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Real-scale fire tests of one bedroom apartments with regard to tenability assessment

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ABSTRACT

Statistics reveal that people mostly die in bedrooms or lounges, from smoking-related fires. However, at present, little is known of this phenomenon, especially in terms of identifying which fire effects first injure people. Through several real-scale fire tests, two different sets of fire scenarios are explored in a single bedroom apartment. As in everyday life, the test room is equipped with furniture, clothes and items supplied from major retailers. It is heavily instrumented with sensors to record tenability-related data (thermocouples, heat fluxmeters, gas analyzer including 3 FTIRs, opacimeters and several cameras for video recording).

The first set of tests explores a bed fire scenario, in which a person has fallen asleep, accidentally lighting its quilt, and then its mattress, e.g. with a cigarette or a small flame. The door and window remain closed during the entire test, and the fire decreases rapidly to become insignificant because of a lack of oxygen.

The second set of tests explores a wastepaper basket fire scenario, with a first person leaving the room quickly, while a second person – who is potentially disabled – cannot leave the room. As the door remains open, there is enough oxygen supply, and the fire grows to flashover.

The test results are designated as reference for calculation models validation. In addition, their interpretation in terms of tenability is presented; fire effects are classified and discussed. All this work also highlights the importance of smoke alarms in such premises.

1. Introduction and background

1.1. Objectives

Small-room fires are frequent and may have fatal consequences. People have to be alerted and have to evacuate before the situation becomes untenable. Adverse fire effects on people are related to thermal and/or toxic effects which are indirectly enhanced by the loss of visibility. Although it is considered that people mostly die from toxic effects during a fire, there is a lack of knowledge on what effect drives tenability conditions in a given situation and fire scenario.

The main objective of the study is to determine which fire effect occurs first in a few simple scenarios using ISO 13571 [1] as a tool to carry out tenability assessment. Another objective is to produce a set of data for various fire scenarios, in order to further validate fire models. An additional objective of this study is to investigate the efficiency of smoke alarms regarding the tenability conditions at the moment alarm activates and during escape, as France recently adopted a regulation introducing smoke alarms in dwelling.

1.2. Background

Experiments accompanied with an analysis of tenability conditions during fire growth have seldom been the object of an in-depth study. Condit et al. conducted one of the first attempts in 1978 [2]. They studied well-ventilated fire scenarios of room corner tests, where walls include combustible insulation protected by gypsum boards. The tenability conditions were studied using animal models. They concluded that the toxic threat from combustible insulation materials was secondary to that of combustible furnishings of the room from fire initiation to an advanced growth stage when the insulation protected by gypsum thermal barrier became involved.

In 1985, a series of similar experiments was performed at South-West Research Institute on furnished rooms [3]. Grand et al. [4] studied fully furnished and finished 20 m² rooms reproducing a typical

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hotel arrangement. The test facility consisted of a fire room at right angles to the end of a corridor with another room off the corridor. The second room contained animals to assess both pre-flashover and flashover toxic effects. Both room doors were open. The fire ignition scenario was sufficient to allow flashover conditions in the fire room. The rooms and corridor were fully instrumented with thermocouples, heat flux meters, smoke opacimeters, and gas sampling trains. In the few minutes prior to visual flashover, the toxic hazard of this fire scenario increased dramatically. At a 1.7 m height in the fire room, the temperature rose to 650 °C, carbon monoxide concentration reached 70,000 μL/L, dioxygen concentration dropped to zero, and the hydrogen cyanide level exceeded 1000 μL/L. Nevertheless, the analysis techniques available at the time didn't allow differentiating which fire effect occurred first in the fire room.

In Japan, Morikawa et al. [5,6] performed similar studies in the eighties, focusing only on toxicity. Two compartment fire experiments were conducted in a two-storey building to investigate the evolution of toxic gases and atmosphere toxicity in the burn room and its surrounding area. The first fire was set to analyze the combustion of natural polymer contents, and the other, synthetic polymer contents. Major toxicants evolved including CO, HCN, HCl, SO_2, NO and formaldehyde were measured and toxic effects were evaluated by applying a simple toxicity model. Mice and rabbits were used as test animals and exposed to fire effluent gases in the burn room and exposure boxes. For rabbits, blood analysis and other biological examinations were carried out to find out the cause of the death or incapacitation. The results suggest that HCN contributes to some extent to death or incapacitation in the fires studied. The analytical techniques available at the time were not accurate enough to have proper time-resolved information for all species. Nevertheless, the use of animal model allowed in some terms the validation of indirect toxicity models.

In Sweden, in 1987, Sundström performed full-scale tests of upholstered furniture [7]. The tested item was ignited with a small wood crib and then it was allowed to burn freely without restriction of air supply. The parameters measured were heat release, the mass burning rates and carbon oxides release. Results have been introduced in a simple fire model in order to illustrate the risk for further fire spread and visibility for escape in addition to the toxicity due to carbon monoxide production. This calculation did not consider the evolution of fire conditions with time, and so did not allow tenability conditions in a room scenario to be differentiated.

In 2000, Purser applied more modern assessment techniques for compartment fires as fire scenario, the ventilation, etc. and dose-related tenability models [8] were taken under consideration, using the Fractional Effective Dose methodology. He studied tenability conditions outside the fire room – in connected corridors and additional rooms. Purser concluded that fires are likely to become oxygen vitiated, producing large amounts of smoke and toxic products, be it in conditions prone to induce flashover or largely under ventilated. One conclusion was that the main hazard which affects building occupants was the rapid contamination of building spaces by toxic smoke. In his study, visual obscuration and smoke irritancy limited escape efficiency which, by way of consequence, affected escape behavior and reduced travel speed. This may be followed by incapacitation, primarily due to the exposure to asphyxiant gases (mainly CO and HCN), leading to death. Purser presented a series of full-scale fire tests conducted in enclosed test rigs and buildings, in which detailed smoke, heat, toxic gases and detections measurements were made. However, the gas measurement techniques used at that time were not as accurate as nowadays.

In 2003, Gann et al. studied experimental room-scale fire tests to produce data on toxic products yields in both pre-flashover and post-flashover fires [9]. The examined combustible products were individual items, such as a sofa made of upholstered cushions on a steel frame, particleboard bookcases with a PVC-laminated finish, and household electric cable. They were burned in a room with a long adjacent corridor. The yields of CO, CO_2, HCN, HCl, and carbonaceous soot were determined. Other toxicants (e.g., NO_2, formaldehyde and acrolein) were not found. The toxicant yields from sofa cushion fires in a closed room were similar to those from pre-flashover fires of the same cushions in a room with the door open. The use of Fourier transform infrared (FTIR) spectroscopy was shown to be useful to obtain toxicant concentration data. The losses of CO, HCN, and HCl as they flowed down the corridor were found to be dependent on the combustible. The data provided turned out useful for modeling, although limited because of their uncertainties. Hirschler [10] argued that, consequent to these uncertainties, the work overestimated the quantities of HCl and HCN released. In consequence, it seriously overestimated the toxicological importance of gases such as HCN and HCl in post-flashover conditions. In addition, the very low concentrations of toxicants measured at pre-flashover conditions might have indicated that such pre-flashover fires do not generate extremely toxic atmospheres. This study only considered individual items in well-ventilated fire scenarios.

In 2004, Peacock et al. [11] performed a large number of simulations using zone models to predict the relative times at which smoke inhalation and heat exposure would result in incapacitation. Fires in three building types were modeled with gas species yields. Rates of heat release for design fires derived from a review of real-scale fire test data. Incapacitation equations were taken from ISO 13571. Sub-lethal smoke effects were deemed important when incapacitation from smoke inhalation occurred prior to thermal effects. Real-scale HCl yield data were incorporated when available. The modeling indicated that the yield would need to be 5–10 times higher for incapacitation from HCl to precede incapacitation from narcotic gases, including CO, CO_2, HCN and reduced O_2 concentration. In addition, fires originating from concealed spaces in any type of occupancy were a real threat. Sublethal effects of smoke appeared not likely to be of prime concern for open fires in single or two-compartment occupancies themselves. Sublethal effects, however, may be important in adjacent spaces or buildings with high ceilings and large rooms and occupancies in which fires would be detected promptly and from which escape or rescue would require a few minutes. This study introduced ISO 13571 for tenability calculation. It should be recalled that the standard was at a preliminary drafting stage at this time. The study was a numerical one based on experimental input data, but results were not compared with experimental identical situations in the analysis.

More recent real-scale tests focused on fire dynamics and structural assessment, such as the Dalmarnock experiments [12,13]. Consequently, these tests did not focus on tenability assessment during fire growth phase, as they were not designed for such purpose. Only CO, CO_2 and O_2 gas measurement were performed, to monitor combustion efficiency.

This review highlights that very few room experiments have been performed using enclosures equipped as in everyday life; they mainly concerned single items fires. The large majority of studies focused on well-ventilated scenarios that led to flashover. Tenability conditions were assessed in corridors adjacent to the room involved in fire, but few studies were performed on tenability conditions in the room of fire itself at the early stages of fire growth. FTIR gas analysis and consideration of more recent assessment techniques such as ISO 13571 have been introduced in few recent studies; these techniques have been improved since. The present publication intends to complement these former studies by providing a series of well instrumented dwelling