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STUDY REPORT

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REPORT ON THE EFFECT OF PASSIVE VENTILATION ON THE RATE OF FIRE DEVELOPMENT IN DWELLINGS

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Abstract

This is a report of a study carried out to determine whether the increased use of window units fitted with a fixed amount of passive ventilation was likely to have any significant effect on fire safety in houses. A small two-bedroom dwelling was studied and computer simulations of fire growth carried out for a range of fire scenarios, with and without passive ventilation included.

It was observed that, for a given fire scenario, no significant change in life safety resulted for an occupant in the room where the fire started, but some improvement was noted for occupants located in rooms remote from the fire and where passive ventilation was fitted to the head of the windows.

It was concluded that, from a practical standpoint, only relatively small differences in fire development occur with and without the installation of fixed passive ventilation, and that these differences are likely to be outweighed by possible differences in the heat output of the fire due to changes in the ignitability and burning rates of furniture and lining materials.

Introduction

BRANZ research (Bassett, 1992) has shown that typical modern low-cost houses in New Zealand tend to be relatively air-tight in comparison with many older houses. This has been attributed in part to the 'sheet' nature of common modern building materials, such as plasterboard or wood composite linings, and to aluminium windows and doors. Together, these result in air leakage rates which are much lower than for traditional tongue and groove linings or timber windows. It has been established that this relatively low ventilation rate may be contributing to environmental problems such as excessive condensation and mildew growth, so practical measures were investigated to provide an adequate level of ventilation in this type of building.

An obvious solution would be for windows to be opened more regularly. However, with houses frequently vacated during the day, this is not always possible. Some window manufacturers have incorporated permanent vents into pre-assembled window units to ensure that a low-level background ventilation rate can exist at all times, yet still enable the windows to be secure against intruders.

The study covered in this report was carried out to determine whether the increased use of window units fitted with passive ventilators was likely to have any significant effect on fire safety in houses. It is known that ventilation and air supply affect how fires develop, and the location of ventilation openings in buildings may also be an important factor.

The study also illustrates the practical application of fire hazard assessment using a computer-based fire and smoke transport model.

Methodology

Fire and Smoke Transport Modelling

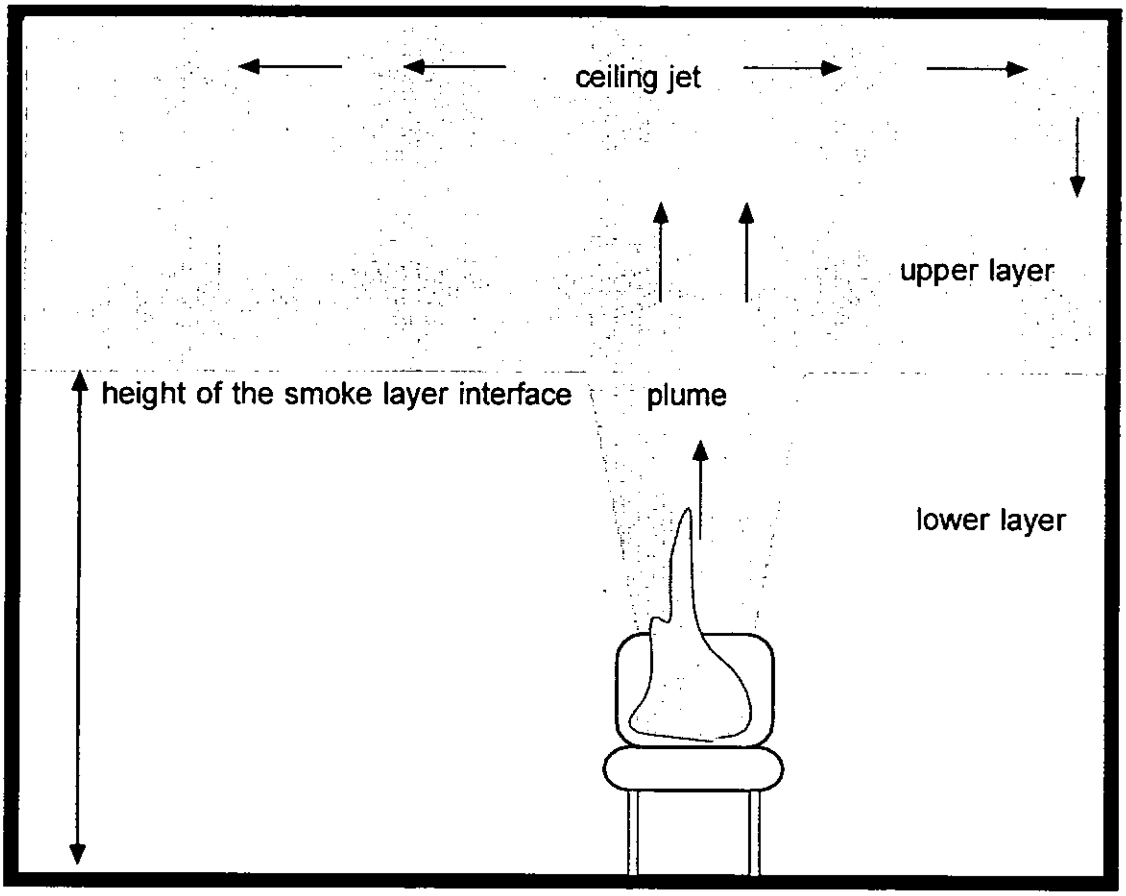
The multi-compartment fire and smoke transport model FAST (Jones and Peacock, 1988) was used to predict the environment in a dwelling over a period of time following ignition. FAST is a zone model which divides each room into two volumes (an upper layer and a lower layer), as shown in Figure 1. Each layer is assumed to have uniform properties (temperature, smoke concentration), and therefore conditions will only vary with height in a room and not with horizontal position.

Given a user-defined fire, FAST uses principles of conservation of mass, momentum and energy to calculate parameters such as temperature, smoke layer depth and smoke and gas concentrations for each layer in each room as a function of time.

This study makes no attempt to validate the accuracy of FAST or, in fact, to predict the actual time frame upon which a fire would develop in the particular building considered. FAST is used here to compare the outcomes of a number of different fire scenarios and thereby enable conclusions to be made about the likely relative effects of changing the ventilation in the building.

The criteria used to compare the results of different fire scenarios and ventilation conditions was the time until untenable conditions occurred in each room. The shorter the time to untenable conditions, the less time available for the occupants to effect their escape, and the greater is the threat to life safety in the building. The most probable causes of untenability are discussed later in this report.

FIGURE 1 : ZONE MODEL CONCEPT



Input Parameters

Description of House

The house selected for analysis was a small two-bedroom Housing New Zealand dwelling. It was constructed with a common fire wall with another similar dwelling. The building was timber frame construction lined on the interior with paper faced gypsum plasterboard and clad on the exterior with fibre cement sheets. The house was carpeted in the lounge/dining room, bedrooms and hallways. Vinyl flooring was used in other rooms. The interior doors were hollow-core with varnished plywood facings. A floor plan is shown in Figure 2.

Fire Scenarios

Twelve different fire scenarios were considered. Half of these used bedroom 1 as the room of fire origin, while three used the kitchen as the room of origin. Three further fire scenarios used the lounge/dining area as the room of origin. Various combinations were considered, including:

- passive ventilation present or not present
- passive ventilation located at the top (i.e. high) and bottom (i.e. low) of the windows
- door to room of fire origin open or closed

A description of each fire scenario is given in Table 1.

FIGURE 2 : FLOOR PLAN OF DWELLING

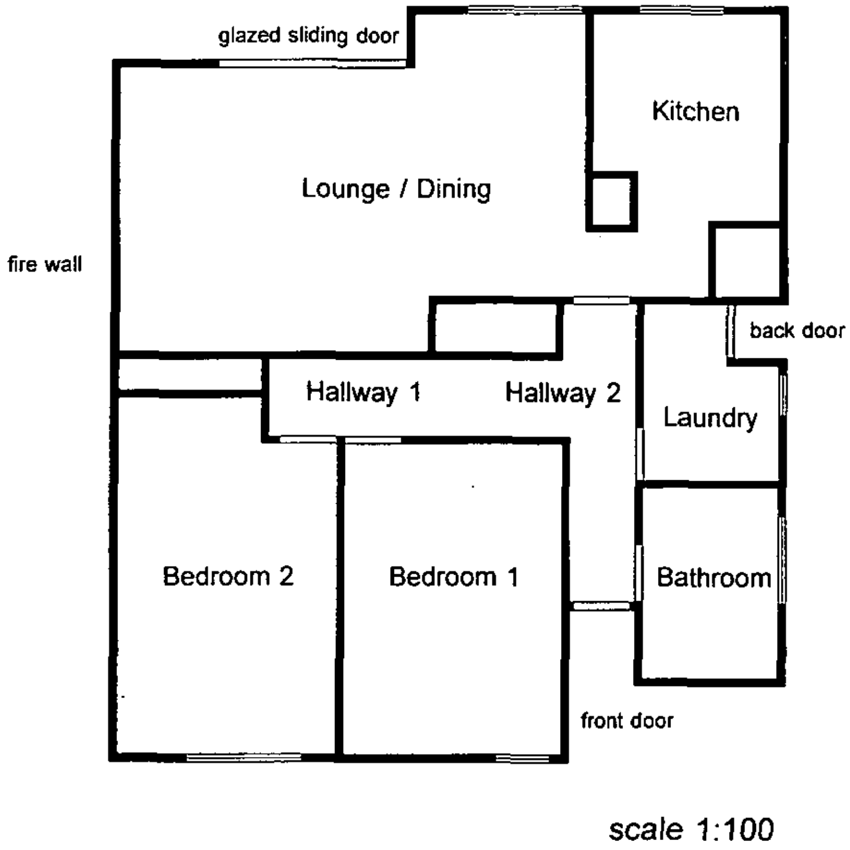


TABLE 1 : DESCRIPTION OF FIRE SCENARIOS

	Fire in Bedroom 1						Fire in Lounge			Fire in Kitchen		
Fire Scenario No.	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
door to fire room open	X	X	X				X	X	X	X	X	X
door to fire room closed				X	X	X						
no passive ventilators	X			X			X			X		
passive ventilators high		X			X			X			X	
passive ventilators low			X			X			X			X

Modelling Smoke Spread Between Rooms

The house was divided into six interconnected compartments for the modelling of fire and smoke spread. This was the maximum number of interconnected compartments allowed by FAST. The bathroom was not represented in any fire scenario, so it was assumed the door to that room was closed and there was no leakage allowing smoke to enter the bathroom from other spaces. The relevant compartments used for the bedroom fires (scenarios R1 to R6) are shown in Figure 3, while the compartments used for the lounge fires (scenarios R7 to R9) and kitchen fires (scenarios R10 to R12) are shown in Figure 4. The openings between each compartment, and between compartments and the exterior, were specified as input to FAST. Essentially these openings were the glazed areas in windows and doors and they were assumed to be fully closed at the start of the fire.

Passive Ventilation Options

UK building regulations (Dept of Environment, 1992) recommend a minimum level of background ventilation of 4000 mm^2 per habitable room, and this has been shown to be suitable in New Zealand (Bassett, 1994). This was satisfied in the above dwelling by providing a total of 35,000 mm^2 of fixed opening distributed around the width of all windows. For each window, for modelling purposes, the passive ventilator was represented as a horizontal vent 5 mm high by the width of the window. The passive vent was located at either the sill or the head of the window, depending on the particular scenario.

Natural Leakage Rates

Apart from any passive ventilation to be provided, the building was assumed to have an inherent amount of natural leakage. Leakage to the exterior was assumed to occur in the regions of windows and was represented by a vertical vent 0.5% of the window width wide (i.e. 5 mm per metre width of window) over the height of the window. This corresponded to an airtightness of approximately 3 air-changes per hour at 50 Pa. Bassett (1992) observed that for New Zealand houses built after 1980, 93% had 50 Pa air-change rates of between 5 and 16 air-changes per hour, so the natural airtightness of this building was well above average. This had been confirmed by previous BRANZ research (Bassett, 1994). The leakage area was assumed to represent all leakage from the rooms to the exterior and not just that associated with the windows. Leakage around closed interior doors was arbitrarily represented by 3 mm wide gaps around the perimeter of the door leaf.

FIGURE 3 : COMPARTMENTS MODELLED FOR BEDROOM FIRES

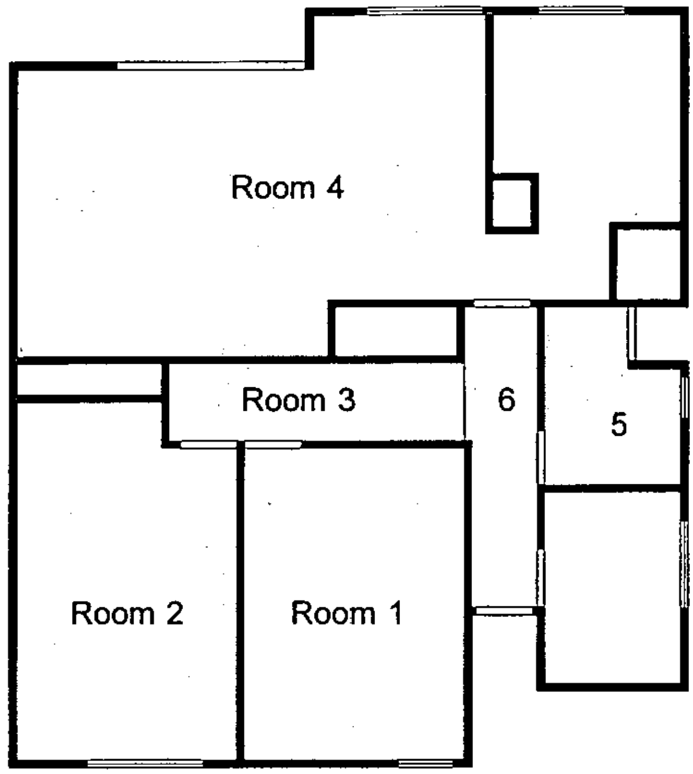
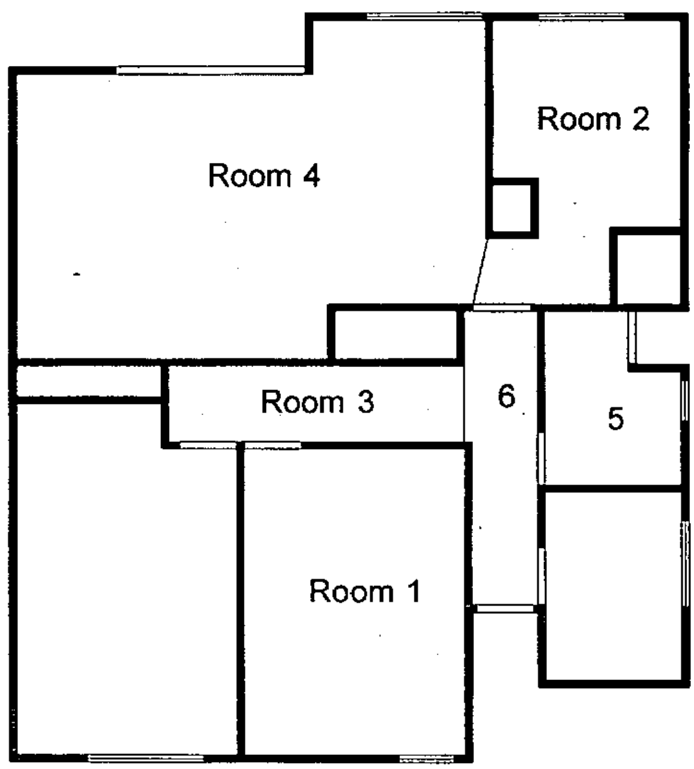


FIGURE 4 : COMPARTMENTS MODELLED FOR LOUNGE AND KITCHEN FIRES



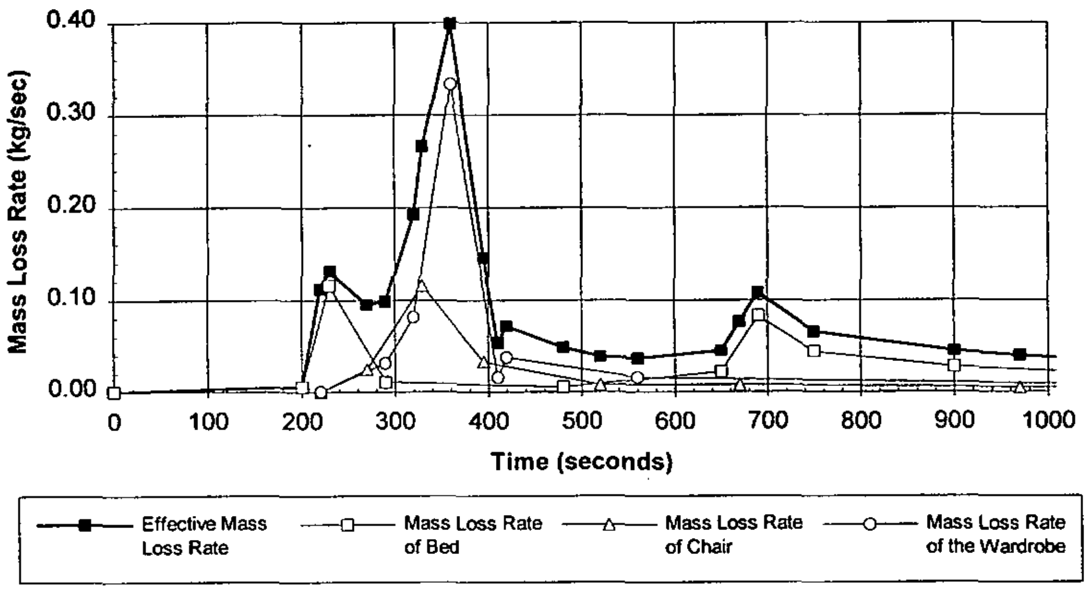
Design Fires

Three design fires were considered: a bedroom fire, a kitchen fire and a fire in the lounge/dining room.

Bedroom Fire

The bed was assumed to be the first item ignited. The fire was then assumed to spread from the bed to an adjacent chair and to a nearby wardrobe. Mass loss rates and soot and gas species yields as a function of time for each item were taken from a database in HAZARD I (Bukowski et al, 1991). The mass loss rates were combined on a single time-line as shown in Figure 5. Effective heat of combustion, effective mass loss rate and species yields as a function of time were determined for input into the FAST model.

FIGURE 5 : MASS LOSS RATE FOR THE BEDROOM FIRE

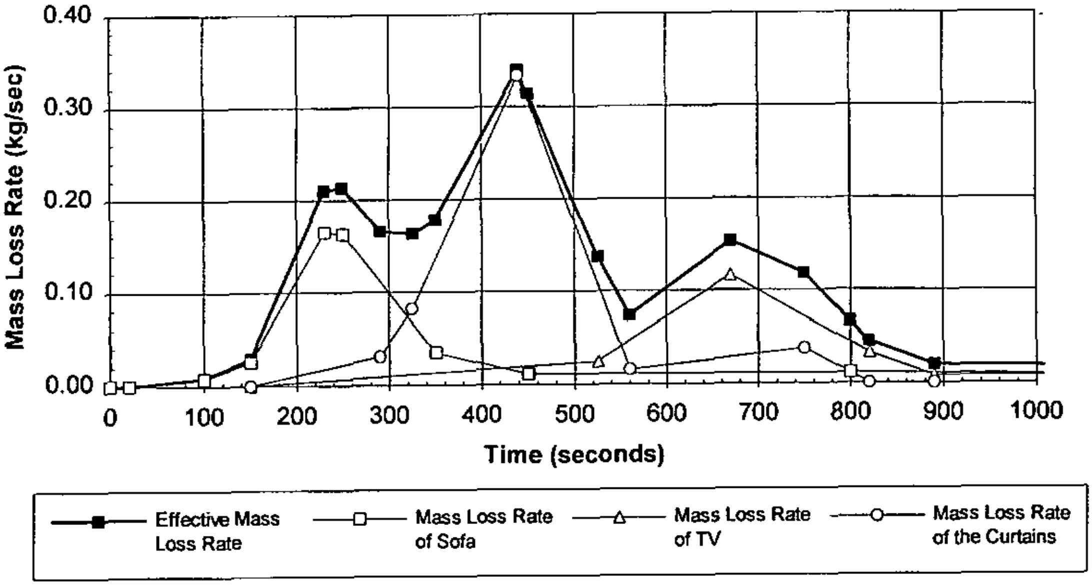


Lounge Room Fire

A sofa with wood frame and polyurethane cushions with polypropylene cover was assumed to be the first item ignited. The fire was then assumed to spread from the sofa to an adjacent television set and to a nearby curtain.

Mass loss rates, effective heat of combustion, soot and gas species yields as a function of time for each item were determined as described for the bedroom fire. Again the mass loss rates were combined on a single time-line as shown in Figure 6.

FIGURE 6 : MASS LOSS RATE FOR THE LOUNGE ROOM FIRE

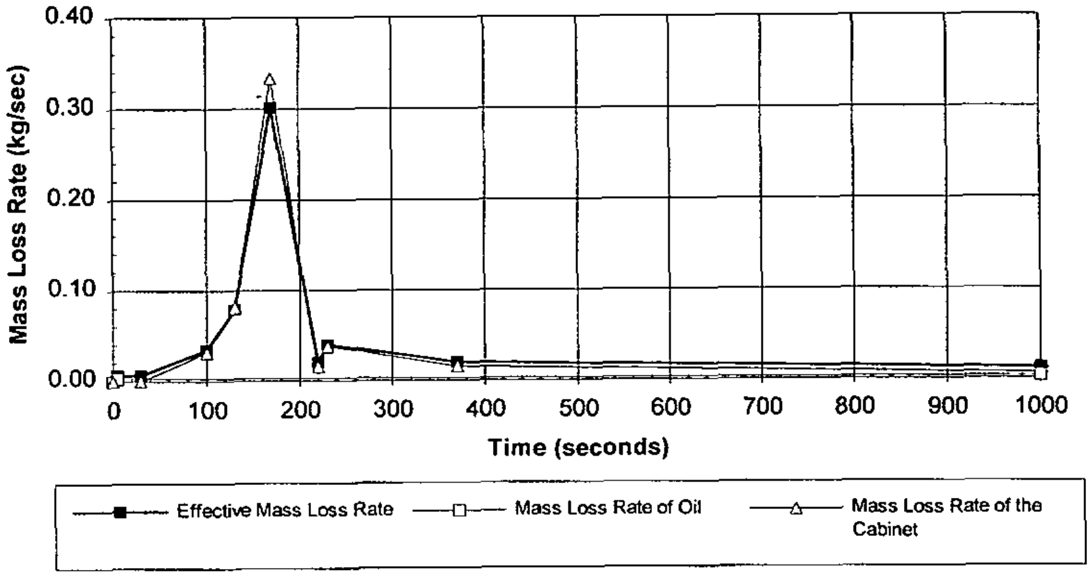


Kitchen Fire

A pan of cooking oil on a stove hotplate was assumed to overheat and ignite, spreading to and igniting nearby overhead kitchen cupboards.

Mass loss rates, effective heat of combustion, soot and gas species yields as a function of time for each item were determined as described for the bedroom fire. The mass loss rate as a function of time is shown in Figure 7. (Note that the effective peak mass loss rate is a weighted average for the items involved. In this case it appears less than the peak mass loss rate of the cabinet alone.)

FIGURE 7 : MASS LOSS RATE FOR THE KITCHEN FIRE



Criteria for Window Breakage

Skelly, Roby and Beyler (1991) carried out an experimental investigation of glass breakage in compartment fires and concluded that a 90°C temperature difference between the central heated portion of the pane and the glass edge could result in failure of the glass. In this study, window breakage was assumed to have occurred when, within a specified compartment, the upper wall temperature exceeded 100°C and the upper smoke layer had descended below the soffit of the window. When this condition was true the simulation was stopped, the vent was opened to 90% (to represent some of the window glass remaining in the edge of the frame) and the simulation was then restarted from the time of window breakage.

Criteria for Flashover

Flashover was assumed to have occurred within a compartment when the radiative heat flux on a horizontal target in the room reached 20 kW/m^2 (Drysdale, 1985). Flashover represents a transition where the flaming regime changes from individual items burning to all exposed combustibles in the room burning. A person cannot survive in a room where the fire has developed to the flashover stage.

In this study, the time to flashover is noted. At times after flashover the heat release rate curves shown in the previous section may no longer represent the real situation as additional items in the room of origin, and perhaps in adjoining rooms, start to burn. This has not been accounted for in the mass loss rates used as input to FAST.

Criteria for Untenable Conditions

People may become adversely affected and incapacitated by the effects of fire and smoke. This section discusses the various factors which may threaten people and cause conditions to become life-threatening. However, each factor is considered in isolation from the others, so potential synergistic effects are not accounted for, and the actual time to untenable conditions could be less.

Radiative Heat

A limit on the radiant heat flux received by a horizontal target in the lower layer as a result of the hot upper layer radiating downward was set at 4 kW/m^2. This level of radiation can be tolerated by people for about 15 seconds (Purser, 1988).

The following tenability limits may relate either to the upper or lower gas layers depending on the position of the smoke layer interface. If the height of the smoke layer interface is greater than 1.5 m above the floor level (the approximate nose height of a standing adult) then the limits are applied to the lower layer, since a standing adult would be inhaling air from the lower layer. Conversely, if the height of the smoke layer interface is 1.5 m or less above the floor level, the limits are applied to the upper layer, since a standing adult could be inhaling from the upper smoke layer.

In addition, some of the tenability limits below are time-dependent. Where this is the case a time of 10 minutes exposure has been selected, and it was assumed that the house occupants would have evacuated the dwelling before this time.

Visibility

Optical density is used to define visibility through smoke. Tewarson (1988) gives the following expression relating to visibility and optical density.

$\ell_v = K_v(D / l)$ where

ℓ_v = maximum distance over which an observer can see an object or read a sign (m)

K_v = effective visibility constant (depends on type of smoke and light source)

D = optical density

l = optical path length (m)

A limit of 2 m visibility is recommended by Babrauskas (1979). This corresponds to optical density per metre *(D/l)* of approximately 0.5 m^{-1} (Purser, 1988).

Convective Heat

Convected heat can cause skin pain and burns. Purser (1988) gives an expression relating time to incapacitation to the air temperature.

$$t_{Ih} = e^{5.1849-0.0273T}$$

where

t_{Ih} = time to incapacitation (min)

T = air temperature (°C)

Substituting 10 minutes in the above expression and solving for T gives an upper limit on the air temperature of 105°C.

Low Oxygen Hypoxia

Reduced oxygen levels can result in reduced exercise tolerance, severe incapacitation, lethargy, loss of consciousness and, ultimately, death. Purser (1988) gives an expression relating time to loss of consciousness with the percentage oxygen concentration in the air as follows:

$$t_{Io} = e^{8.13-0.54(20.9-\%O_2)}$$

where

$$t_{Io} = \text{time to loss of consciousness (min)}$$

$$\%O_2 = \text{oxygen concentration}$$

Substituting 10 minutes in the above expression and solving for $\%O_2$ gives a lower limit on the oxygen concentration of 10%.

Carbon Dioxide

Increased carbon dioxide levels can result in respiratory distress, dizziness and loss of consciousness. Purser (1988) gives an expression relating time to loss of consciousness with the percentage carbon dioxide concentration as follows:

$$t_{ICO_2} = e^{6.1623-0.5189\times\%CO_2}$$

where

$$t_{ICO_2} = \text{time to unconsciousness by carbon dioxide (min)}$$

$$\%CO_2 = \text{concentration of carbon dioxide in the air}$$

Substituting 10 minutes in the above expression and solving for $\%CO_2$ gives an upper limit on the carbon dioxide concentration of 7.5%.

Carbon Monoxide

Increased levels of carbon monoxide cause toxic effects when a certain dose in the form of carboxyhemoglobin (COHb) is inhaled (Purser, 1988). The following expression relating COHb concentration, volume of air breathed and exposure time is given by Purser (1988).

$$\%COHb = (3.317\times10^{-5})\times \mathrm{CO}^{1.036}\times RMV \times t$$

where

$$\%COHb = \text{carboxyhemoglobin concentration (incapacitation at approx 40\%)}$$

$$\mathrm{CO} = \text{concentration of CO in the air (ppm)}$$

$$RMV = \text{volume of air breathed (L / min) (8.5 L / min for adult at rest)}$$

$$t = \text{exposure time (min)}$$

Substituting 10 minutes in the above expression and using the given values for $\%COHb$ and RMV gives an upper limit on the carbon monoxide concentration of 12,600 ppm.

Results

Each of the fire scenarios described earlier was modelled using FAST. A selection of the outputs obtained is shown here. Each scenario consisted of multiple restarts, where the run was stopped (for example when conditions indicated window breakage would have occurred), a change was made, and the run restarted.

Figure 8 shows the upper layer temperatures for the six bedroom fire scenarios. Figure 9 shows the variation in the height of the smoke layer interface in the bedroom with time. Figures 10 and 11 respectively show the upper layer oxygen concentration and the heat release rate in the bedroom.

Figure 12 shows the upper layer temperatures for the three lounge room fire scenarios, while Figure 13 shows the variation in the height of the smoke layer interface in the lounge with time. Figures 14 and 15 respectively show the upper layer oxygen concentration and the heat release rate in the lounge.

Figure 16 shows the upper layer temperatures for the three kitchen fire scenarios, while Figure 17 shows the variation in the height of the smoke layer interface in the kitchen with time. Figures 18 and 19 respectively show the upper layer oxygen concentration and the heat release rate in the kitchen.

Figures 20 to 23 show the time for untenable conditions to occur in each room for each fire scenario. The results were output at 10 second intervals, so this is the minimum resolution applicable to the figures.

FIGURE 8 : BEDROOM FIRES - UPPER LAYER TEMPERATURE IN BEDROOM

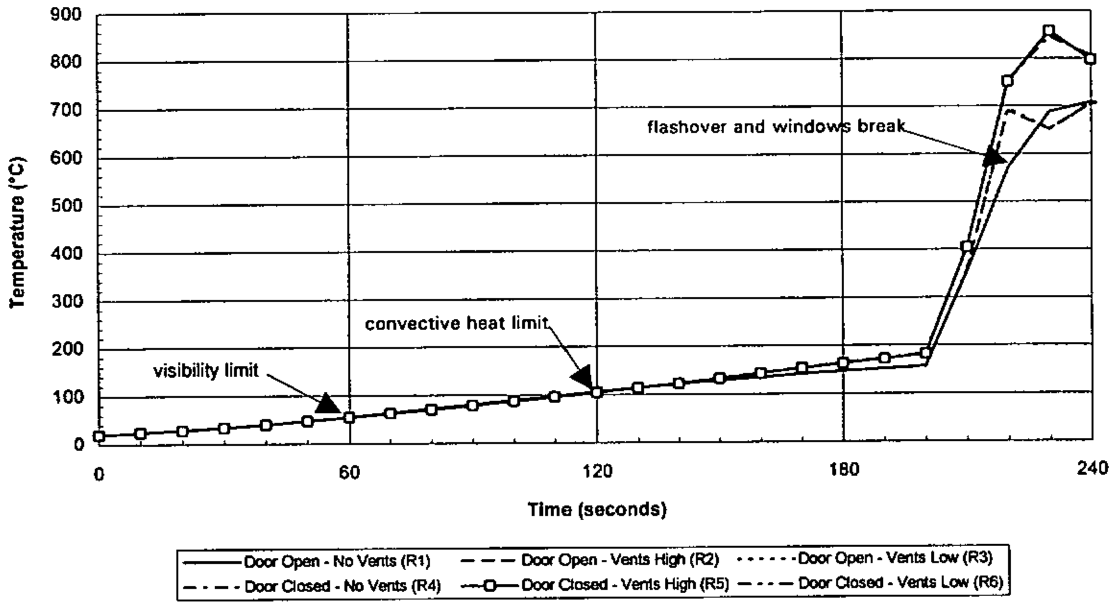


FIGURE 9 : BEDROOM FIRES - SMOKE LAYER INTERFACE IN BEDROOM

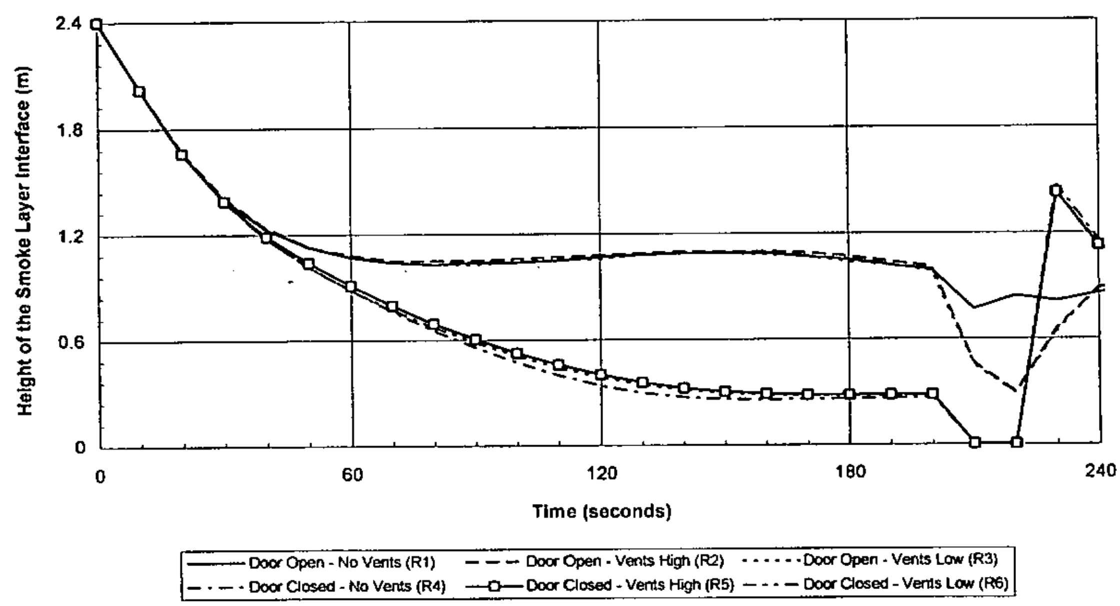


FIGURE 10 : BEDROOM FIRES - UPPER LAYER OXYGEN CONCENTRATION IN BEDROOM

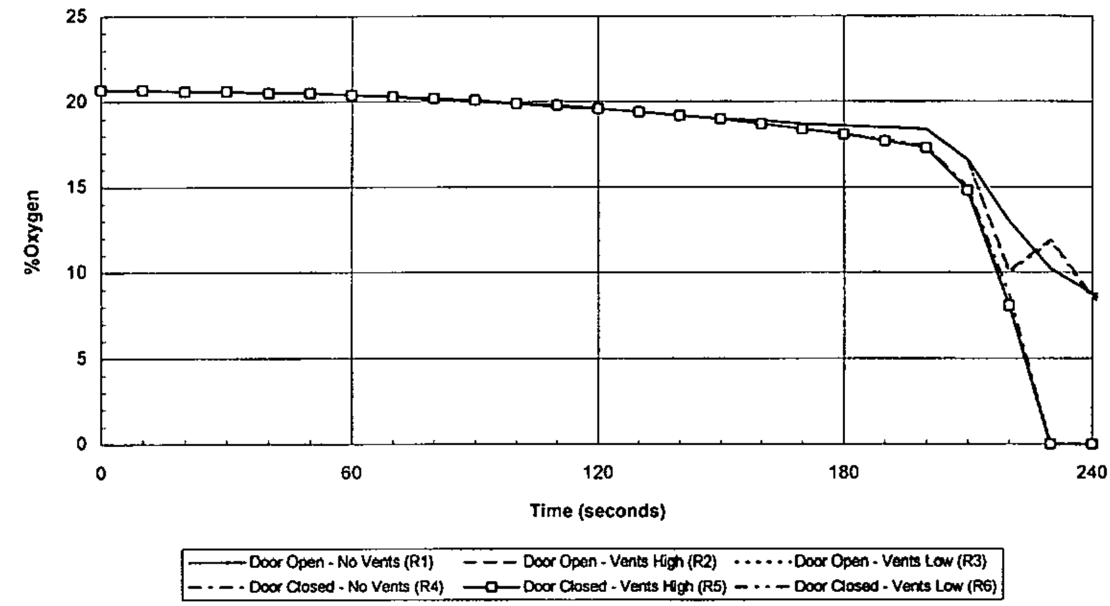


FIGURE 11 : BEDROOM FIRES - HEAT RELEASE RATE IN BEDROOM

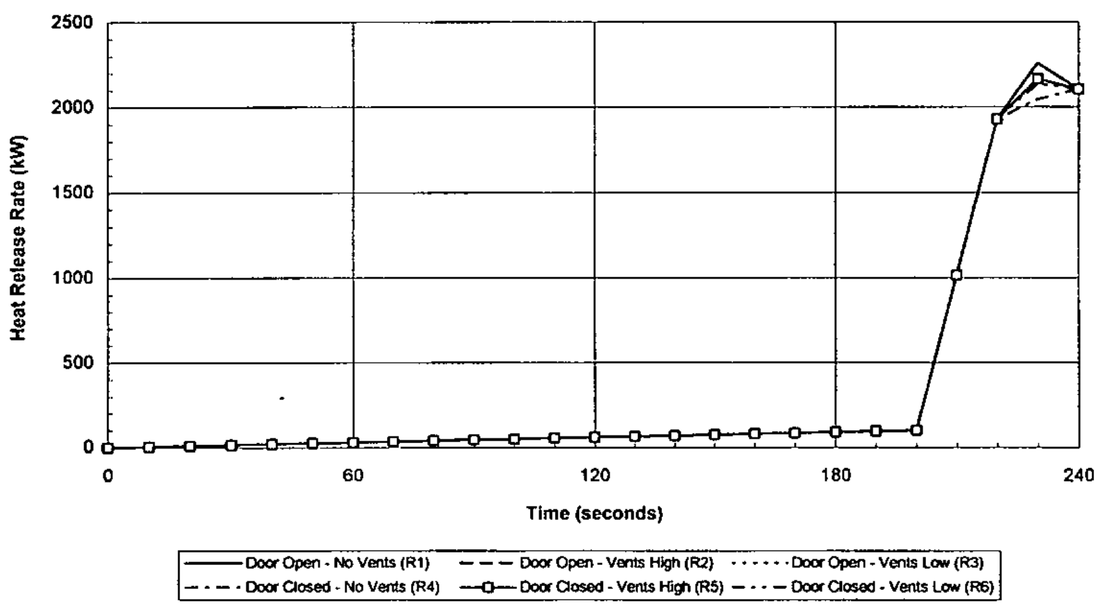


FIGURE 12 : LOUNGE FIRES - UPPER LAYER TEMPERATURE IN LOUNGE

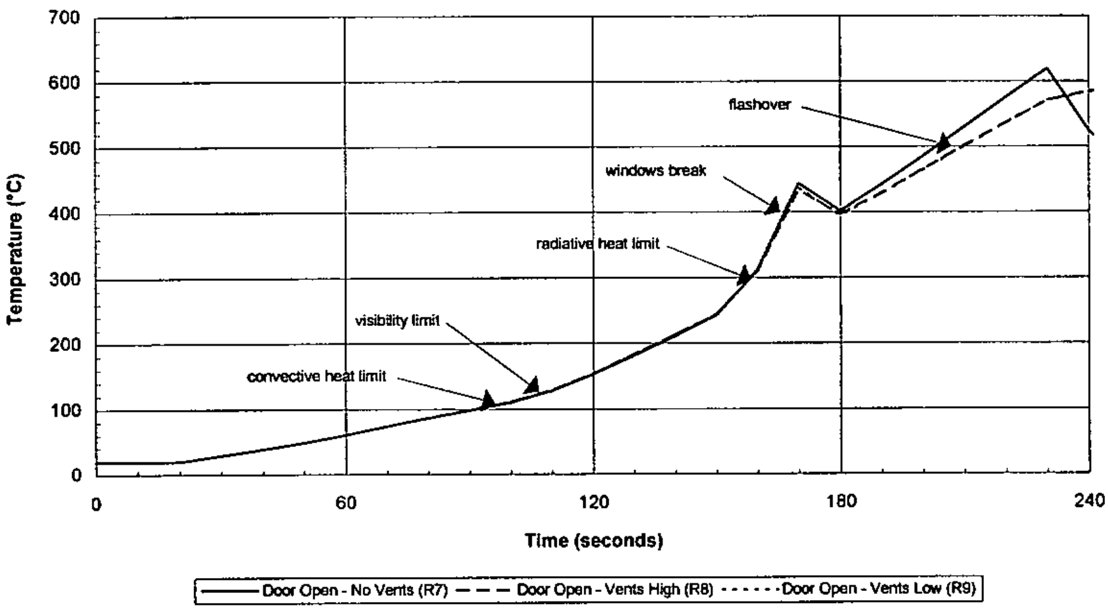


FIGURE 13 : LOUNGE FIRES - SMOKE LAYER INTERFACE IN LOUNGE

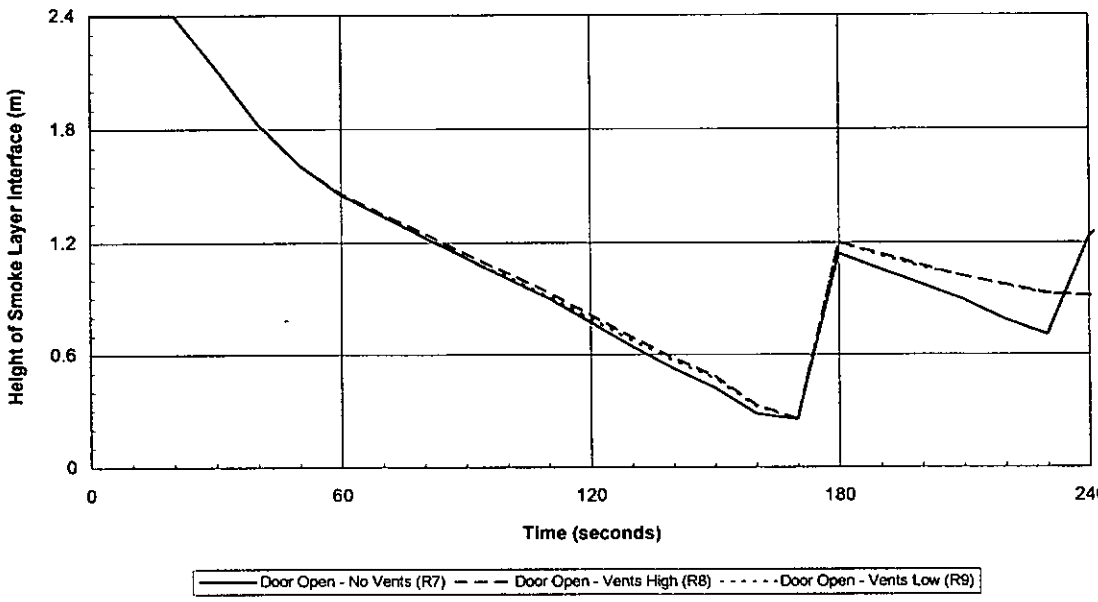


FIGURE 14 : LOUNGE FIRES - UPPER LAYER OXYGEN CONCENTRATION IN LOUNGE

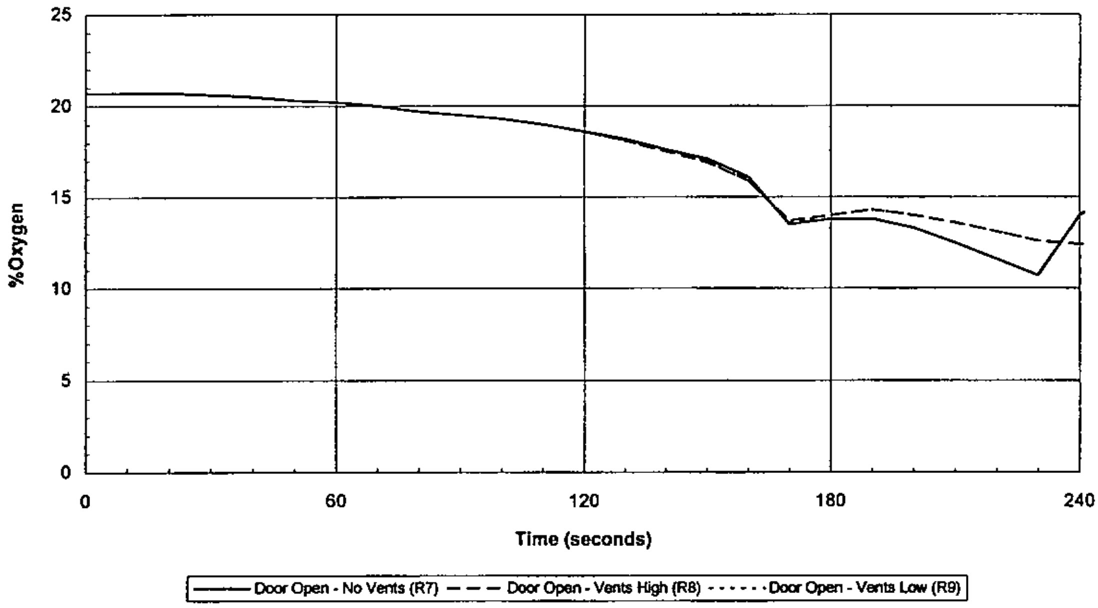


FIGURE 15 : LOUNGE FIRES - HEAT RELEASE RATE IN LOUNGE

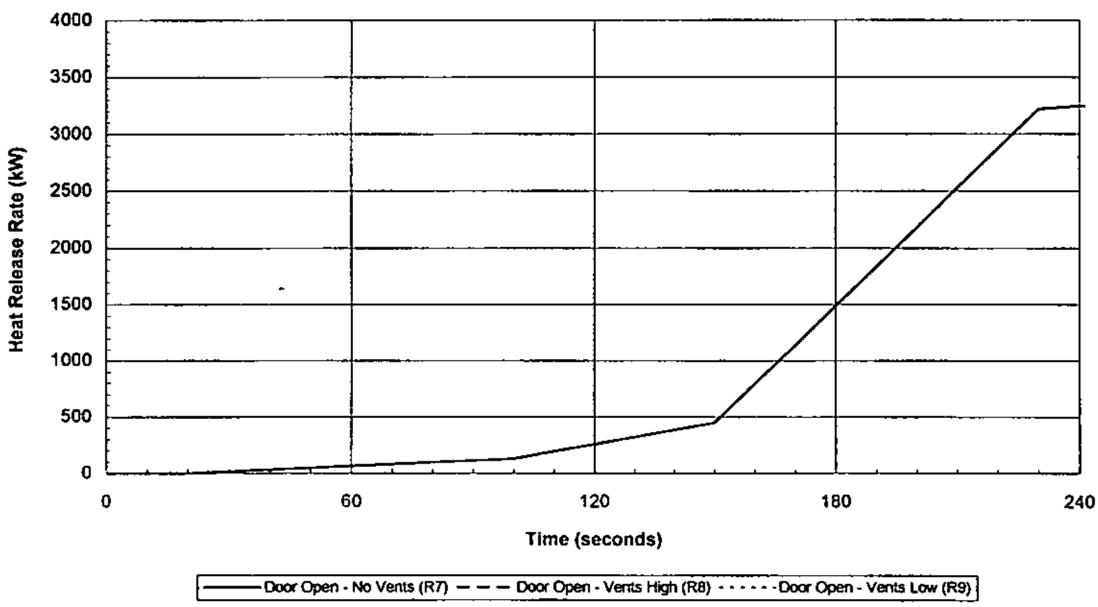


FIGURE 16 : KITCHEN FIRES - UPPER LAYER TEMPERATURE IN KITCHEN

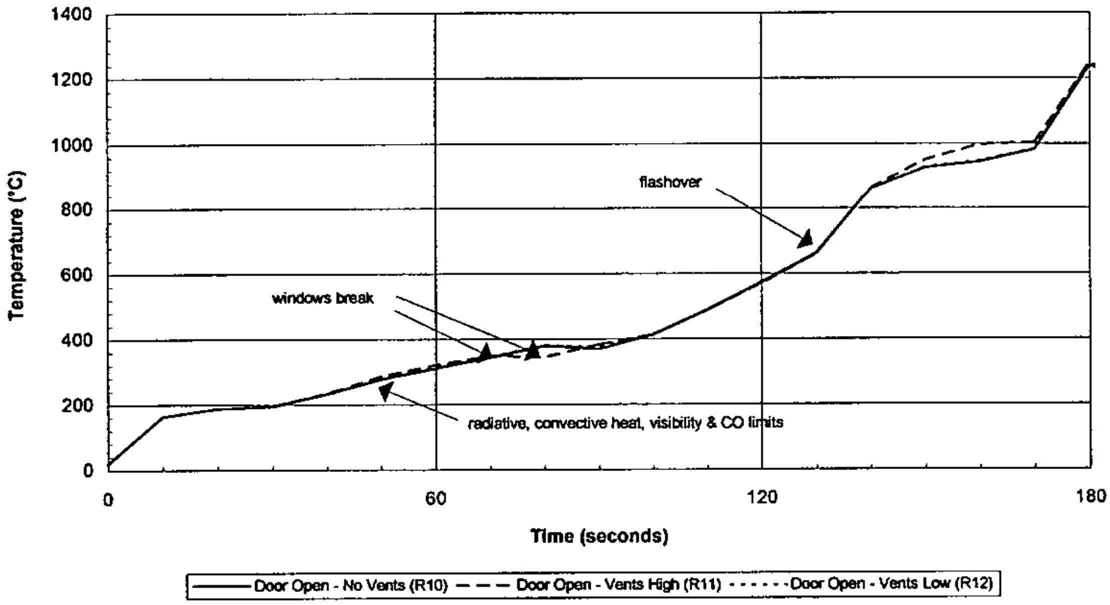


FIGURE 17 : KITCHEN FIRES - SMOKE LAYER INTERFACE IN KITCHEN

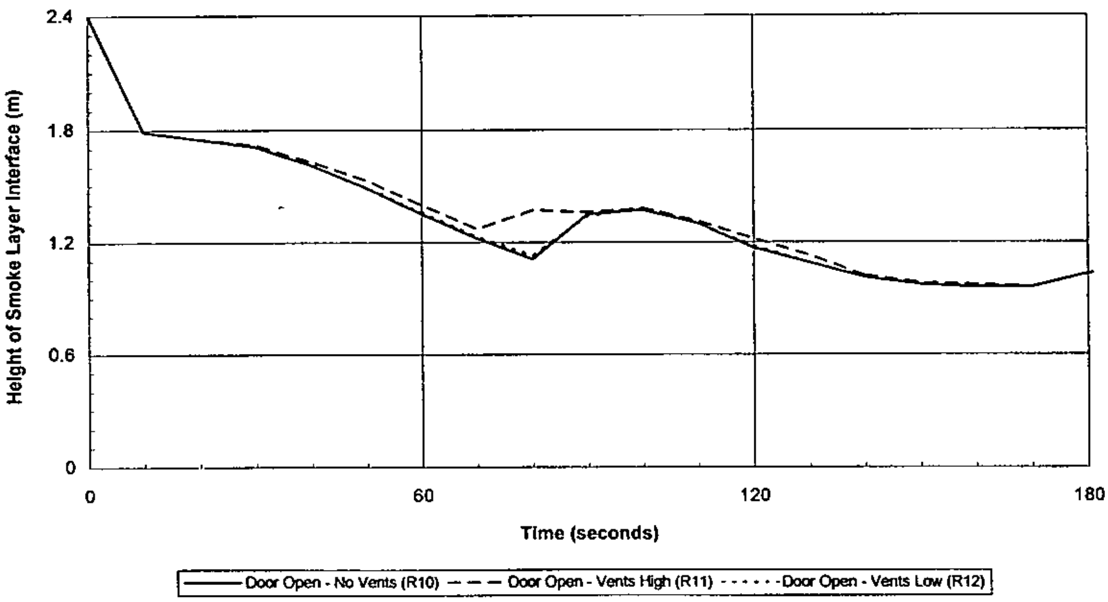


FIGURE 18 : KITCHEN FIRES - UPPER LAYER OXYGEN CONCENTRATION IN KITCHEN

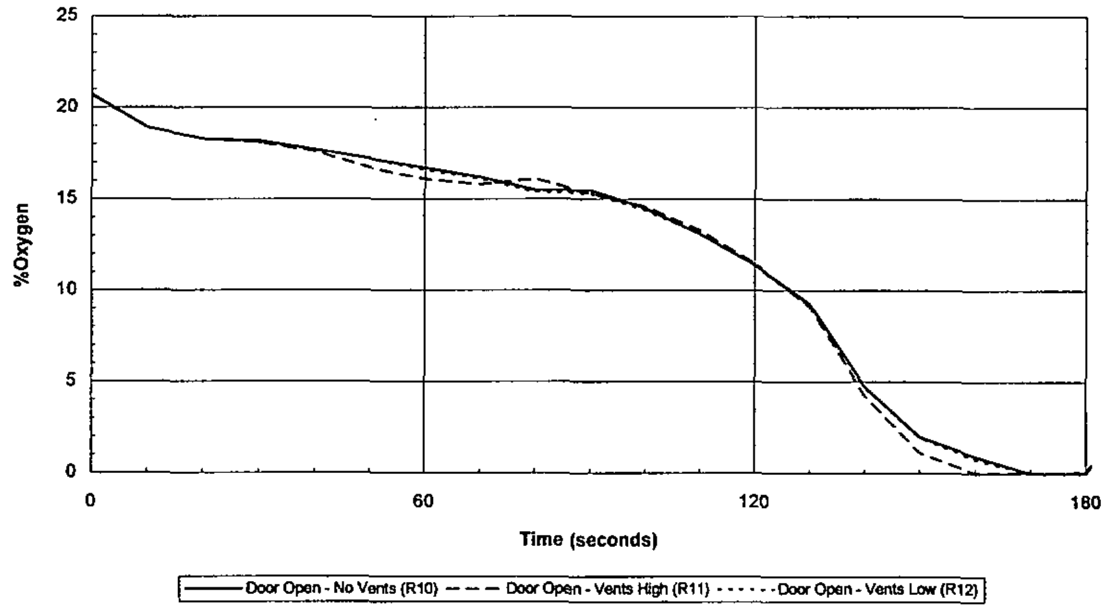


FIGURE 19 : KITCHEN FIRES - HEAT RELEASE RATE IN KITCHEN

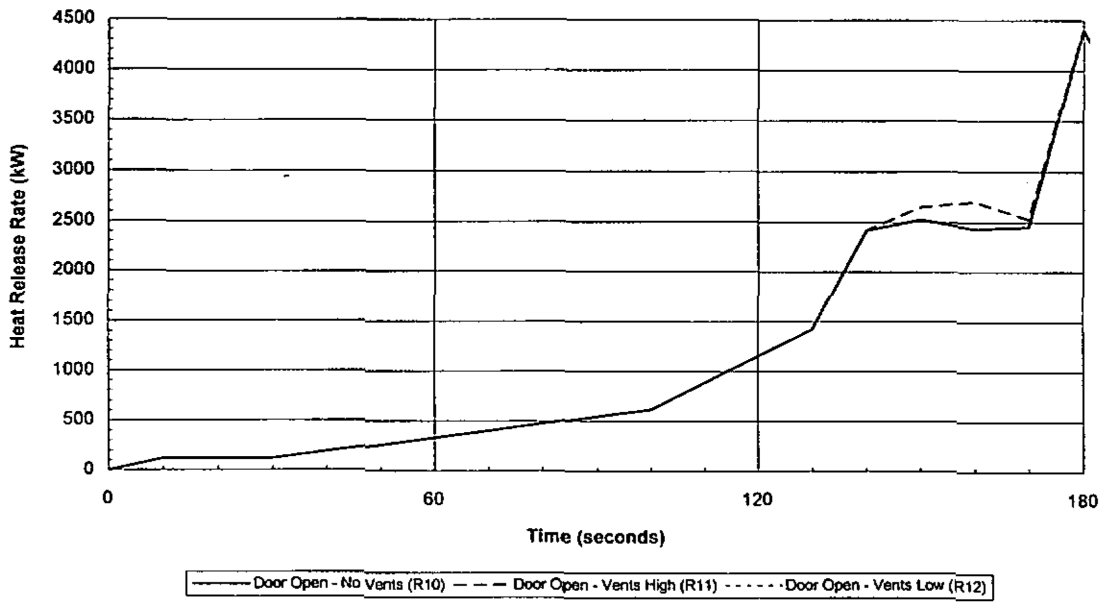
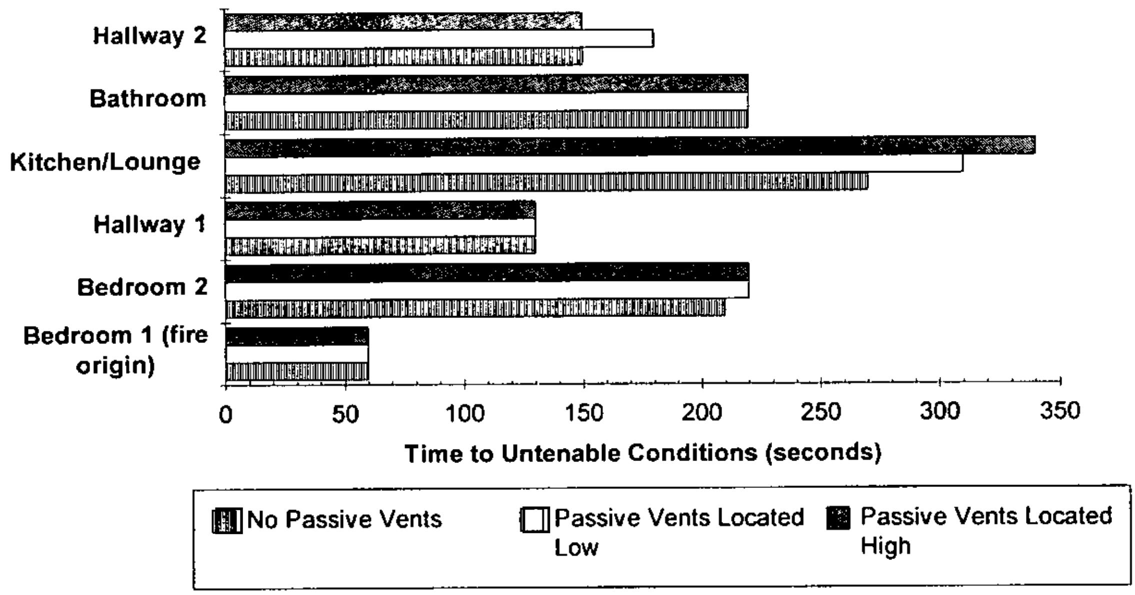
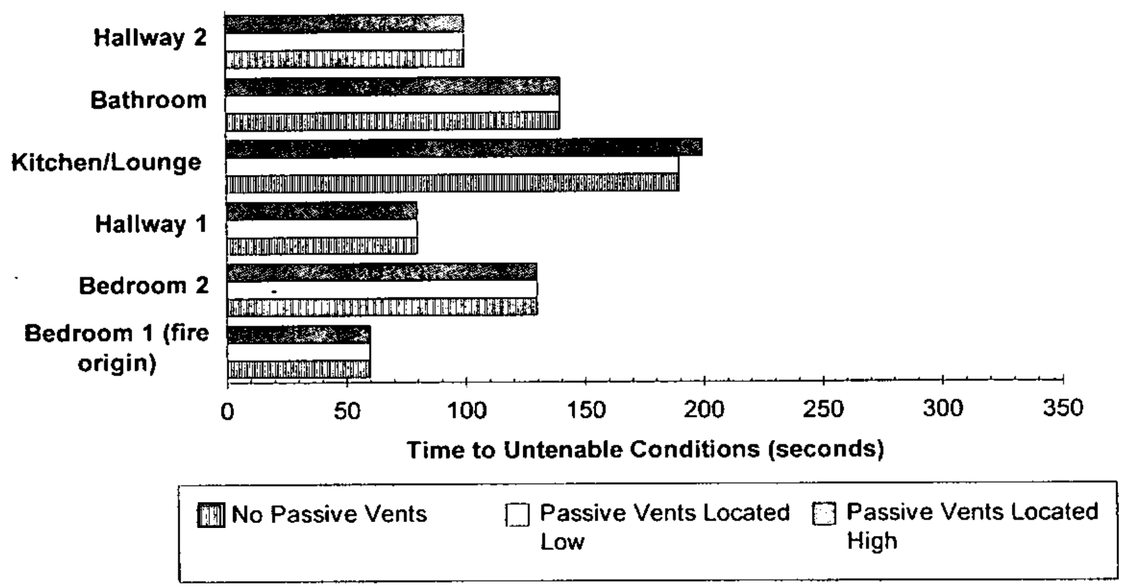


FIGURE 20 : TIME TO UNTENABLE CONDITIONS FOR BEDROOM FIRE WITH DOOR CLOSED



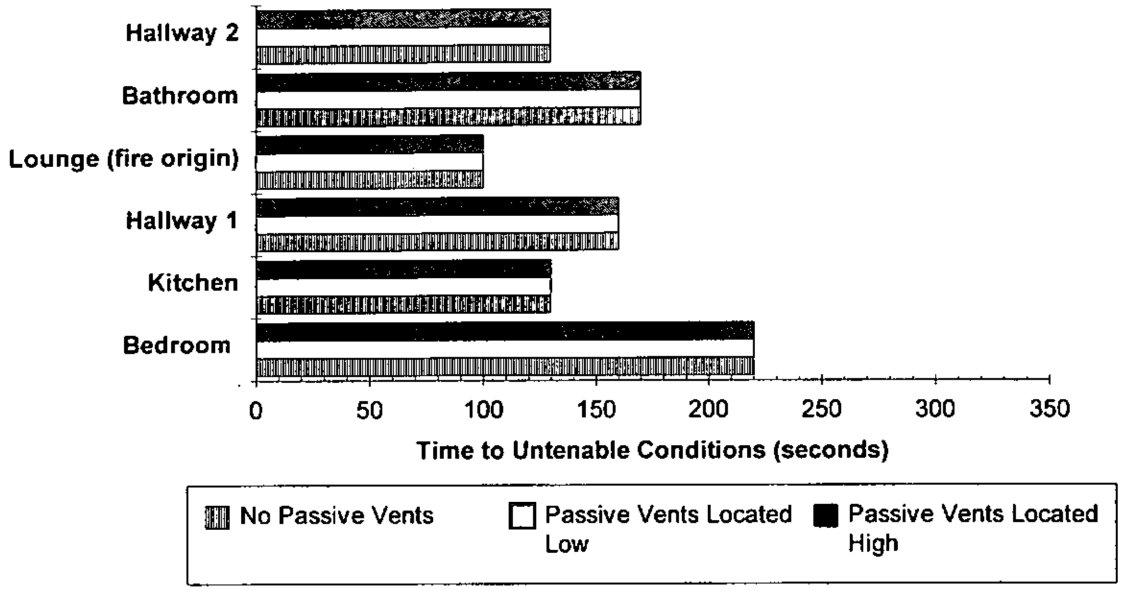
In all cases poor visibility was the limiting condition for untenability.

FIGURE 21 : TIME TO UNTENABLE CONDITIONS FOR BEDROOM FIRE WITH DOOR OPEN



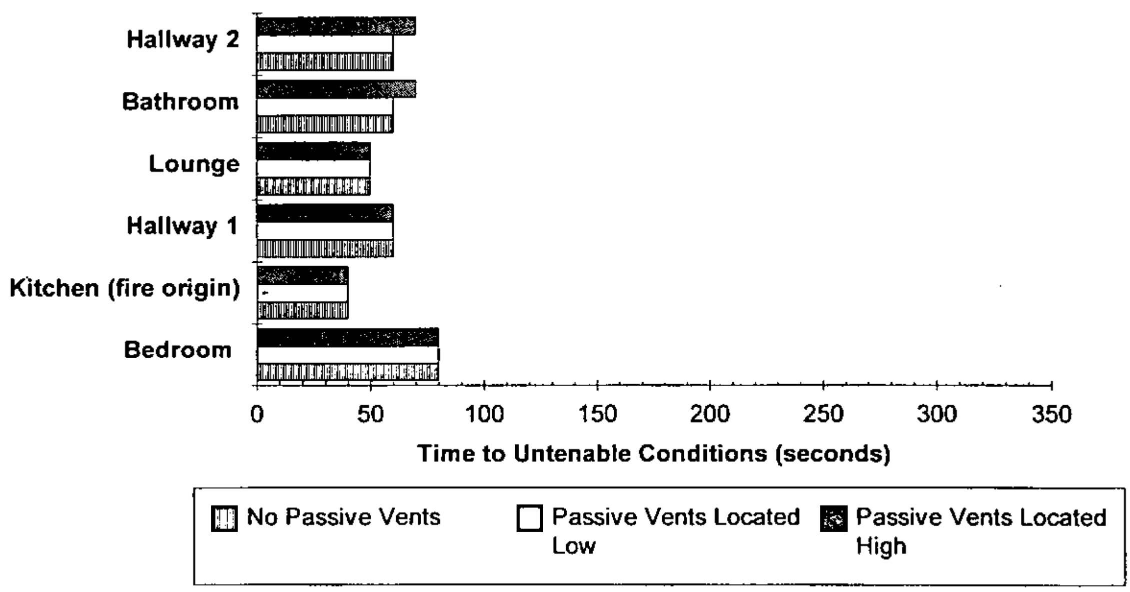
In all cases poor visibility was the limiting condition for untenability.

FIGURE 22 : TIME TO UNTENABLE CONDITIONS FOR LOUNGE FIRE



Poor visibility was the limiting factor in all rooms except the lounge where convective heat was the limiting factor. In the kitchen conditions became untenable due to poor visibility and convective heat occurring at the same time.

FIGURE 23 : TIME TO UNTENABLE CONDITIONS FOR KITCHEN FIRE



Poor visibility and high carbon monoxide levels, jointly, were the conditions causing untenability in all rooms. Convective heat also reached an untenable level in the kitchen, lounge and hallway 2 at the same time.

Discussion

Effect of Passive Vents

Figures 8 to 23 show that the effect of using permanently open passive vents is relatively small.

For an occupant initially located within a room of fire origin, passive ventilation (located either high or low) did not significantly affect the time to untenable conditions. This is shown in Figures 20 to 23 for the room of fire origin.

Figures 9, 13 and 17 show that passive ventilation located at the window head helps to delay the rate at which the smoke layer interface progresses toward the floor. However it can also be seen that the differences in the position of the smoke layer interface are relatively small and, in practical terms, of little consequence to the room occupants.

For an occupant located in a room distant from the room of fire origin, and where the door to the fire room is open (see Figures 21, 22 and 23), there is no difference between having no passive ventilation and having passive ventilation located at low level (i.e. at window sills). A small improvement in conditions is noticed when the passive ventilation is located at a high level (i.e. at window heads), but the increase in time for untenable conditions to be achieved is still relatively small (Figure 21 shows 10 seconds for the kitchen/lounge rooms).

For an occupant located in a room distant from the room of fire origin, and where the door to the fire room is closed (see Figure 20), some benefit (in some rooms) is obtained from providing passive ventilation. One example in this study (Scenario No R5) showed the time for untenable conditions to develop in the kitchen/lounge increase by over 1 minute with passive ventilation at the window heads, compared with no vents fitted. The relevance of this time difference can be questioned, as it relates to the time when the smoke interface passed through the 1.5 m level, and thus the time it was assumed the occupant started breathing from the upper layer instead of the lower layer.

Effect of Open or Closed Door to Fire Room

An open door to the room of fire origin allows the fire to spread to other rooms in the house at an earlier stage. Figures 20 and 21 show that, where the door to the room of fire origin is closed, the time to untenable conditions is increased in all rooms, except the room of fire origin. Therefore, a closed door provides additional time for occupants to escape from other rooms in the building provided the time at which they become aware of the fire does not change. In this case, the additional time lies between 50 and 80 seconds. Consequently, closers fitted to internal doors and smoke alarms installed throughout the house would be a positive strategy to improve life safety.

Effect of Fire Size

The kitchen fire described by the mass loss rate curves in Figure 7 develops faster than either the bedroom or lounge room fires, reaching a mass loss rate of 0.3 kg/sec in approximately 170 seconds, compared with 350 seconds for the bedroom fire and 430 seconds for the lounge room fire. The times to flashover are similar for the bedroom fires and the lounge room fires, being in the range 210 to 230 seconds. The time to flashover for the kitchen fires is 130 seconds. The specification of the fire in terms of mass loss rates and effective heat of combustion for the burning items has a significant impact on the time-scale at which the fire develops. Thus, potentially different time-histories for the effects of the fire can result from changing the design fire specification. These effects are significantly larger than the differences observed between the various passive ventilation options studied here.

Conclusions

1. The presence or otherwise of permanently installed passive ventilators in domestic dwellings is unlikely to have a significant effect on the rate of fire development within the building, and hence on life-safety in the building.

2. For an occupant initially located within a room of fire origin, passive ventilation would have no impact on life safety.

3. For an occupant located in a room distant from the room of fire origin, and where the door to the fire room is open, there is no difference between having no passive ventilation and having passive ventilation located at a low level (i.e. at window sills). A small improvement in safety conditions is noticed when the passive ventilation is located at a high level (i.e. at window heads), but the increase in time for untenable conditions to be achieved is still relatively small.

4. For an occupant located in a room distant from the room of fire origin, and where the door to the fire room is closed, there is some benefit (in some rooms) obtained from providing passive ventilation. One example in this study (Scenario No 5) showed the time for untenable conditions to be developed increase by over 1 minute through installing passive ventilation at the window heads.

5. Even if a small advantage can be gained by installing passive ventilation at a high level in rooms, the possible benefits can be totally outweighed by changes in the ignitability and burning rates of the room contents (fire load).

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