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MODELLING POST-FLASHOVER FIRES WITH FASTLite

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ABSTRACT

This paper describes the post-flashover use of the FASTLite program and illustrates typical output for a post-flashover fire in a single room. The program is shown to model heat release and fire duration in a rational way, but some calculated compartment temperatures appear to be too high. Suggestions are made for using the program in its current form and for future improvements.

FASTLite

FASTLite is a suite of engineering tools for estimating fire growth and smoke transport in building fires. It is produced by the Fire Modelling and Applications Group of the Building and Fire Research Laboratory of the National Institute of Standards and Technology (NIST). FASTLite was released in May 1996 on CD-ROM. Copies are available free of charge from NIST. The FASTLite program is also available on the World Wide Web at http://fast.nist.gov/. The calculations in this paper were made using version 1.0b, obtained by applying an update from the web to version 1.0 from the CD. The output post-flashover fire temperatures from version 1.0b are significantly less than those from version 1.0. Minor corrections and improvements are in progress, with the latest version available on the web.

The software includes a User Guide which can be printed as necessary. The same guide is available as a NIST report[1]. FASTLite runs on any DOS based computer (386 or better). It has a graphical user interface which makes data entry and operation of the program very easy.

FASTLite has grown from several tools which have been widely used in the fire engineering community. The range of applications is similar to FPEtool which was developed by H.E. (Bud) Nelson[2] during the 1980's. The FPEtool suite of programs contained two simple fire growth models; ASETBX and FIRE SIMULATOR. The fire growth model in FASTLite is a stripped down version of the C-FAST zone model[3].

FASTLite allows fire modelling of up to three interconnected rooms. The user specifies the geometry of the rooms and the heat release rate of an input fire. Before flashover, the input heat release rate is followed unless it becomes constrained by the available ventilation. The calculations are the same as in the C-FAST model. Typical output includes the layer height, temperatures and concentrations of gas species in both layers, floor and wall temperatures, and the heat flux to the floor.

Post-Flashover Calculation

In the FASTLite model, flashover is assumed to occur when the upper layer temperature reaches 600°C, a widely accepted flashover criterion. This temperature corresponds to radiation at floor level of about 32 kW/m^2, which would cause all exposed combustible surfaces to ignite quickly.

The FASTLite program pauses at the time of flashover and gives the user the opportunity to modify window openings. After flashover, there are two options for heat release rate. Either the C-FAST calculations are continued based on the initial design fire, or if the "flashover" option is turned on, the initial design fire is ignored and rate of heat release is calculated with new subroutines based on the post-flashover fuel and window openings.

The calculation of heat release rate for the post-flashover fire is similar to that used in the FIRE SIMULATOR section of FPEtool, described by Deal[4]. The calculations have been improved so that the duration of burning is directly proportional to the amount of available fuel. The FASTLite equations for heat release rate in post-flashover fires are not documented in the User Guide or elsewhere, but are summarized in this paper.

For all post-flashover calculations other than heat release rate, it is assumed that FASTLite uses the same C-FAST calculations as used before flashover. The use of the zone model approximations have not been justified in the literature for turbulent post-flashover fires, but the model seems to give reasonable results as discussed below.

Input information

The main variables such as room geometry, window location, adjacent rooms etc. are all defined when calculating the pre-flashover fire. The following additional items must be input via the "flashover" screen, for use in post-flashover fires.

Fuel density: The average density of the fuel is required. The fuel is input as a volume, so the program needs the density to convert it to mass.

Heat of combustion: The heat of combustion is needed. This is the amount of energy released when unit mass of fuel is burned. FASTLite allows this value to be different from the pre-flashover value. For wood fuel, Tran[5] gives average typical heat of combustion of oven dry wood around 20 MJ/kg but found that the effective heat of combustion in the OSU Apparatus was in the range 13 to 15 MJ/kg. The NFPA Handbook[6] gives the typical range of heat of combustion as 18 to 21 MJ/kg.

For materials such as wood which contain some moisture under ambient conditions, the net calorific value ΔH_c (MJ/kg) can be calculated from

$$\Delta H_c = \Delta H_{c,d} (1 - 0.01\, m_c) - 0.025\, m_c \qquad (1)$$

where $\Delta H_{c,d}$ is the heat of combustion of oven dry wood

m_c is the moisture content as a percentage by weight, given by $m_c = (100 \times m_d) / (100 + m_d)$

where m_d is the moisture content as a percentage of the dry weight, as usually used for wood products.

For example, for typical wood with $\Delta H_{c,d}$ = 17 – 20 MJ/kg, and a moisture content of m_d = 12%, the above equations give m_c = 10.7%, hence ΔH_c = 14.9 – 17.6 MJ/kg. Babrauskas[7] recommends a value of 12 MJ/kg for heat of combustion of wood, which presumably includes the fuel fraction (see below).

Fuel fraction: This is an efficiency factor by which the heat of combustion is reduced. Babrauskas[8] suggests a value in the range 0.5 to 0.9. Böhm and Hadvig[9] recommend a value of no more than 0.7 for ventilation controlled fires. In FASTLite, reducing the value of the fuel fraction reduces the total quantity of energy released when the fuel is burned, and also reduces the heat release rate for fuel area controlled fires, but does not reduce the heat release rate for ventilation controlled fires.

Heat of gasification: This is the amount of energy required to pyrolyze a unit mass of fuel. For heat of gasification, Drysdale[10] reports values for wood ranging from 1.7 to 5.9 MJ/kg and for plastics ranging from 1.2 to 3.7 MJ/kg. The highest figures in these ranges should be used to get realistic results. Increasing the value of L_v reduces the heat release rate for fuel controlled fires, but does not change the total quantity of energy released when the fuel is burned.

Available fuel: For post-flashover fires, the fuel must be input as a volume, assumed to be in layers (up to three layers) over the internal surfaces of the fire room. The layers burn simultaneously, not sequentially, which is not clear from the User Guide. Input requires both the area and thickness of the fuel, on horizontal or vertical surfaces, or both. The fuel surface area is input as a proportion of internal surface areas of the compartment. For vertical fuel, this is the proportion of the total wall surface area ignoring openings, and for horizontal fuel this is the proportion of the floor area and ceiling area combined. Burning of fuel on horizontal and vertical surfaces is identical.

The FASTLite program calculates the volume of fuel from the input dimensions, then multiplies by density to get the mass of the fuel, and by heat of combustion to get the total energy content of the fuel.

To derive input data from fuel load expressed as *fuel load energy density* (MJ/m^2 floor area), it is necessary to:

1. Divide the fuel load energy density by the heat of combustion (MJ/kg) to obtain the mass of fuel per unit floor area (kg/m^2).

2. Multiply the mass of fuel per unit floor area by the floor area (m^2) to obtain the total mass of fuel (kg).

3. Divide the mass of fuel by the density (kg/m^3) to obtain the total volume of fuel (m^3).

4. Select a suitable surface area for the fuel (m^2), being the wall area, floor and ceiling area, or both.

5. Divide the volume of fuel by the surface area to obtain the thickness (m).

6. Input the fuel area and thickness on the horizontal or vertical surfaces used in Step 4.

Note that in FASTLite there is no difference between horizontal and vertical surfaces in the combustion calculations. It is possible to arrange the fuel in different thicknesses over different areas, resulting in changes in the heat release rate as the fire progresses, with thin fuels burning out more quickly than thick fuels.

The pre-flashover design fire is ignored after flashover, so any unburned fuel in the burning item of the original design fire is not included in the post-flashover calculations.

Heat release rate calculations

FASTLite calculates two heat release rates, one governed by the available fuel surface area and the other governed by the available ventilation. The lower of these two is used in the simulation. The heat release rate calculated in this way is decoupled from the energy balance of the enclosure, which is subsequently used to calculate temperatures. The fuel area and thickness can be manipulated as desired by the user to enforce either fuel or ventilation controlled burning. It would be useful to have the option of enforcing ventilation control regardless of the fuel geometry.

Fuel surface area control:

The fuel area controlled heat release rate is calculated using the usual theory[10] from the mass loss rate, m ($g/s.m^2$) using

$$m = q_i / L_v \quad (2)$$

where qi is the incident radiation reaching the fuel surface (the total heat flux less any losses expressed as a heat flux through the fuel surface) (kW/m^2)

Lv is the heat of gasification (MJ/kg)

The fuel area controlled heat release rate Q_{fuel} (kW) is then

$$Q_{fuel} = m A_{fuel} \chi \Delta H_c \quad (3)$$

where A_{fuel} is the exposed surface area of the fuel (m^2)

χ is the fuel fraction

ΔH_c is the heat of combustion of the fuel (MJ/kg)

The incident radiation q_i is set in FASTLite as 70 kW/m^2. This value cannot be changed by the user. If a change were considered necessary, changing the value of the heat of gasification L_v would have the same effect.

Equations [2] and [3] are based on the assumption that the rate of heat release is proportional to the imposed heat flux, with no influence of the thickness or shape of the fuel. This is appropriate for liquid or plastic fuels, but for wood, the burning rate also depends on the thickness of the slab or the size of the sticks. Babrauskas[8] reports that for burning of thick slabs of wood, the surface regression rate is v_p is approximately constant at

$$v_p = 8.5 - 10.0 \times 10^{-6} \text{ m/s}$$
$$(0.5 - 0.6 \text{ mm/min}) \quad (4)$$

For thinner slabs the regression rate increases according to

$$v_p = 2.2 \times 10^{-6} D^{-0.6} \text{ m/s} \quad (5)$$

where D is the thickness of the slab (m)

These equations for regression rate can be compared with the calculation from Eq. [3]. Using typical values of ΔH_c = 16 MJ/kg, χ = 0.9 and L_v = 6 MJ/kg, Eq. [3] gives a heat release rate Q_{fuel} = 168 kW for one square meter of fuel surface. Dividing by heat of combustion $\chi\ \Delta H_c$ = 14.4 MJ/kg and density of 500 kg/m^3, this corresponds to a regression rate of 23.3 × 10^{-6} m/s (1.4 mm/min) which is more than twice the expected rate for a thick slab from Eq. [4]. A calculation using Eq. [5] shows that the FASTLite regression rate is about that expected for a wood slab 25 mm thick. Thinner slabs burn even faster.

A suggested improvement to FASTLite is to base the burning rate of wood on Eqs. [4] and [5] with burning rate equations for sticks or cribs incorporated using relationships such as those described by Babrauskas [8]. This would require a more rigorous description of the fuel, but would give more accurate results for fuel controlled fires, subject to the limited information available on burning rates in fully developed fires.

Ventilation control:

The ventilation controlled heat release rate is governed by the rate of air flow in through a vertical wall opening, given by

$$m_{air} = 0.5\ A_v \sqrt{H_v} \qquad (6)$$

where m_{air} is the flow of incoming air (kg/s)
A_v is the area of the window opening (m^2)
H_v is the height of the opening (m)

If there is more than one opening, the $A_v\sqrt{H_v}$ terms are summed for all of the openings. Drysdale[10] shows how this equation can be derived by considering the inward flow of air and outward flow of combustion products through an opening.

The ventilation controlled heat release rate Q_{vent} (kW) is calculated using the relationship that combustion using the oxygen in 1 kg of air releases approximately 3000 kJ of heat energy, giving

$$Q_{vent} = 3000\ m_{air} \qquad (7)$$

There is no way for the user to allow for less than complete mixing and combustion, because the efficiency factor (fuel fraction), χ does not appear in Eq. [6] or [7]. Changing the heat of combustion or heat of gasification has no effect on heat release rate if the fire is ventilation controlled.

An inconsistency in this version of FASTLite is that ceiling openings are ignored in estimation of the heat release rate, but flow through the openings is included in the post-flashover fire calculation. This would produce serious errors for a room with ceiling openings, but the problem will be corrected in the next release of FASTLite.

Calculated heat release rates:

The lower of Q_{fuel} or Q_{vent} is used in all subsequent calculations. Output from typical runs of FASTLite shows a slightly lower heat release rate which gradually reduces over the duration of the fire.

Output from several runs shows that fires which are strongly fuel controlled have a good energy balance in that the total heat released during the post-flashover fire is equal to the energy stored in the fuel, and there are no unburned hydrocarbons in the upper layer. The output peak heat release rate is close to Q_{fuel} and there is very little drop during the course of the fire. This behavior is expected because there should be a fuel-lean atmosphere in a fuel controlled fire with all of the heat being released within the room and no transport of unburned gases out the window. FASTLite uses Eq. [2] to track the amount of fuel remaining, and the heat release rate drops to zero when all the fuel is consumed.

For ventilation controlled fires, typical output shows that the total energy released is 80–90% of the energy stored in the fuel, the peak heat release rate is 90–97% of Q_{vent}, unburned hydrocarbons account for 1–5% of the gases in the upper layer, and there is a 10–15% drop in the output heat release rate during the course of the fire. The reason for this drop in heat release rate is not known, but the program appears to be allowing for unburned fuel being transported outside through the window as unburned hydrocarbons. Fires that are slightly fuel controlled behave like the ventilation controlled fires.

EXAMPLE

The use of FASTLite for modelling post-flashover fires is illustrated below for a typical single room.

Input

The room is 5.0 m × 5.0 m in plan area, 3.0 m high. There is one window opening 2.0 m high with a sill 0.5 m above the floor. The width of the window is 0.5 m in the pre-flashover condition, and varies after flashover to give a range of opening factors as shown in Table 1. The opening factor is $A\sqrt{H}/A_t$ where A is the area of the window, H is the height of the window and A_t is the total area of internal surfaces of the compartment. The opening factor is used later to compare output temperatures with other time temperature curves.

The wall and ceiling materials are selected as a single layer of 16 mm thick gypsum board, and the floor as concrete. The materials database in FASTLite is difficult to use because only specific heat and emissivity are listed in the properties window. The other thermal properties are contained in the THERMAL.DF file, but there is no key to the different properties. Some of them appear to be the same as used in CFAST[3]. The gypsum plaster used in this example has a density of 790 kg/m^3, thermal conductivity of 0.16 W/mK and specific heat of 900 J/kgK. A cavity wall would have better insulating properties than a single layer of gypsum board used here. There are some wall assemblies listed in the database but with insufficient information to use them with confidence.

The initial design fire is specified as a t^2 fire with medium growth rate for 7 minutes (to 2.07 MW) then constant heat output for five minutes before a 7 minute decay phase. Flashover occurred before commencement of the decay phase in all example runs. Default values are used for the lower oxygen limit (10%), initial fuel temperature (20°C), gaseous ignition temperature (220°C), and radiative fraction (0.3).

Table 1. Window sizes in FASTLite example runs, after flashover

Height (m)	Width (m)	Opening factor (m$^{1/2}$)
2.0	0.5	0.013
2.0	1.0	0.026
2.0	2.0	0.051
2.0	4.0	0.103

For the post-flashover fire, the fuel is assumed to be wood with the following properties:

Heat of combustion 16 MJ/kg

Density 500 kg/m^3

Heat of gasification 6 MJ/kg

Fuel fraction 0.9

For most runs the fuel load energy density is taken as 400 MJ per m^2 of floor area.

For the floor area of 25 m^2, the total fuel load is 400 × 25 = 10,000 MJ = 10 GJ.

The total mass is 10,000/16 = 625 kg.

The volume of wood is 625/500 = 1.25 m^3.

This fuel can be distributed as a uniform layer

50 mm over the floor (area 25 m^2)or 25 mm thick over the floor and ceiling (area 50 m^2)

or 12.5 mm thick over an area of twice the floor and ceiling areas (area 100 m^2)

The area and thickness are varied in different ways to get fuel controlled burning or ventilation controlled burning. For a small window size, most fires will be ventilation controlled. For a large window opening, it is necessary to smear the fuel in a very thin layer over a very large surface area to achieve ventilation controlled burning.

A summary of the runs is shown in Table 2. The fuel quantity shown is the gross quantity. The available fuel is 90% of this quantity because the fuel fraction has been taken as 0.9. The fuel controlled heat release rate (HRR) and ventilation controlled heat release rate in Table 2 are calculated from Eqs. [3] and [7], respectively.

Output

Typical output is shown for several computer runs, varying the width of the window and the arrangement of the wood fuel. The figures below show how the input parameters can be used to predict burning rates, durations and tempera-

Table 2. Summary of FASTLite example runs.

Run No.	Window width	Fuel area	Fuel thickness	Fuel quantity	Fuel controlled HRR	Ventilation controlled HRR	Maximum temperature
	(m)	(m^2)	(mm)	(GJ)	(MW)	(MW)	(°C)
1	4.0	100	12.5	10	16.8	17.0	1661
2	2.0	100	12.5	10	16.8	8.5	1476
3	1.0	100	12.5	10	16.8	4.2	1244
4	0.5	100	12.5	10	16.8	2.1	992
5	1.0	100	6.25	5	16.8	4.2	1118
6	1.0	100	25.0	20	16.8	4.2	1339
7	4.0	25	50.0	10	4.2	17.0	623
8	2.0	25	50.0	10	4.2	8.5	959
9	1.0	25	50.0	10	4.2	4.2	1245
10	2.0	25	25.0	5	4.2	8.5	893
11	2.0	25	100.0	20	4.2	8.5	1008

tures for a range of ventilation and fuel control conditions.

Ventilation controlled burning

Figure 1 shows time temperature curves for four ventilation controlled fires. All of these fires have the same fuel placed in a thin layer over large area to ensure ventilation control. As the window width is increased, the heat release rate increases, and shorter hotter fires occur. The run numbers are those shown in Table 2.

Figure 2 shows the effect of varying the total fuel load for a fixed window size. The heat release rate is the same for all three fires, but the duration increases as expected. The fuel load was increased by increasing the thickness of the fuel, keeping it in a thin layer to ensure ventilation control.

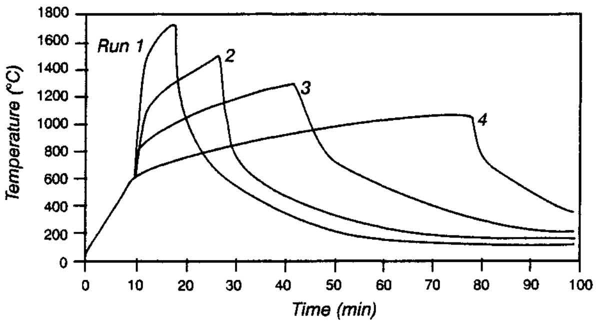

Figure 1. Time Temperature Curves for Ventilation Controlled Burning, with Constant Fuel Load and Varying Window Size.

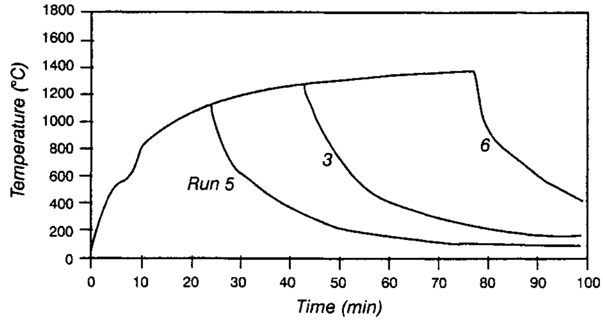

Figure 2. Time Temperature Curves for Ventilation Controlled Burning, with Constant Window Size and Varying Fuel Load.

Fuel controlled burning

Fuel controlled burning can be obtained by changing the fuel from a large thin layer to a smaller thicker layer of the same volume. Figure 3 shows the effect of changing the window width for a fuel controlled fire. All three fires have the same

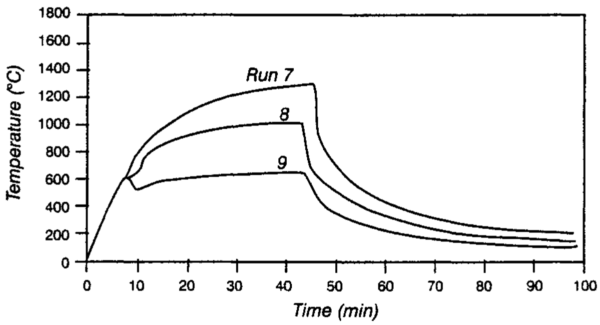

Figure 3. Time Temperature Curves for Fuel Controlled Burning, with Constant Fuel Load and Varying Window Size.

fuel area, hence the same rate of heat release. Increasing the window size does not affect the heat release rate because the fires are fuel controlled, but it reduces the compartment temperatures because more heat is carried away by the vent flows.

Figure 4 shows the effect of varying the total fuel load for a fixed window size, for a fuel controlled fire. All three fires have the same window size, and same area of fuel, but the thickness of fuel is increased to change the total fuel load, hence the duration of the fire.

Radiative fraction

Figure 5 shows the temperatures from three runs with different values for the radiative fraction. The default value of 0.3 is shown for run number 3 (central curve on Figure 5). It can be seen that changing the value between 0 and 0.5 has a small influence on the rate of temperature increase immediately after flashover, but otherwise has very little effect on compartment temperatures.

Wall and ceiling materials

Figure 6 shows the effect of changing the walls from gypsum plaster to concrete or brick, for

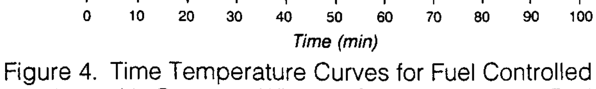

Figure 4. Time Temperature Curves for Fuel Controlled Burning, with Constant Window Size and Varying Fuel Load.

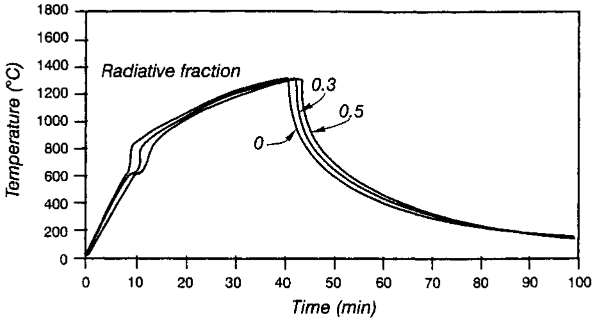

Figure 5. Time Temperature Curves for Ventilation Controlled Burning, with Varying Radiative Fraction.

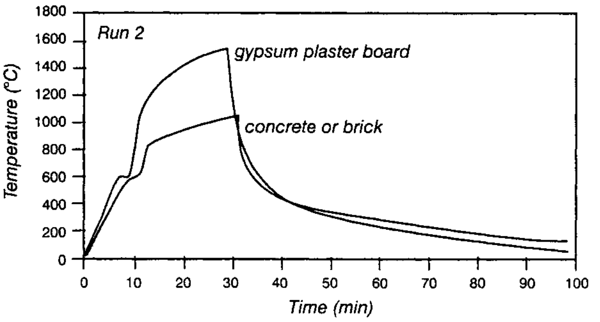

Figure 6. Time Temperature Curves for Run 2 Comparing Gypsum Plaster Board with Concrete.

Run 2. The temperatures were almost identical for concrete (150 mm thick) and brick (75 mm thick), much lower than those for gypsum plaster. It can be seen that the thermal properties of the walls and ceiling have a very large effect on the temperatures. It was intended to make several other comparative runs with concrete, sheet steel and other materials, but difficulties with FASTLite made this impossible. The program "locked up" at flashover or soon after flashover for almost all runs with materials other than gypsum plaster.

Temperature comparisons

In general the FASTLite output follows expected trends, but temperatures for ventilation controlled fires are higher than anticipated. It is important to be using the latest version of FASTLite because the output temperatures from version 1.0b of FASTLite are only 75 to 80% of those from version 1.0.

As a comparison with other studies, Figure 7 shows the predictions of Magnusson and Thelandersson[11] for ventilation controlled fires in a "Type A" compartment which has bounding surfaces with a thermal conductivity of 0.81 W/mK and a heat capacity of 1.67 MJ/m^3K. Note that the fuel load in their curves is MJ per m^2 of total surface area. The fuel load of 400 MJ/m^2 floor area used in most of the FASTLite runs corresponds to 91 MJ/m^2 total surface area, for which the maximum temperature does not exceed 1,000°C, less than shown in Figure 1.

Figure 8 shows a similar set of time temperature curves produced from the COMPF2 program[12] calculated by Thomas et al[13] for "pessimized" ventilation controlled fires in a room the same size and similar construction as for the FASTLite

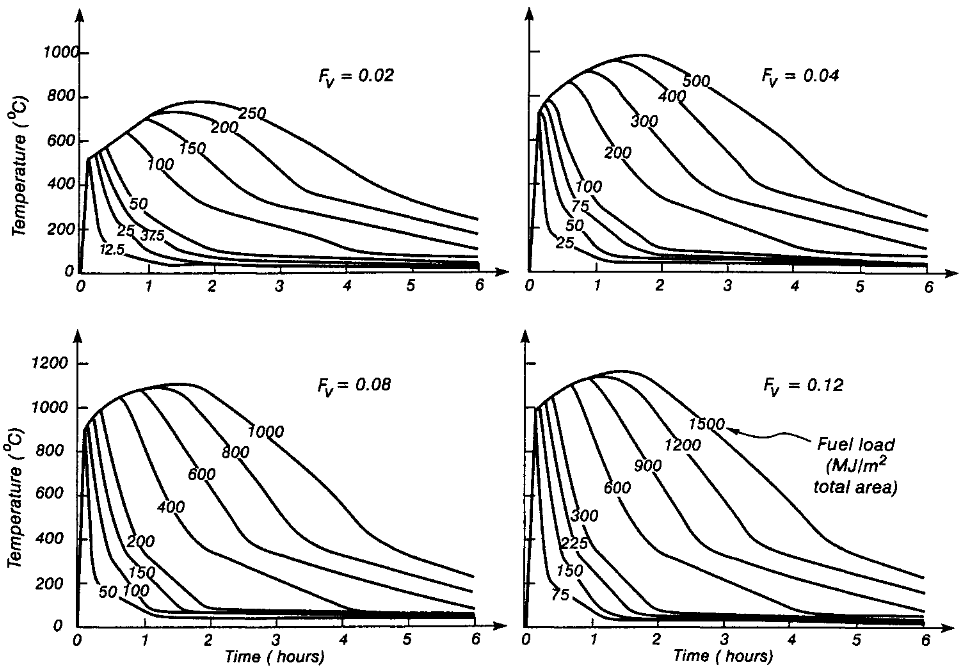

Figure 7. Time Temperature Curves for Ventilation Controlled Fires (from reference 11).

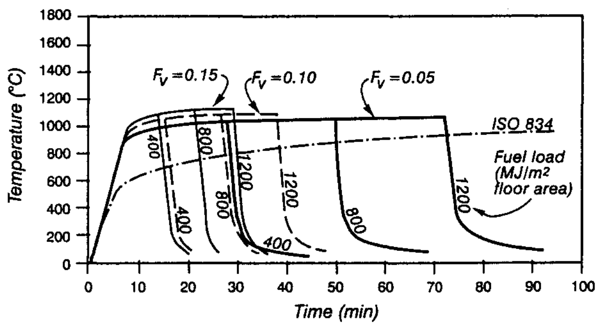

Figure 8. Pessimized Time Temperature Curves for Ventilation Controlled Fires, Obtained from COMPF2 (reference 13).

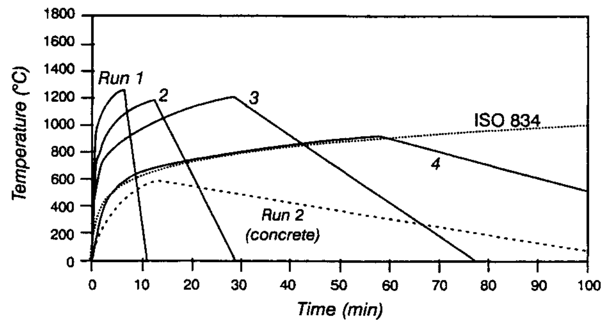

Figure 9. Parametric Time Temperature Curves for Ventilation Controlled Fires from the Eurocode.

runs. The maximum temperatures in these fires are all between 1,000 and 1,100°C, less than the FASTLite output. Figures 8 and 9 also include the ISO 834 standard fire curve for comparison.

As another comparison, Figure 9 shows the parametric time-temperature curves from the Eurocode[14] for the same fuel load and ventilation conditions as used in FASTLite runs 1 to 4. These curves used the same thermal properties of gypsum plaster as described in the FASTLite input. The Eurocode parametric time-temperature curves have been developed as an empirical approximation to the curves of Magnusson and Thelandersson shown in Figure 7, for design of fire-exposed structures. These curves are considered to be useful in the burning phase, but the duration of the parametric fires is only two thirds of that predicted by the accepted equations used in FASTLite, and the rate of decay is unrealistically slow for low ventilation or large thermal inertia. Figure 9 also shows the parametric time-temperature curve for Run 2 using the thermal properties of concrete from the FASTLite database, as a comparison with Figure 6. In all cases, the FASTLite temperatures appear rather high.

It appears that some correction is needed to the FASTLite model if realistic temperatures are to be predicted. Given the present model, the only way for a user to manipulate the runs to achieve lower temperatures is to reduce the heat release rate (only possible for fuel controlled fires), or to increase the thermal conductivity of walls. Any such manipulations would require guesswork which would not produce useful results. It is understood that the present model does not allow for radiation through window openings, which may have some impact when the windows are large. Modifications to FASTLite to correct these problems are in progress.

Layer height and gas concentrations

Figures 10 to 13 show the output from a FASTLite run for a typical ventilation controlled fire (Run number 3). Figure 10 shows how the interface between the hot and cold layers drops during the fire. After about seven minutes of the fire (just before flashover) the layer interface is less than 400 mm from the floor, lower than the window sill. When the fire goes out the layer rises close to the ceiling. Several other computer runs with the same size of window higher or lower in the wall made very little difference to the output values.

Figure 11 shows oxygen and carbon dioxide concentrations in the upper layer throughout the fire. In the post-flashover phase, the upper layer has zero oxygen and 12% carbon dioxide. There is no change after the fire stops burning, although the upper layer becomes much thinner. Figure 12 shows that in the lower layer, the oxygen concentration drops to less than 15% during the post-flashover burning period, rising to ambient levels when the burning stops. Carbon dioxide concentration rises to over 5% in the same period.

Unburned hydrocarbons are shown in Figure 13 at a different scale. These are always less than 1% in the lower layer until the fire stops burning, and less than 2% in the upper layer, remaining constant after burning ceases.

FASTLite also gives the temperatures of the lower layer of gas and surface temperatures of the walls ceiling and floor. These are not plotted here, but as expected, the ceiling, wall and floor temperatures all approach the upper layer temperature as the fire progresses. The lower layer gas temperature is much cooler because it contains incoming air.

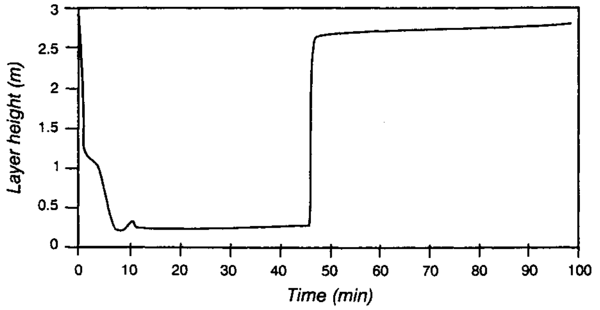

Figure 10. Variation of Upper Layer Height with Time.

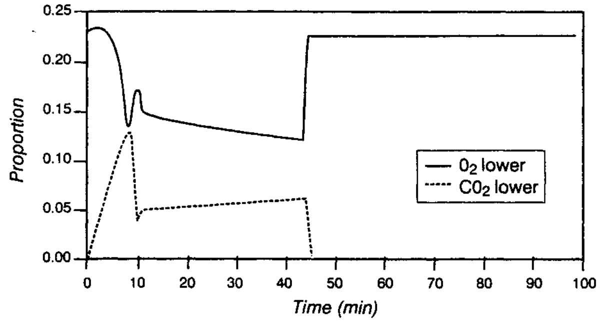

Figure 12. Oxygen and Carbon Dioxide Concentrations in the Lower Layer.

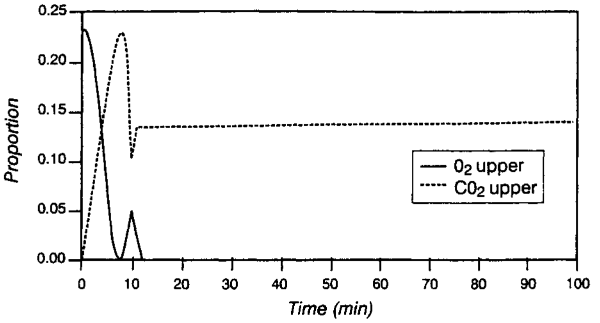

Figure 11. Oxygen and Carbon Dioxide Concentrations in the Upper Layer.

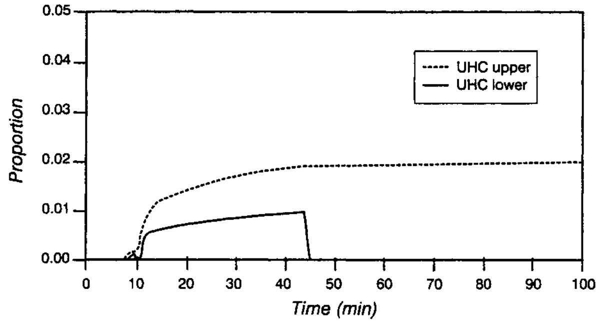

Figure 13. Unburned Hydrocarbon Concentrations in the Upper and Lower Layers.

Suggestions for Improvements

The following suggestions are made for improving FASTLite for predicting the behavior of post-flashover fires.

- Allow for fuel to be input as energy density (MJ/m^2) or total energy or mass.
- For fuel control, give options for stick burning based on surface area and thickness, or crib burning based on crib porosity.
- Allow for ventilation control to be enforced, as an option when fuel geometry is not well known.
- Allow for a combustion efficiency factor to apply to the heat release rate for ventilation controlled fires.
- Allow for ceiling openings to be changed at flashover.
- Provide an option for the heat in the unburned portion of the initial design fire to be released after flashover, rather than having two completely separate fuel sources before and after flashover.
- Give more detail of the thermal properties of the wall and floor materials, and allow for physical changes such as loss of moisture.
- Allow for radiation through window openings and make any other corrections necessary to give more realistic temperature predictions.
- Give a summary output showing the final destination of all the components of fuel energy.
- Correct the bugs that cause the program to lock-up for materials other than gypsum plaster.

Conclusions

- The FASTLite program is relatively easy to use for post-flashover fires, although input of the fuel quantity and geometry is rather awkward.
- FASTLite predicts the heat release rate based on either ventilation control or fuel area control, and calculates the fire duration accordingly.
- Calculated temperatures for ventilation controlled fires are higher than predicted by other models, especially if window openings are large. Temperature calculations should be verified before FASTLite can be recommended for general use by designers.
- More research into the behaviour of post-flashover fires is needed.

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Notation

A_{fuel}	exposed surface area of the fuel	m^2
A_v	area of the window opening	m^2
D	thickness of slab	m
H_v	height of the opening	m
ΔH_c	net calorific value	MJ/kg
$\Delta H_{c,d}$	heat of combustion of oven dry wood	MJ/kg
L_v	heat of gasification	MJ/kg
m	mass loss rate	g/s.m^2
m_{air}	flow of incoming air	kg/s
m_c	moisture content as a percentage by weight,	%
m_d	the moisture content as a percentage of the dry weight	%
q_i	incident radiation reaching the fuel surface	kW/m^2
Q_{fuel}	fuel area controlled heat release rate	kW
Q_{vent}	ventilation controlled heat release rate	kW
v_p	surface regression rate	m/s
χ	fuel fraction	

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