MODELLING SMOKE SPREAD THROUGH BARRIER SYSTEMS.

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ABSTRACT

Smoke is the major cause of fatalities in building fires and yet many Building Codes and Regulations focus on the fire resistance of barriers with little emphasis on smoke resistance or to the performance of prescribed smoke resisting systems. This paper will describe a method for modelling smoke spread through barriers and include a simple example of modelling smoke spread through an apartment door to a public corridor with and without smoke seals. The results of the analysis will be compared with experimental data.

INTRODUCTION

A number of studies undertaken in the US have estimated that of the order of 75% of fire fatalities are caused by smoke inhalation or a combination of smoke inhalation and burns (Gann R G et al[i]). Published UK statistics for 2004[ii] provide the following breakdown of the causes of fire fatalities which indicates 68% of fire fatalities were caused by smoke inhalation or a combination of smoke inhalation and burns.

US Statistics reported by Brennan P[iii] also indicated that approximately 30% of fatalities occur during escape attempts

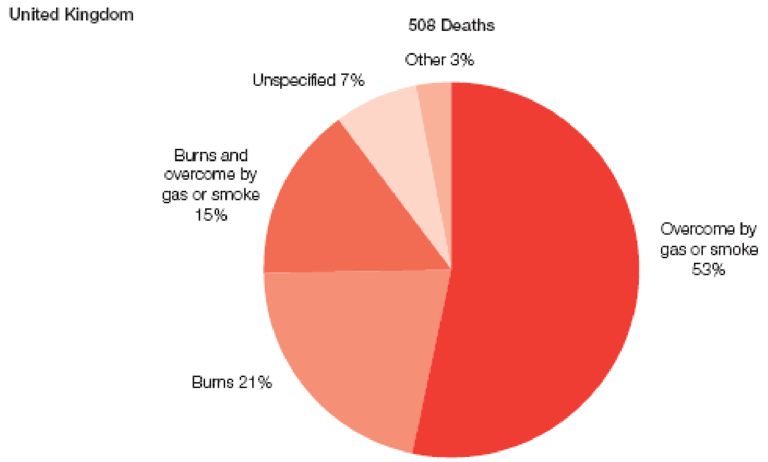

Figure 1 - Causes of Fire Fatalities
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Whilst the availability of fire statistics in Australia is limited, it is reasonable to expect similar trends (i.e. the majority of fatalities will be the result of exposure to smoke).

The Building Code of Australia, like many other national and international codes, makes extensive use of fire resistant barriers to control the spread of fire but has only limited Deemed-to-Satisfy Provisions for smoke resistant barriers. The use of smoke barriers or combined fire and smoke barriers in Alternative Solutions has shown that there are opportunities for developing more cost effective smoke hazard management solutions particularly where functional elements such as walls and acoustic barriers can be adapted to act as smoke barriers.

However, the greater adoption of smoke barriers has been hindered by a lack of knowledge of how to quantify and specify required performance levels together with the limited availability of tested systems with proven performance levels..

The publication of AS 1530.7:1998 *Smoke control door and shutter assemblies- Ambient and medium temperature leakage test procedure* provided, for the first time, a means of quantifying the performance of smoke doors in Australia. Though the document is not referenced in the Building Code of Australia, many suppliers have voluntarily tested products to this standard in order to demonstrate ‘best practice’ in providing products of known performance to the market.

The remainder of this paper will describe how to quantify or specify the performance of smoke resisting barriers by consideration of a typical application comprising doors separating apartments from public corridors.

RELEVANT BUILDING CODE OF AUSTRALIA REQUIREMENTS FOR DOORS LEADING TO PUBLIC CORRIDORS

In an apartment building, BCA Deemed-to-Satisfy Provision C3.11 prescribes provisions for sole-occupancy-unit doors, doors to public corridors, lobbies and fire isolated exits, amongst other things to Bounding Construction in Class 2 (apartment) buildings.

This prescribes the following protection for a doorway—

(i) in a building of Type A construction — a self-closing –/60/30 fire door; and

(ii) in a building of Type B or C construction — a self-closing, tight fitting, solid core door, not less than 35 mm thick.

The relevant BCA Performance Requirements if an Alternative Solution is being considered is to be identified in accordance with BCA Clause A0.10 which requires the following steps:

(a) Identify the relevant *Deemed-to-Satisfy Provision* of each Section or Part that is to be the subject of the *Alternative Solution*, and

(b) Identify the *Performance Requirements* from the same Sections or Parts that are directly relevant to the identified *Deemed-to-Satisfy Provisions*, and

(c) Identify *Performance Requirements* from other Sections and Parts that are relevant to any aspects of the *Alternative Solution* proposed or that are affected by the application of the *Deemed-to-Satisfy Provisions*, that are the subject of the *Alternative Solution*."

Example

(a) For a variation to a door way forming part of the bounding construction to a sole-occupancy-unit in an apartment building (BCA Class 2) the relevant BCA Deemed-to-Satisfy Provision would be C3.11.

(b) The relevant BCA Performance Requirement from the same Section or Part is BCA Performance Requirement CP2, which is reproduced below:

BCA Performance Requirement CP2

(a) A building must have elements which will, to the degree necessary, avoid the spread of fire—

(i) to exits; and
(ii) to sole-occupancy units and public corridors; and
(iii) between buildings; and
(iv) in a building

(b) Avoidance of the spread of fire referred to in (a) must be appropriate to—

- (i) the function or use of the building; and
- (ii) the fire load; and
- (iii) the potential fire intensity; and
- (iv) the fire hazard; and
- (v) the number of storeys in the building; and
- (vi) its proximity to other property; and
- (vii) any active fire safety systems installed in the building; and
- (viii) the size of any fire compartment; and
- (ix) fire brigade intervention; and
- (x) other elements they support; and
- (xi) the evacuation time.

(c) Since the public corridor represents an evacuation route, BCA Performance Requirement EP2.2 is also particularly relevant:

BCA Performance Requirement EP2.2

(a) In the event of a fire in a building the conditions in any *evacuation route* must be maintained for the period of time occupants take to evacuate the part of the building so that—

- (i) the temperature will not endanger human life; and
- (ii) the level of visibility will enable the *evacuation route* to be determined; and
- (iii) the level of toxicity will not endanger human life.

(b) The period of time occupants take to evacuate referred to in (a) must be appropriate to—

- (i) the number, mobility and other characteristics of the occupants; and
- (ii) the function or use of the building; and
- (iii) the travel distance and other characteristics of the building; and
- (iv) the *fire load*; and
- (v) the potential *fire intensity*; and
- (vi) the *fire hazard*; and
- (vii) any active *fire safety systems* installed in the building; and
- (viii) *fire brigade* intervention.

Depending upon the particular building configuration and use other BCA Performance Requirements may be relevant. For the purposes of this example the focus will be on the performance of "tight fitting solid core doors not less than 35mm thick " and the relevance to BCA Performance Requirements CP2 and EP2.2.

METHODS OF QUANTIFYING SMOKE LEAKAGE THROUGH CLOSED DOORS

It is possible to calculate smoke leakage between the leaf and frame and undercut reasonably accurately provided the following:

- door leaf remains flat,
- the dimensions of the gaps around the edge of the door leaf are known, and
- no seals are fitted using appropriate flow equations.

The selected flow equation should be appropriate to the type of flow conditions (turbulent, transitional or viscous) that are applicable to the configuration and pressure differential. Since most door leaves tend to distort when exposed to modest levels of heat (<50°C) these methods should only be used for smoke close to ambient temperature.

Details of an appropriate calculation method that can be applied to turbulent, transitional and viscous flows have been documented by Klote and Milke[iv] based on the work of Gross and Haberman[v] but including an approximation developed by Forney GP. The method is based on Equation 1.

$$Q = \frac{\upsilon x L N Q}{D_h} \qquad \text{- Equation 1}$$

Where
NQ = Dimensionless flow rate
NP = dimensionless pressure differential
R_e = Reynolds Number
a = thickness of gap perpendicular to flow (refer Figure 2)
x = depth of gap in flow direction (refer figure 2)
ΔP = pressure differential across gap
D_p = hydraulic diameter (2a)
ρ = density of gas in gap
ν = kinematic viscosity

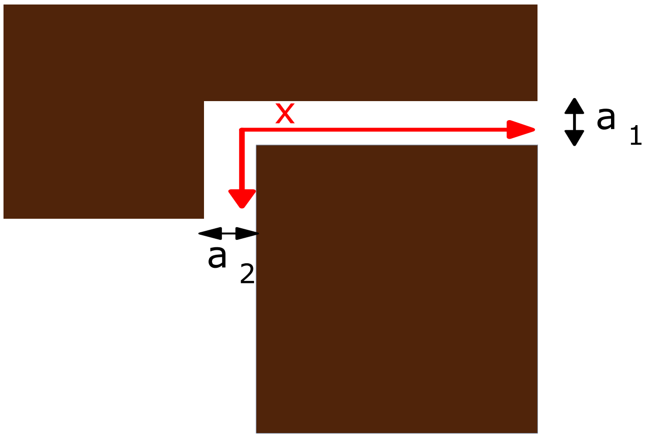

Figure 2 - Door Gap Dimensions for single bend configuration

Equation 2 is used to calculate the dimensionless pressure differential (NP). The dimensionless flow rate (NQ) is then calculated using the appropriate relationship from Equations 3 to 5; depending upon the type of flow.

$$NP = \frac{\Delta \mathrm{P}\,\mathrm{D}_\mathrm{h}^2}{\rho v^2}\left(\frac{D_h}{x}\right)^2 \qquad \text{– Equation 2}$$

For $NP \leq 250$ $\quad NQ = 0.01042NP$ - Region 1 Viscous dominated – Equation 3

For $250 < NP < 10^6$ $\quad NQ = 0.016984NP^{\alpha}$ - Region 2 transition – Equation 4

Where $\alpha = 1.01746 - 0.044181\log_{10}(NP)$

For $NP > 10^6$ $\quad NQ = 0.555NP^{1/2}$ - Region 3 kinematic dominated – Equation 5

Factors can be used to allow for flow reductions due to single bends (refer Figure 2) or double bends depending on the magnitude of the Dimensionless Pressure Differential.

AS 1530.7:1998 is a test method that allows smoke leakage through door assemblies to be measured at both ambient and medium temperatures (200°C). The test method has been refined and a new version of AS 1530.7 is expected to be published in 2007. Essentially the test method comprises an enclosure that can be sealed and heated to 200°C whilst being pressurised. The mass flow of air required to maintain the nominated pressure is equal to the leakage through the specimen after allowances are made for equipment leakage. A typical test configuration is shown in Figure 3.

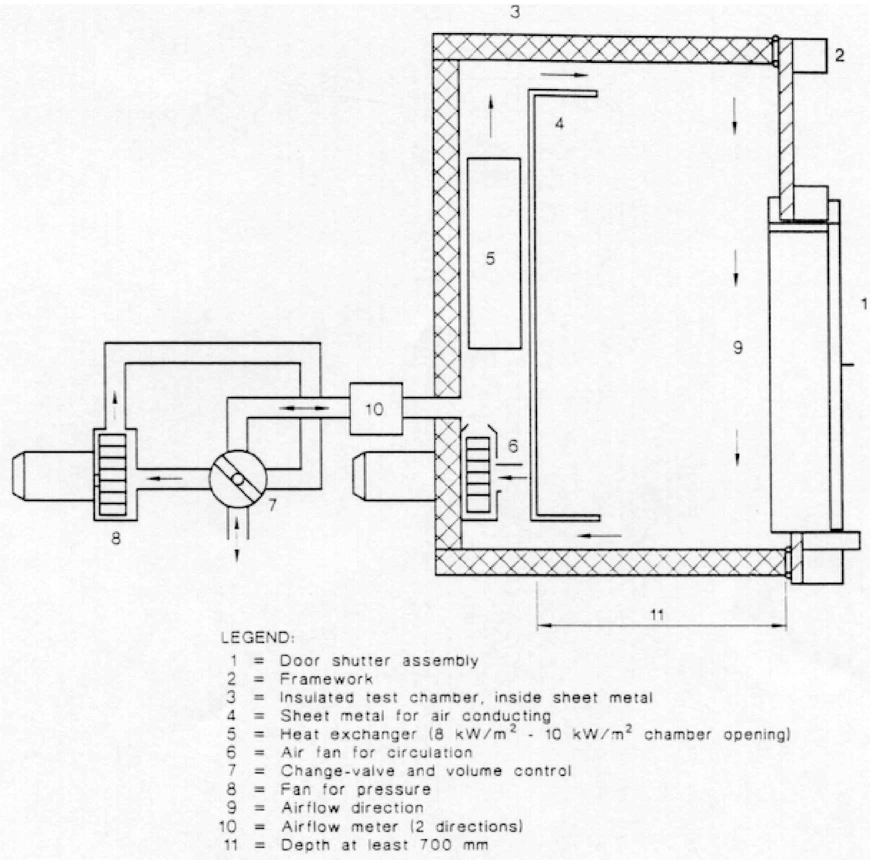

FIGURE B1 TEST CHAMBER (PRINCIPLE)

Figure 3 - Schematic of AS 1530.7 test apparatus

The 2007 edition will incorporate many improvements from the 1998 edition including:

- Extension of the scope to a broad range of elements of construction in addition to doorsets.
- Exposure to 200°C for extended periods (e.g. 30 minutes for doorsets, 120 minutes for dampers).
- More detailed description of the test procedure and calculation methods to improve repeatability.

COMPARISON OF CALCULATED AND MEASURED LEAKAGE THROUGH CLOSED DOORS WITHOUT SEALS

A quality timber doorset installation will have clearances around the edge of the door leaf of the order of 2-3mm. If the clearances are reduced much below 3mm the door leaf will catch on the frame and not close properly.

The term ‘tightly fitting solid core door’ is used in the BCA, but not defined. It has been suggested that the term ‘tightly fitting’ refers to the minimisation of the gap between the door stop and face of the door leaf (shown as dimension ‘a2’ in Figure 2). However, there are also practical limitations to how small this gap can be due to the following limitations:

- on the straightness of the door and/or frame,
- setting of door hardware,
- distortion of the door leaf after installation due to changing moisture content, and
- the need for the doorset to be self closing and self latching.

Typically, the practical limit for the ‘a2’ dimension would be in the range of 1-2mm.

Experimental data on the performance of solid-core doors without smoke seals at ambient temperatures was included in England et al[vi]. The results from a test performed in the US on a 2.038m x 826mm wide x 35mm thick door leaf with a 15mm doorstop and nominal 3mm clearances were included.

The doorset was tested swinging in to the enclosure such that the door leaf was pushed towards the stop and swinging away from the pressure such that the pressure would push the door leaf away from the stop. The results are presented in Table 1 together with calculated leakage rates using the method described above for the configuration with the sill sealed.

Table 1 - Experimental and Calculated Leakage Rates at ambient temperatures

Description	Leakage m^3/h	
	Pressure 12.5 Pa	**Pressure 25Pa**
Test data no seals to head and side opening inwards (door pushed against stop)	90	132
Calculated leakage with 2.2mm assumed gap	90	139
Test data no seals to head and side opening outwards (door pushed away from stop)	167	246
Calculated leakage with 3.3 mm assumed gap	164	246

Note: Calculations based on Gap length-4.9m and Gap depth 53mm with single bend.

A test following the general principles of AS 1530.7 was performed on a doorset similar in size to that used to generate the results in Table 1. The doorset was set up with clearances of approximately 3mm between the stop and face and around the edge of the door leaf with the sill fully sealed[vii]. With a pressure differential of 4.4Pa the measured leakage rate was $68m^3/h$ and $70m^3/h$ with the door opening towards and away from the positive pressure respectively.

Using the calculation method described in this paper with a 3mm gap width and pressure differential of 4.4Pa, a leakage rate of $74m^3/h$ can be calculated. Substituting the 4.4Pa differential with 12.5Pa yields a leakage rate of $142m^3/h$ which is reasonably consistent with the results in Table 1 for a similar configuration.

Subsequently, the same doorset was tested at medium temperatures (200°C) opening towards the pressure after exposure to 200°C for in excess of 90 minutes with a pressure differential of 5.8Pa[viii]. Deflection of the top and bottom latch edges away from the doorstop had occurred at the time the measurements were taken. The measured leakage was $111m^3/h$ at this temperature and pressure. The calculated leakage for these conditions using the original gap dimensions was $93m^3/h$.

The calculations and test results correlate well at ambient temperatures and demonstrate a high sensitivity to gap dimensions within the range of clearances likely to be encountered in practice. Errors are introduced at medium temperatures due to the door deflections modifying gap sizes.

Subsequently, an experiment was undertaken by Warrington Fire Research[ix] with a door assembly specially set up with the door leaf tight against the doorstop and clearances around the perimeter of the leaf averaging 2.4mm at the head and 2.8mm at the sides. The sill was sealed to isolate the measured performance to the head and sides. The measured leakage was approximately $69m^3/h$ at a pressure differential of approximately 12.5Pa and was independent of the direction of swing. This would be expected since the door leaf was set up to rest against the stop and the relatively low pressure would not overcome the closer forces.

The value of $69m^3/h$ should therefore be viewed as the lower bound (or expected best resistance to smoke spread) for leakage around a tightly fitting solid-core door at ambient conditions since it is unlikely that a doorset with such close gap clearance tolerances would remain operational in the long-term due to minor distortions of a door leaf that may occur due to changing environmental conditions. A leakage rate of $100m^3/h$ at a pressure differential of 12.5 Pa would be a more appropriate value at ambient conditions with higher values expected if the doorset is exposed to medium (200°C) or higher temperatures.

PERFORMANCE OF TIMBER DOORSETS WITH SEALS

Types of door seals

There are many types of seals used to minimise smoke leakage around the head and sides of doorsets at ambient, medium and high temperatures including:

- Wiper seals fitted to the edges of the door leaf
- Compression seals mounted on door stops
- Integral seals mounted in frames
- Compression / wiper combination seals
- Intumescent seals (normally used in conjunction with other seals to enhance high temperature performance.

Similarly, there are many types of sill seals but this paper has focussed on seals for the head and sides.

Each type of seal has its strengths and weaknesses. For example, wiper seals can accommodate significant differential movement of the door leaf relative to the frame but they can also cause significant increases to opening and closing forces making doors difficult to operate for some people, whereas compression seals can have a minimal impact on operational forces but can be susceptible to differential movement.

Establishing the performance of doorsets with seals

The interactions of the doorset and seals are complex particularly at elevated temperatures and many doors and seals tend to be proprietary products rather than generic products. Therefore, the most practical way to evaluate the performance of a door with smoke seals fitted is to rely on test data generated from a standard testing and reporting procedure. In Australia, this means using AS 1530.7 in much the same way as the performance of fire doors and other fire resisting elements has been measured in accordance with AS 1530.4 for many years.

The following results obtained with a particular type of solid core door mounted in a steel frame with a compression seal. The tests were performed as part of a Warrington Fire Research (Aust) Pty Ltd internal research project[xxi]. The products / components were brought from retail outlets and the specific manufacturers have not been identified in this paper. Due to the complex inter-actions, these results should not be applied to other systems, though the results provide a useful insight into some critical parameters.

Test Series 1 was performed on a solid timber cored door leaf 2040 x 820mm x 38mm thick with a compression seal fitted to the top and sides of a steel frame with a 15mm stop and with the sill sealed.

With a closing force of 20N and seals carefully aligned the leakage rate opening towards and away from the test enclosure at ambient conditions was approximately 2m^3/h at a pressure differential of 25Pa. However, the leakage rates after exposure to elevated temperatures are substantially higher, shown in Table 2. These were measured with the door opening towards the pressure and heated enclosure after exposure to 200°C for between 28 and 50 minutes following from a 30 minute period where the temperature had been progressively increased to 200°C.

Test Series 2 was performed on a similar doorset to Series 1 and with a similar set-up. With a closing force of 19N the leakage rate opening towards and away from the test enclosure at ambient conditions was approximately 2m^3/h and 4m^3/h at a pressure differential of 10Pa and 25Pa respectively. The Series 2 doorset was exposed to a less severe early heating regime to the Series 1 doorset with temperatures being maintained at approximately 100°C between approximately 5 and 25minutes after commencement of heating. The temperature was increased to approximately 200°C by 35 minutes and air leakage measurements were taken at pressure differentials of 25Pa and 10Pa after the temperature had been held at 200°C for 25-40minutes. The results are shown in Table 2.

Also included in Table 2 is the calculated “effective gap width”. The effective gap width is defined as the gap width that would be expected to provide a similar leakage rate based on the equations presented earlier in this paper if there is no movement of the door leaf relative to the frame.

Table 2 - Leakage Data for solid-core door with compression seals fitted

Test Series	Leakage rate – m^3/h (equivalent gap width mm) for specified pressure differential			
	5Pa	**10Pa**	**21Pa**	**25Pa**
1	59 (2.5mm)	89(2.4mm)	100(1.9)	
2		81(2.25mm)		106(1.8)

The results indicate that after exposure to 200°C for more than 30 minutes the compression seal had a minimal effect on the reduction of smoke spread with the particular doorset tested. The trend of the results is consistent with progressive deterioration of the doorsets' performance because:

- the higher pressure readings were the first to be taken in the series and the effective leakage width is lower for these readings
- the early heating severity was less for series 2 and the effective leakage areas were also less indicating less deterioration in performance

It should be noted that there are a number of proprietary systems available in Australia that utilise compatible seals and door assemblies that have been tested in accordance with AS1530.7-1998 and shown to be capable of achieving leakage rates substantially less than 10m^3/h for a similar configuration to the Series 1 and 2 tests after exposure to 200°C for in excess of 30 minutes.

Example Calculation of Smoke Spread to a Corridor Through a Closed Door

There is a substantial volume of work available detailing methods of modelling smoke spread between enclosures through large openings and subsequent smoke filling such as the sub routines within FAST. There are also models such as those presented earlier in this paper for calculating leakage through small openings but once the volume of smoke passing through a closed door is known it is necessary to consider how the smoke plumes form at the door clearances and mix with the enclosure air.

Observations made during a series of fire resistance tests with a corridor mounted in front of a door exposed to fire resistance tests[xii] indicated that there are two modes of smoke filling of a corridor separated from a fire by a closed door:

Formation of a plume and a hot layer that can be analysed by a simple zone model and use of an interface height to judge tenability.

Formation of a weak / plume or no plume enabling conditions to be predicted by a simple network model assuming full mixing of gases and using, smoke concentration, visibility or temperature to judge tenability.

For smoke at medium temperatures (200°C) it is postulated that after passing through the door and mixing only a week plume would form and that a simple network model balancing the mass of air flowing into and out of the enclosure would be sufficiently.

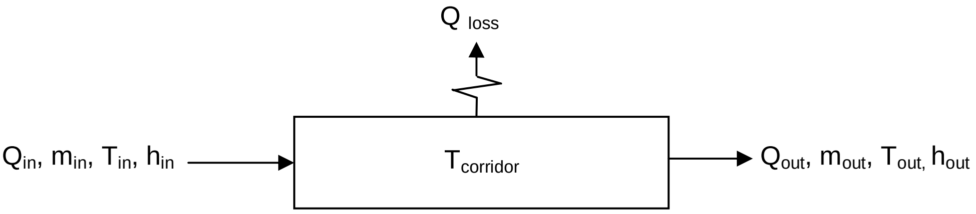

Figure 4 – Schematic of basic heat and mass balance around corridor

Thus, the net rate of heat flow into the enclosure is given by the equation:

$$Q_{net} = Q_{in} - Q_{out} - Q_{loss} = m_{in} h_{in} - m_{out} h_{out} - Q_{loss} \qquad \text{- Equation 6}$$

Where

Q is the rate of heat flow J/s

m is the mass flowrate m^3/s

h is the enthalpy of flow at calculated T kJ/kg

T_{in} is the temperature of smoke flowing into the enclosure K

T_{out} is the temperature of the smoke flowing out of the enclosure °C

Initially, heat loss to surroundings through walls (Q_{loss}) has been assumed to be negligible in order to provide a basic model, such that $Q_{loss} = 0$.

The average temperature increase of the enclosure during a time increment can then be calculated using the following equation:

$$\Delta T = Q_{net}\,\Delta t / (m_{corridor}\, c_{corridor}) \qquad \text{- Equation 7}$$

Where

ΔT is the temperature increase K

Δt is the time increment s

c is the heat capacity of air J/kg/K

As a reasonable approximation the heat capacity of air can be assumed constant and mass flowrate through the system to being constant, substituting for Q yields the following relationship

$\Delta T = m(h_{in} - h_{out})\, \Delta t / \rho_{encl}\, V_{encl}$ - Equation 8

Where

ρ_{encl} is the density of air in corridor at T kg/m^3
V_{encl} is the volume of the corridor m^3

The simple network model assumes:

- instantaneous mixing of gases throughout the corridor
- the enclosure is vented at a low level
- there is no loss of heat from the gases to the door edges and enclosure lining and
- smoke particles pass unobstructed through the gaps around the doors.

A spread sheet can be readily set up to undertake the iterative calculations.

The configuration used in the test described below and shown in Figures 3 and 4 was modelled and the results compared with the experimental data:

A medium temperature air leakage test was performed on a solid core doorset with compression type smoke seals. The doorset was built into a lightweight wall which was fitted into a test frame and mounted in front of the Warrington Fire Research medium temperature air leakage rig. After the doorset had been exposed to 200°C for 44minutes a 6m long x 1.8m wide x 2.4m high instrumented corridor was mounted in front of the doorset as shown in Figure 4.

The measured leakage determined in accordance with AS 1530.7 was found to be $83m^3$/hour at 200°C and atmospheric pressure.

Temperatures were measured by 5 arrays of thermocouples distributed along the length of the corridor as shown in Figure 5 at 7 different heights. Figure 6 shows a plot of the average temperature at each height against time.

Figure 5 – External view of test arrangement

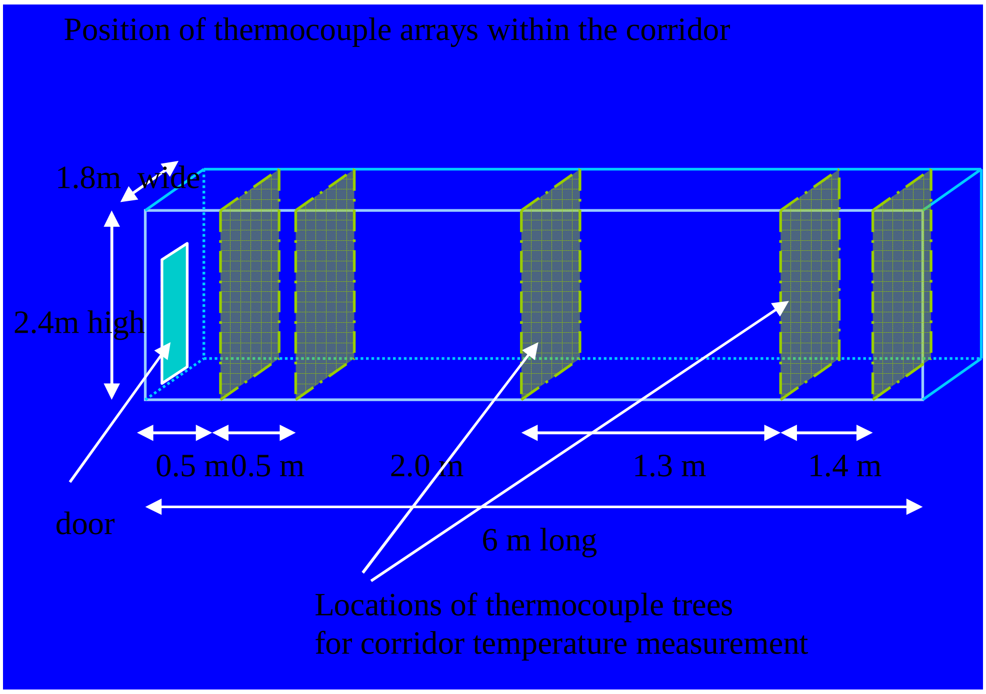

Figure 6 – Temperature measurement positions in corridor

From Figure 6 it can be seen that there was significant mixing of gases between the layers but some stratification also occurred. This can be visualised in Figure 7.

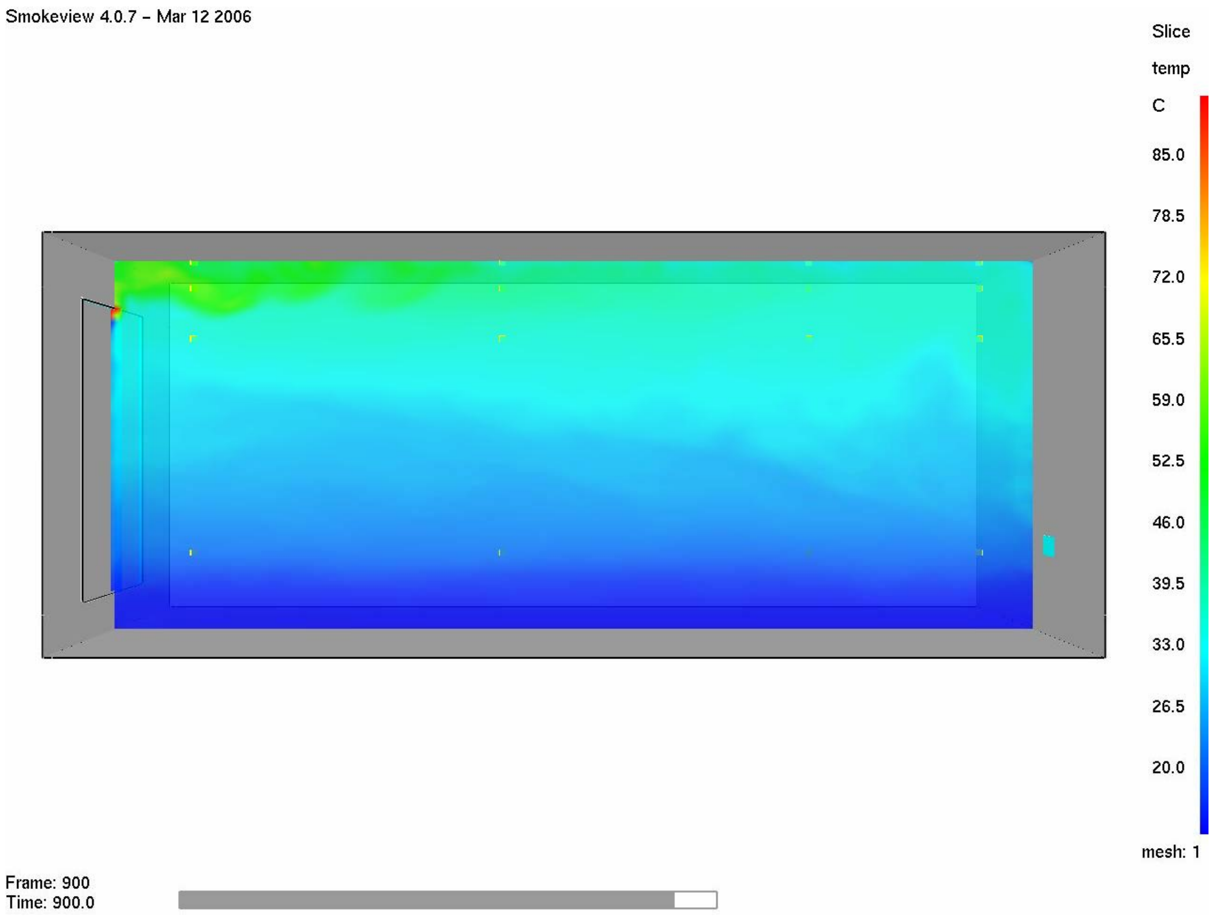

Figure 7 – Visualisation of temperature distribution in corridor

Figure 9 shows a plot of measured mean temperature of the enclosure and temperature calculated using the simple network model. It can be seen that there is a very large over prediction in temperature by the model which is to be expected because substantial heat losses from the boundaries of a small enclosure would be expected and have not been included from the network model. From an examination of Figure 8 it can be seen that by 20 minutes steady state conditions had been reached with a temperature of approximately 60°C at ceiling level and an average enclosure temperature of 40°C

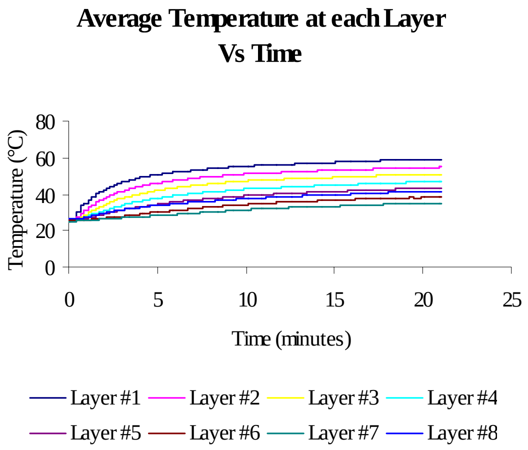

Figure 8 – Measured Corridor Temperatures

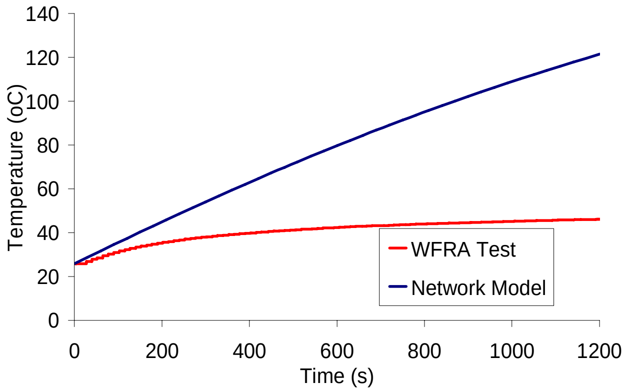

Figure 9 – Calculated and Measured Average Enclosure Temperatures

A crude estimate of the likely heat losses through the boundaries once steady state conditions had occurred after 20 minutes indicated that they would of the same order of magnitude as the estimated heat flow into the enclosure. Further development of the model to incorporate heat losses through boundaries would be beneficial but it is reasonable to use the model for comparison and as an indicator of smoke movement.

SENSITIVITY OF ENCLOSURE TEMPERATURES AND VISIBILITY TO DOORSET LEAKAGE.

The range of performance of door and seal combinations is potentially large and depends mainly on the compatibility of the door and seals and in particular the ability of seals to accommodate the deflection of the door leaf relative to the frame when exposed to medium temperatures.

The following provides an indication of the potential range of performances that can be expected at relatively modest pressure differentials of 10 Pa after exposure to 200°C for at least 30 minutes ignoring leakage at sill level:

- Better performing door / seal combinations can achieve leakage rates substantially less than 10m^3/h at press,

- Incompatible door / seal combinations can have leakage rates in excess of 80m^3/h, and
- Tightly fitting solid core doors with no seals can have leakage rates of the order of 160m^3/h.

In order to compare the impact of doorsets of varying performance the network model was used to calculate the time taken for the temperature of a 6m x 1.8m x 2.4m corridor to exceed 50°C. For common fuels visibility would be expected to be zero or close to zero for an enclosure temperature rise of 50°C as demonstrated by results from a series of tests where the only source of smoke was approximately 2m of plywood (Young and England)[xiii].

Table 3 Comparative performance of door and seal combinations

General description	Leakage rate m^3/h	Calculated time to exceed 50°C - min
High performance door / seal combination	5	86
Good performance door / seal combination	10	43
Poor performing door / seal combination	40	11
Incompatible door/seal combination	80	5
Tightly fitting solid core door	160	2.5

The resident response to an alarm in an apartment building is likely to be slow since the residents may be asleep, distracted or slow to respond until a cue is reinforced. Studies have indicated that the average time to commence evacuation can be greater than 5 minutes with some residents not commencing evacuation after 20 minutes (Proulx G and Fay R)[xiv]. Therefore, if visibility is to be maintained in evacuation routes the results indicate that high performance seals should be considered.

CONCLUSIONS

This paper has identified that smoke is a major cause of fire fatalities and that the BCA Performance Requirements require tenable conditions to be maintained in public corridors to allow occupants to evacuate safely.

It has been demonstrated that leakage rates around the edges of door leaves can be calculated, providing good correlation with experimental data if the gap dimensions are known. Door leaves can deflect considerably when exposed to 200°C for 30 minutes and the performance of doorsets with and without seals can vary significantly from the performance demonstrated at ambient temperature. Therefore, reliance needs to be placed on measured performance obtained from subjecting doorsets to standard testing and report procedures, such as AS 1530.7 with exposure to 200°C for at least 30 minutes.

Test methods for assessing smoke spread at high temperatures would also be a substantial aid to designers and regulators but whilst some methods have been proposed, standardisation of these methods is incomplete.

A simple network model for calculating the conditions in an small enclosure such as a corridor was derived, however, when the calculated conditions were compared to experimental data it was found to over predict enclosure temperatures. This over prediction is thought to be the result of neglecting heat losses from the enclosure and further development of the model to allow for these heat losses would be beneficial. The method has not been validated for larger enclosures where the use of Computational Fluid Dynamics may be more appropriate to differentiate areas within the larger enclosures. These aspects are being further investigated.

The model was used to compare the impact of different performance levels of doors separating apartments from a corridor and it was shown that the time to untenable conditions could be substantially increased by the use of high quality door and seal combinations. The results also indicate that for some door / seal combinations and doors without seals when exposed to medium temperatures visibility in corridors could be compromised prior to commencement of evacuation. This effect would be more pronounced when a doorset is exposed to higher temperatures as demonstrated by Young and England 1999.

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