Comparison between a Simple and a More Complex Zone Model in Fire Engineering

STAFFAN BENGTSON
The Swedish Fire Protection Association
Sweden

BENGT HÄGGLUND
National Defence Research Institute
Sweden

FREDDY MADSEN
The Danish Fire Protection Association, DFPA
Denmark

ABSTRACT

In this paper the calculation of critical events in a fire situation defined as time for smoke logging and flashover is shown using two different fire models. Two models were used, a revised DFPA version of the simple model ASETB and the more complex model DSLAYV. Both of these are single-room models. They assume near-floor-elevation leakage and they have a capability for simulating the effect of ceiling ventilation to the outside ambient. In using the two models, the difference in calculated times is never larger than 15 % showing that ASETB works well as an engineering tool. The error which occurs when you are using wrong description of the fire growth is much larger.

1. INTRODUCTION

By different reasons there has been a growing demand in fire engineering to create models by which it's possible to predict the effect of a fire in it's first stages.

A lot of different fire models has been created during the last decades with changing degree of complexity. In this article the outcome of a more simple method is compared with a more complex method. The reason for using the simple model is that it can be handled with a simple personal computer and that means that many calculations can be performed very quickly at a low cost, so that using fire models in design of fire safety is not restricted to large or prestige buildings.

2. A SHORT DESCRIPTION OF THE SIMULATION MODELS

In the two models ASETB (1, 2, 3) and DSLAYV (4, 5) the technique to divide the fire room in two zones with different temperatures is used.

The outlay which also accounts for roof-venting is described in Figure 1 and 2. For given values of the vent area the model predicts the depth and temperature of the smoke layer.

Copyright © International Association for Fire Safety Science

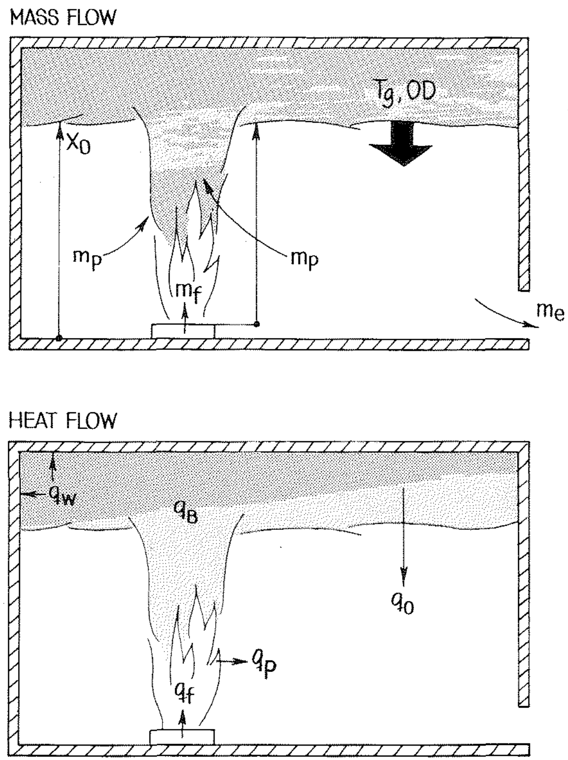

Fig. 1 The smoke filling simulation model.

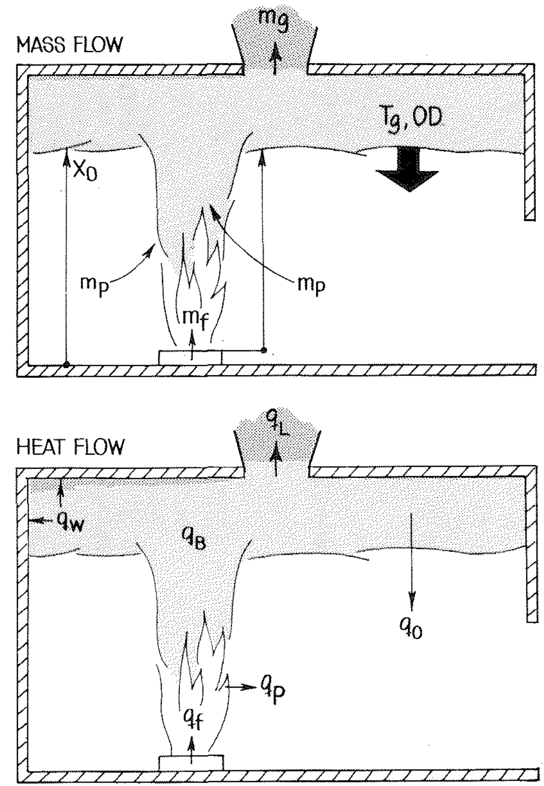

Fig. 2 The smoke filling simulation model including the effect of fire ventilation.

Input data common for the two models are the geometry of the room and the heat release of the fire.

In DSLAYV the heat and mass flow is calculated by solving the conservation equations for the two layers. To do these calculations you need a computer with a capacity of the order 1Mb.

In ASETB some simplifying assumptions are made. To calculate the temperature and the total mass flow in the plume a dimensionless value (Q*) of Q (rate of the fire's energy release) is used (eq 1)

$$Q^* = (1-\lambda_r) \; Q / \left[\rho_a C_p T_a (gZ)^{\frac{1}{2}} Z^2 \right] \qquad \text{eq 1}$$

where

λ_r = effective fraction of Q radiated from the combustion zone

ρ_a = ambient density (kg/m^3)

C_p = specific heat capacity $(J/kg, {}^oC)$

T_a = ambient temperatur $({}^oK)$

g = acceleration of gravity $(9.81\ m/sek^2)$

Z = elevation (m)

Cooper has in ASETB assumed λ_r to be constant and having the value 0.35. In that way 65 % of the total heat release is convected upward and used to raise the temperature of the smoke layer.

To make the calculations simple it's also necessary to give a constant value to λ_c which is defined as the combined instantaneous fraction of Q lost by the combustion zone, the plume gases, and the hot upper layer gases to the bounding surfaces of the room and it's contents. λ_c is made up of radiation losses and convection losses. Cooper recommends λ_c values between 0.6 and 0.9.

Included orginally in DSLAYV was a capability of modeling ceiling ventilation. This involves use of

$$m_c = C_d A_c \rho_o \left\{ 2g \; T_o/T_g (1 - T_o/T_g) \; (H - X_D) \right\}^{\frac{1}{2}} \qquad \text{eq 2}$$

m_c = rate of out flow of hot gases through the vent, kg/s

A_c = area of vent opening (m^2)

C_d = vent opening flow coefficient

H = height of room (m)

X_D = height of smoke layer (m)

T_o = ambient temperature $({}^oK)$

T_g = temperature of hot gases $({}^oK)$

Use of the above requires that the near-floor leakage path involves an area large enough for the pressure at the floor of the room to be virtually identical to the outside ambient pressure.

We have used eq 2 to add a ceiling ventilation capability to ASETB which was not included in its original version. The DSLAYV model and this revised ASETB model were used in comparision calculations which are described below.

3. COMPARISONS

In the following the lower level of the smoke layer and its temperature calculated by the two different methods is compared when using different input parameters. The difference in calculated times to critical events, smoke logging and flashover is also presented.

3.1 Input data

In table 1 is the different input data for the 26 runs shown. The fire has been described by an exponential growing fire (eq 3)

$$Q\,(t) = Q_o \exp\left((\ln 2)\; t/d\right) \qquad \text{eq 3}$$

where

$Q(t)$ = heat release rate (kW)

Q_o = initial heat release rate (kW)

d = doubling time (s)

t = time (s)

t_{fv} in table 1 is the time when the ceiling vents are opened. When non-zero-area ceiling vents are simulated in the calculations, t_{fv} and C_d of eq 2 are always taken to be 300 s and 0.6 respectively.

3.2 Results from DSLAYV

In fig 3 (run 19, 20, 21) is shown the effect of varying the ceiling height from 4 to 10 m in a room with the floor area 1000 m^2 and with real fire vent area 10 m^2.

The doubling time is 120 s.

The λ_c-value calculated in DSLAYV in these runs varies between 1.0 and 0.7.

Other runs show that a wrong guessing of the doubling time and initial heat output value gives very large discrepancies in the calculated values.

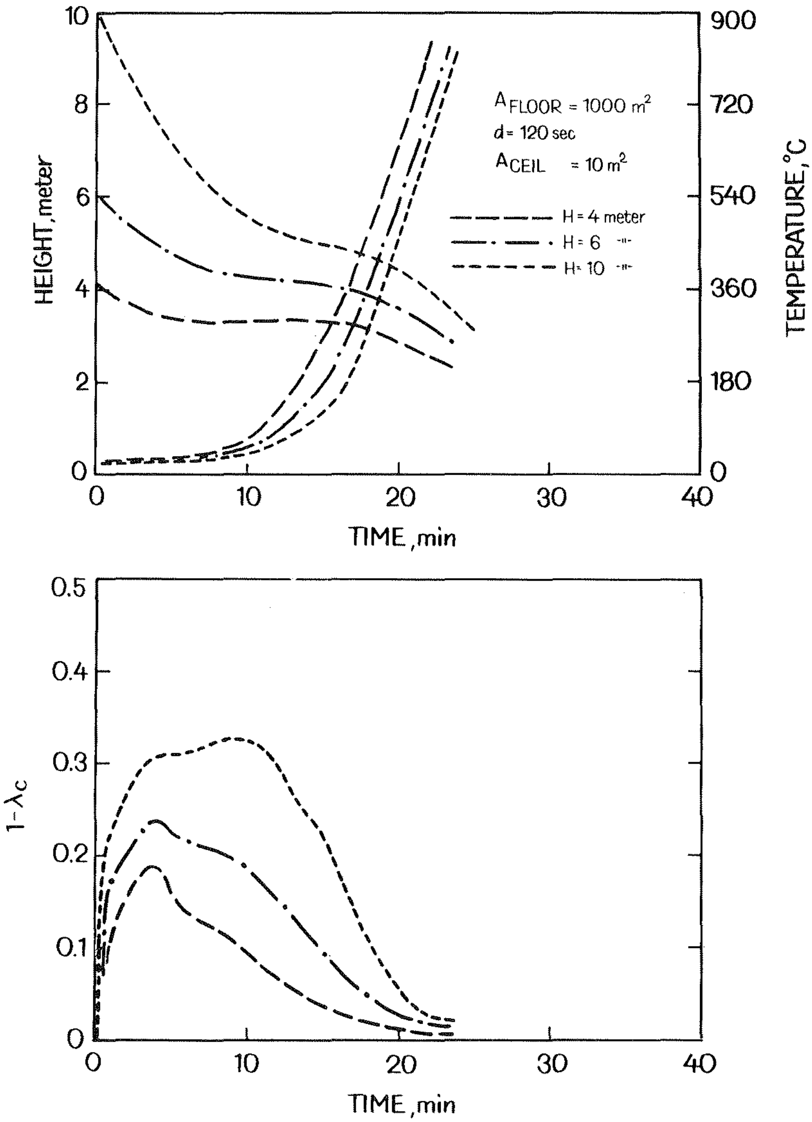

Fig. 3 The level of the smoke layer and the temperatures in runs 19, 20 and 21.

3.3 Results from ASETB

In running ASETB a constant λ_c-value of 0.8 has been used.

In fig 4 and 5 is shown the smoke layer and its temperature calculated by ASETB and DSLAYV in runs 19 and 21 (fig 4) and 8 and 10 (fig 5). From the figures can be seen that the difference in prediction of the smoke layer is quite small. The difference in temperature at a specific time is larger especially when using fire ventilation and at larger doubling times. Now this difference isn't of great importance but differences between time to critical events. This is described in the next section.

3.4 Time to critical events

Different judgements can be used to quantify a critical event when escape isn't possible and fighting a fire is difficult and dangerous. In this paper time until the smoke reaches 3 m from the floor and when the temperature of the hot layer is higher than 600 ^{o}C have been used. In table 2 times until these critical events are occurring is presented.

As can be seen from table 2 the differences which are defined as value (DSLAYV)-value (ASETB) are never larger than 15 % of the DSLAYV-value.

A wrong value of the doubling timed gives much larger differences. In run 8, 9 and 10 the time until the smoke reaches 3 m above the floor is 820, 1050 and 1540 seconds, respectively. The doubling times used are 120, 240 and 360 seconds. The error can be of the magnitude 20-50 % if there is a difference of 2 minutes in the doubling times.

A Wrong guess of the initial heat release (run 9 and 18) can also give a difference of 50 % in calculated time until a critical event.

3.5 Conclusions

As can be seen from 3.4 the differences in calculated time by ASETB and DSLAYV until critical events occur are of the order 15 %.

In these calculations important parameters has been greatly varied. The error is much larger when using the wrong heat release rate described by doubling time and initial heat release rate.

This fact indicates that ASETB can be used as an engineering tool with good accuracy.

Further efforts should therefore be directed to the description of fire growth instead of giving more details to fire models.

TABELL 1 Input data

Run Nr	Floor area m^2	Room height (m)	D (s)	Q_o (kW)	A_S (m^2)	t_{fv} (s)
1	200	4	120	50	10	300
2	200	10	360	50	10	300
3	200	4	120	50	0	-
4	200	10	360	50	0	-
5	1000	4	120	50	25	300
6	1000	6	120	50	25	300
7	1000	10	120	50	25	300
8	1000	6	120	50	0	-
9	1000	6	240	50	0	-
10	1000	6	360	50	0	-
11	1000	6	120	50	50	300
12	1000	6	120	50	100	300
13	2000	4	120	50	50	300
14	2000	10	360	50	50	300
15	2000	6	240	50	50	300
16	2000	4	120	50	0	-
17	2000	10	360	50	0	-
18	1000	6	240	500	0	-
19	1000	4	120	50	10	300
20	1000	6	120	50	10	300
21	1000	10	120	50	10	300
22	1000	6	120	50	5	300
23	1000	6	120	50	15	300
24	2000	4	120	50	20	300
25	2000	10	360	50	20	300
26	2000	6	240	50	20	300

TABELL 2 Time (s) to critical events

Run Nr	Smoke 3 m above floor DSLAYV	ASETB	** Δ	600 °C in the smoke layer DSLAYV	ASETB	** Δ
1	100,340*,950*	30,330*,1030*	-80	1000	1120	-120
2	>1800	>3700		>1800	3730	
3	100	130	-30	930	885	45
4	350	380	-30	>1800	2590	
5	>1400	1270		1120	1240	-120
6	1540	>1400		1220	1340	-120
7	>1400	>1500		1310	1430	-120
8	600	663	-63	1200	1225	- 25
9	820	900	-80	2300	2230	70
10	1050	1020	30	>2400	3140	
11	to large fire vent area					
12	- " -					
13	>1800			1280	1290	- 10
14	>1800	>4500		>1800	4480	
15	>1800	>2800		>1800	2800	
16	540	645	-105	1110	1240	-130
17	1760	1980	-220	>1800	3760	
18	420	490	- 70	1500	1410	90
19	1180	1050	130	1160	1175	- 15
20	1380	1180	200	1240	1260	- 20
21	1520	1270	250	1360	1355	5
22	920	1000	- 80	1220	1225	- 5
23	1440	1280	160	1260	1295	- 35
24	1440	1235	205	1240	1240	0
25	>1800	>4160		>1800	4160	
26	>1800	2680		>1800	2630	

* The smoke is moving around the 3-m level

** Difference in calculated times between DSLAYV and ASETB

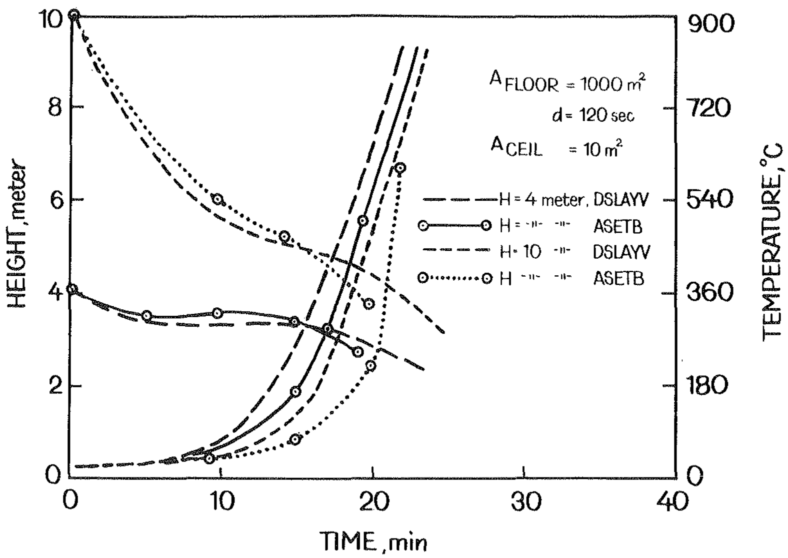

Fig. 4 Comparison between the level of the smoke and temperature calculated by DSLAYV and ASETB in runs 19 and 21.

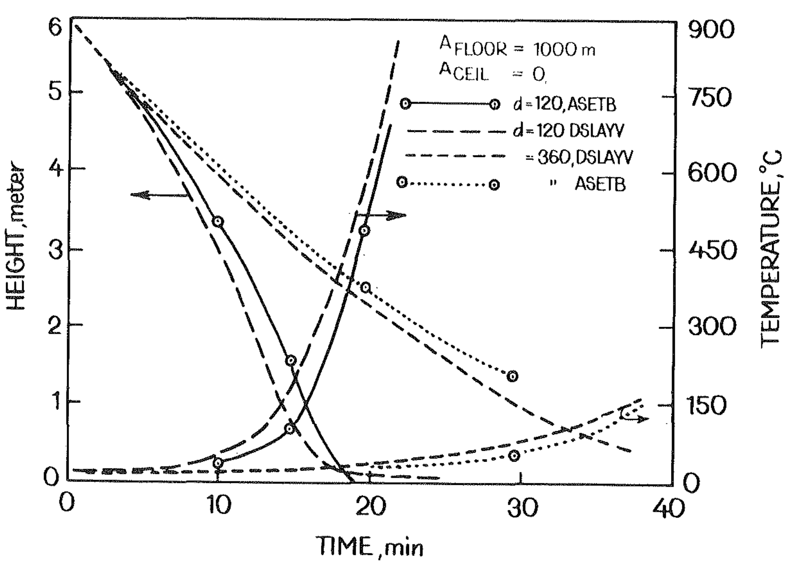

Fig. 5 Comparison between the level of the smoke and temperature calculated by DSLAYV and ASETB in runs 8 and 10.

4. REFERENCES

1 Cooper, L.; Estimating Safe Available Egress Time from Fires, Washington, NBSIR 80-2172, Center for Fire Research, National Bureau of Standards, 1981.

2 Walton, W.D.; ASET-B: A Room Fire Program For Personal Computer, NBSIR 85-3144-1, Center for Fire Research, National Bureau of Standards, December 1985.

3 DANISH FIRE PROTECTION ASSOCIATION; Fire Model BRAND

4 Hägglund, B; Simulating fires in natural and forced ventilated enclosures. FOA, Stockholm, Report C 20637-2.4, 1986.

5 Bengtson, S., Hägglund, B.; The use of a Zone Model in Fire Engineering Application, The First International Symposium on Fire Safety Science Gaithersburg, Md, USA. October 1985.