Simulation of Fire in a Typical Room of a Hotel

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ABSTRACT

Three simulations of the fire behaviour of a typical room of a hotel were done. A benchmark with a real scale test was proposed by the CNRS Fire Research Group (GDR incendies) . The main goal was to verify the accuracy of the predictions of various models of fire behaviour in functions of the modelling decisions taken by different groups of researchers. Few data was given to the researchers: The dimensions of the room, the thermal data of the walls and the total mass of the furniture into the room, as well as some guidance about the positioning of these items through pictures took before the test.

In this study the zone model CFAST V.6.0.4, the field model FDS V.5.0 and the simplified analytical models of Thomas and Mc Caffrey were used. In all the cases the quality of the results obtained depends on the input data. The input data were obtained from three different sources: the literature, the data base of materials of the Laboratoire National de métrologie et d'Essais (LNE) and the experience of the researcher of the Fire Engineering Division of the LNE.

1. PRESENTATION OF THE BENCHMARK

A. Description of the room

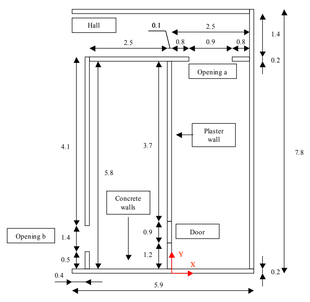


Figure 1 : General dimensions [m – without scale]

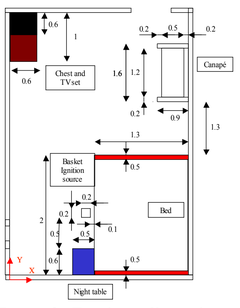


Figure 2 : Furniture dimensions [m – without scale]

Characteristics of the room and the test:

- The hall is a protection wall without a ceiling, it does not stop the evacuation of the smoke that exits by the door.
- Under the bed, the ground is covered by a carpet.
- The door at the left hand side of the room remains closed during the test (see figure 1).
- The fire began at the plastic basket near to the bed. It contains papers.

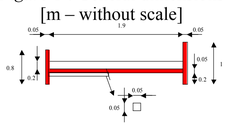


Figure 3: Dimensions of the bed and springer [m – without scale]

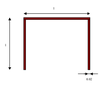


Figure 4: Chest dimensions [m – without scale]

The *figure 8* shows the ignition of the fire source. The basket was near to the bed and to the night table. The fire was propagated under the bed by mean of the carpet. The mean development of the fire occurred between 12 and 13 minutes after the basquet ignition, just when the bed and the mat were in fire.

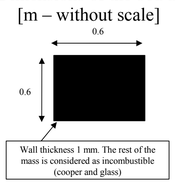


Figure 5: Dimensions of the TV set [m – without scale]

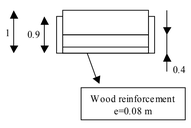


Figure 6: Dimensions of the canapé [m – without scale]

Figure 7: View of the inner of the room

Figure 8 : Ignition of the plastic basquet

B. Material characterisation

Remark: The characteristics of the materials involved in the test were unknown. Those characteristics have been estimated from experience and LNE database, and adjusted to fit with the mass given.

- *Matress:* Polyether polyurethane foam (PPUF)
- *Canapé:* Fabric + PPUF + wood reinforcement
- *Springer:* Fir (composed of 70% de cellulose and 30% lignin)
- *Bed:* Fir + padding of PPUF
- *TV set:* ABS + cooper
- *Chest:* Fir
- *Night table:* Fir
- *Carpet:* Carpet

Table I: Mass of the furniture present into the room before the begin of the test, as given

Furniture	Mass (kg)
Carpet	4.6
Bed	30.8
Springer	74
Television	40.6
Chest	24.2
Mattress	18.6
Canape	69.2
Night table	22.6
Paper + Others	1
Total	285.6

2. SIMPLIFIED MODEL, ANALYTICAL APPROACH

A. Before the Flash-Over

An horizontal upholstered furniture is characterised by a "moderate" growth of the fire. The fire growth is a function of the fire front spread. The Heat Release Rate (HRR) is given by the equation: $\mathbf{Q = \alpha . t^2}$ where $\alpha = 11.72$ W s^{-2}. This equation is used until the fire reaches the "Critical Heat Release (CHR)". The CHR is necessary to obtain the flash-over condition. Different methods allow to calculate the CHR:

Simplified model of Thomas

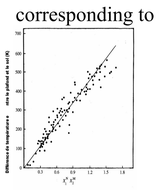
The simplified model of Thomas allows to estimate the HRR needed to reach the flash-over condition. It consists on a simplification of the energetic balance of the room

$$Q_{FO} = 7.8 \cdot A_t + 378\left(A_w \cdot \sqrt{H_w}\right)$$

H_w : Height of the door [m]
Q_{FO} : HRR at the flash over condition [kW]
A_t : Total area of the walls of the room [m²]
A_w : Surface of the door [m²]

Simplified model of Mc Caffrey

Thomas and Mc Caffrey have shown (Based on tests where the temperature of the hot layer was hotter than 600 °C) that the temperature under the ceiling may be linked with two dimension-less variables X_1 and X_2 corresponding to the Heat Release and the energy lost by heat dissipation.



$$X_1 = \frac{Q}{g^{1/2}\,|C_p \cdot \gamma_0|\,T_0 \cdot A_w \cdot H^{5/2}}$$

$$X_2 = \frac{h_k \cdot A_t}{g^{1/2}\,|C_p \cdot \gamma_0|\,A_w \cdot H^{1/2}}$$

Q_c : Heat release [kW]
C_p : Thermal capacity of the smoke [kJ/kg.K]
r_o : Smoke density[kg/m³]
T_o : Environment temperature [K]
A_w: Surface of the opening [m²]
H : Height of the opening [m]
H_k : Effective coefficient of heat loss by the wall [kW/m².K]
A_t : Internal surface of heat exchange [m²]

The correlations allow to obtain the Mc Caffrey equation: $\Delta T = 480 \cdot X_1^{2/3} \cdot X_2^{1/3}$

Solution of the Mc Caffrey equation by:

- Drysdale*: $Q_{FO} = 610 \cdot \left(h_k \cdot A_t \cdot A_w \cdot \sqrt{H}\right)^{1/2}$
- Peacok**: $Q_{FO} = 740 \cdot \left(h_k \cdot A_t \cdot A_w \cdot \sqrt{H}\right)^{1/2}$
- Hägglund and Babrauskas $Q_{FO} = 1050 \cdot A_t \cdot \left(\frac{1{,}2}{A_t / A_w\sqrt{H}} + 0{,}247\right)^3$

* The CHV for the flash-over corresponds to a temperature increase up to 500 K.
** The temperature of the hot layer >600°C)

The Effective Coefficient of Thermal transfer of the wall h_k, is hard to be calculated. For a fire under development it is approached to:

$$h_k = \frac{k}{\delta}$$

h_k : Effective coefficient of heat loss by the wall [kW/m².K]
K : Thermal conductivity of the wall [W/m.K]
d : Wall thickness [m]

$$h_k = \sqrt{\frac{\rho \cdot C_p \cdot k}{t}}$$

C_p : Thermal capacity of the wall [kJ/kg.K]
r : Densité du matériau de paroi [kg/m³]
t :Temps d'exposition à la chaleur [s]

t corresponds to the fire growth stage. It is calculated for the combustion of furniture items such as seats. Babrauskas calculated a t value of 200 s (The influence of that time to the final value is very low for times lower than ten minutes).

The value used was Q_{FO}=1200 kW. For a fire following the "moderate" curve, the time to reach this value is 320 seconds. At that moment the smoke temperature is 600 °C.

Model	Heat release at the flash-over [kW]
Thomas	1203
Mc Caffrey - Solution of Drysdale	1012
Mc Caffrey - Solution of Peacok	1227
Mc Caffrey - Solution of Hagglung	1729

B. Post Flash-Over

The heat release rate is controlled by the rate of decomposition of the available solid fuel and the ventilation. According to the furniture present in the room, about 80% of the combustible mass is similar to wood (ΔH_c= 17 MJ/kg) and 20% is similar to PPUF (ΔH_c=27 MJ/kg). The global weighed enthalpy is ΔH_c= 19 MJ/kg. The Petterson formula allows to calculate the HRR post flash-over: $Q_C = 0{,}09 \cdot A_W \sqrt{H} \cdot \Delta Hc$

The heat release after the flash-over is 4 031 kW. It remains as a steady value during the developed fire, as long as most of the combustible is available. The total combustible load is about 5 415 MJ for 285 kg of combustible, with 80% only really available to burn (expert opinion). The steady post flash-over fire continues until 70% of the total combustible charge is burnt, then decreases until 80% of the fuel is consumed.

The temperature into the room may be calculated using the curves of Petterson.

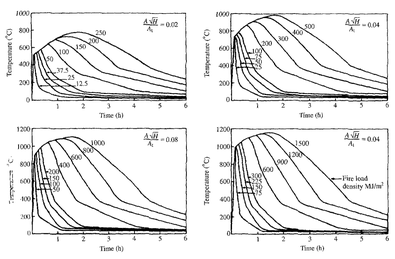


Figure 9: Petterson curves

3. SIMULATION BASED ON ZONE MODEL : CFAST V. 6.0

The ordinary differential equations used into the CFAST model are established from the mass and energy conservation balance, the law of perfect gases and other relations for the density and the internal energy evolution. These equations allow to calculate, in function of time and for each room, quantities as pressures and temperatures for both the hot and the cold layer, as well as the height of the neutral plane through the exchanges of mass and energy between the layers and the fire plume. Many approaches and hypothesis are needed in order to model the physical phenomena taken into account within CFAST

Into the CFAST model, the room is studied and divided into two volumes: A hot layer at the top of the volume and a cold layer at the bottom. The properties of each layer of gas are the mass m_i, the inner energy E_i, the density ρ_i, the temperature T_i and the volume V_i. The pressure, deigned by P is assumed uniform in the whole room.

For the simulation, different curves of heat release rate in function of time were associated to start up occurrences related to temperatures or thermal flux attained by the furniture. Thus, the heat sources ignite successively in function of their environment conditions. The different heat sources are shown below:

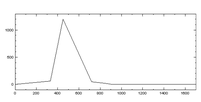


Figure 10: HRR of the **mattress and bed support**. Ignition at t= 0

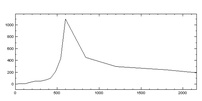


Figure 11: HRR of the **canape**. Ignition at temperature greater than 280°C

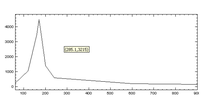


Figure 12 : HRR of the **chest**. Ignition at a heat flux greater than 30 kW/m²

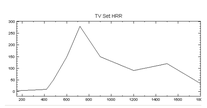


Figure 13 : HRR of the **TV set**. Ignition at a heat flux greater than 20 kW/m².

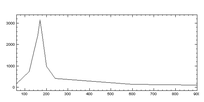


Figure 14 : HRR of the **night table**. Ignition at temperature greater than 280°C.

Carpet. 644 kW during 230 s. Ignition at a heat flux greater than 20 kW/m².

Figure 15: Results of the CFAST simulation at 1020 seconds (left) and 1320 seconds (right). The color show the height and the temperatures of the hot layer. Cones = heat source (furniture).

4. SIMULATION BASED ON FIELD MODEL: FDS V. 5.0

The decomposition rates were calculated (by modelling of the pyrolysis). Thus, the reactions on the solid phase during the combustion were controlled by the thermal balances into the solids. The ignition properties of the materials are input data of the simulations; deducted from the step 1.B.

Simulation by modelling the pyrolysis

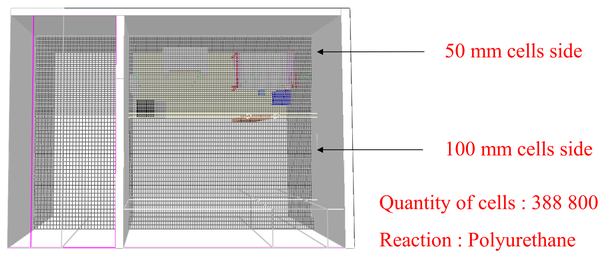


Figure 10: Two different cells dimensions by mesh – Top view

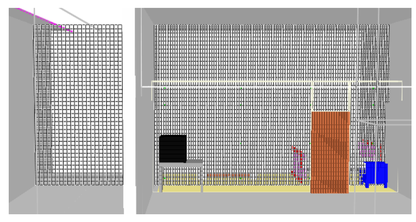


Figure 11: Mesh – Lateral view

Stages of the thermal decomposition of the wood

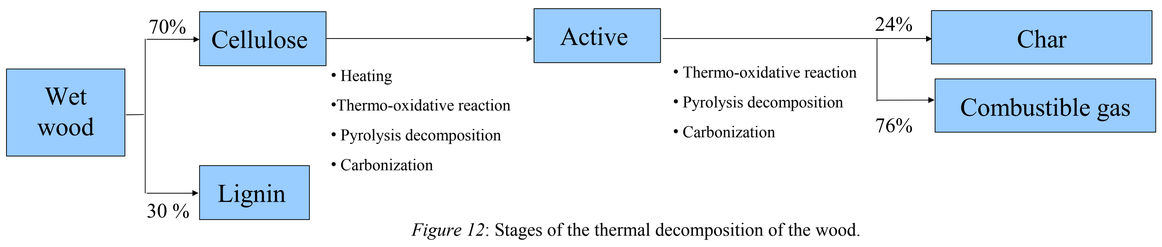
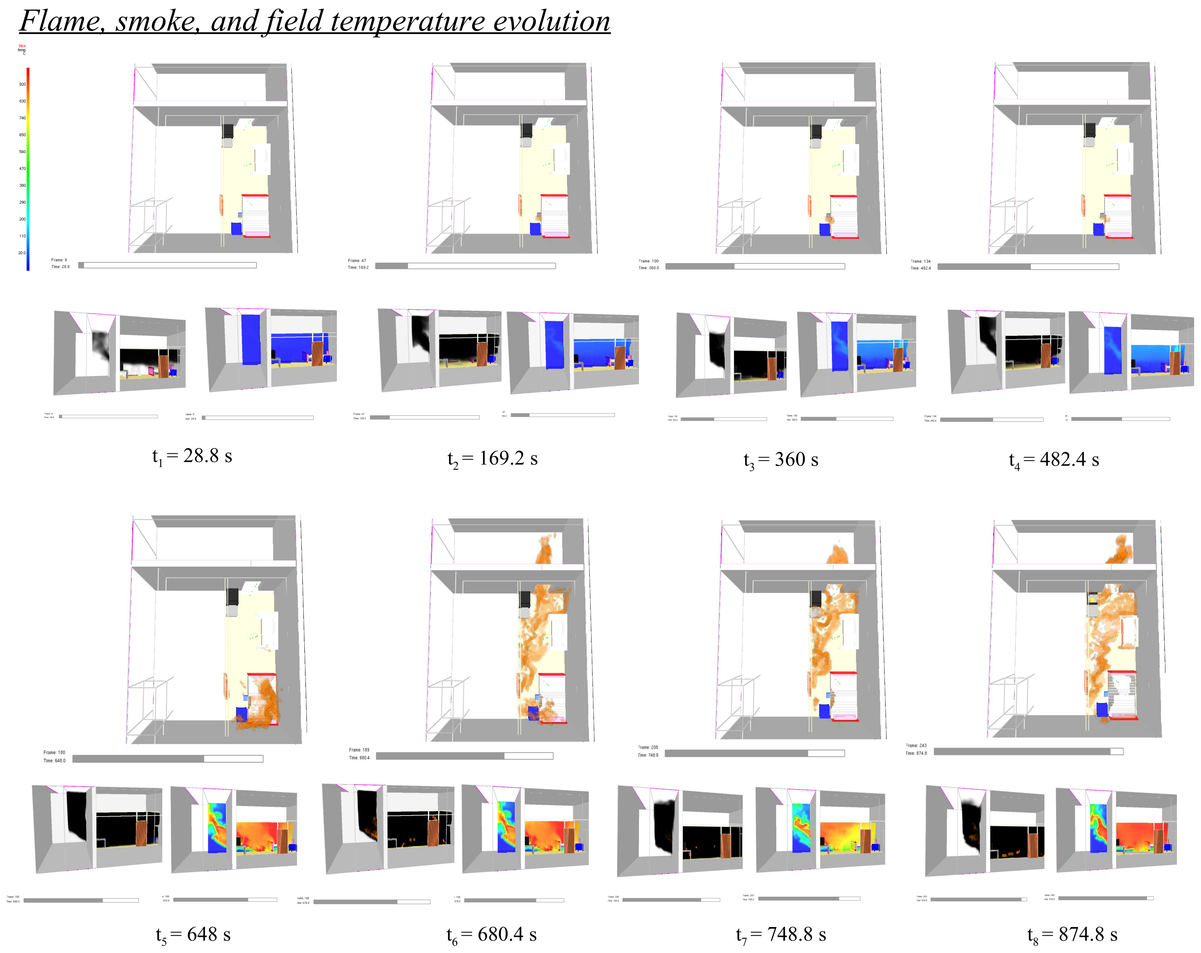


Figure 12: Stages of the thermal decomposition of the wood.

The decomposition of the materials, except for the TV set, were calculated with a modelled pyrolysis. The heat release rate of the TV set was imposed (according to an experimental curve). All the thermal and ignition properties were taken from the LNE data base or from the literature.

Flame, smoke, and field temperature evolution



5. COMPARISON OF RESULTS

Two comparisons are carried out: global heat release rate (*Figure 13*), calculated by the three models (field, zone, analytic) vs experiment, and mean temperature of the hot layer (*Figure 14*), calculated by the three models vs experiment.

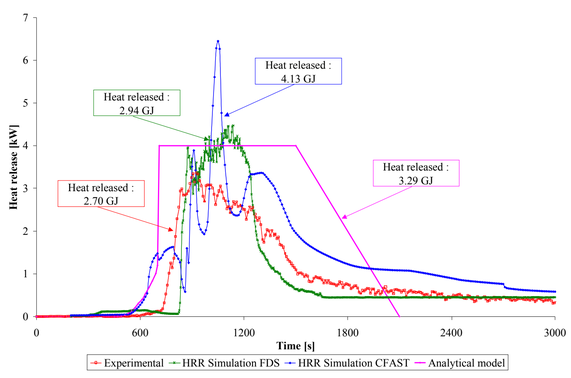


Figure 13: Comparison of the heat release rates calculated with the three models vs experimental

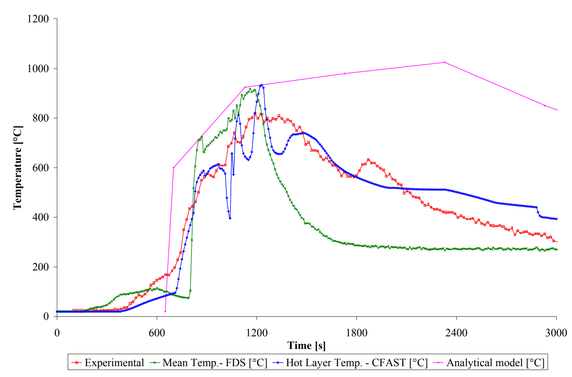


Figure 14: Comparison of the temperatures calculated with the three models (Simplified, gases; CFAST, hot layer; FDS 2 m from the floor) vs experimental

6. CONCLUSIONS AND PERSPECTIVES

The HRR experimental curve (*Figure 13*), was well reproduced by the three models. The maximum levels of HRR are 3.4 MW for the experiment, 4.2 MW for FDS, 6.4 MW for CFAST and 4 MW for the simplified model. The maximum of HRR predicted by CFAST (1 100 seconds) may appear as incorrect because of its magnitude. However, it corresponds just to a local peak very brief in duration.

The integration of the curves of HRR shows that the real thermal charge is bigger than the calculated. This is partly due to the lack of information about the real thermal properties of the materials.

In general, the peak experimental temperature (*Figure 14*) has been well predicted by the three models. The maxima of temperature are around 900 °C in all the cases. During the test, the flash-over of the room occurred arround 650 seconds after the start of the test. The CFAST simulation reproduced very well the experimental temperature and the HRR, however the fire source has not been modelled. FDS predicted a faster flash-over than what occurred in the experiment. The simplified model predicted higher temperatures than found during the experiment.

The CFAST simulation predicted a global behaviour of the temperature near to the measurements. However, the FDS simulation shows a very good correspondence with the experimental curve until about 1 100 seconds after the start of the test. Beyond that time, an important divergence appears. It is due mainly to the very slow reaction of the wood in the simulation (low heat release).

That research could be continued and improved by adjusting the thermal parameters of the materials considered for the simulations. Doing so, the divergence between the curves could be reduced.