Modeling a real backdraft incident fire

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Abstract

This paper reports the fire conditions that occurred in a townhouse and the results of software simulations that were performed to provide insight on the peculiar thermal conditions that developed. Fire rescue was called by the occupants of the house when they became aware that smoky conditions were developing on the second floor. Two of the firefighters entered the bedroom where the smoke was originating from and a short time after a flame front invested them while propagating them backward into the stairwell. The post fire investigation determined that the fire started as a consequence of the smoldering combustion of material contained in a wardrobe located adjacent to one of the room walls. A simulation scenario was developed based on the information obtained on the actual building geometry, material thermal properties and the fire behaviour. The calculations that best represented the actual fire conditions indicate that the partial opening of the window and bedroom door provided outside air (oxygen) to a pre-heated, under ventilated fire compartment.
Keywords: smouldering combustion, backdraft, fire models, fire investigation.

1 Introduction

Part of the mission of the department of the firefighters, public rescue and civil defence is to conduct basic and applied fire research, including fire investigations, for the purposes of understanding fundamental fire behaviour and to reduce losses from fire. On February 3, 2003, a fire in a townhouse near Lucca

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caused two firefighters to be injured. Investigation on fire causes were conducted by the local fire brigade and police station. Computer simulations were made to provide insight on the fire development and thermal conditions that may have existed in the townhouse during the fire.

2 Fire scenario

The fire occurred in a masonry dwelling of ordinary construction. The building was inserted between two others that were not involved and contained only one apartment on three stories, connected through an enclosed stairway, with the basement entrance faced on the access road (Figure 1).

The occupants of the house, while staying in the first floor rooms, became aware that, starting from a closed bedroom, smoky conditions were developing in the second floor. They exited the residence via the front door at ground level and called for the fire rescue. The first engine arrived on the fire scene in approximately 20 minutes and entered in the house via the front door. Conditions on the second floor were described as smoky, with smoke coming from the doorway and the window of a room located in the second floor. To lessen the smoke level and provide ventilation, the firefighters started to open partially the front window.

Figure 1: External view of the 2nd floor room originating the fire and of the window that vented out the backdraft flame (pointed by the arrow) All the pictures have been taken about one hour later the fire event.

After some minutes, two of the firefighters, entered the house and through the stairs, reached the second floor room. They reported that the second floor was at that time fully charged with smoke. They opened the door, entered the bedroom and while orienteering to reach the window, one of them saw in the dark a small flame. Soon after a flame front invested them, while propagating backward to the doorway and then into the stairwell. The flame vented out through a window left open located in proximity of the first floor on the front of the house and then extinguished after few seconds. Thanks to the personnel protection equipment, the two firefighters did not suffer appreciable burn injuries. An amateur video has recorded the scene and became an important source of information when later reviewed by the fire department. The tape showed the flame venting out through the only fully open window, without appreciable flame persistence. Damage to the house was mainly limited to the bedroom originating the fire – a closed door prevented fire spreading. There was no fire extension to the other rooms or to the adjacent buildings and no structural damage observed.

Figure 2: Detail of the 2nd floor stairway lamp showing cover destruction.

Figure 3: 2nd floor stairway. The room originating the fire is on the left side.

The stairway from the first to the second floor showed only few appreciable effect of the backdraft flame impingement on the ceiling and walls except for the destruction of the lamp cover located on the second floor ceiling (Figure 2), the partial melting of the light switch located on the left side, near the bedroom doorway (Figure 3). The ladder shown in Figure 3 was used by the firefighters to access the wooden roof structure, after extinguishing the fire, to verify that no fire propagation and smoldering combustion had occurred.

The bedroom had significant deposits of soot throughout, with limited thermal damage. The gypsum board walls and ceiling remained intact. A wardrobe and some furniture located adjacently two walls were completely destroyed by the fire (Figures 4, 5 and 6).

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Figure 4: Detail of one wall in the room originating the fire. The wardrobe gone completely destroyed was located near this wall.

Figure 5: Detail of one room wall (next to Figure 4).

Figure 6: Detail of the bedroom door (next to Figure 5).

The bed showed signs of pyrolysis and limited burning on the upper portions of the back cushions (Figure 7). The triangular shape of the combusted part was attributed to the fire propagation from adjacent furniture, gone completely carbonized.

Figure 7: Detail of the bed.

3 Cause and origin

The information provided by the firefighters involved and the evidence described was of a classic backdraft, usually persisting only few seconds before exhausting its fuel supply. The post fire investigation determined that the fire started as a consequence of the smoldering combustion of the material contained in a wardrobe, located adjacent to a wall that contained inside a flue gas duct of an adjacent house chimney. A slow soot combustion fire occurred in the flue gas duct. This initial event provided the heat source that, by thermal conduction through the poor insulating wall, originated the smoldering combustion inside the wardrobe. It was witnessed that the wardrobe got usually warm even during normal chimney operation. The occupant and the firefighters confirmed that the bedroom door and the window were initially kept closed, so that there were negligible external source of combustion air. After the firefighters opened slightly the bedroom window, acting from the outside, an amateur video shows an increase in the smoke production. However, when the firefighters opened the door, the resulting fire gases, rich in carbon monoxide, flowed downward into the stairwell with high velocity and exited through the only open window located in proximity of the first floor.

4 Model results

NIST has developed a computational fluid dynamics (CFD) fire model using large eddy simulation (LES) techniques, called Fire Dynamics Simulator (FDS). The CFD model requires that the room or building of interest be divided into small rectangular control volumes or computational cells. The CFD model computes the density, velocity, temperature, pressure and species concentration of the gas in each cell based on the conservation laws of mass, momentum, and energy to model the movement of fire gases. FDS utilizes material properties of the furnishings, walls, floors, and ceilings to simulate fire spread. A complete description of the FDS model is given in reference [1]. FDS requires as inputs the geometry of the building, the computational cell size, the location of the ignition source, the ignition source, thermal properties of walls, furnishings and the size, location, and timing of vent openings to the outside which critically influence fire growth and spread. The timing of the vent openings, used in the simulation, are based on an approximate timeline of the fire fighting activities and on a real time video taken by an amateur. The floor plan of the second floor of the townhouse and of the stairwell are shown in Figure 8. The placement and size of the interior walls, doorways, and windows were taken from the dimensioned floor plans drawn by personnel of the Fire Brigade.

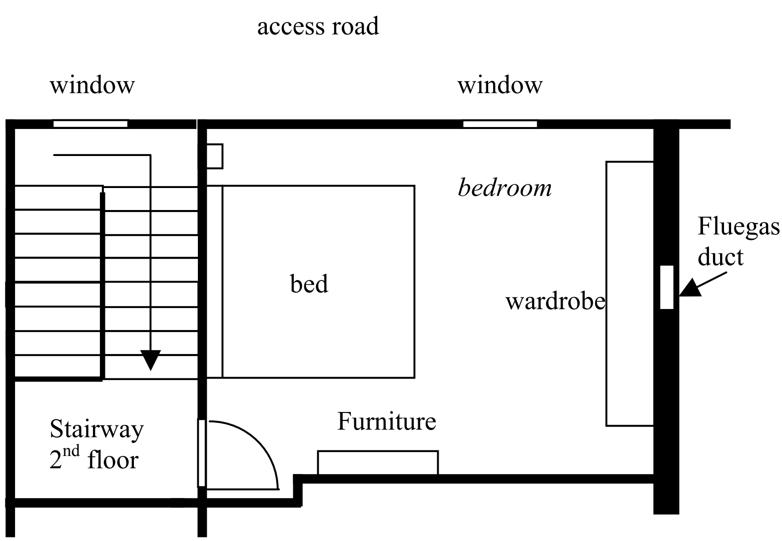

Figure 8: 2nd floor plan view.

As in the fire incident, the bedroom window and door were kept closed during the simulation, till the firefighters opened them. The front window on the second floor was kept closed while the one located on the first floor, where the backdraft was vented out (see Figure 1), remained opened during the entire simulation. For the FDS simulation, a specified heat flux from the wall adjacent to the wardrobe was used to start the fire growth as the ignition source. Starting the simulation with a flaming ignition enabled fire development to be modeled within a reasonable computational time. The actual fire may have taken several hours to develop to the flaming stage, if eventually reached. As the simulated fire spreads from the ignition source, and then to other items in the room, it depletes its supply of oxygen for combustion. When a fire occurs in a closed room where the only ventilation is due to leakage, it can become limited by the available oxygen and produce large amounts of unburned fuel. If the leakage rate is low enough the fire may enter a smoldering stage. Temperatures within the bedroom has been estimated much lower than flashover temperatures but significantly higher than the ambient. Upon venting, a gravity current carries fresh air into the compartment. This air mixes with the excess pyrolyzates producing a flammable pre-mixed gas, which can be ignited by a flame or a glowing ember, generating a flame front moving through the compartment toward a vent. This entire process: the accumulation of unburned gaseous fuel, the propagation of an oxygen rich gravity current creating a mixed region and carrying it to the ignition source, the ignition and propagation of an eventually turbulent deflagration vented out, altogether constitutes a backdraft [2, 3].

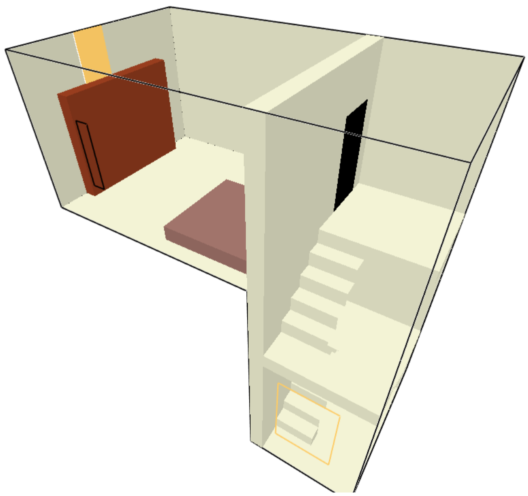

Figure 9: Perspective view of townhouse.

The FDS calculations supported the hypothesis that unburned fuel and CO accumulated in the bedroom, resulting in a backdraft after few minutes of venting the bedroom. Reported conditions such as smoke accumulation in the second floor and the "exotic" propagation of the deflagration downward the stairway were reproduced by the model (Figure 10). Some assumptions were necessary in performing these calculations, which may have an impact on the model's predictions. The results are sensitive to the volume of the apartment and to the size and locations of ventilation openings. All of these were known by actual measurements taken by the fire department during their investigation and by witness report and a real time amateur video. It was reported that the bedroom door and window were closed, up to firefighters arrival. So the assumption of no additional leakage was justified. The combustion was predominately ventilation controlled, making the results insensitive to fuel loading and the specific burning characteristics of the fuel. The generation rate of unburned fuel and CO in poor ventilation conditions should be affected by energy feedback from the environment and any flames present during the time of ventilation controlled combustion. The FDS model does not contain such a self-consistent combustion model, so the quantity of unburned fuel and CO production has been estimated and subject to a sensitivity analysis. The field data of the heat release per unit volume during backdraft evolution are reported in Figure 10.

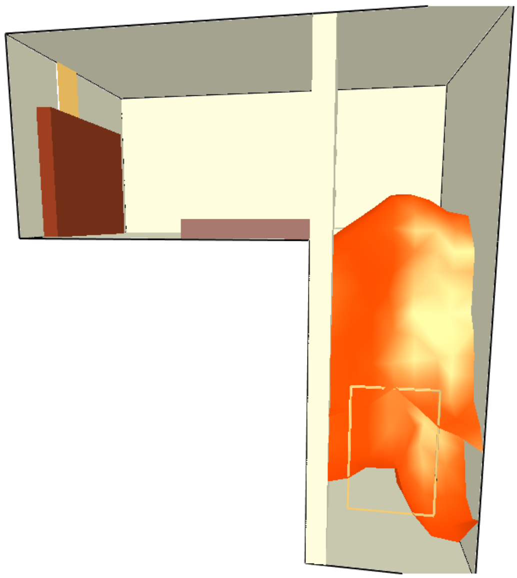

Figure 10: Field data of the heat release per unit volume (kW/m^3) during backdraft evolution.

A temperature profile inside the bedroom during backdraft is shown in Figure 11. The values are in the range of 200-250°C, much lower than flashover temperatures as expected. This figure is compatible with the observed fire scenario and are indeed necessary to support the production of relatively dense unburned fuel, prior to cold air mixing, necessary to allow downward flame propagation from second floor to the first floor window, were the deflagration was vented out.

5 Lessons learned

The fire service community has long recognized the hazards associated with backdrafts. Typically, firefighters are involved in initial search and rescue or suppression operations when the backdraft occurs. Current tactics for reducing the backdraft hazards are to vent the structure prior to entry. However, the ventilation process is often a second priority to the rescue operation. Indeed, unless it is restricted to roof venting, ventilation may facilitate rather than prevent a backdraft. Even if neither the occupant nor the firefighters get seriously injured, it is fundamental to analyze the incident to increase the overall consciousness of safety culture and avoid the risk that valuable information get lost unreported as because no one had been injured. It has also pointed out the benefits of the use of modern, computer fire modeling in the reconstruction of fire incidents to understand critical factors for mitigating their impacts.

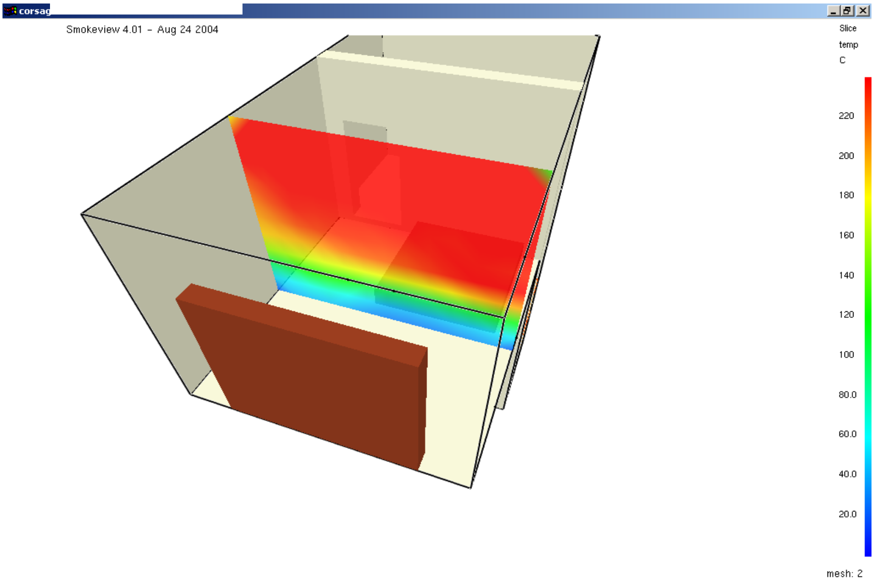

Figure 11: Temperature profile inside the bedroom (°C) during backdraft.

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