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Invited Paper

SPRINKLER ACTIVATION SUBMODEL FOR A ZONE-MODEL COMPUTER PROGRAM

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SYNOPSIS

Ceiling jet smoke is considered on the previously developed fire plume model, and the resulting formulae are applied to computation of sprinkler activation time. As the plume model is central to zone modelling software, sprinkler activation time calculations are also included into a zone modelling program, JET. Cooling of the hot layer by an activated sprinkler has been taken into account. The predictions of the program JET have been found to be close to experimental data relating to sprinkler activation and ceiling jet temperature and velocities.

Key words

Sprinkler, Ceiling jet, Computer software, Zone model.

INTRODUCTION

The impact of sprinklers on smoke development can be quite significant[1,2]. The computer programs which compute the sprinkler response time, DETACT[3], LAVENT[4] and FPETOOL[5], have along been readily available to fire engineers. Recently developed models LAVENTS[6,7] and RADISM[8] consider sprinkler action within the frames zone models which are based on Heskestad's plume model[9]. Tow more computer programms have also become known: TDISX by Factory Mutual Research Corporation (FMRC)[10] and SPRINK 1.0 by Sleights[11] which has been created for solder link sprinklers and warehouse fires. TDISX has not been made available to the public, and only some results of computation can be found in publications. On the other hand, SPRINK 1.0 is available, and all the relevant issues have been disclosed in reference[11].

In the programs[3-5] temperature rise of a sprinkler sensor is calculated upon the theory by Heskestad and Smith[12] and Evans and Stroup[13].

$$\frac{dT_s}{dt} = \frac{(T_j - T_s)\sqrt{V_j}}{RTI} \qquad (1)$$

However following later work by Heskestad and Bill[14], and also by Ingason[15] this equation has been modified, to account for heat conduction into the supporting structure:

$$\frac{dT_s}{dt} = \frac{\sqrt{V_j}}{RTI}\left[(T_j - T_0) - \left(1 + \frac{C}{\sqrt{V_j}}\right)(T_s - T_0)\right] \tag{2}$$

Following this progress, modern sprinklers are now subjected to plunge tests where the results are interpreted by formula (2), and the customer is normally given two parameters: Response Time Index RTI and conduction factor C. Unfortunately, a fire engineer does not yet have an adequate computing tool to predict the time of sprinkler activation using equation (2). TDISX is not available to the public, and SPRINK 1.0 requires knowledge of many parameters of the link which may be not available, and it does not cover glass bulb sprinklers. Therefore, many practical engineers are still using the programs based on formula (1), while sprinkler tests are presently based upon formula (2). As Heskestad and Bill have shown, the difference in RTI obtained by these two methods can be significant (see Table 3 of reference[14]).

Most of the above mentioned programs aim only at finding sprinkler activation time. The normal practice in using zone models now is to consider a fire with its heat output developing as square of time ("t-square fire") and cap the heat output at the time of sprinkler activation, assuming that heat output would stabilise, without any other change. This is not enough. According to Mawhinney and Tamura, sprinkler activation can cause a 50% decrease in heat output[1]. It also causes two important effects: decrease in hot layer temperature by the sprinkled water and downdrag of the smoke to the level below the hot layer interface (see Heskestad[15]). LAVENTS[6,7] covers a range of phenomena associated with sprinkler activation, including downdrag.

The aim of this study has been to create an engineering tool within the frames of the zone model by Shestopal and Grubits[17] describing sprinkler activation with the help of equation (2), and an attempt is made to predict the depth and temperature of the hot layer as a result of sprinkler activation taking into account cooling of the hot layer. The downdrag of the hot layer has not been considered.

SPRINKLER ACTIVATION TIME

Theoretical analysis

The plume model developed by Shestopal and Grubits[17] has been used as a basis for calculations. This model computes temperature and axial velocities fields for an axisymmetric uninhibited fire plume. A Gaussian distribution of temperatures and velocities was assumed by these authors with equal half-widths of the distributions given by:

$$V_z = V_{zc}\exp(-r^2/R^2) \quad \text{and} \quad T_p - T_0 = (T_{pc} - T_0)\exp(-r^2/R^2) \tag{3}$$

This allows us to compute mass flow M, heat flow Q and flow of kinetic energy K in the plume at ceiling level:

$$M = \int_0^\infty 2\pi r V_z \rho\, dr = \pi R^2 V_{zc} \rho_0 \Psi \tag{4}$$

$$Q = \int_0^\infty 2\pi r V_z \rho c_p \left(T_p - T_0\right) dr = \pi R^2 V_{zc} \rho_0 T_0 (1 - \Psi) \tag{5}$$

$$K = \int_0^\infty 2\pi r V_z \rho \frac{V_z^2}{2} dr = \frac{1}{2} \pi R^2 V_{zc}^3 \rho_0 \frac{1}{\psi^2} \left(\frac{\psi - 2}{2} + \Psi \right) \tag{6}$$

where

$$\psi = \left(T_{pc} - T_0\right) / T_0 \qquad \text{and} \qquad \Psi = \ln(1 + \psi) / \psi \tag{7}$$

More detailed calculations of these values can be found in the publication[17].

Within the framework of a zone model which considers a uniform hot smoke layer, the ceiling jet is approximated by an axisymmetric layer of variable thickness but uniform temperature and velocity distribution. Then the average temperature of the ceiling jet close to the plume can be estimated as

$$T_j = T_0 + \frac{Q}{M c_p} \tag{8}$$

We neglect the losses of the kinetic energy when the gas flow turns from the upward direction to the horizontal direction at the ceiling. This allows us to estimate smoke velocity in the ceiling jet in close proximity to the plume:

$$V_j = \sqrt{\frac{2K}{M}} \tag{9}$$

At a distance from the plume, this value is corrected for the entrainment of the external air. As it is usually done for the plumes, the entrainment is assumed to be proportional to V_j:

$$\frac{dM}{dr} = C \rho_0 V_j \sqrt{\frac{T_0}{T_j}} 2\pi r \tag{10}$$

Here we encounter the same difficulty as with the plume: the entrainment coefficient C is unknown. We overcome this difficulty by assuming a value for C which results in the calculated values being in the best possible correspondence with experimental observations[18,19] by Madrzykowski. Good agreement with the experimental data[19] has been achieved by assuming C = 0.15. However, with a constant C, activation times for one set of data, namely for a smaller fire at a large distance from the sprinkler, were underestimated. This might happen, if at larger distances the ceiling jet dissipates in the hot layer. Such a dissipation can be described as an increased entrainment from the hot layer into the jet. Hence, some dependence of the coefficient C on the ratio was assumed. Namely,

$$C = 0.15* \begin{cases} 1 & W < W_o \\ .1 + 0.07* (W-W_o)^2 & W > W_o \end{cases} \tag{11}$$

$W = Q/r^{1.5}$ where W_o equals 12.0, if Q is in MW and r is in meters.

As a result, we arrive at a ceiling jet of the thickness increasing with the radius, whereas velocity and temperature decrease with the radius. Then the thickness is:

$$a = \frac{M}{2\pi r \rho V_j} \tag{12}$$

If the calculated thickness of the ceiling jet is less than the thickness of the hot layer, equation (10) has to be modified: the right-hand side of this equation should be multiplied by $\sqrt{T_{hl} / T_0}$.

The velocity of the ceiling jet will decrease with the radius. Of all the mechanisms of this decrease (entrainment, friction at the ceiling, kinetic energy dissipation, heat loss) let us consider entrainment as a leading mechanism. However, we cannot assume that the entrained air initially had no radial velocity at all. Such an assumption results in velocities which are too low when compared with the experimental data[19]. This can be explained by the general turbulent rotational movement of the air in the compartment, due to the fire plume itself. A good agreement with the experimental data can be achieved if we assume an incomplete impact of the entrained air according to the equation

$$\frac{1}{V_j}\frac{dV_j}{dr} = -0.5\frac{dM}{dr}\frac{1}{M} \tag{13}$$

The temperature in the location of the sprinkler is calculated using equation (8).

The rate of the temperature rise of the sprinkler sensor is calculated on the basis of the theory by Heskestad and Bill[14] (equation 2). This approach can also handle the situations where sprinkler data has been obtained in a plunge test without account of heat conduction, because assuming C = 0, we arrive at equation (1).

COMPARISON WITH EXPERIMENTAL DATA

The developed computer program JET has been run for the 24 scenarios tested by Madrzykowski[18,19]. A comparison of the results with the experimental data is presented in Table 1. The program was run with the assumption that the heat output of the fire does not vary with time. The temperature increase and velocity of the ceiling jet was computed at the location of the sprinkler. Both the experimental and the computed results show that ceiling jet temperature increases with time even for a constant heat release rate. In the model this result is due to interaction of the smoke plume with the hot layer growing in thickness and temperature. The experimental and computed temperature in Table 1 were compared at times which are 0.75 of the maximum times in the diagrams of Madrzykowski[19]. Computed ceiling jet velocities do not vary significantly with time. Nor do the experimental results. The comparison of the tested and predicted velocities was made for the same times as the temperatures.

The data listed in Table 1 show that the largest deviations of the computed results from the experiment are for 115 kW heat output fires. The reason for this is that the studies[18,19] have been done with the sprinklers tested on the basis of equation (1). This equation does not describe well enough the situations of relatively small heat output, when activation time is long and heat conductance is significant. If this set of data for sprinkler activation time is ignored, theoretical prediction of the experimental results looks significantly better (see the last row of Table 1). Table 1 shows that prediction of temperatures and velocities is good enough even for 115 kW fires.

Program JET has produced results much closer to the experimental data than program DETACT recommended as preferable by Madrzykowski. Complete numerical comparison is not possible, because in many cases DETACT predicts no activation at all. Table 2 compares JET with LAVENT and FPETOOL. It can be seen that the predictions of JET are in the best agreement, LAVENT tends to underestimate activation times, and FPETOOL results, as well as ours, are conservative.

The results of the program JET have also been compared with the experimental data on ceiling jet temperature obtained by H-Z. Yu and others at Factory Mutual Research Corporation[10]. The original reports of FMRC have not been made available to us, and we used the data cited by Sleights[11]. The results of this comparison are presented in Figure 1. Experimental ceiling jet temperature data for a 5-tier warehouse fire are plotted together with computed results for SPRINK1 and TDISX taken from[11] and results obtained by our program JET. The figure shows that JET produces results closer to the experimental data than SPRINK 1, and TDISX and JET are comparable: TDISX is closer to the tests in the time range 40 to 67 S, and JET is better in the range 70 to 80 s. Besides, JET tends to underestimate the temperature, which on at the conservative side.

The results of Table 2 and Figure 1 do not fully reflect the advantages of JET. DETACT, FPETOOL and SPRINK 1 ignore the configuration of the room, computing activation times for an infinite ceiling, whereas JET takes into account room dimensions explicitly, given that height and area of the room and sizes of openings are entries to the program. Consequently the computed results depend on room configuration. This is in agreement with the results obtained by Gupta[20]. he tested sprinklers in an enclosure 1.22 x 1.22 x 1.22 m^3 and varied the height of the wall opening. The diameter of his burner was 0.6 m, quite large compared with the size of the enclosure, and the flame was circular.

Therefore, program JET cannot be expected to produce numerical result close to the tests, because it is based on a plume model with unconstrained entrainment where flaming part of the plume was assumed to have uniform temperature. Also JET calculates internally the area of fire bed, proportionally to the heat release rate, which is applicable to pool fires, but does not correspond to the conditions of the test[20]. However, qualitative results relating to dependence of sprinkler activation time on the size of a door opening can be compared with JET calculations. Such a comparison is presented in Table 3. Calculations by JET calculations. Such a comparison is presented in Tale 3. Calculations by JET have been conducted for a compartment of the same size and for the same heat release rates as in[20] for a burner in the centre of the floor. The sprinkler 68°C and RTI 240 $(\mathrm{m.s})^{1/2}$ was supposed to be immediately above the plume. The comparison of the test results[20] and calculations by JET are presented in Table 3. The dependence of the results on door size in tests and calculations is similar.

COOLING OF A HOT LAYER

Calculations of interaction of a sprinkler spray with a hot layer in JET is based on the theoretical work by Heskestad[16].

With nozzle diameter D and water flow F_w (being program entries), diameter of a droplet d is computed as

$$d = 0.084\left(\frac{D}{u_n}\right)^{2/3} \qquad \text{where} \qquad u_n = \frac{F_w}{\pi D^2/4} \tag{14}$$

Here and below all dimensions are in metric units. Following a numerical example considered in[16], we asssume droplet velocity $u_p = 0.4\ u_n$ and gas velocity within spray 0.4 u_p. Then equation (29) of[16] for the heat transfer coefficient h reads as

$$h = \frac{5.16\cdot 10^{-5} + 1.092\cdot 10^{-3}\left(\frac{T_0}{T_{hl}}\right)^{0.5}\left(\frac{T_0}{T_{hl}+245}\right)^{0.4} u_n d^{0.5}}{\left[1+1.16\cdot 10^{-4}(T_{hl}-273)^{1.19}\right]\left(\frac{T_0}{T_{hl}}\right)^{0.85} d} \tag{15}$$

Assuming that the length of the droplet trajectory in the hot layer is twice the hot layer thickness, the heat absorbed by the water spray of one sprinkler per second will be:

$$H = \frac{30 F_w \delta_{hl}(T_{hl} - T_0)h}{d u_n} \tag{16}$$

These calculations should be considered as a way to produce a first approximation of the cooling effect of a sprinkler spray, because the numerical assumptions for some configurations might not be accurate enough. A more rigorous approach can be found in the latest works by Cooper[6,7].

According to Mawhinney and Tamura[1] sprinklers reduce the heat output of a fire by a half. In JET this effect can be independently taken into account.

COMPUTER IMPLEMENTATION

Sprinkler activation is just one feature of program JET. In essence, program JET is a computer implementation of the zone model described in[17] with an addition for computing sprinkler activation. Program JET combines all major features of one-room zone model programs described in this work. It allows to model a compartment with two wall openings, a roof vent and mechanical ventilation. The entries of the program are listed in the Appendix. JET is a 32-bit Windows program and is written in C computer language. It is not an independent product, but is one of 18 programs of FIREWIND collection.

Figure 2 shows the introductory screen of program JET with the entries relating to the sprinklers. The distance between sprinklers is referred to as "spacing". The program assumes that one sprinkler can skip, and the maximum distance from a fire source to a sprinkler which becomes activated equals to this spacing. If more sprinklers are activated, the program does not take them into account. The results of the computation are presented in graphical (see Figure 3) and tabular form. They can be printed or saved on a clipboard or in a metafile for subsequent use in other Windows applications, such as a word processor.

The practice of using program JET in engineering projects has shown that JET especially good for relatively small compartments, being sensitive to room size, ventilation etc., because the hot layer is sensitive to these parameters. For large compartments, like big and high warehouses, JET tends to overestimate sprinkler activation time. The reason for this is that the model does not take into account non-uniform temperature and velocity distribution in the ceiling jet. Therefore, FIREWIND has two programs to compute sprinkler activation time: JET and SPRINKLER is a Windows implementation of program DETACT written for unconfined ceilings and can be recommended for large compartments. Hence, these two programs are complementary.

CONCLUSIONS

The computer program JET permits the computation of the hot layer development taking account of sprinkler activation and resulting cooling of the hot layer. Sprinkler activation time computed by this program is in good agreement with the available experimental data.

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NOTATIONS

a : Thickness of ceiling jet
C : Dimensionless entrainment coefficient
c_p : Heat capacity of smoke J/Kg.K
d : Diameter of a water droplet, m
F_w : Water flow per one sprinkler, m^3/s
K : Flow of kinetic energy of the axial flow in the plume, W
M : Mass flow in the plume, kg/s
P_j : Flow of potential energy of ceiling jet per unit width, W/m
Q : Heat flow in the plume, W
q : Heat loss per unit of ceiling area W/m^2
r : Distance from the axis of the plume, m
R : Half-width of Gaussian distribution, m
RTI : Response Time Index of sprinkler, $(m.s.)^{1/2}$
t : time, s
T_{hl} : Temperature of the hot layer, K
T_j : Temperature of ceiling jet, K
T_o : Ambient temperature, K
T_p : Temperature in the plume, K
T_{pc} : Centerline temperature in the plume, K
T_s : Temperature of the sprinkler sensor, K
V_j : Average velocity in the ceiling jet, m/s
V_z : Axial velocity in the plume, m/s
V_{zc} : Centerline velocity in the plum, m/s
δ_{hl} : Thickness of the hot layer, m
ρ : Smoke density, kg/m^3
ρ_o : Air density at ambient temperature, kg/m^3
Υ : Dimensionless temperature increase
Ψ : Dimensionless auxiliary variable defined in equation (7)

REFERENCES

1. Mawhinney, J.R., Tamura, G.T. Effect of automatic sprinkler protection on smoke control systems. ASHRAE Transactions, vol. 100, No. 1, 1994, 494-513.
2. Persson, B., Ingason, H., "Modelling of interaction between sprinklers and fire vents – present knowledge", Report 1996:32, Swedish National Testing and Research Institute, Fire Technology, Boras, Sweden, 1996.
3. Evans, D.D., Stroup, D.W., "Methods to calculate the response time of heat and smoke detectors installed below large unobstructed ceilings", Fire Technology, vol. 22, 1986, 54-65.
4. Davis, W.D., Cooper, L.Y., "Estimating the environment and the response of sprinkler links in compartment fires with draft curtains and fusible link-activated ceiling vents – Part II: user guide for the computer code LAVENT", NBSIR 89-4122, U.S. National Institute of Standards and Technology.
5. Nelson, H.E., "FPETOOL: Fire protection engineering tools for hazard estimation, NISTIR Report 4380, National Institute of Standards and Technology, August 1990.
6. Cooper, L.Y., "The interaction of an isolated sprinkler spray and a two-layer compartment fire environment. Phenomena and model simulations". *Fire Safety Journal,* vol. 25, 1995, 89-107.
7. Cooper, L.Y., "Interaction of an isolated sprinkler spray and a two-layer compartment fire environment", International Journal of Heat and Mass Transfer, vol. 38, 1995, 679-690.
8. Hinkley, P.L., "Sprinkler operation and the effect of venting: studies using a zone model", BRE Report CI/SfB 66 (68.54) (K23), 1992.
9. Heskestad, G., "Engineering relations for fire plumes", *Fire Safety Journal,* vol. 7, 1984, p. 25.
10. Yu, H-Z, "A sprinkler response prediction – computer program for warehouse applications", Technical Report FMRC J.I. OR2E.I.RA, Factory Mutual Research Corporation, Norwood, MA, 1992.
11. Sleights, J.E., "SPRINK 1.0 a sprinkler response computer program for warehouse storage fires", M.S. thesis, Worcester Polytechnic Institute, MA, USA, 1993.
12. Heskestad, G., Smith, H.F., "Plunge test for determination of sprinkler sensitivity", FMRC J.I., Factory Mutual Research Corporation, Norwood, Masschusettes, December 1980.
13. Evans, D.D., Stroup, D.W. "Methods to calculate the response time of heat and smoke detectors installed below large unobstructed ceilings", *Fire Technology,* vol. 22, No. 1, 1985, 54-65.

14. Heskestad, G., Bill, R.G. Jr., "Quantification of thermal responsiveness of automatic sprinklers including conduction effects", *Fire Safety Journal,* vol. 14, 1988, 113-125.
15. Ingason, H., "Thermal response models for glass bulb sprinklers", Swedish National Testing and Research Institute, Fire Technology, SP Report 1992:12.
16. Heskestad, G., "Sprinkler/hot layer interaction", NIST-GCR-91-590, Factory Mutual Research, Norwood, Mass., September 1990.
17. Shestopal, V.O., Grubits, S.J., "Computer program for an uninhibited smoke plume and associated computer software", *Fire Technology,* vol. 29, No. 3, 1993, 246-267.
18. Madrzykowski, D., "Evaluation of sprinkler activation prediction methods", ASIAFLAM '95, Proceedings. Inter Science Communications Limited, London 1995, p. 211-218.
19. Madrzykowski, D., "The effects of recessed sprinkler installation on sprinkler activation time and prediction", M.S. thesis, University of Maryland, College Park, MD, 1993.
20. Gupta, A.K. "Estimating sprinkler actuation time in compartments", ASIAFLAM '95, Proceedings. Inter Science Communications Limited, London 1995, p. 219-230.

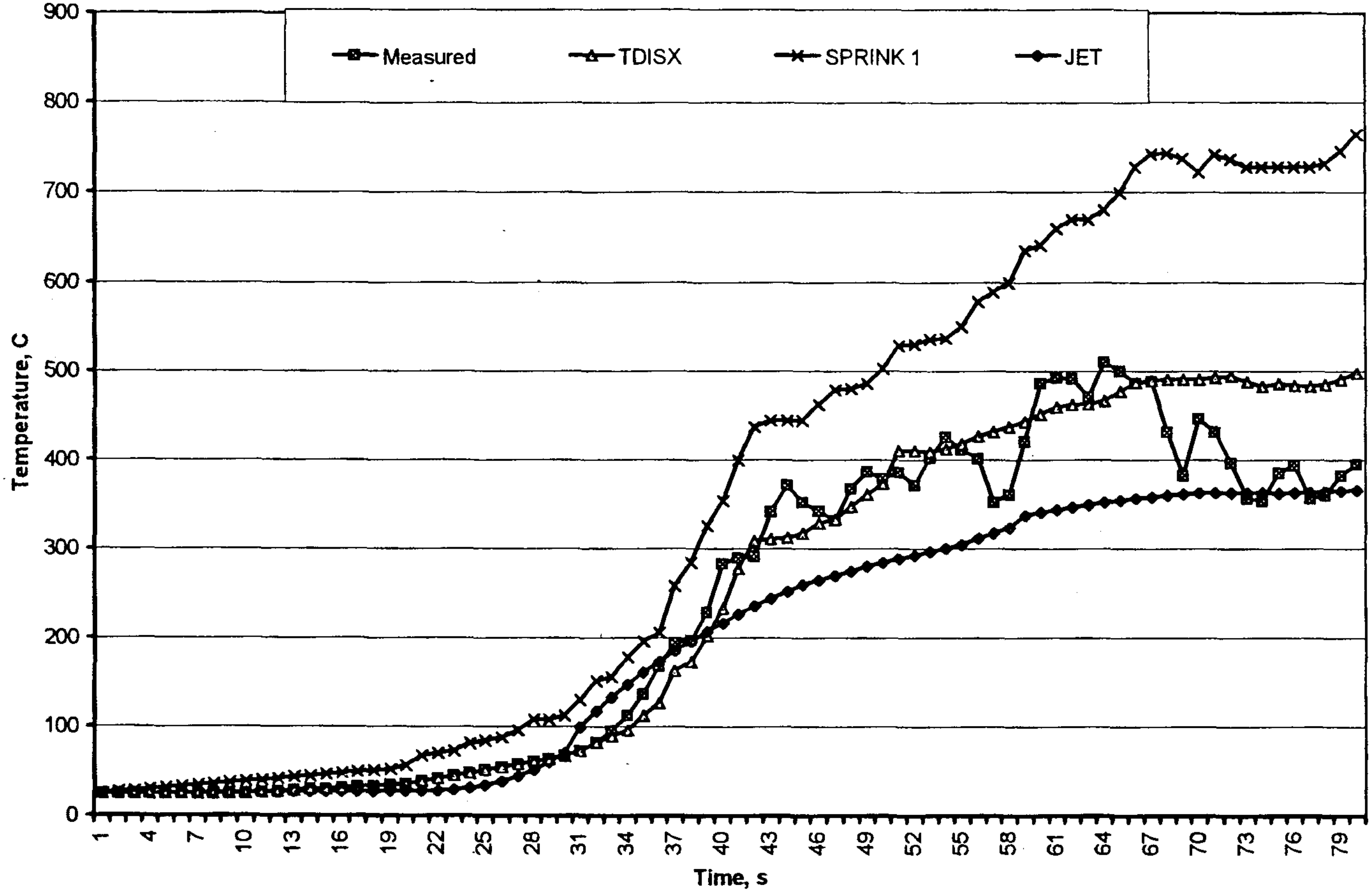
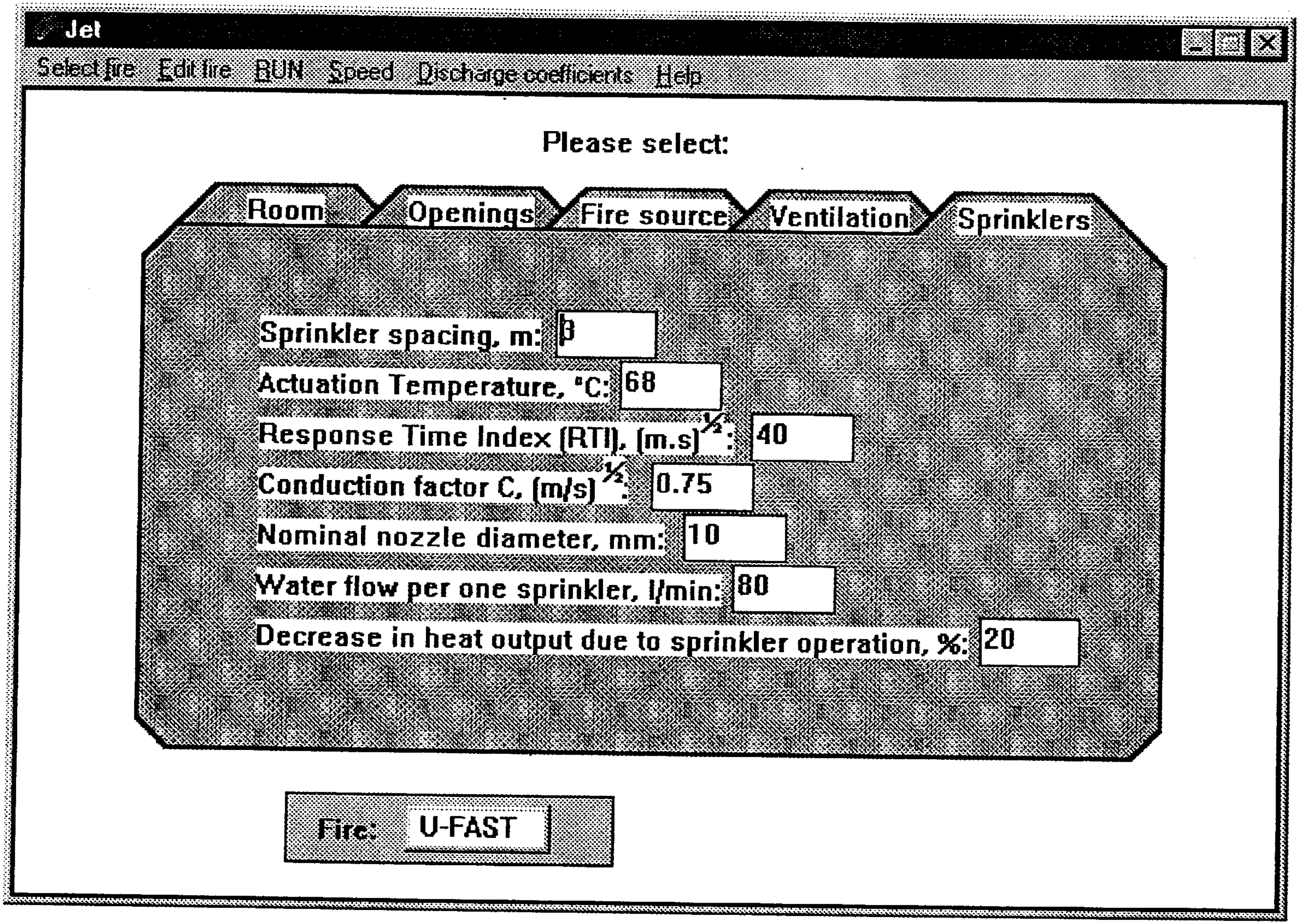


Figure 1. Computer simulation of FMRC 5-tier warehouse fire.
Ceiling jet temperatures, r = 2.16 m, 0.203 m from the ceiling.



Sprinkler spacing, m: 3

Actuation Temperature, °C: 68

Response Time Index (RTI), $(m.s)^{1/2}$: 40

Conduction factor C, $(m/s)^{1/2}$: 0.75

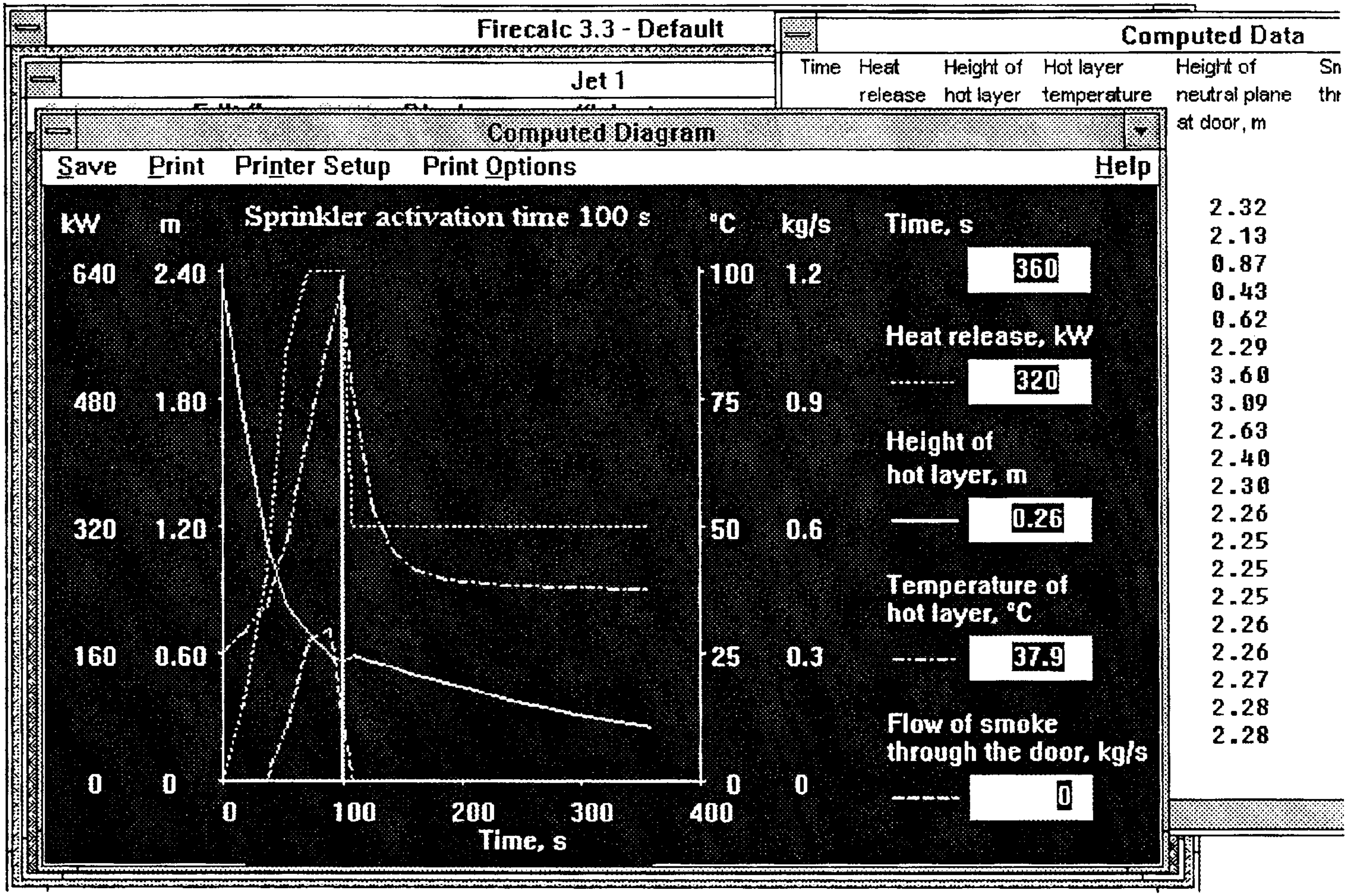
Nominal nozzle diameter, mm: 10

Water flow per one sprinkler, l/min: 80

Decrease in heat output due to sprinkler operation, %: 20

Fire: U-FAST

Fig. 2. Introductory screen of program JET with the entries relating to sprinklers.



Time, s 360

Heat release, kW 320

Height of hot layer, m 0.26

Temperature of hot layer, °C 37.9

Flow of smoke through the door, kg/s 0

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Time  Heat     Height of  Hot layer    Height of      Sn
      release  hot layer  temperature  neutral plane  thr
                                       at door, m

                                         2.32
                                         2.13
                                         0.87
                                         0.43
                                         0.62
                                         2.29
                                         3.60
                                         3.09
                                         2.63
                                         2.40
                                         2.30
                                         2.26
                                         2.25
                                         2.25
                                         2.25
                                         2.26
                                         2.26
                                         2.27
                                         2.28
                                         2.28
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Fig. 3. Computed results of program JET.

Table 1. Comparison of computed results with experimental data [18, 19].
RTI, $(m.s)^{1/2}$: QR bulb 42.1, QR link 34.1, SS bulb 234.8, SS link 129.8
Activation temperatures, °C: bulb 68, link 74.
Position of sprinklers: pendant at the ceiling.
Room size, m: 18.9 x 9.1 x 2.35.

Heat output, kW/ Distance, m	Temperature, °C		Velocity, m/s		Sprinkler type	Activation time, s	
	Tested	Computed	Tested	Computed		Tested	Computed
115 / 1.5	67	64	0.92	0.96	QR bulb	166 ± 4	86
					QR link	205 ± 95	92
					SS bulb	307 ± 53	247
					SS link	302 ± 67	225
155 / 1.5	76	83	1.2	1.19	QR bulb	46 ± 15	52
					QR link	71 ± 46	53
					SS bulb	155 ± 12	181
					SS link	148 ± 2	133
215 / 1.5	82	101	0.95	1.30	QR bulb	31 ± 3	38
					QR link	43 ± 15	38
					SS bulb	107 ± 17	131
					SS link	88 ± 13	94
290 / 1.5	107	123	1.7	1.45	QR bulb	27 ± 10	30
					QR link	32 ± 19	30
					SS bulb	91 ± 20	99
					SS link	81 ± 25	71
290 / 3.0	56	70	0.88	0.72	QR bulb	84 ± 18	88
					QR link	110 ± 10	89
					SS bulb	202 ± 27	220
					SS link	201 ± 22	165
520 / 3.0	169	147	1.5	1.59	QR bulb	23 ± 6	25
					QR link	28 ± 5	24
					SS bulb	80 ± 10	75
					SS link	72 ± 8	53
Standard error		15.0 °C		24.2%			21.0
Without 115 / 1.5							15.1

Table 2. Comprison deviation of predicted activation times from the experimental results [19]

Software	JET		LAVENT	FPETOOL
	all tests	115 kW excluded		
Relative mean deviation, %	–6.6	–1.3	–14.8	13.4
Standard error, %	21.0	15.1	31.4	36.1

Table 3. Dependence of sprinkler activation times on door height
Size of the enclosure, m: 1.22 x 1.22 x 1.22
Door width, m: 0.3
Sprinkler RTI 240 $(m.s)^{1/2}$, 68°C at the ceiling centre.

Heat Output, kW	Door height, m	Activation time, s	
		Tested [20]	Computed
8	0.9	343	149
	0.75	263	130
	0.6	185	115
12.5	0.9	153	98
	0.75	127	88
	0.6	116	81
16.36	0.9	106	78
	0.75	96	72

Appendix
Entries of program JET

Room:	Ceiling height Room area Properties of room lining material: Density Thermal conductivity Specific heat Average thickness of walls, roof and floor
Openings:	Height of door opening above the floor Door width and height Pressure behind the door Height of window ledge above the floor Window width and height Delay to opening (breakage) of the window
Fire:	Flame temperature Ambient temperature Optical density of smoke at the source Number of independent fire sources Height of fire source above the floor
Ventilation:	Effective area of ceiling ventilation Delay to opening of ceiling vents Capacity of mechanical ventilation Height of mechanical ventilation inlets Delay to ventilation start-up Pressure above the ceiling vents
Sprinklers:	Sprinkler spacing Actuation temperature Response time index Conduction factor Nominal nozzle diameter Water flow per one sprinkler Decrease of heat output due to sprinkler activation

Note: Heat release rate is entered as a table of up to 12 time dependent values. Heat release rate between these 12 entries is computed internally by linear interpolation.