Title: Global Analysis of Multi-Compartment Full-Scale Fire Tests ('Rabot2012')

Author names and affiliations: Tarek Beji[a], Steven Verstockt[b], Rik Van de Walle[b], Bart Merci[a]

[a] Ghent University – UGent, Dept. Flow, Heat and Combustion Mechanics, Sint-Pietersnieuwstraat 41, B-9000 Ghent, Belgium

[b] Dept. Electronics and Information Systems, Multimedia Lab, Ghent University – iMinds, Gaston Crommenlaan 8, Bus 201, B-9050 Ledeberg-Ghent, Belgium

E-mail addresses of the authors:

1. Tarek Beji: Tarek.Beji@UGent.be
2. Steven Verstockt: Steven.Verstockt@UGent.be
3. Rik Van de Walle: rik.vandewalle@UGent.be
4. Bart Merci: Bart.Merci@UGent.be

Corresponding author:

Dr. Tarek Beji

Ghent University – UGent, Department of Flow, Heat and Combustion Mechanics, St. Pietersnieuwstraat 41 – 9000 Gent

Tel : ++32 9 264 98 46; Fax : ++32 9 264 35 75

E-mail: Tarek.Beji@UGent.be

Global Analysis of Multi-Compartment Full-Scale Fire Tests (‘Rabot2012’)

Abstract

A global analysis is presented of a series of four multi-compartment full-scale fire tests carried out in an apartment located in a high-rise building (called the ‘Rabot’ tower in the city of Ghent, Belgium) in 2012. The data set, available at http://multimedialab.elis.ugent.be/rabot2012/, is called ‘Rabot2012’. These tests are believed to provide a valuable set of experimental data for fire modelling (CFD and two-zone) and monitoring purposes, for a number of reasons. First of all, the fuel package of intermediate complexity (*i.e.* two to three furniture items) and the ignition location were designed to focus on the initial flame spread and then the possible occurrence of secondary (and in one test tertiary) ignition. Also, very good repeatability is illustrated during the first minutes of the tests. Regarding the sensing aspect, in addition to the conventional tools such as thermocouples and velocity probes, a Video Fire Analysis (VFA) has been performed by applying smoke and flame detection algorithms to the footages obtained from a multi-view video network. Moreover, laboratory tests have been performed, putting the fuel packages as applied in the full-scale tests under a hood in free-burning conditions. The repeatability during the first minutes is confirmed and subsequent differences in fire development (free burning versus compartment set-up) are explained. This presentation of the ‘Rabot2012’ fire tests comprises: (1) a detailed description of the experimental set-up (*i.e.* geometry, fuel package and instrumentation), (2) an overview of the fire scenarios obtained in each of the four tests, and (3) a detailed account of the data processing carried out. Finally, elements of exploitation of the collected set of data are discussed.

Keywords:

Enclosure fire, multi-compartment, full-scale fire tests, fire modelling, video monitoring.

1. Introduction

Several experimental studies have already been conducted on compartment fires in the past in order to gain insight into the fire dynamics (*e.g.* [1-2]). A wide variety of scenarios (*e.g.,* single room and multi-compartments, pool fires and furniture fires, over-ventilated and under-ventilated fires, etc.) have been investigated. The experimental data provided has been used for the evaluation and validation of fire models (zone or CFD models, *e.g.* [3-4]). Yet, there is a continuing demand for full-scale experimental data on enclosure fires. This serves as motivation for the present paper on different multi-compartment fire scenarios.

Despite the continuing advances, today's capabilities of *a priori* predictions of the fire development in realistic scenarios remain limited. This has been highlighted clearly in round-robin results reported in [4] on the 'Dalmarnock' tests [1], which involved a fully furnished living room (9 furniture items). Drastic differences in the predictions of the fire development have been reported, such as the occurrence of flashover or not. Such differences can be caused by several issues including not only the lack of accuracy in the applied models and the dependency on the user, but also the complexity of the problem to be tackled. Therefore, in the experiments presented in this paper, fuel packages of intermediate complexity (in between a simple pool fire and a fully furnished compartment fire) have been used, with the objective of evaluating and improving fire prediction tools. The relatively simple furniture layout (*i.e.* two or three furniture items) and the ignition protocol allow focusing on the: (i) initial flame spread, (ii) secondary (and if applicable tertiary) ignition, and (iii) subsequent fire development.

The present tests have been designed to include multi-compartment aspects and to develop and validate video analysis techniques for fire size and smoke layer height detection [5-6]. Moreover, although the density of the measurement points inside the apartment is much less than what was done in the 'Dalmarnock' tests [1], it is sufficient to reconstruct the fire scenario and characterize the induced thermal environment. Temperature and velocity measurements are post-processed in the present paper in the context of two-zone calculations since these are considered valuable in the context of fire forecasting tools [7]. The paper describes also a tool to evaluate video fire detection (VFD) and video fire analysis (VFA) algorithms, comparing video profiles of smoke layer height to heights obtained from temperature measurements in each compartment. Through a flame detection algorithm, the fire heat release rate (HRR) can be reconstructed from flame dimensions and can be fed into fire models and their output compared to the actual measurements of temperature and smoke layer height [8].

The full-scale fire tests have been performed in a high-rise building, called 'Rabot tower', in Ghent (Belgium), in 2012. Therefore, the data set has been labelled 'Rabot2012'. The experimental data are available online at http://multimedialab.elis.ugent.be/rabot2012/ On that website, data are also found on laboratory fire tests. Indeed, the fuel packages have also been tested in 'free burning' conditions under a hood, in order to actually measure the fire HRR as additional data. As explained below, very good repeatability is illustrated during the first minutes of the fire, while differences in fire development are observed between the free burning conditions and the compartment conditions afterwards, as expected.

The remainder of the paper is organized as follows. First, a detailed description of the experimental set-up (geometry, fuel package and instrumentation) is provided. Then, a section is devoted to the flame spread analysis through video data. An overall description of the fire scenarios is provided next, based on visual observations from video footage. This is followed by a quantitative description, based on a data processing procedure applied to temperature measurements. Finally, elements of exploitation of the dataset ‘Rabot2012’ are suggested, before drawing the main conclusions and points for future work.

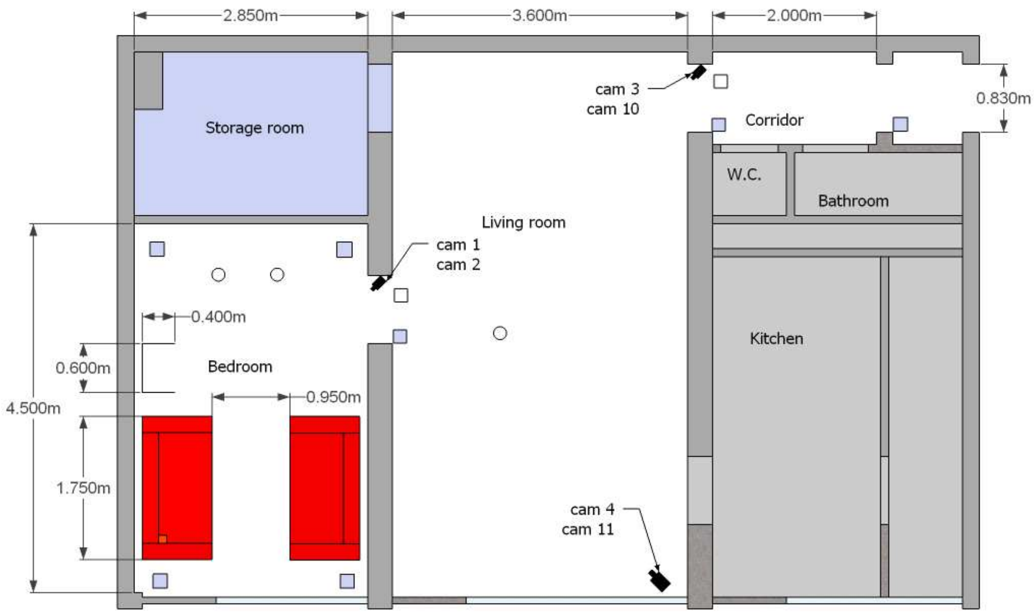
2. Experimental setup

The four full-scale multi-compartment fire tests have been conducted in an apartment in a high-rise building. In all four tests the fire was allowed to self-extinguish, *i.e.*, there was no fire brigade intervention. In addition to these tests, complementary laboratory tests with free burning of the fuel load underneath a hood.

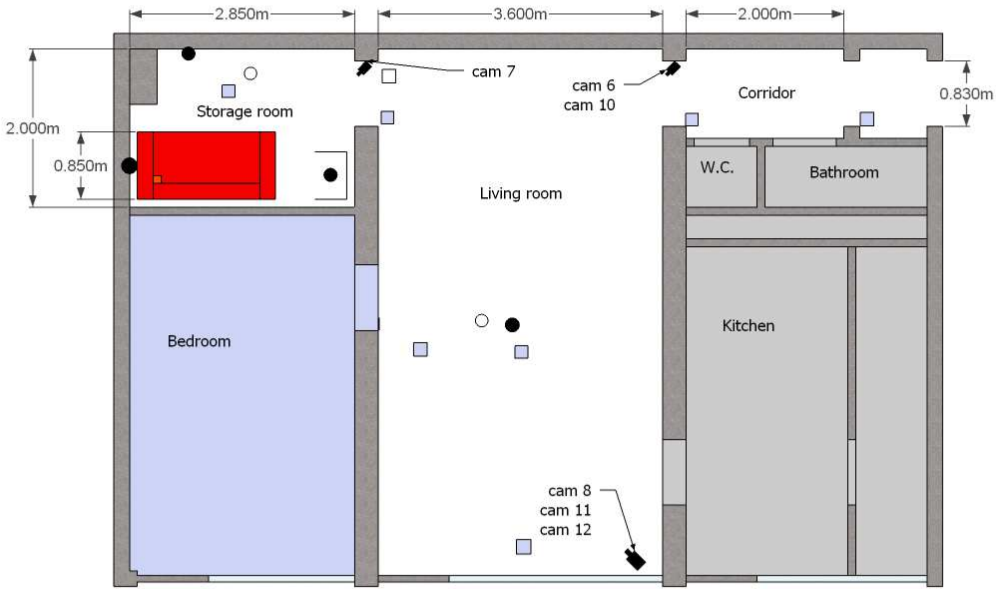
2.1. Apartment layout

The apartment consists of a storage room, a bedroom, a living room, a W.C., a bathroom, a kitchen and a corridor (see Fig. 1). Two rooms have been used as ‘fire’ rooms: the bedroom (2.7 m × 4.4 m × 2.5 m) and the storage room (2.7 m × 2.0 m × 2.5 m). The entry to the kitchen has been sealed with a fire resistant panel for all four tests. The doors to the W.C. and bathroom were closed during all tests. The entrance to the apartment and the exit to the stairs were always completely open. In Tests 1 and 3, the bedroom was used as a fire room. The door to the living room was open. The door of the storage room was closed for Test 1 and sealed with a fire resistant panel for Test 3 (because the door was damaged after the first test). In Tests 2 and 4, the fire room was the storage room. The door to the living room was open. The door of the bedroom was sealed with a fire resistant panel. Therefore, in all four tests, the smoke and heat flow path is kept the same: from the fire room into the living room, into the corridor and then to the outside.

The ceiling linings were composed of 2-cm thick gypsum plasterboard and a 30-cm thick concrete slab. The wall linings were composed of: (1) thin wall paper, (2) 2-cm thick gypsum plasterboard, (3) 3-cm thick fibre insulating board, and (4) a 30-cm brick layer. The floor covering in the rooms was vinyl layer on top of a 30-cm thick concrete slab.



(a) Tests 1 and 3



(b) Tests 2 and 4

Figure 1. Plan view of experimental compartment showing furniture layout (to scale) with the main dimensions and fire-monitoring sensor locations (solid squares: thermocouple trees, open squares: bidirectional velocity probe trees, open circles: Gardon gauges, solid circles: copper plates (only in Test 2), black symbols at the doorways and near the window of the living room: video cameras). The location of the ignition is indicated by a square positioned on the seat cushion of the sofa.

2.2. Fuel distribution and ignition

The fuel packages used in the experiments consisted of two types of furniture items: (1) identical sofas made of polyurethane and covered with a fabric and (2) identical bookcases made of wood and filled with paper items of different densities (*e.g.* lightweight paper and magazines). In the bedroom (*i.e.*, the fire room for Tests 1 and 3), two sofas were placed against the walls near the window and facing each other. The bookcase was placed near the firstly ignited sofa against the wall and facing the doorway (see Fig. 1a). In the storage room (*i.e.*, the fire room for Tests 2 and 4), one sofa was placed in the back corner against the wall. The bookcase was placed near the sofa as shown in Fig. 1b.

The fire was ignited in one corner of the first sofa using a lighter and six small wooden cribs soaked in heptane. Figure 1 shows that the positioning of the ignition allows monitoring the initial flame spread over the sofa using the video camera placed at the doorway during a substantial period, when only the first sofa is burning. From the modelling perspective, the challenge is to predict this flame spread and the subsequent occurrence (or not) of secondary and tertiary ignition. If secondary (and/or tertiary) ignition occurs, it is also important to predict at what time this happens.

2.3. Instrumentation

Different types of sensors were used to monitor the fire:

1. thermocouples,
2. bidirectional velocity probes,
3. Gardon gauges and copper plates (calibrated against Gardon gauges), and
4. video cameras.

Seven thermocouple trees, with 9 thermocouples each, were spread throughout the apartment (*i.e.,* fire room and adjacent rooms) as follows. Three trees were placed in the doorways for the entry to (i) the apartment, (ii) the living room, and (iii) the fire room (*i.e.*, bedroom or storage room) in order to monitor the temperature evolution in time over the height at the door openings. The remaining trees were placed in the fire room and the living room.

A tree of 9 bidirectional air velocity probes was placed in the doorway between the fire room and the corridor, except for Test 3, where it was placed in the doorway between the living room and the corridor.

Gardon gauges were used to measure the heat fluxes (see Fig. 1). The gauges placed in the fire room were positioned at one meter height facing the initial fire spread. The gauge placed in the adjacent living room was positioned approximately in the centre of the room at floor level. For the second test, additional heat flux measurements were performed using copper plates that were calibrated against Gardon gauges (see Fig. 1b).

Twelve commercial Linksys/Cisco WVC2300 cameras (3 or 4 for each test) with a resolution of 640×480 pixels were used to provide a multi-view dataset of the fires.

2.4. Laboratory tests

Laboratory tests have been performed to provide supplementary information. These support tests involve calorimetry, allowing the characterization of the fuel load in terms of HRR evolution of each of the burning items in free-burn conditions through oxygen depletion analysis of the smoke, collected in a hood. Video Fire Analysis (VFA) has also been performed for these tests by monitoring flame spread and flame height using the flame detection algorithm of [5].

Three tests have been carried out. The first test concerns the sofa and the bookshelf with the same positioning and ignition as described for ‘Test 1’ above. The second and third tests consider the individual burning of the sofa and the bookshelf separately.

3. Flame spread analysis - Repeatability

In this section, flame spread over the first sofa is examined. This aspect of the study is particularly relevant for the prediction of fire growth since the increasing area of the fire has substantial effects on the flame size and the rate of burning. The proposed analysis is a video fire analysis (VFA) that relies on a flame detection algorithm developed in earlier work [5-6]. Figure 2 shows an illustration of the VFA algorithm. The focus is put here on the sideward flame spread in the horizontal direction, r_1, since it is the main component showing the extent of burning over the sofa.

Figure 3 (top) shows flame spread results, reported as the evolution in time of the sideward horizontal distance of the flame front from the point of ignition (or, equivalently, the horizontal distance from the corner of the sofa). Results are shown for Test 1 (Sofa + bookshelf) and Test 2 (only Sofa) for the laboratory ‘free burning’ tests. During the first minutes, the presence of the bookshelf is not yet felt by the growing fire and the repeatability of the tests can be assessed. Figure 3 confirms excellent repeatability during the first 6 minutes, the recorded time at which flames reached the opposite end of the sofa. The bottom figure shows the evolution of the flame height, determined using the flame detection algorithm with the top surface of the seat as reference. Clearly, the repeatability during the first minutes is confirmed. The flame height (or volume) is related to the fire heat release rate [9-11], so Fig. 3 suggests that the heat release rate is higher in Test 2 during the first 4 minutes. This is confirmed in Fig. 4, showing results from HRR measurements through the oxygen depletion technique, collecting the gases from the free-burning conditions in a hood in the lab.

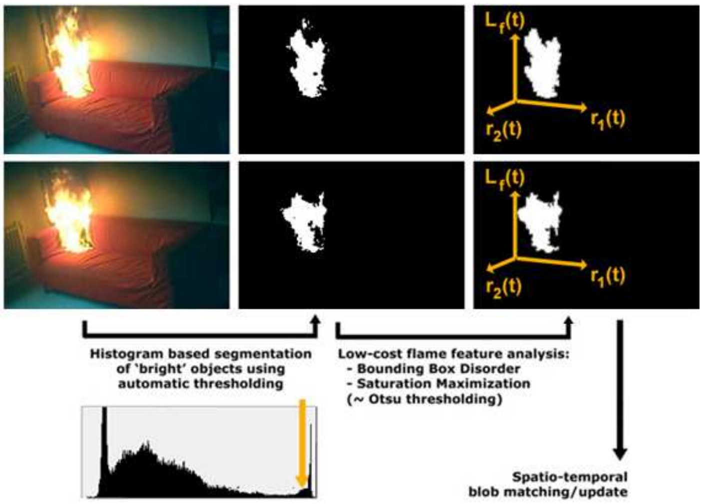
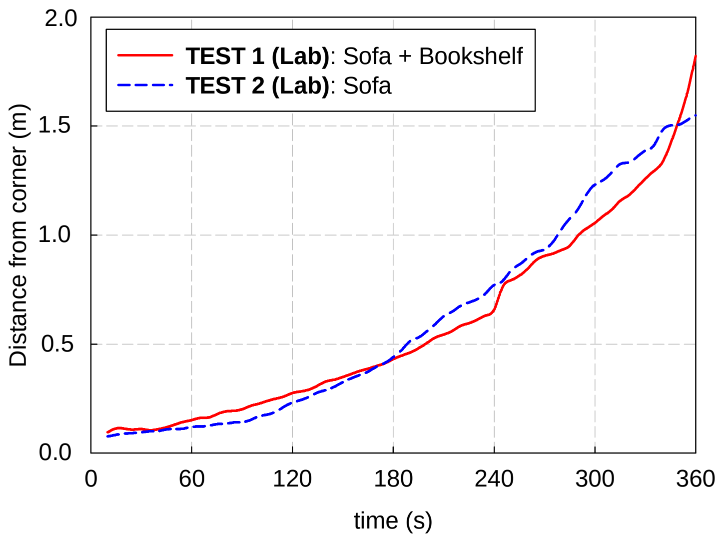


Figure 2. Illustration of the flame detection algorithm used in the Video Fire Analysis (VFA) performed in this work.



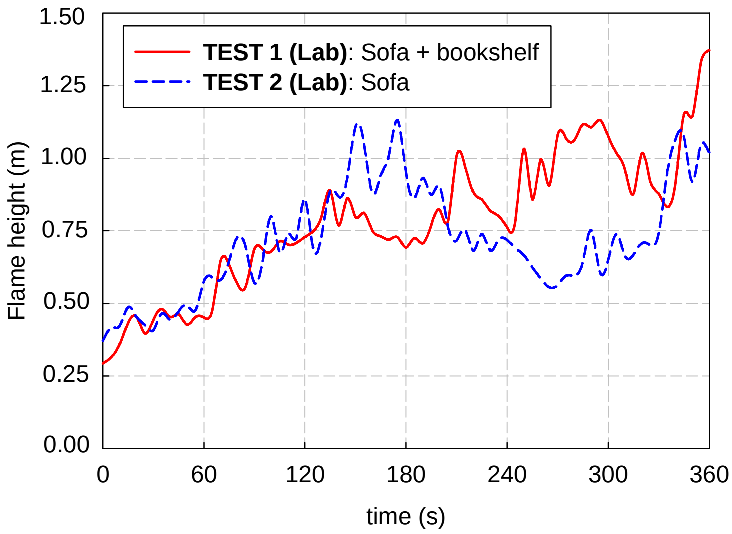


Figure 3. Flame spread: evolution in time of the horizontal position of the flame front from the point of ignition for laboratory tests 1 and 2 (freely burning conditions).

Again, fairly good repeatability for the heat release rate in ‘free-burn’ conditions is observed during the fire growth stage (see Test 1 and Test 2 in Fig. 4). The HRR of the sofa reaches its peak at approximately the same time, around 430 s. Yet, the peak value was 625 kW in Test 1 (Lab) and only 487 kW in Test 2 (Lab), which represents a deviation of 22 %. It is important to note that in Test 1 (Lab), the bookshelf was not involved in the burning until t = 600 s (see the location of the ignition on the sofa and the position of the bookshelf in Fig. 1), making it indeed possible to compare Test 1 (Lab) and Test 2 (Lab) during the initial stages of the fire.

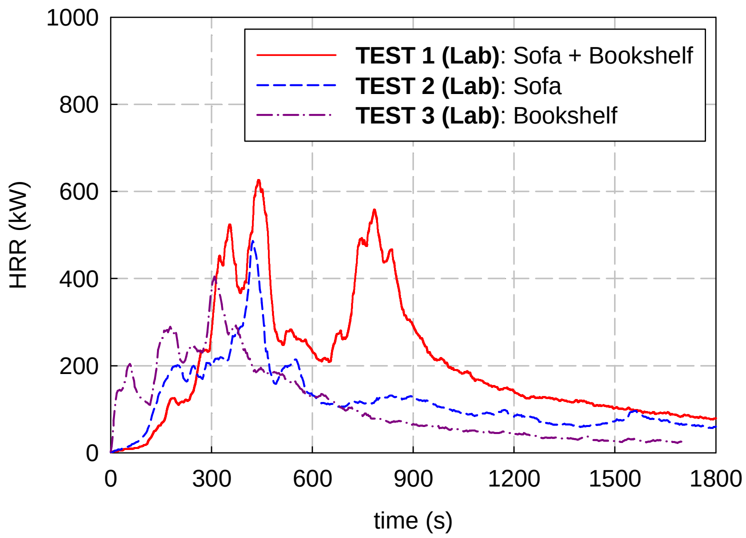
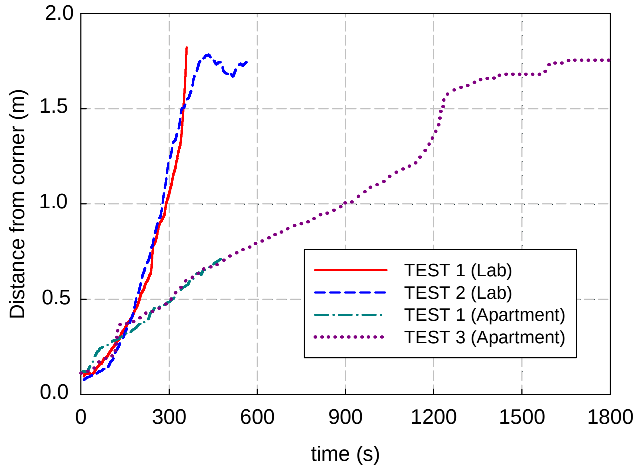


Figure 4. HRR evolution in time for the 'free-burning' laboratory tests.

In Fig. 5, the 'compartment' tests are added to the 'laboratory' tests. The early stages of the fire confirm the excellent repeatability for all four tests during the first three minutes. For the two compartment tests, this excellent repeatability is maintained for seven minutes (after which no visual data are available anymore for Test 1, unfortunately). This excellent repeatability, due to the relative lack in complexity in the fuel, is a very appealing feature of the present data set.



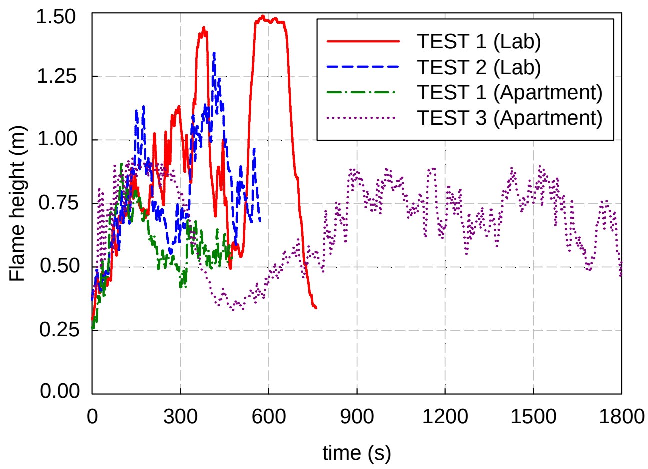


Figure 5. Comparison of the flame spread (top) and flame height (bottom) results for the laboratory tests (Test 1 and Test 2) and the compartment (Test 1 and Test 3).

Figure 6- Sequence of images of flame spread and burning in Test1 (Lab).

Figure 5 also reveals that after the first three minutes, flame spread becomes much (almost four times) faster in ‘free-burning’ conditions than in the compartment tests. This observation may seem at odds with the common sense that enclosure fire dynamics are in general faster than free burning of the same fuel, due to the enhanced thermal feedback to the fuel surface in ‘compartment’ conditions. However, during the first minutes, on which the focus is now, there is no significant heat feedback yet from the walls (let alone the ceiling), since they are still heating up. The primary effect during the fire growth here is therefore not the thermal feedback from the compartment, but the restriction in air entrainment, particularly from the back side of the sofa (Fig. 1). As a consequence, the back side of the sofa is burning in the free conditions (see Fig. 6), leading to higher heat release rates, as can be deduced from the higher flame height than in the compartment conditions (see Fig. 5). Consequently, the flame spread is faster in the free-burning conditions than in the compartment tests.

From the above, it can be concluded that free burning tests are not necessarily representative of the behaviour in compartment tests, especially in terms of flame spread and subsequently secondary ignition, time to flashover and fire duration. Still, they do serve as illustration for the excellent repeatability during the initial stages of the tests.

4. Description of the fire scenarios

In this section a systematic chronological description of each of the four fire scenarios is provided. Ignition time is taken as time t = 0 s. A summary of the main events in each test is provided with a discussion on the observed differences.

4.1. Test 1

At 50 seconds after ignition, light smoke was seen to escape through the doorway into the living room. Thick black smoke filled the upper part of the bedroom and the living room within 2 min 15 s. Smoke was observed at the end of the entry corridor from around t = 3 min 30 s onward. Flames covered half of the sofa at approximately 5 min 30 s after ignition (camera 2). From the video footage of camera 3, flames were not visible during the period between 2 min 15 s and 9 min 30 s because the camera was immersed in thick black smoke. Then, the burning became more intense with a highly luminous flame, visible again from camera 3. At t = 9 min 30 s the flame front reached the opposite corner of the sofa. The nearby bookshelf ignited by flame impingement and was completely engulfed in fire at t = 14 min. The intense simultaneous burning of the first sofa and the bookshelf resulted in a substantial heat build-up. The second sofa ignited at t = 16 min. Cracks were observed in the outside window and small pieces fell out just before complete breakage of the window at t = 30 min. The decay stage of the fire started at about t = 37 min 30 s. After completion of the test, it was noted that almost all the plaster had fallen off the ceiling in both the bedroom and the living room. Some plaster had also fallen off the walls of the bedroom, whereas the walls of the living room had remained intact. Furthermore, burning of the vinyl covering at the location of the three furniture items was observed. A large amount of paper did not burn because it was placed in a "dense" form in the bookshelf.

4.2. Test 2

The fire was confined to the sofa for about 7 to 8 minutes. Afterwards, it rapidly reached the bookshelf. At 5 min after ignition an oscillating layer of thick black smoke was formed in the living room. The amplitude of the oscillations became particularly high from 8 min 30 s onward. At 10 min 30 s after ignition continuous external flaming was recorded during 6.5 minutes. The intensity of external burning (size of external flames) reached its maximum value at around 11 min 30 s. The decay stage of the fire started at around 25 min. At the end of the test, it was noted that almost all the plaster had fallen off the ceiling. Also, a substantial amount of plaster had now fallen off the walls. Due to the extensive external flaming, the upper part of the door between the living room and the corridor was severely damaged.

4.3. Test 3

This test was conducted in the same configuration as Test 1 (same fire room and furniture layout). However, as described above, the walls and ceiling linings and the floor covering had suffered from damage after Test 1. As a result, the thermal boundary conditions of the enclosure are not identical. The initial flame spread stage could be observed from camera 10 up to 5 minutes after ignition. Then, due to the build-up of a layer of black thick smoke in the bedroom and the living room, the flame was not visible in the video footage anymore up to t = 14 min. The burning intensified and the flame became very luminous when it reached the opposite corner of the sofa at approximately t = 15 min 30. The nearby bookshelf ignited by flame impingement and was completely engulfed in fire at t = 30 min. By that time the sofa was almost totally burnt. Contrarily to what was observed in Test 1, the two items (*i.e.* first sofa and bookcase) did not burn simultaneously. Therefore, not enough heat was generated to cause window breakage and ignition of the second sofa, which remained almost intact throughout Test 3. The fire started to decay at 39 min 30 s.

4.4. Test 4

The corner of the sofa was ignited as described above. This test was conducted in the same configuration as Test 2 (same fire room and furniture layout). However, as described above, the walls and ceiling linings and the floor covering were damaged after Test 2. As a result, the thermal boundary conditions of the enclosure are not identical. The fire was confined to the sofa for approximately 7 to 8 minutes. The bookshelf was engulfed in fire shortly thereafter. The smoke layer in the living room started to oscillate strongly at 8 min. In contrast to Test 2, external flaming was observed only during a relatively short period of time (from 13 min 30 s to 15 min) and with lower intensity. The decay stage started at 27 min 30 s.

4.5. Comparison of the four fire scenarios

A summary of the major events in the fire room is provided in Table 1.

Table 1- List of major events observed (Reference time is ignition).

Major events observed	**Test1 (Bedroom)**	**Test2 (Storage room)**	**Test3 (Bedroom)**	**Test4 (Storage room)**
Flame reaches the opposite end of sofa 1	09:30	07:00	15:30	07:00
Bookcase is engulfed in fire	14:00	<10:00	30:00	<13:00
External flaming at the doorway	No	[10:00-17:00]	No	[13:15-15:00]
Sofa 2 ignites	16:00	NA	No	NA
Window breakage	30:00	NA	No	NA

The results displayed in Table 1 show that:

- The confinement significantly enhances flame spread over the sofa in Tests 2 and 4, where the fire room is smaller, the fire reaches the opposite end of sofa 1 faster than in Tests 1 and 3.
- The thermal boundary conditions have a substantial impact on the fire development. This is illustrated by comparing Tests 1 and 3, and 2 and 4, resp. Indeed, although set up to be identical, the heat losses in Tests 3 and 4 are significantly higher than in Tests 1 and 2, due to the damaged insulation after Tests 1 and 2. The consequences are:
    - In Test 3, the increased heat losses into the wall and ceiling weakened the fire such that not enough heat-build up was reached in the fire room to ignite the second sofa, in sharp contrast to Test 1. The burning of the first sofa and the bookcase are also significantly slower in Test 3.
    - In Test 4, external flaming at the doorway lasts for only 1 minute 45 s in Test 4, compared to 7 minutes in Test 2. This is again explained by the increased heat is loss through the ceiling and walls in Test 4.

The prediction of the differences in the fire scenarios as described above in relation to the thermal boundary conditions, poses a challenging problem from a fire modelling perspective. In combination with the repeatability, as argued above, this makes the present data set appealing for model testing purposes.

5. Characterization of the fire scenarios

The dataset is available at http://multimedialab.elis.ugent.be/rabot2012/. In the present section a few aspects, including some post-processing useful for zone modeling, are discussed.

5.1. Temperature and smoke layer height measurements

Thermocouple trees were placed in the fire room. Furthermore, temperature measurements from the thermocouple trees placed at the doorways can be used to calculate the neutral plane height, X_N, upper layer temperature, T_u, and lower layer temperature, T_ℓ, for all compartments (*i.e.* fire room, living room and corridor), useful in the framework of zone modelling. The least-squares method [12] was used. The lower layer and upper layer temperatures are defined as:

$$T_\ell = \frac{1}{X_N}\int_0^{X_N} T\,dz \;\; , T_u = \frac{1}{H_D - X_N}\int_{X_N}^{H_D} T\,dz \tag{1}$$

where H_D is the height of the door and z is the vertical coordinate. The idea is to find, by means of an iterative procedure, the value of X_N that minimizes the following function:

$$\sigma^2 = \frac{1}{X_N}\int_0^{X_N} \left(T - T_\ell\right)^2 dz \; + \; \frac{1}{H_D - X_N}\int_{X_N}^{H_D} \left(T - T_u\right)^2 dz \tag{2}$$

The iterative procedure has been programmed in FORTRAN. The program (i) reads the temperature measurements at each recording time (*i.e.* every 5 s), (ii) makes a linear interpolation between each two measurements with a space resolution of 1 cm, (iii) applies the least-square method, and (iv) provides the temporal profiles of X_N, T_u and T_ℓ.

Figure 7 shows the calculated experimental profiles of upper layer temperature at the doorways for the four tests. These results confirm the visual description of the fire scenarios made earlier in this paper. The most severe fire occurs in Test 2, where the peak upper layer temperature at the exit of the fire room is the highest, around 780 °C due to substantial external burning. In Test 4, the peak upper layer temperature is only 585 °C, still related to external burning (Table 1). The lower temperatures in Tests 3 (compared to Test 1) and 4 (compared to Test 2) confirm the explanation, provided above, on the stronger heat losses in those tests due to the damaged insulation.

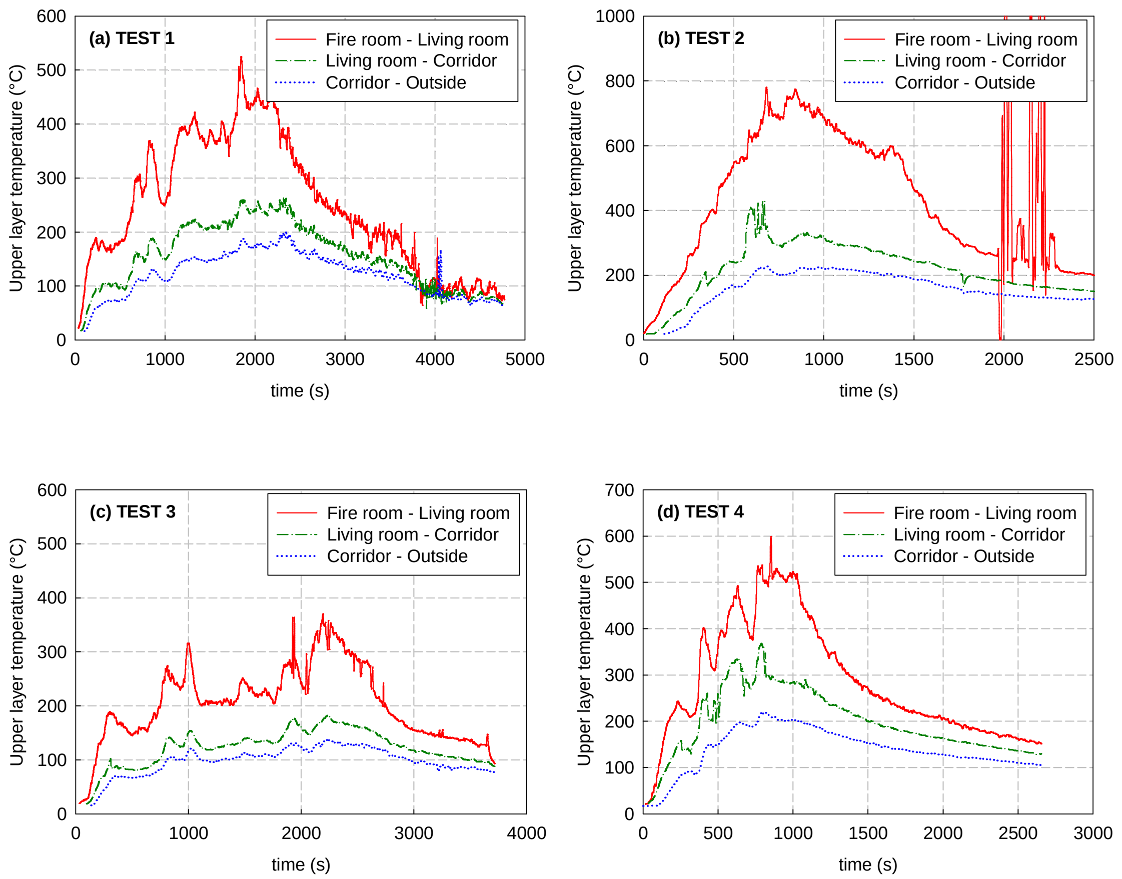


Figure 7. Calculated transient experimental profiles of upper layer temperature at the doorways between the fire room, the living room, the corridor and the outside for each of the four tests.

Fig. 8 shows that, as expected, in general the lowest calculated experimental neutral plane height, X_N, is found at the doorway between the fire room and the living room. The video monitoring results are limited in time in comparison to temperature measurements. The difference in results, for instance for Test 1, between the profile ‘Fire room (Video)’ and the profile ‘Fire room – Living room’ is due to the fact that the positioning of the cameras at the doorway of the fire room allows providing smoke height within the room not at the interface with an adjacent room.

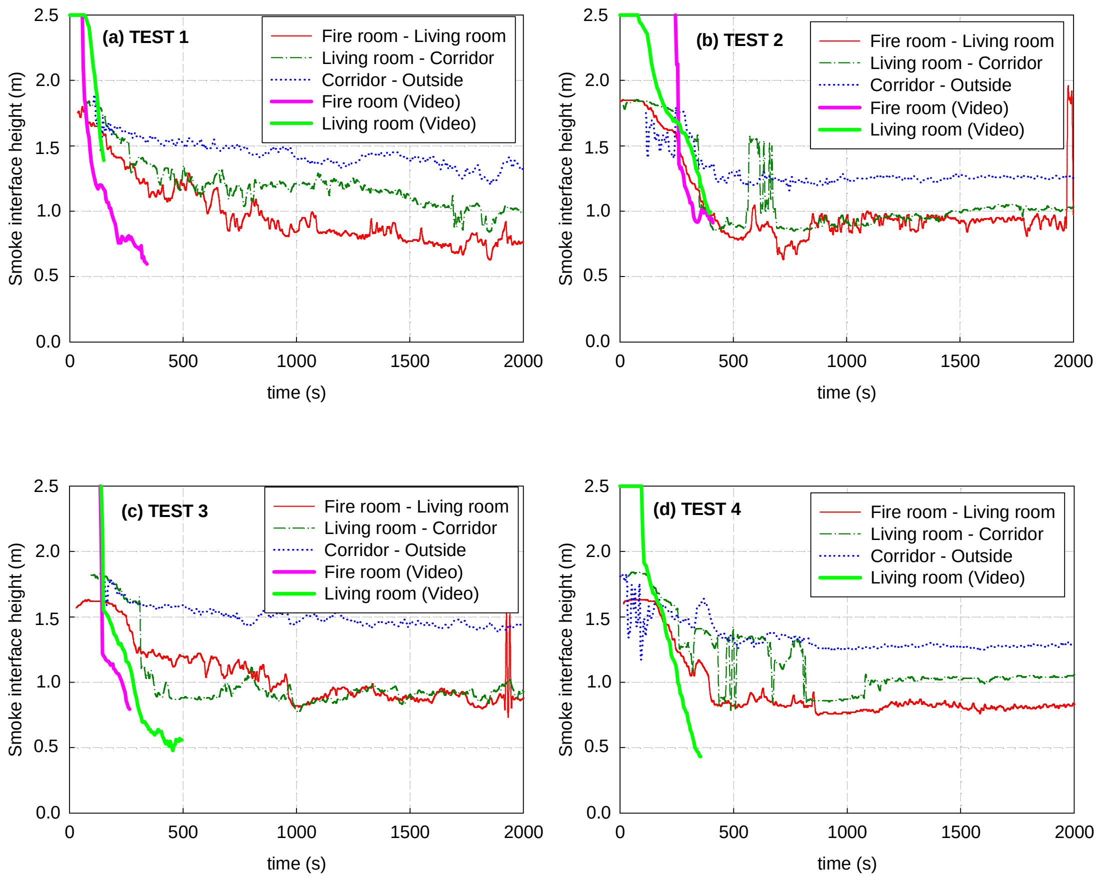


Figure 8. Calculated transient experimental profiles of smoke interface height at the doorways (between the fire room, the living room, the corridor and the outside) from temperature measurements and video measurements of smoke height within the fire room and the living room.

5.2. Velocity measurements

In order to characterize the flow at the doorway, velocity measurements obtained from bidirectional velocity probes were also post-processed in the context of two-zone modelling. Due to heat damage caused to the probes, velocity measurements were only obtained during a limited (but yet important) period of time. The neutral plane height, X_N, is located by performing a linear interpolation between two successive points showing opposite flow directions. The lower layer inflow velocity, v_{in}, was calculated by taking the average of the lowest two points. According to the temperature measurements shown above, these two points were within the air inflow layer during the entire duration of the fire. The average outflow velocity, v_{out}, was deduced by numerical integration using:

$$v_{out} = \frac{1}{(z_N - z_1)} \left\{ \left[\sum_{i=1}^{N-1} \frac{(|v_i| + |v_{i+1}|)}{2} (z_{i+1} - z_i) \right] - \left[|v_{in}| (X_N - z_1) \right] \right\} \tag{3}$$

The velocity probes are numbered (index i) from the lowest one (i =1) to the highest (i =N =8). The variable z denotes the height of each one and v_i the corresponding recorded velocity. The first term between brackets represents the integration of the complete velocity profile. The second term represents the integration of the inflow velocity segment.

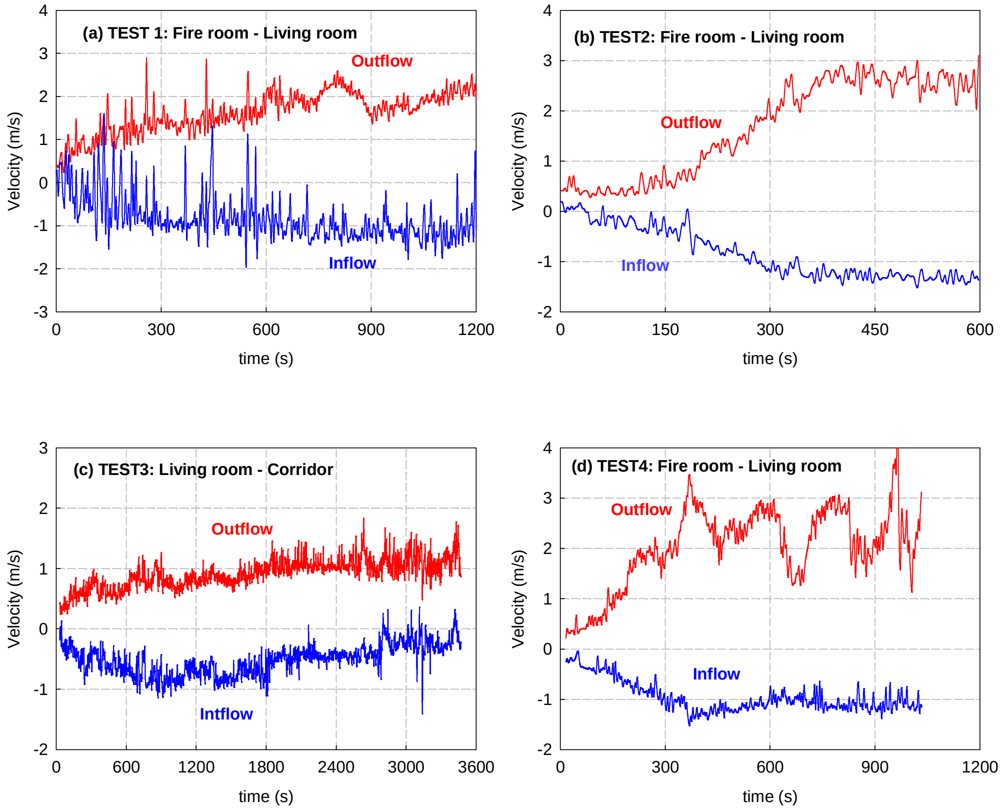


Figure 9. Calculated experimental profiles of inflow and outflow velocity at the doorway between the fire room and the living room for Tests 1, 2 and 4 and at the doorway between the living room and the corridor for Test 3.

Figure 9 shows the calculated experimental profiles of inflow and outflow velocity. The mass flow rates into and out of the doorway are obtained by using the layer temperatures (and the corresponding densities) calculated earlier. For example, in Test 1, the inflow and outflow velocities between 900s and 1200s are respectively around 1.09 m/s and 1.90 m/s. By considering the corresponding lower and upper layer densities, one obtains an outflow rate of 0.92 kg/s and an inflow rate of 0.93 kg/s. Thus, the mass balance is satisfied very well (under quasi-steady state assumptions).

5.3. Heat flux measurements

The induced thermal environment in each of the fire scenarios considered is also monitored using Gardon gauges, measuring heat fluxes. Figure 10 shows significant differences in the recorded values between Test 1 and Test 3 and Test 2 and Test 4. This is in accordance with the reported differences in temperature measurements and in line with the explanations given above on the fire dynamics in relation to the thermal boundary conditions.

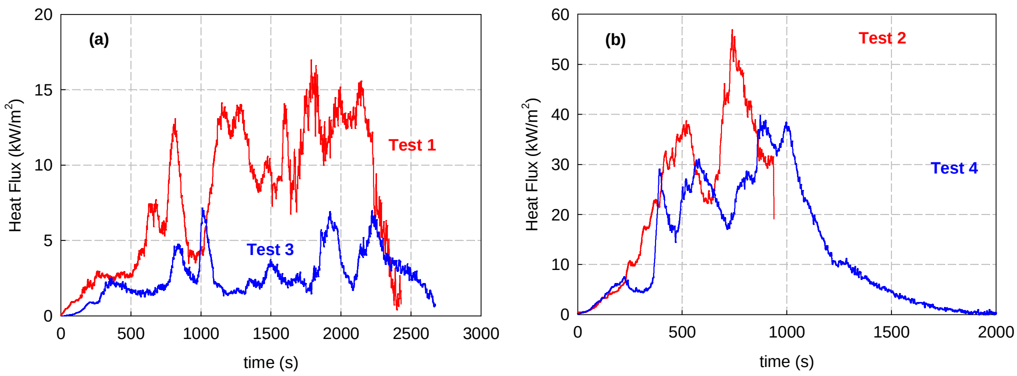


Figure 10. Heat flux measurements in the fire room (see Fig. 1) for the four tests.

6. Exploitation of the data

The comprehensive data set obtained from the experiments as presented in this paper can be used to address a wide variety of problems investigated in the fire safety community. In this section, several possibilities of using the data are described.

First, the obtained experimental results can also be used to further assess the capabilities of fire models (CFD or two-zone models) and the related uncertainties. For example, the substantial difference between the fire scenarios of Tests 1 and 3 (and also between Test 2 and Test 4), despite their very similar set-up (except for the thermal boundary conditions), is a very challenging case for fire models to predict.

A second relevant application is ‘fire forecasting’ where a fire model displays the real-time evolution of the smoke interface height and temperature and the subsequent predictions for tenability conditions in the building. Such tool could help the decision making process during the intervention of fire fighters [13]. This procedure requires an estimate of the real-time HRR profile for a given period of time assuming for instance an α-t^2 profile. There are mainly two methodologies that can be used for this matter.

1. The first approach consists of considering a radially growing fire. The information obtained on the spread rate using the video camera can be used to calculate the burning area. Multiplying the latter by a constant Heat Release Rate per Unit Area (HRRPUA) provides a first estimate of the HRR. This calculation can be refined by considering additional information such as the flame height. The main drawback of this approach is that it relies on a good positioning of the video camera with respect to the fire location in order to have flame monitoring for a sufficiently long period of time.
2. The second approach relies on the measured smoke layer height and temperature to estimate the HRR. It is referred to as Inverse Fire Modelling (IFM) (*e.g.* [14-15]). The main advantage of this method lies in the fact that it is simpler to monitor the smoke layer height and temperature than the flame spread rate and flame height.

The data gathered in the context of the ‘Rabot’ fire tests can be used to further investigate the novel topic of ‘fire forecasting’ for real applications using Data Assimilation (DA).

7. Conclusions

The multi-compartment full-scale 'Rabot2012' fire tests provide a comprehensive set of experimental data that can be used to address several aspects in research on enclosure fire dynamics. The main characteristics of the set-up are the multi-compartment and full-scale nature with a fuel package of intermediate complexity (*i.e.,* two to three furniture items).

Excellent repeatability has been illustrated during the initial stages of the fire, making the data set appealing for the assessment of fire models. The data set is also useful in the context of fire forecasting.

It has been explained why the free-burning tests reveal faster fire growth than the same set-up in the compartment: the primary effect concerns improved air entrainment, leading to shorter flames and stronger radiation feedback from the flames to the fuel surface (while the compartment walls and ceiling are still heating up).

It has been confirmed that the fire dynamics is faster in case of smaller fire room size.

The major effect of the thermal boundary conditions, in terms of the presence or not or (undamaged) insulation material at the compartment walls, on the fire dynamics has been illustrated. This led to significantly slower fire development in case of increased heat losses, with the significant difference that the second sofa does not ignite (whereas it does ignite for the identical set-up with insulated walls).

From a fire modelling perspective, the variety of scenarios offers input data for a number of challenges: flame spread over a sofa, influence of the thermal boundary conditions, external flaming, multi-compartment heat and smoke spread, etc.

Regarding the fire monitoring aspect, in addition to the conventional diagnostic tools (*e.g.* thermocouples and velocity probes), Video Fire Analysis (VFA) has been illustrated for real practical applications. The VFA results presented here in terms of (1) flame spread, (2) flame height, and (3) smoke interface height are promising, despite the difficulties related to the positioning of the camera with respect to the fire location and the smoke-free zone. An overview of the tests and the experimental data are available at http://multimedialab.elis.ugent.be/rabot2012/.

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List of figure captions

Figure 8. Calculated transient experimental profiles of smoke interface height at the doorways (between the fire room, the living room, the corridor and the outside) from temperature measurements and video measurements of smoke height within the fire room and the living room.

Figure 9. Calculated experimental profiles of inflow and outflow velocity at the doorway between the fire room and the living room for Tests 1, 2 and 4 and at the doorway between the living room and the corridor for Test 3.

Figure 10. Heat flux measurements in the fire room (see Fig. 1) for the four tests.

List of Table captions

Table 1- List of major events observed (Reference time is ignition).