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Fire Science Living Lab for Flashover Prediction †

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Abstract: There is a huge demand for new techniques and technologies to tackle life-threatening in fire emergencies. Enclosure fires are a type of emergency involving firefighters whose lives are sometimes put at risk. In any confined fire, the emergency team may encounter two types of combustion environments, ventilated or under-ventilated. The rapidly changing behaviour of this scenario depends on multiple factors such as enclosure size, ventilation, or type and quantity of fuel involved. However, the difficulty of handling this situation coupled with the potential for human error, even if there is undivided attention to the task in hand, remains an unresolved challenge for firefighters today. New technologies based in Thermal Imaging Cameras can help firefighters to prevent this situation. Fire Science Living Lab is presented as a solution to test new technologies for this area. This papers shows a resume about the process to develop a prediction system in a living lab for one of the most dangerous situation for firefighters, flashover.

Keywords: flashover; LivingLab; artificial intelligence; CFD software; prediction; thermal vision camera; thermal image

1. Introduction

Confined fires, a common type of emergency in the world at large, can have serious consequences for people and they can produce structural problems in buildings. This type of fire can occur in spaces with different uses, such as blocks of houses, garages, single-family homes and commercial establishments. Currently it is very difficult to obtain accurate data to evaluate confined space fires in Europe, because there is no database available of this dangerous type of emergency. Furthermore, there is no data available on how this type of enclosure fire affects emergency teams, materials or victims.

Flashover or generalised sudden combustion refers to a rapid transition to a fully developed fire (see Figure 1a) that occurs in an enclosure whereby suddenly all the combustible surfaces (that until that moment were not involved in the fire) begin to burn due to the radiation coming from the gas layer in the ceiling area. This causes the entire volume of the room to be occupied by flames, a fact that marks the maximum development of the fire. A radiation of up to 170 kW $/\mathrm{m}^2$ [1] can be reached, a much higher value than the one used to test the firefighters clothing. In the Table 1 the different radiation values are shown, and they can be compared with the maximum heat flux for a post-flashover case. It is important to note that the heat flux for protective clothing (80 $\mathrm{kW/m^2}$ according with NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting) is well below this value.

Table 1. Approximate Radiant Heat Flux [1]

Approximate Radiant Heat Flux (kW/m^2)	Comment or Observed Effect
170	Maximum heat flux as currently measured in a post-flashover fire compartment.
80	Heat flux for protective clothing Thermal Protective Performance (TPP) Test. [1]
52	Fiberboard ignites spontaneously after 5 s. [2]
29	Wood ignites spontaneously after prolonged exposure. [3]
20	Heat flux on a residential family room floor at the beginning of flashover. [4]
16	Human skin experiences sudden pain and blisters after 5-s exposure with second-degree burn injury. [5]
12.5	Wood volatiles ignite with intended exposure [6] and piloted ignition.
10.4	Human skin experiences pain with 3-s exposure and blisters in 9 s with second-degree burn injury. [7,8]
6.4	Human skin experiences pain with a second exposure and blisters in 18 s with second-degree burn injury. [9,10]
4.5	Human skin becomes blistered with a 30-s exposure, causing a second-degree burn injury. [11]
2.5	Common thermal radiation exposure while fire fighting. [12] This energy level may cause burn injuries with prolonged exposure.
1.4	Thermal radiation from the sun. Potential sunburn in 30 min or less. [13]

[1] From NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting. [2] From Lawson, "Fire and the Atomic Bomb." [3] From Lawson, "Fire and the Atomic Bomb." [4] From Fang and Breese, "Fire Development in Residential Basement Rooms." [5] From NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting. [6] From Lawson and Simms, "The Ignition ofWood by Radiation," pp. 288–292. [7] From NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting. [8] From Lawson, "Fire and the Atomic Bomb." [9] From NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting. [10] From Tan, "Flare System Design Simplified," pp. 172–176. [11] From NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting. [12] From U.S. Fire Administration, "Minimum Standards on Structural Fire Fighting Protective Clothing and Equipment." [13] From Bennett and Myers, Momentum, Heat, and Mass Transfer.

The NFPA [1] also defines flashover as the transient phase in the development of an indoor fire in which surfaces exposed to thermal radiation reach their ignition temperature almost simultaneously and the fire spreads rapidly throughout the space available within the enclosure.

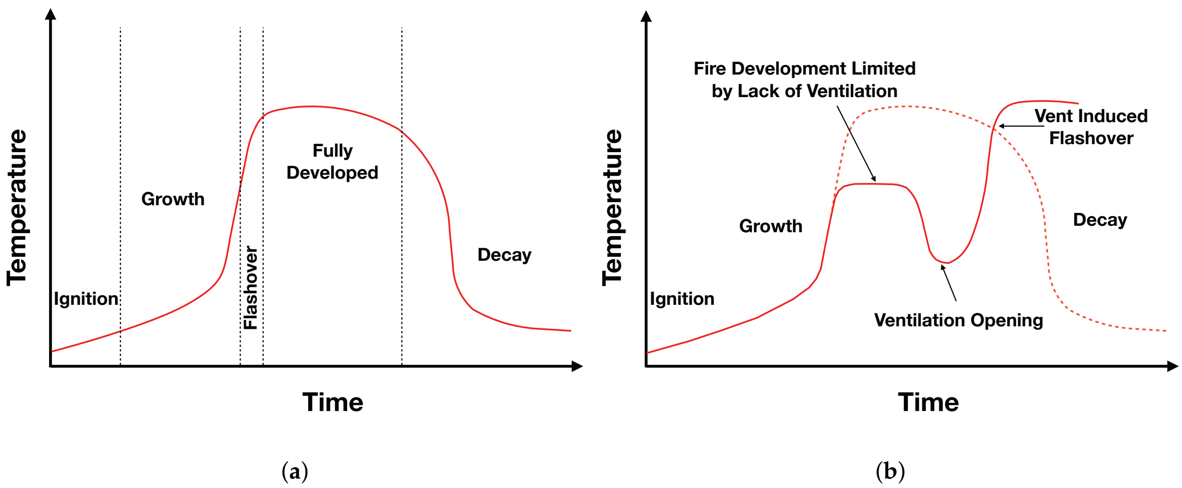

Figure 1. Flashover development. (**a**) Flashover as a transition phase in the fire standard curve before fully developed fire stage in an enclosure. (**b**) Vent induced flashover.

The development of flashover occurs in confined spaces with constant air supply (not presenting deficiencies of oxygen) or in under-ventilated confined spaces where fire dynamics change (e.g., induced ventilation by fans or breaking or opening of a window or door) and the situation changes from ventilation-controlled to fuel-controlled, this is known as ventilation induced flashover. Taking this into account, a minimum amount of fuel is necessary to generate sufficient combustible gases and radiation for the development of these phenomena. Flashover can correspond to an indoor fire at its full development stage, even with ventilation openings, but its power and occurrence is determined by the location and size of the ventilation opening to the exterior.

The Fire Development curve (see Figure 1a) shows the time history of a fuel-limited fire. The quantity of oxygen in pre-flashover phase inside the enclosure is enough to maintain the combustion and consume all the fuel. As more fuel becomes involved in the fire, the energy level continues to increase until all the fuel available is burning (fully developed). Then, as the fuel is burned away, the energy level begins to decay. At all times, enough oxygen is available to mix with the heated gases (fuel) to enable the completion of the fire triangle and the generation of energy. Once the fully developed phase is achieved, in most cases the fuel mass release rate becomes so high that the air supply rate becomes insufficient to consume all release pyrolysis gases (fuel-controlled to ventilation-controlled) [2].

The question is whether firefighters can predict this kind of phenomena in an effective way. In recent years, due to the incorporation of thermal imaging cameras (TIC) for fire services, has made it possible to detect several potentially dangerous situations for emergency services involved in fire and rescue. The cameras provide the user with valuable real-time information that, in the hands of trained professionals, can be of vital importance to their safety [3]. However, attention must be focused on certain types of fires in confined spaces, such as fires in which flashover phenomenon are likely to occur [1]. In this situation, it is very important for emergency teams to have a better understanding of enclosure fire dynamics so as to anticipate the possible consequences. Sometimes this is not possible due to the rapid response multitasking nature of the emergency and the corresponding stress that these situations generate for the firefighter. This means that TIC is a magnificent tool to help firefighters in these kinds of emergencies, minimising their work load and displaying a thermal image of the situation in real-time. Currently, TIC models used by fire services have several functions such as person detection or location of hot spots, among others. Moreover, the display shows a scale of temperatures, which changes automatically between two modes (high and low sensibility). The scale shows the temperature of the specific area in the display (located in the centre of the image (Figure 2, right). It means that when a firefighter wants to know the temperature of a target, he must aim the central area of the display towards the target. However, this does not work in the same way in the event of a smoke layer because the temperature shown by the camera is the reflection temperature and not the inside temperature of the smoke layer. Due to the visible light wavelength, small airborne particles, such as carbon particles in the smoke layer or water vapour can interfere with reflecting visible light. By contrast, infrared light has a longer wavelength than visible light and therefore, is not easily reflected by smoke layer particles. Therefore, this fact must be taken into account for smoke layer measurement with thermal cameras.

Attempting a prevention of the flashover phenomenon described in this paper, the firefighter handling the TIC must monitor the temperature of the hot gas layer to detect changes in the environment. However, this method is not very accurate because flashover depends on multiple factors such as compartment configuration, fuel and ventilation among others, and most importantly, the human factor.

The aim of this paper is to show a brief description of this research and highlight the importance of fire science living lab to develop and test new technologies in this line of work.

The outline of this paper is as follows. Firstly, we review how these kinds of phenomena are modelled and present the cutting-edge technology to simulate it. Secondly we show a brief explanation about the method for comparing images from simulating software with images from thermal imaging cameras. thirdly, we explain what kind of technology has been applied to predict flashover. Fourth, we include a Fire Science Living Lab section, where how is structured the living lab is explained. Conclusions and future lines of work can be consulted in the last section.

2. Image Acquisition

To predict these phenomena accurately, it is necessary to have a deep knowledge of their physical and chemical causes. Numerous experiments have been carried out and numerical modelling techniques have been developed to improve safety and reduce risks in confined fires to obtain higher accuracy for fire extinguishing systems. Full-scale experiments to deepen the knowledge about flashover phenomena are destructive and quite expensive, limiting these to small structures. Furthermore, it is difficult to find real information about flashover situations and fire services do not have a database of real cases with technical data about these phenomena. There are different techniques available related to fire and combustion ranging from simple algebraic correlations that can be solved with a calculator, two Zone Models or Lumped Parameter Models [4], which represent a space as a small number of elements, to CFD (Computational Fluids Dynamics) or Field Models [5], which approximate a space as a large number of discrete volumes. Field Models increasingly incorporates complex representations for enclosure fires and numerous studies have been carried out to validate different CFD techniques. It is important to resolve the fire chemistry and soot formation and combustion processes within the fire model itself. To simulate the problem we used a CFD software, given its simulation accuracy. In fact, CFD simulations offer users the possibility of exploring the scenario in thermal mode.

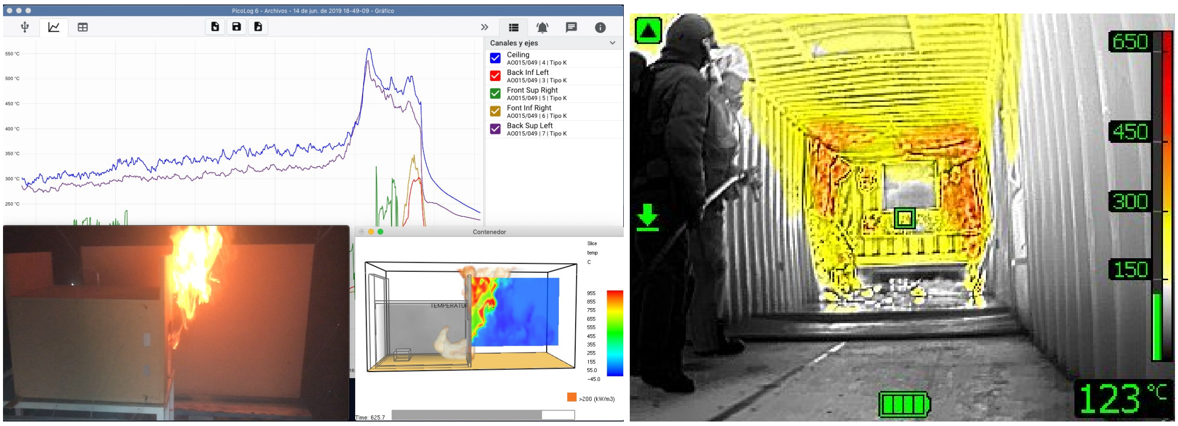

Figure 2. Experiments in the fire container at San Vicente Fire Station, Alicante.

For this work Fire Dynamics Simulator (FDS) has been used to simulate a flashover situation in a small scale experiments. In order to validate the thermal image from FDS, a series of small scale experiment were designed to compare the results with the data obtained from the simulations. The experiments were carried out inside a fire container (Figure 3). Fire container is made from a shipping container. A typical ISO shipping container is made from a 'weathering steel' as specified UNE-EN 10025-5:2007 (Hot rolled products of structural steels - Part5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance). The Fire container function is to obtain adequate conditions (without wind) for the correct experimental procedure. In order to create a useful dataset from simulated images with predicting purposes, we must confirm that the images obtained from FDS is similar to images from the thermal image camera (Figure 4). The problem is that it is not possible to compare obtained images from this software with a thermal image camera directly. Some transformations have to be done before it. In this line, a model-based imaging of mid-infrared radiation was developed. Radiation and buoyancy were evaluated by comparing qualitatively measured and computed images of mid-infrared radiation intensities. This technique was used in this work for obtaining time-dependent quantitative images of the radiation intensity from smoke coming out of the enclosure vent.

Figure 3. Fire container at San Vicente Fire Station.

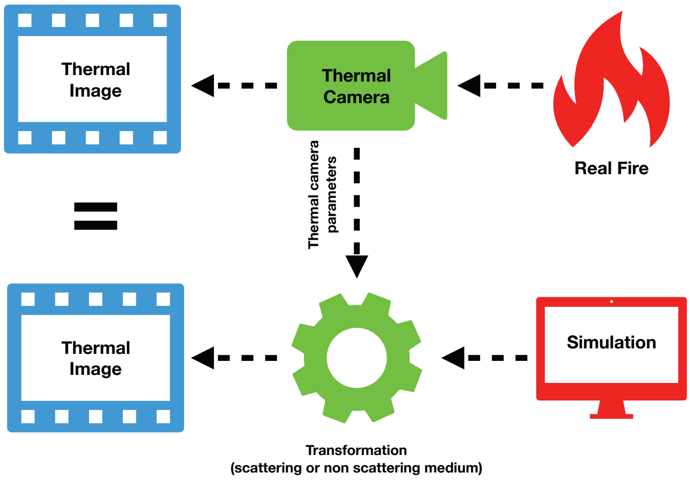

Figure 4. Image transformation.

3. Flashover Occurrence Prediction

AI research focuses on the study of intelligent agents. Through AI techniques a device can take actions that maximise the chances of successfully completing a task based on environment perception. Nowadays, AI techniques, such as flame detection [6,7], fire spread [8], fire and smoke classification [9], flashover occurrence [10,11], thermal interface location in a single compartment fire [12] or temperature and velocity profiles [13] among others, have been proven to predict certain fire-related situations. Different approaches have been used to research fire prediction, the most commonly adopted approach is artificial neural networks (ANN). ANN is a learning algorithm which is usually used to model complex relationships between inputs and outputs, to find patterns in data or to capture the statistical structure in an unknown joint probability distribution between observed variables. The use of this kind of technology applied to fire science in recent years is on the rise, more specifically convolutional neural networks (CNN) seem to be more appropriate as they are proven to be highly effective on visual and thermal image dataset [14]. Several cases of enclosure fires were designed using FDS. The images obtained were used to train a CNN to predict flashover conditions. Finally, this technology was implemented in a thermal camera to test it in the Fire Science Living Lab in real time. Results obtained from this were used to improve the prediction. Not only feedback about prediction technology was received from firefighters but also new knowledge about methods for using this technology in real time in handle thermal cameras were acquired.

4. Fire Science Living Lab

In a fire emergency time is crucial to prevent a dangerous situation. Consequently major, predictions should be done in real time. The main problem of testing this technology in a laboratory is that the number of scenarios are limited by the resources. Different types of constructions, number of vents, weather conditions, fuels and situations have to be taken into account. Fire Science Living Lab give us the opportunity of testing this technology in real emergencies. This laboratory is composed of thirteen fire stations in Alicante Province Fire Service. Each fire station has two thermal cameras for its use in different situations. Currently, flashover prediction technology has being tested by firefighters in Fire Science Living Lab (Figure 5). Notice this fire service works 24/7 and it is organised in five shifts. It means we have the opportunity to test it in different weather conditions along 24 h a day. Even the firefighter who handles the thermal camera changes every day. Feedback data about prediction technology and human application about it in thermal cameras were analysed. Fire Science Living Lab is promoting by Alicante Province Fire Service in collaboration with Alicante University.

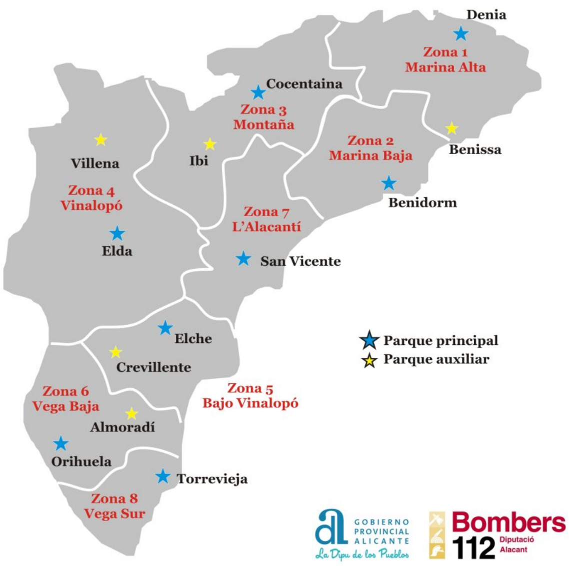

Figure 5. Fire Science Living Lab.

5. Conclusions and Future Work

In this manuscript, a brief summary of an ongoing project has been presented. First, we start with a review of the state of the art, to continue proposing an image modelling and simulation. Finally, a prediction for flashover conditions has been shown. Fire Science Living Lab has been used to develop and test new technologies. It has been an impulse to accelerate the test technology process. We envisage future research using the Fire Science Living Lab to test technologies. Not only fire science technologies or products can be test in this kind of lab but also health and sport research could be carried out. Notice firefighters during emergencies are under a lot of stress and extreme physical conditions.

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