The Use of a Zone Model in Fire Engineering Application

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SUMMARY

In this paper is shown the possibility to modernize fire protection en-
gineering in a way that it will be on the same level as other parts of the
design of a building. A fire simulation model will be presented shortly.
The model predicts the time for smoke-logging, flash-over and detection
events for a given geometry of the building. The input parameter is the fire
growth curve. In a special section it is shown how the fire growth can be
predicted. Sometimes the fire area is known, but more often statistical
information has to be used. Finally some engineering applications are
indicated, where the consequences of a fire in a bus garage and a textile
factory are discussed.

1. INTRODUCTION

During the last few decades extensive efforts have been made to create
analytical models by which it is possible to judge the safety level objec-
tively. There are three main reasons for this interest:

a) As the costs of fire safety measures are increasing the cost
    effectiveness is of great interest.

b) Architects and consulting engineers have found that rigid praxis,
    inflexible building codes and insurance recommendations very often
    are a hindrance to an effective design of a building.

c) By quantitative analyzis you wish to obtain information on the effec-
    tiveness of new types of measure systems without waiting for expe-
    rience from real fires.

In spite of the fact that there now exist analytical models to describe a
fire and the threat from it, few attempts have been made to use them as
an engineering tool. In the following will be demonstrated how it is
possible with the knowledge of today to predict with good accuracy the
threat from fire and the effect of various fire safety measures. Similar
analyzis have been made by Bengtson, Hägglund and Ramachandran (1-5).

2. THE SIMULATION MODEL

The threat from fire is calculated by a zone model which is described in
(6). Its physical outlay is described in Figure 1. The enclosure is divi-
ded into two homogeneous layers, a layer next to the ceiling which con-
tains the hot combustion products and one next to the floor which con-
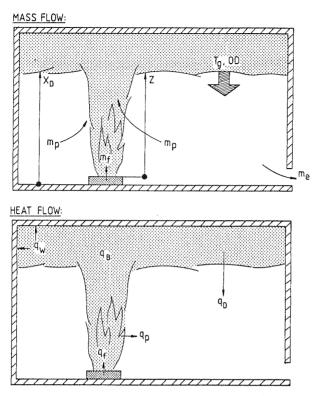
MASS FLOW:

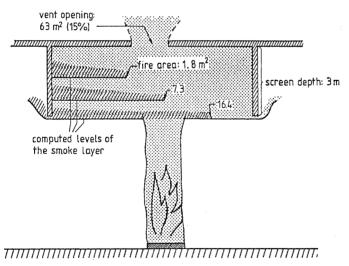HEAT FLOW:

Figure 1. The smoke filling simulation model

Figure 2. Computed levels of the smoke layer for kerosene fires of area 1.8, 7.3 and 16.4 m^2.

tains fresh air. The interface moves down at a velocity determined by the rate of air entrained into the fire plume (m_p) and by the rate of mass flow through leaks close to the floor (m_e). By means of a mass balance for the lower cool region it is possible to calculate this drop velocity.

The burning item releases heat at a rate q_f. The heat is lost by radiation and convection to the enclosing structures of the upper gas layer (q_w). The upper layer also loses heat by radiation to the lower cool region of the enclosure (q_p). Other loss terms are the radiant heat from the fire plume (q_p) and the heat to rise the temperature of the upper layer (q_B). By means of a heat balance for the upper gas layer, including the fire plume, the temperature of the descending smoke layer is computed.

In addition to the closed-single-space model, a model which accounts for roof-venting is inserted into the model. For given values of the vent area and the depth of screens, extending downwards from the ceiling, the model predicts the depth and temperature of the smoke layer.

COMPARISON WITH EXPERIMENTAL FIRES

In the following is shown the agreement between calculated results and the measured data from two experimental series with roof-venting.

In the first series, experimental fires were conducted in a central test cell of an aircraft hangar (7). The floor area of the test cell was 20x21 meters and the height approximately 15 meters. Trays of aviation kerosene were burnt with the areas of 1.8, 7.3 and 16,4 m². The duration of the steady-state burning was 3-4 minutes and the linear burning rate was approximately 4 mm/min. The effective discharge area of the vents was 1.125 %, 4.5 % or 9 % of the floor area. The depth of the screens was 0, 1.5 or 3 meters.

Figures 2 and 3 display the results of the model in comparison with the measured data. In Figure 2 the computed levels of the smoke layer are displayed for the roof vent of the largest area (63 m²) and the screen depth of 3 meter. For the biggest fire (16.4 m²) the computed layer thickness was a few cm below the screens. The result agrees well with what is stated from the experimental observations: "In the experiments involving the greatest outlet venting and the 3-m draught curtains very little spillover of smoke into the roof beyond the test cell occurred". Figure 3 shows the average values of the measured temperature rise of the hot gases below the roof in the test cell as a function of fire size and the distance below the roof – and for all combinations of the test variables in the experimental series. The computed values – based on an upper homogeneous and isothermal zone – are in good agreement with the measured data. The distribution of the filled points in the figure refers to different test conditions.

In the second series, experimental fires were conducted in an industrial building (8). The floor area of the building was 1000 m² and the height 9.5 meter. Various numbers of wood cribs were burnt and various areas of fire ventilation were available. In Figure 4 the computed height of the smoke layer from one experiment is compared with the one observed. The agreement is fairly good.

3. THE DESIGN FIRE

The design fire can either be described by the horizontal fire area or the heat output as a function of time. The scenario can be chosen in at least
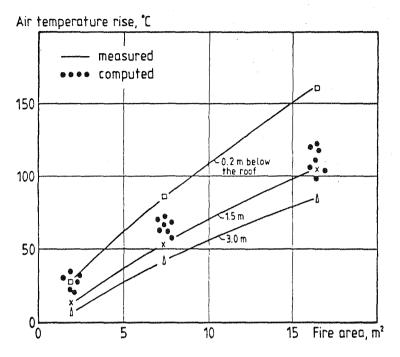
Air temperature rise, °C

Figure 3. Measured and computed values of the temperatures near the ceiling for kerosene fires of area 1.8, 7.3 and 16.4 m^2.
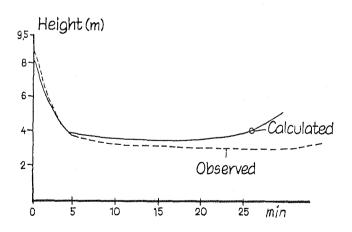

Figure 4. Measured and computed values of the smoke layer for a wood crib fire in an industrial building

four different ways:

a) Known fire area

b) Experiences from fire tests

c) Experiences from real fires using sprinkler statistics

d) Experiences from real fires using statistical information
   on fire area

3.1 Known fire area

Very seldom the fire area is exactly known. An exception may be, however,
if the expected fire will be in an oil tray or a similar object, or in a
container for refuse. Experiences from fires with only one burning item
can also be used, which may be the case in a bus garage, for example, where
you know depending on how the fire is expected to start and on the material
inside the bus - when the bus windows are breaking and the whole bus is bur-
ning. You also have a good knowledge of how long it will take before the
next bus catches fire.

3.2 Experiences from fire tests

Hägglund has used information from tests at the Factory Mutual laboratories
to predict the fire growth as a function of time (2). The fire growth was
assumed to be an exponential function of time obtained in a series of full-
scale tests (9). Doubling times between 1 and 5 minutes were reported which
can be representative of stored goods under similar conditions like for in-
stance in the tests. Bengtson and Hägglund have in (3) used data on burning
furniture items to predict the times for smoke-filling and temperatures in
single enclosures like patient rooms, assembly halls and atrium buildings.

3.3 Experiences from real fires using sprinkler statistics

This method has been used by Bengtson in (1) and in the preliminary work
for the Swedish Fire Ventilation Design Guide (10). The fire area in these
works has been related to the hazard groups as defined in the sprinkler
regulation. This has been done by using information from fires where sprink-
lers have operated. In (10) the fire area at operation time was assumed to
be the same as the sprinkler area in the hazard group. It is evident, how-
ever, that it is a mistake to give the same value of the fire area as the
sprinkler area at operation time for sprinklers. Bengtson therefore made
some modifications of the fire growth rates as presented in (1). As there
were some rough assumptions which had to be made a cooperation between the
Swedish Fire Protection Association and the Fire Research Station was ini-
tiated to develop better fire growth models. This work is presented below.

3.4 Experiences from real fires using statistical information on fire area

In United Kingdom information is collected from almost any fire to which
the fire brigade is called. The information can be analyzed in different
ways. The area damaged after ignition is reported, for example, and also
the time period between an estimated fire-start and the control of the
fire. The number of jets is also reported. All information is categorized
depending on the activity in the building. For the various groups the in-
formation can be related to where the fire started: production areas,
storage areas and "other" areas. The statistical information, which is
gathered and administered by the Fire Research Station, has been used for
various applications (4-5).

4. ENGINEERING APPLICATIONS

Computer-based analyzis by the model in the solution of two fire protec-
tion engineering problems is demonstrated below. The consequences of a fire
in a bus garage and in a textile factory are discussed.

4.1 Bus fire in a garage

In the garages for the transportation companies there are many buses parked
during the night, which means that a fire can produce extensive communica-
tion problems for the passengers the day after a fire. The question has
therefore been raised how to protect the buses against fire. For this engi-
neering work the simulation model presented in this paper has been used.

In Figure 5 the calculated smoke-filling times are presented for a garage
with floor area of 4000 m² and of a height of 5 meters. Also the tempera-
tures of the smoke layer are displayed in the figure. The calculations are
based on two heat output scenarios, 20 and 40 MW. 20 MW corresponds to one
bus burning and 40 MW to two buses burning. The time given in the figure is
the time after flash-over of the bus. Flash-over of the bus is assumed to
occur 10 minutes after the fire start. At that stage the bus windows collap-
se and smoke and hot gases flow out into the garage. That means that the
heat output is zero until 10 minutes after the fire starts and then grows
to 20 MW. The fire area is constant until the next bus, which is parked
close to the first one, is ignited, which will take only 2-3 minutes.

As can be noticed from the figure the garage – with one bus burning – can
be smoke-filled down to the level of 3 meter about 15 minutes after the
fire starts. The temperatur of the smoke layer at that time is
about 150 °C.

The consequences of the fire.

If sprinkler is installed, the first bus will be totally damaged, the neigh-
bouring buses probably only damaged by heat and perhaps 10-20 buses only
damaged by smoke.

If there is no sprinkler system installed or if it is out of work the fire
brigade must check the fire. To give them any chance at all a fire detec-
tion system must be installed.

If the attendance time is 10 minutes this means that the fire brigade can
start fighting the fire about 21 minutes after the fire start. Flash-over
in the garage has not yet occurred but the smoke is down to 1.5-2 m from
the floor and at least 2 buses are burning. This means that the fire is
extremely difficult to fight, especially as there are only 0,5 meters bet-
ween the buses, which makes it impossible to send in any fire men. A total
damage is a probable result. If a fire ventilation system correctly desig-
ned, is provided together with a fire detection system fire fighting may
be possible and the result will be that only 2 buses are damaged.

4.2 Fire in a textile factory

Data on fire areas from textile factories were used as input in the fire
simulation model. As the statistics give you the area damaged after the
fire is extinguished, but the equation for fire growth describes the fire
size at a specific time, you probably get some exaggeration of the threat.
It is not certain that the whole area is burning at the same time. In futu-
re works this problem must be analyzed. The rate of fire growth presented
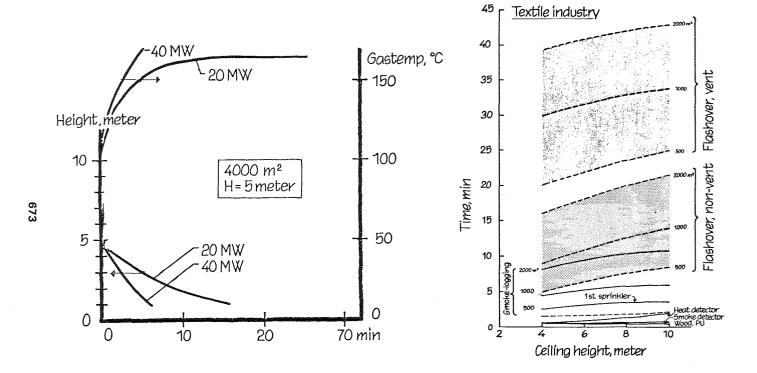in (4) was used, defined by eq 1

Figure 5. Computed values of the smoke layer and temperature for a bus fire in a garage

Figure 6. Flashover time, smoke filling and detection events in a textile industry

$$A = 4.7 \cdot e^{0.063 \cdot t} \qquad\qquad (1)$$

where A denotes the area damaged in t minutes. The calculated result is presented in Figure 6 for single enclosures of various sizes and ventilation conditions. The floor area ranges from 500 to 2000 m^2 and the ceiling height from 4 to 10 meters. Two ventilation conditions are considered, NON-VENT and VENT. Under the ventilation condition NON-VENT the enclosure is assumed to be closed except for openings close to the floor. Under the ventilation condition VENT vents are assumed to be opened in the roof.

The critical events when smoke-logging and flash-over occur in the single enlosures are denoted by SMOK-LOGGING and FLASH-OVER in the figure. Flash-over is assumed to occur when the computed gas temperature for the entire volume reaches 300 $^{\circ}$C as an average. The detection events are denoted by SPRINKLER, HEAT DETECTOR and SMOKE DETECTOR – representing the time when the first sprinkler, heat and smoke detector will operate. The sprinkler-head is assumed to be located 2.5 meters from the plume axis of the fire and the heat and smoke detector 4 and 7 meters, respectively, from the axis. The criteria of the events are based on works by Alpert [11] and by Heskestad and Delichatsios [12].

The number of hose reel-jets reported to Fire Research Station which must be used to fight the fire may be related to the fire area, eq 2

$$nojet = 4 \cdot lnA_F + 2.71 \qquad\qquad (2)$$

When giving this correlation it is expected that 5 hose-reel-jets correspond to 1 main-jet. The equation is valid for production areas.

Comments on the computed results will be given at the presentation of this paper.

5. FUTURE WORK

In the future the theories presented in this paper have to be verified in various ways. The rates of fire growth for various industrial groups should be determined to be used as input in analytical models. The rate of fire growth at the beginning of the fire should be studied in more detail as it has a great influence especially on the detection times for heat and smoke detectors. The computed results and predictions should be compared with real fires as regards, for example, detection events and observed times to flash-over.

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