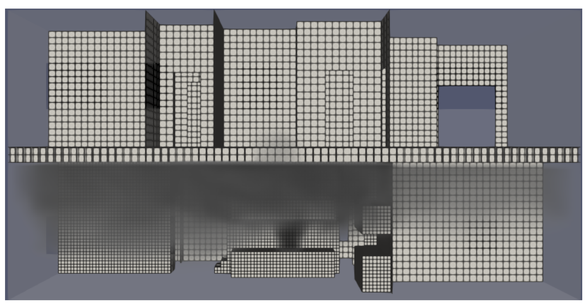
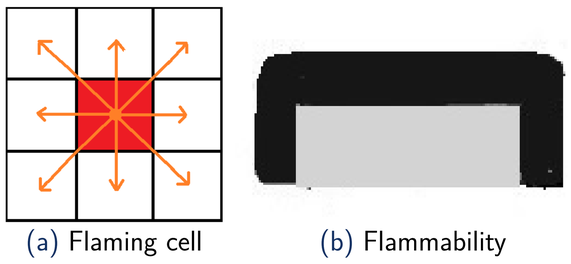


Figure: Smoke on the grid

Both static and non-static sources of smoke are simulated.

Non-static sources

The burning of household objects is not simulated by solving the precise chemical equations of combustion. Instead, using as input the flammability of objects and the initial fire source as black and white pictures, we match each point in the floor to a 2-d grid, in which each burning cell passes the flame to its neighbors, after a time, inversely proportional to their flammability.



(a) Flaming cell (b) Flammability

Using this model an approximation of the burning of real objects, according to experimental data is achieved.

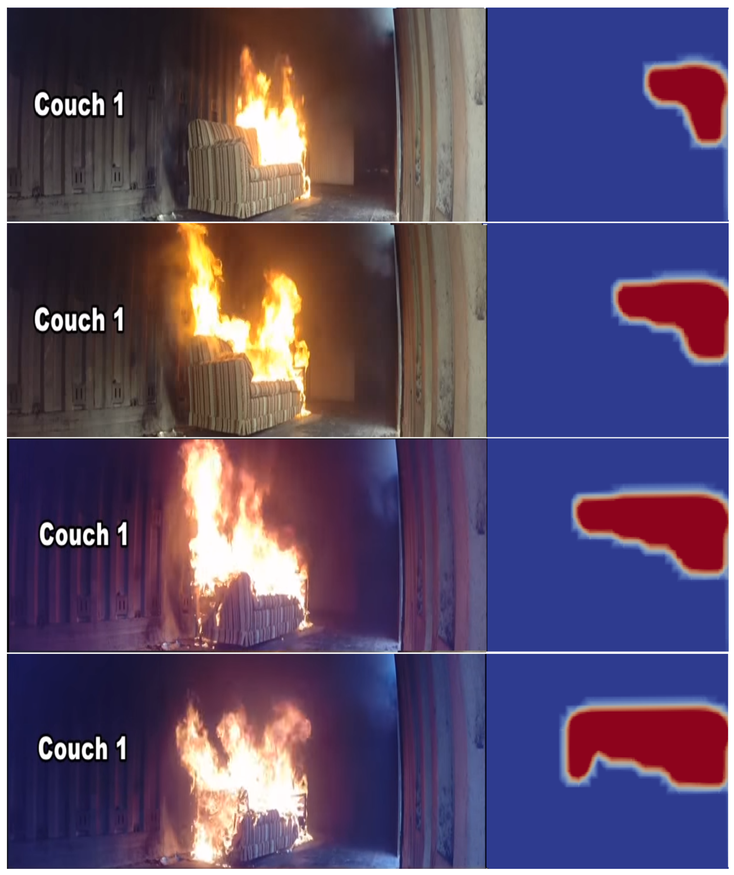


Figure: Couch burning experiment of the Fire Department of Cape Girardeau.(left) and the resultant smoke source (right)

Evacuations scenarios

The criterion of safe evacuation of any space is that the density of the smoke at the heigh of two meters is: $D = CO2 <= 2db/m$

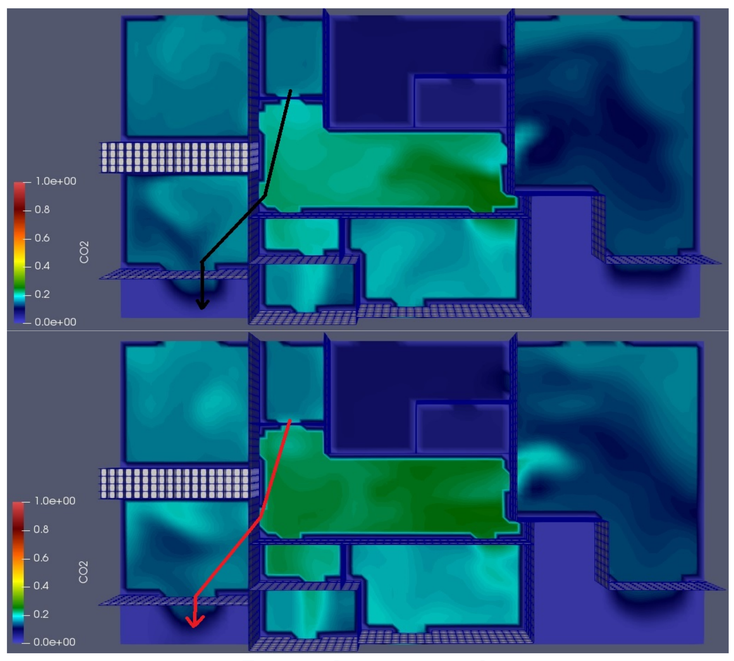


Figure: Green is unsafe

Sources

[1] John R. Hall, Jr. *Fatal effects of fire*. Fire Analysis and Research Division National Fire Protection Association , March 2011

[2] Tuomo Rinne et al. *Experimental Validation of the FDS Simulations of Smoke and Toxic Gas Concentrations* . VTT Working Papers 66