FIRE AND SECURITY CONSULTING SERVICES
ABN 67 166 244 105

17 McKenna Court
NOOSAVILLE
QUEENSLAND, 4566
AUSTRALIA

Phone: +61 (0)7 5455 5148, Mobile: 0409 399 190, Email: rafoster@bigpond.net.au

PREDICTING THE RESPONSE TIME OF FIRE DETECTORS

Fire and Security Consulting Services is frequently asked about the response time of fire detectors.

Fire Engineering calculations often require that the response time of thermal (heat), and smoke detectors be determined to effect further calculations in respect to:-

1. Activation of occupant warning alarms;
2. Activation of Fire Brigade Alarms; and
3. Activation of smoke exhaust or ventilation systems.

Many computer fire modelling software programmes such as BranzFire and CFast incorporate subroutines that determine smoke detector and / or sprinkler activation with others such as FireCalc only providing calculations for sprinkler operation.

All these programmes are based on data determined by both testing and basic principles such as described below which can be used to determine activation times without recourse to the programmes.

Thermal Detectors

The response time of thermal detectors can be determined by using the suite of computer programmes from the National Bureau of Standards in the USA known generally as DETACT. Within that suite there are four programmes:

DET 12	Fixed Temperature Operation, Metric Units.
DET 13	Fixed Temperature Operation, Imperial Units.
DET 13C	Fixed Temperature Operation, Imperial Units, file input.
DETACT-T2	Fixed Temperature and Rate of Rise operation, metric or Imperial Units.

Within Australia, it is recommended that the programme DETACT-T2 be used where AS 1670 contemplates the use of combination fixed temperature and Rate of Rise detectors.

To properly determine the response time of a thermal detector the following data is required:

- Ambient temperature, usually 21^{o}C.
- Activation temperature, usually 57^{o}C, but may be 88^{o}C (see note 1below).
- Rate of Rise, usually 6^{o}C per minute (see note 1 below).
- Ceiling Height.
- Detector spacing, for AS 1670 systems, 7.2metres (see note 2 below).
- Fire growth rate.
- Detector Response Time Index. RTI.

Note 1 In Australia there are five standard types of thermal detector:-

1. Type A – Fixed temperature of 57^{o}C and 'rate of rise'.
2. Type B – Fixed temperature of 57^{o}C only.
3. Type C – Fixed temperature of 88^{o}C and 'rate of rise'.
4. Type D – Fixed temperature of 88^{o}C only'.
5. Type E – Fixed temperature of varying temperatures.

Note 2 In Australia, detector spacing is determined by Australian Standard AS1670.1 – Fire detection, warning, control and intercom systems – System design, installation and commissioning. Part 1: Fire. This standard contemplates installation at 7.2m centres as depicted in Figure 1 below.

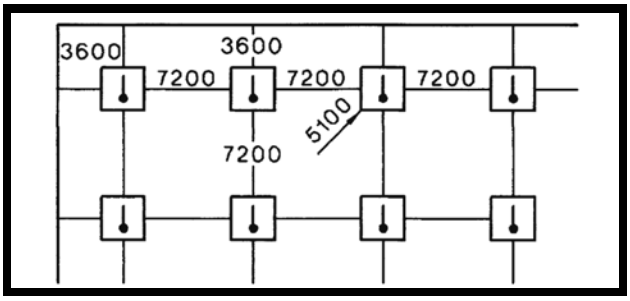


Figure 1 – AS1670 Thermal Detector Spacing

In Australia you will be hard pressed to find out the RTI of detectors from manufacturers so the following will be of assistance.

The SFPE Handbook of Fire Protection Engineering in Section 3, Chapter 1, page 3-9, table 3-1.4 reproduces the chart shown in Figure 2 from NFPA 72E. This chart provides the "time constants" for any detector dependant on the activation temperature and "listed" spacing. The text then goes on to show how the RTI can be determined using the formula shown where 'tau' is the time constant from the table and 'u' is the reference velocity as either 5ft/sec or 1.5m/sec. The resultant RTI will be either imperial or metric dependant on which number for 'u' is used as the 'tau' number from the table is dimensionless.

TABLE 3-1.4 ***Time Constants for Any Listed Detector (DET TC) (s)****

Listed Spacing (ft)	UL (°F)						FM All Temp.
	128°	135°	145°	160°	170°	196°	
10	400	330	262	195	160	97	195
15	250	190	156	110	89	45	110
20	165	135	105	70	52	17	70
25	124	100	78	48	32		48
30	95	80	61	36	22		36
40	71	57	41	18			
50	59	44	30				
70	36	24	9				

NOTE: These time constants are based on an analysis of the Underwriters Laboratories Inc. and Factory Mutual listing test procedures. Plunge test results performed on the detector to be used will give a more accurate time constant.

* At a reference velocity of 5 ft s. (1.5 m/sec)

(Reproduced from NFPA 72E-1984, Appendix C.[2])

$$\mathrm{RTI} = \tau_0 u_0^{1/2}$$

Figure 2 – NFPA 72E Chart

The next requirement is to obtain the listed spacing. Figure 3 shows an extract from the UL listing shows that for a Wormald Mk.1 combination detector (Type A); the time constant is 44 and the listed spacing is 50ft.

WORMALD U S INC, MARINETTE WI 54143 **S2575 (N)**

Model MK1, fixed-temperature, combination fixed temperature, rate-of-rise operation. Temperature ratings, 135, 194 F

Distance between thermostats on smooth ceilings and large bays shall not be in excess of 50 ft and distance of thermostat from any wall or partition shall not be more than 25 ft for the combination type.

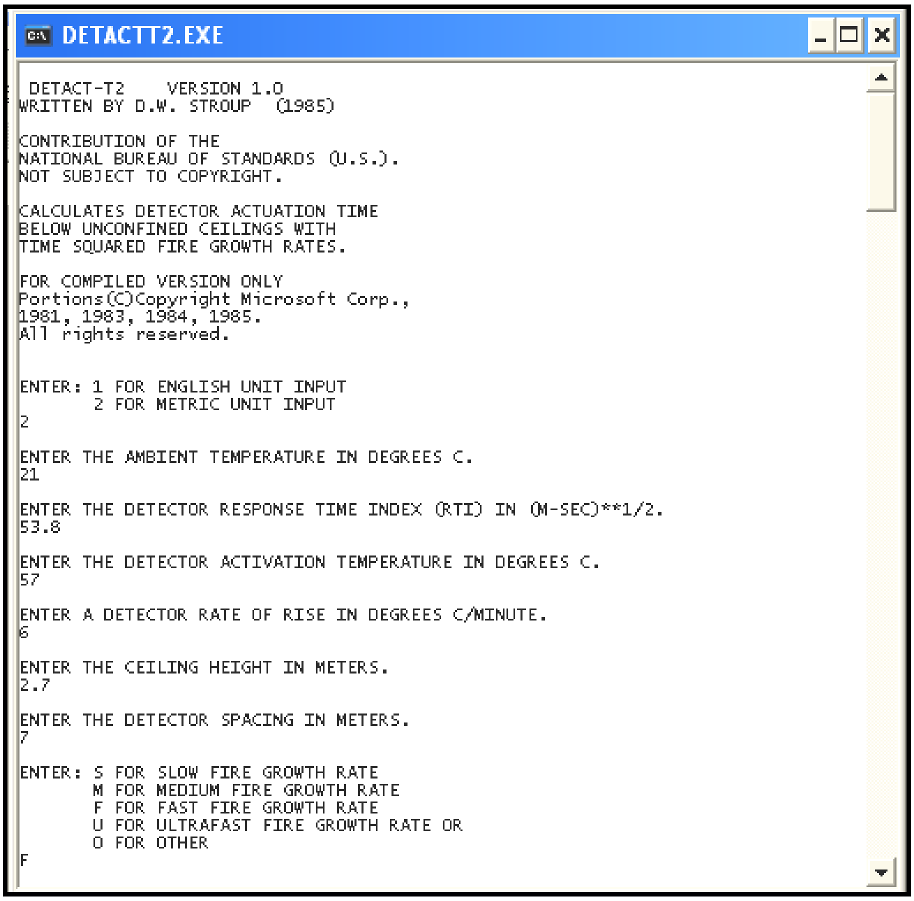
Distance between thermostats on smooth ceilings and large bays shall not be more than 15 ft and distance of thermostat from any wall or partition shall not be more than 7½ ft for the fixed temperature type.

Figure 3 – UL Listing of a typical detector (Wormald Mk. 1)

Therefore for this detector, RTI = 44 x $(1.5)^{0.5}$ = 53.8 metric.

With the above information at hand we can now use DETACT-T2 to determine the response time in any given situation.

Figure 4 shows the input of a particular scenario and Figure 5, the corresponding results.



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DETACTT2.EXE

 DETACT-T2    VERSION 1.0
WRITTEN BY D.W. STROUP  (1985)

CONTRIBUTION OF THE
NATIONAL BUREAU OF STANDARDS (U.S.).
NOT SUBJECT TO COPYRIGHT.

CALCULATES DETECTOR ACTUATION TIME
BELOW UNCONFINED CEILINGS WITH
TIME SQUARED FIRE GROWTH RATES.

FOR COMPILED VERSION ONLY
Portions(C)Copyright Microsoft Corp.,
1981, 1983, 1984, 1985.
All rights reserved.


ENTER: 1 FOR ENGLISH UNIT INPUT
       2 FOR METRIC UNIT INPUT
2

ENTER THE AMBIENT TEMPERATURE IN DEGREES C.
21

ENTER THE DETECTOR RESPONSE TIME INDEX (RTI) IN (M-SEC)**1/2.
53.8

ENTER THE DETECTOR ACTIVATION TEMPERATURE IN DEGREES C.
57

ENTER A DETECTOR RATE OF RISE IN DEGREES C/MINUTE.
6

ENTER THE CEILING HEIGHT IN METERS.
2.7

ENTER THE DETECTOR SPACING IN METERS.
7

ENTER: S FOR SLOW FIRE GROWTH RATE
       M FOR MEDIUM FIRE GROWTH RATE
       F FOR FAST FIRE GROWTH RATE
       U FOR ULTRAFAST FIRE GROWTH RATE OR
       O FOR OTHER
F
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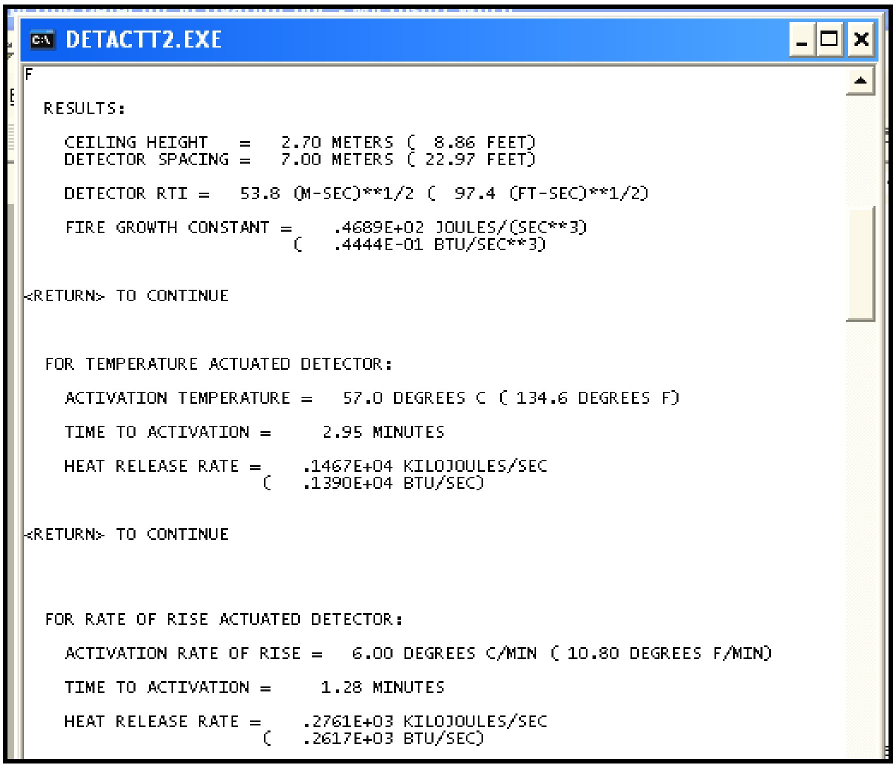
Figure 4 - DETACT-T2 Inputs



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DETACTT2.EXE
F

 RESULTS:

   CEILING HEIGHT   =    2.70 METERS (  8.86 FEET)
   DETECTOR SPACING =    7.00 METERS ( 22.97 FEET)

   DETECTOR RTI =    53.8 (M-SEC)**1/2 (  97.4 (FT-SEC)**1/2)

   FIRE GROWTH CONSTANT =     .4689E+02 JOULES/(SEC**3)
                         (    .4444E-01 BTU/SEC**3)

<RETURN> TO CONTINUE


 FOR TEMPERATURE ACTUATED DETECTOR:

   ACTIVATION TEMPERATURE =    57.0 DEGREES C ( 134.6 DEGREES F)

   TIME TO ACTIVATION =      2.95 MINUTES

   HEAT RELEASE RATE =     .1467E+04 KILOJOULES/SEC
                      (    .1390E+04 BTU/SEC)

<RETURN> TO CONTINUE


 FOR RATE OF RISE ACTUATED DETECTOR:

   ACTIVATION RATE OF RISE =    6.00 DEGREES C/MIN ( 10.80 DEGREES F/MIN)

   TIME TO ACTIVATION =      1.28 MINUTES

   HEAT RELEASE RATE =     .2761E+03 KILOJOULES/SEC
                      (    .2617E+03 BTU/SEC)
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Figure 5 - DETACT-T2 Results

Smoke Detectors

The response time of smoke detectors will depend entirely on three factors:

1. The type of detector, either ionisation or photo-optical.
2. The type of fuel involved.
3. The optical density of the smoke produced.

In the NIST programme HAZARD I, it is suggested that the response time of smoke detectors be calculated by the resident DETACT programme using an RTI of 1. This is probably valid for the purposes of the entire HAZARD I programme in residential occupancies, where other criteria such as Tenability is accounted for, but where we need to demonstrate in isolation the response time it is suggested the following. The NIST programmes FAST and CFAST are an evolution of HAZARD I and maintain the same system of determining smoke detector activation.

In the CSIRO suite of programmes entitled FIRECALC, the programme HotLayer is used to determine compartment conditions in a fire. Part of the output is the optical density of the smoke layer at the ceiling and these figures can be used to estimate the time for smoke detector activation.

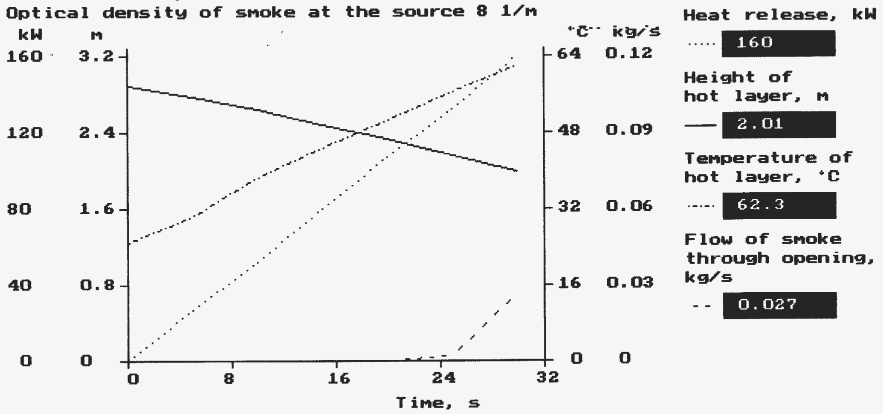
Figure 6 depicts a fire scenario in the fist 30 seconds of an ULTRA-FAST fire in a specified situation. You will see that at 10 seconds that the ceiling jet optical density is 0.06 1/m.

FIRECALC, v.2.3, update 24 January 1997
(C) CSIRO, div. BCE, North Ryde, N.S.W., Australia

Program HotLayer
Hot layer model: room with one opening and ceiling ventilation.
Fire in the middle of the room (unimpeded entrainment).

Ceiling height 2.9 m
Room area 60 m²
Width of opening 0.8 m
Height of opening 2.2 m
Height of opening above the floor 0 m
Height of fire source above the floor 0 m
Number of independent fire sources 1
Optical density of smoke at the source 8 1/m

Flame temperature 900 °C
Ambient temperature 25 °C
No ventilation.



Time s	Heat release kW	Height of hot layer m	Height of neutral plane m	Hot layer temperature oC	Flow of smoke through opening kg/s	Ceiling jet temperature oC	Ceiling jet optical density 1/m
0	0	2.9	2.9	25	0	25	0
5	27	2.79	2.79	30.7	0	40.9	0.38
10	53	2.65	2.65	38.6	0	49.2	0.59 ★
15	80	2.5	2.5	44.9	0	57.2	0.79
20	107	2.34	2.34	50.8	0	65.2	0.99
25	133	2.17	2.14	56.5	0.002	73.2	1.19
30	160	2.01	1.97	62.3	0.027	81.7	1.4

Figure 6 – HotLayer Results

Figure 7 below, is a comparison of optical density and obscuration based on data from Drysdale – An Introduction to Fire Dynamics, and data from the SSL test requirements for smoke detectors, AS1603.2, which requires tested smoke detectors to activate when the smoke outside the detector is between 3 and 12% per metre.

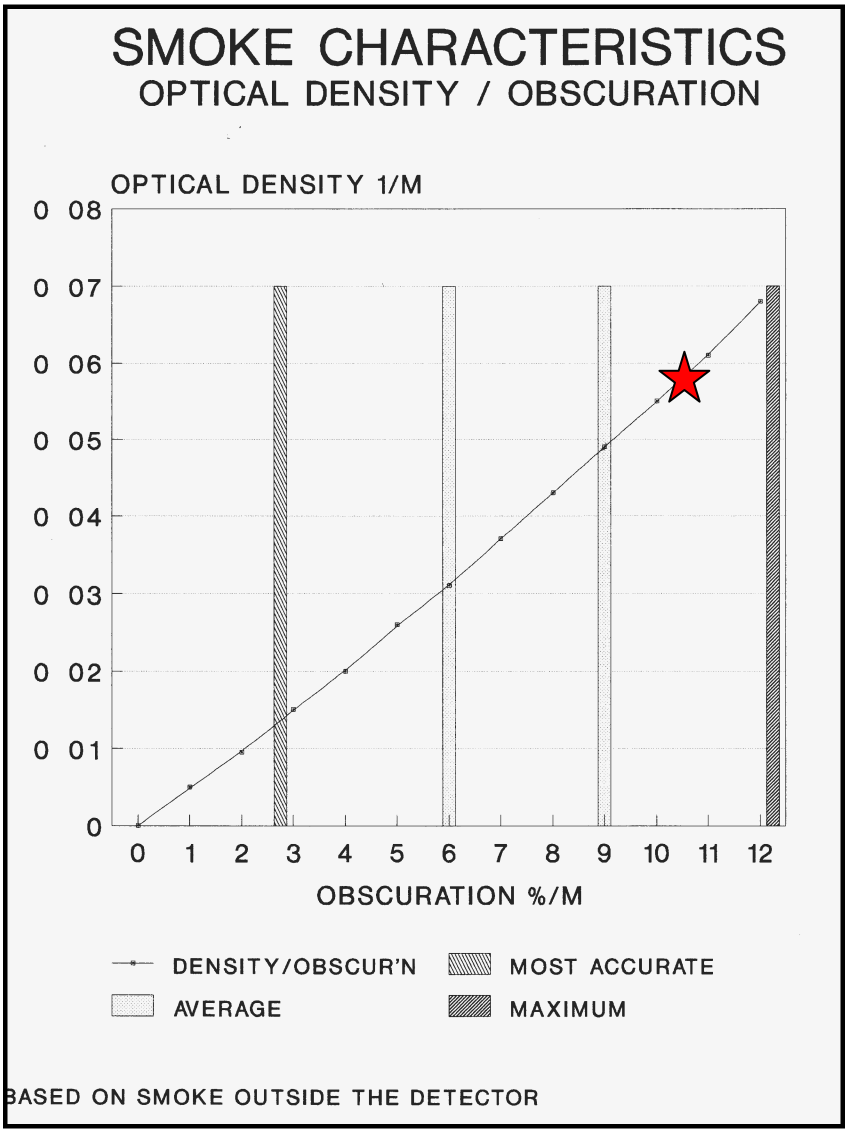


Figure 7 – Optical Density / Obscuration

The optical density of 0.06 equates to an obscuration of 10.5% which is above the average value allowable in the AS 1603.2/SSL tests for operation of the detector.

Acordingly the predicted response time in this scenario is 10 seconds. In practice and using an analogue addressible detection system where detector polling time needs to be included, the alarm response time is likely to be between 30 and 60 seconds.

I trust that this paper provides information that you will find helpful.

Prepared by:

Richard A Foster Dip Mech Eng; Dip Mar Eng; MSFPE; Member IE (Aust) SFS

Fire Safety Engineer

QFRS Accredited Fire safety Advisor

Principal – Fire and Security Consulting Services