Fire Brigade Intervention Model for Residential Buildin[g] in Australia

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ABSTRACT

A risk assessment model is being developed in the Centre for Environmental Safety and Risk Engineering at the Victoria University of Technology to support the use of a performance-based code in Australia which has been in effect since July 1997. One of the central parts of the model is the fire brigade model. This paper provides both a description of the fire brigade model for residential buildings and an outline of how this model is incorporated into the overall risk assessment model.

KEYWORD: risk assessment, life safety, fire brigade, performance-based code

INTRODUCTION

A performance-based code has been introduced in Australia [1], with the aim to provide flexibility to building designs such that the construction cost can be reduced and life safety level is equivalent or higher than the buildings which are designed using deem-to-satisfy provisions.

To facilitate of the use of the performance-based code, a risk assessment model CESARE-RISK is being developed in the Centre for Environmental Safety and Risk Engineering (CESARE) at the Victoria University of Technology under contract to the Fire Code Reform Centre Ltd [2]. The model is intend to be used initially for residential buildings only, with the feasibility of applying to other building types in future. One of the key parts of the risk assessment model is the Fire Brigade Intervention Model. A conceptual fire brigade model has been developed by the Australasian Fire Authority Council (AFAC) for all building types in Australia [3] which is both complex and detailed in nature. This paper details a simpler model for residential buildings only and describes the use of this model in the overall risk assessment model.

MODEL CONCEPTS

The Fire Code Reform Centre (FCRC) Limited was established in 1995 by the Australian Building Code Board (which represents all the states and territory governments) in conjunction with major industrial organisations to undertake major building code reforms in Australia. One of tasks is to modify the existing prescription-based code for residential buildings which include apartment buildings, hotels, motels, hostels and aged care centres. Because of the large variation in the building designs, a generic building layout as shown in Figure 1 is considered for risk assessment purpose, where RFO denotes the room of fire origin, AFO denotes the apartment of fire origin, ANFO denotes all the apartment of non-fire origin at the fire floor, AAL denotes all the apartments at another level.

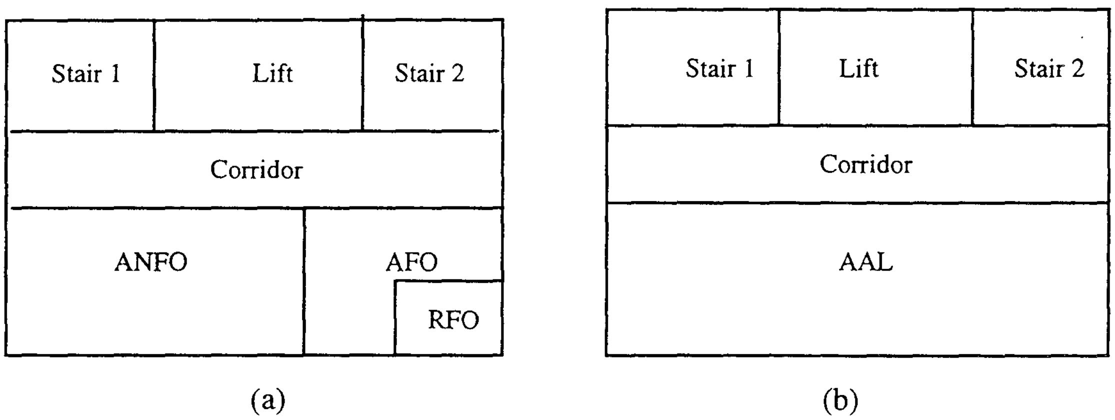

Figure 1 Generic Building Layout (a) Level of Fire Origin (b) Other Levels.

The risk assessment for this generic building is classified as level 3 analysis by the Fire Engineering Design Brief (FEDB) [4]. Such an analysis relies on probabilistic analysis of fire occurrence, detection and suppression systems, occupant response, barrier performance, fire and smoke spread and fire brigade response and intervention. A schematic drawing about the risk assessment model is given in Figure 2. Details of the model are given in [5]. This paper describes the details of the fire brigade model.

The fire brigade model for residential buildings is named Fire Intervention for REsidential Buildings (FIREB). In the FIREB model, the fire brigade intervention is categorised into five stages as shown in Figure 3: Alarm Stage, Receipt and Assembling Stage, Travel Stage, Preparation Stage and Fire Fighting & Search and Rescue Stage.

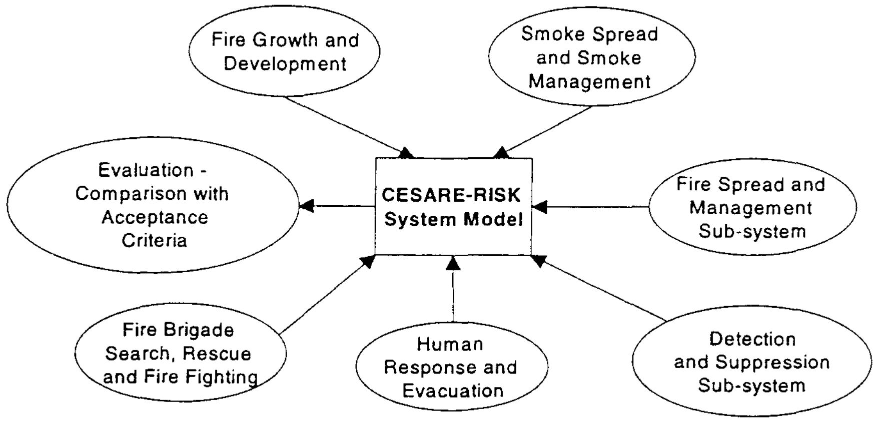

Figure 2 Risk Assessment Model

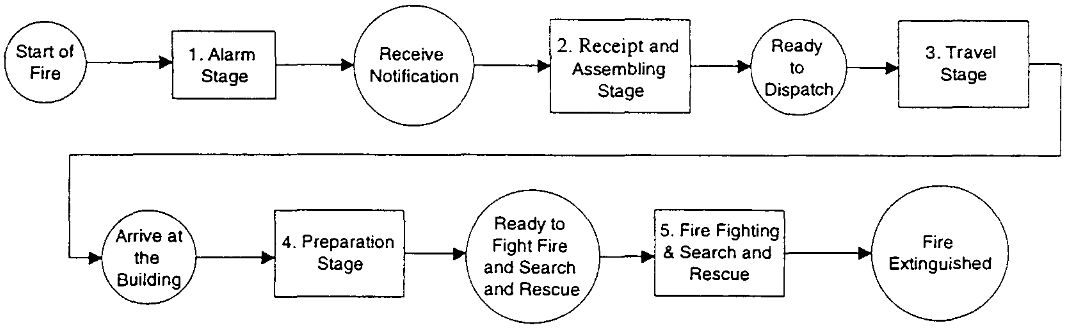

Figure 3: Fire Brigade Intervention

Stages 2, 3 and 4, that is, Receipt & Assembling Stage, Travel Stage and Preparation Stage are considered using a probabilistic model which is named the Fire Brigade Arrival Model (submodel). The input to this submodel is the notification time which can be either auto-detection or phone call. For each defined fire scenario, three values of the notification time with certain probability attached [2] will be used as the input to this submodel. The output of this submodel is the time of fire brigade starting fire fighting and/or search and rescue. The probabilistic nature of both the input and the other variables within these three stages are considered in the probabilistic model. Further the output is also a probabilistic variable. Three values are then generated from the output of the model, that is, the time of fire brigade arrival, according to the three-realisation method [6, 7], and these three values are used as the start time for fire fighting and search and rescue actions which forms three sub-scenarios as shown in Figure 4.

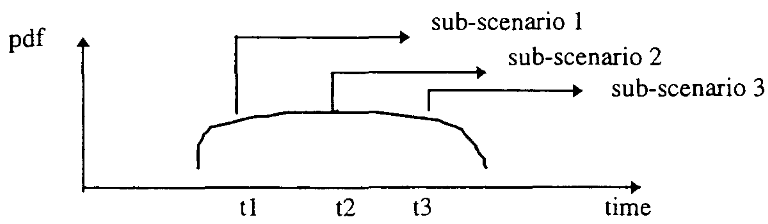

Figure 4 Three-realisation method for the time of fire brigade arrival for each fire scenario

The following sections gives details for each of the five stages in FIREB. Unless otherwise stated, all data are from [3].

ALARM STAGE

After outbreak of a fire, fire brigade may receive notifications from people or via electronic means for buildings which have direct connection to the fire brigade. The time of notification to the fire brigade via electronic means can be estimated as the sum of the time of activation of subsystem that is linked to the fire brigade (which can be detector, sprinkler etc) and the delay time prior to sending an electronic message to the fire brigade, that is,

$$t_{a/e} = t_{act} + t_{d/e} \tag{1}$$

where ta/e is the time of receiving notification via electronic means, tact is the time of activation of the subsystem which is connected to the fire brigade, $t_{d/e}$ is the delay time to sending an electronic message to the fire brigade include the follows:

- time to verify the alarm, which is estimated to be 15 s,
- time to de-pressurise a suppression system (sprinkler system) if the system connected to the fire brigade; this time is estimated to be 180 - 360 s for a AS 2118.1 system [8].

Further, tact can be predicted by the detector activation models and sprinkler activation model developed by Moore [9, 10].

The time of fire brigade receiving notification from people via telephone is estimated by comparing the time with ta/e from fire brigade statistics Δt1 which is currently under investigation by Melbourne Fire Brigade (MFB). If Δt1 is known, the time of phone call can be estimated as:

From an analysis of existing statistics: $\Delta t1 = t_{ph} - t_{a/e} = t_{ph} - t_{act} - t_{d/e}$ (2)

Hence predicted time of telephone notification: $t_{ph} = t_{act} + t_{d/e} + \Delta t1$ (3)

RECEIPT AND ASSEMBLING STAGE

The total time required at this stage is the time for receipt of notification plus the time of response.

(a) Receipt

(i) Direct Electronic Notification:
The receipt time is the time to relay dispatch information only.

- If a fully electronic CAD system is installed, the time to relay dispatch information is 0.
- If a part manual electronic CAD system is installed, the time to relay dispatch information is 15 s.

(ii) Phone Call
The receipt time is the time to receive and take down verbal information plus the time to relay dispatch information.

- Time to receive and take down verbal information is 60 s.
- The time to relay dispatch information is 30 s.

Therefore, if it is a phone call, the receipt time is 90 s.

(b) Assembling

Time for fire fighters to assemble is given below:

- If the fire fighter is not at the fire station (volunteers), the time to travel to the fire station dress, assemble, assimilate information and leave station is 480 s.
- If the fire fighter is at the fire station, the time to dress, assimilate information and depart is 90 s.
- If the fire fighter is not at the station but on the fire truck, the time to make up and become mobile is 60 s. This case is not considered for this FCRC project because the time compared to the fire fighter at the fire station (90 s) is not large, and using 90 s is conservative.

TRAVEL STAGE

Time to travel from the fire station to the building where fire occurs is calculated using the travel distance divided by travel speed:

$$t_t = \frac{D}{S} \quad (4)$$

where D is the travel distance between the fire station and the building, and S is the travelling speed of the fire brigade.

For a specific building under consideration, the travel distance is known. For This FCRC project which considers a generic building, the travel distance is estimated using the area method and making conservative assumptions. The travel distance is assumed to be 1.5 times the radial distance between the fire station and the building, and the radial distance is half of the maximum distance between two fire stations as shown in Figure 5. For Metropolitan Fire Brigade (MFB) Melbourne, the linear distance between the fire station and the building is estimated to be 3 km.

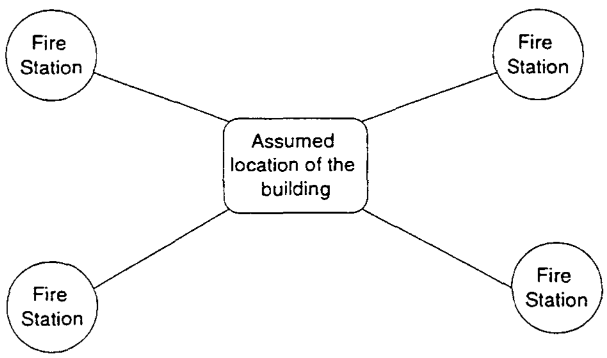

Figure 5: Assumed location of the building in relation to the fire stations

PREPARATION STAGE

On arrival at the building, the preparation stage commences; this stage includes:

- initial information gathering
- assess the fire
- setup equipment

The time to assess the fire is usually done by the officer in charge (OIC) and is conducted in parallel with equipment setup. Thus the time for preparation stage is the time for initial information gathering plus the minimum time of setting up equipment and assessing the fire, that is,

$$t_{pre} = t_{info} + \max(t_{ass} + t_{set}) \tag{6}$$

where t_{pre} is the time for preparation stage, t_{info} is the time for initial information gathering, t_{ass} is the time to assess the fire, and t_{set} is the time to setup the equipment. This assumes that the assessment of the fire and setting up equipment are done concurrently; and the next stage starts after both assessment of the fire and setting up equipment are finished.

(a) Time for Initial Information Gathering

The time for initial information gathering include

- communication with warden (if any)
- checking fire indication panel (FIP)
- talk to occupants

The times are estimated to be

- 60 s if building floor area is less than 1000 m^2
- 75 s if building area is grater than 1000 m^2 but less than 5000 m^2
- 150 s if building area is greater than 5000 m^2 but less than 10000 m^2
- 180 s if building floor area is greater than 10000 m^2.

(b) Time to Assess the Fire

After initial gathering of the information, the officer in charge (OIC) will usually go to the fire enclosure to assess the fire. If the fire is large, OIC will then call in additional resources. The additional resources called in depend on the availability of resource, the location of the fire and the fire size etc. For simplicity, it is assumed that if additional resources are required, the additional resources provided will be the same as the initial resources, and such additional resources can be called in more than once if available.

The time required for OIC to assess the fire is

(I) fully developed fires

- If the fire is a fully developed fire, the fire is large and usually its location and extent is obvious. The time to assess the fire is assumed to 30 s.

(II) Non-fully developed fires

- If the building is less than 3 storey, the time to assess the fire t_{nf1} is the time for OIC to walk to the fire enclosure and return back to the set up area plus an investigation time of 30 s.

- If the building is more than 3 storey, the time to assess the fire t_{nf2} is t_{nf1} plus an investigation time at the level below and above the fire floor.

(c) Time to Setup Equipment

Depending on the location of the fire and the size of the fire, fire brigade will prepare equipment for fire fighting and search and rescue.

The types of equipment used for fire fighting are:

- 65 mm hose utilised to and from pumper appliance
- 38 mm hose utilised from internal hydrant (via high rise pack)
- 65 m of high pressure (HP) hose line connected to the fire appliance

where the 65 m HP line can only be used for up to 3 levels because of its length limit.

The time to setup equipment is the sum of the time of all activities to setup the equipment except those activities are done in parallel with the others and have a shorter time duration. Various activities to setup equipment include:

1. setup hose line
2. done BA & prepare
3. drag hose line to stair entry
4. ascend fire stair with hose line

Assumptions have been made as follows:

- dual headed external hydrant available
- boosted connection provided
- hydrant locations in stairs according to relevant Australian Standard
- pressure and flow available according to relevant Australian Standard

FIRE FIGHTING & SEARCH AND RESCUE STAGE

The fire brigade resources depend on the location of the fire. The fire brigade resources are assumed as follows for the first alarm:

- Major city central business district: 4 trucks, 12 fire fighters
- Other city areas and rural town: 2 trucks, 6 fire fighters.
- Rural country: 1 truck, 6 fire fighters.

Additional resources can be called in after the fire assessment by the officer in charge.

The following fire fighting and search and rescue strategy is assumed:

- for 6 fire fighters (2 trucks):

2 fire fighters fight on the fire
2 fire fighters do search and rescue
1 officer in charge and 1 gets water source

- for 12 fire fighters (4 trucks):

4 fire fighters fight the fire
4 fire fighters do search and rescue
1 officer in charge and 3 does other things

(a) Fire Fighting

The time required for fire fighting depends on the fire severity at the time of the fire brigade arrival, the fire brigade resources, the residual population within the building, and other factors such as availability of water supply and fire fighting equipment. The time of fire extinguishment can be calculated by

$$t_{fe} = t_{ff} + \Delta t \quad (6)$$

where t_{fe} is the time of fire extinguished or burn out, Δt is the time duration from the time when fire fighting starts to the time of fire extinguished or fire burn out, and t_{ff} is the time when fire fighting starts.

For simplicity, it is assumed that there can be only two outcomes resulting from the fire fighting, that is, fire no control and fire extinguished as shown in Figure 6. The outcome is determined by comparing the fire size with the delivered water extinguishing capacity.

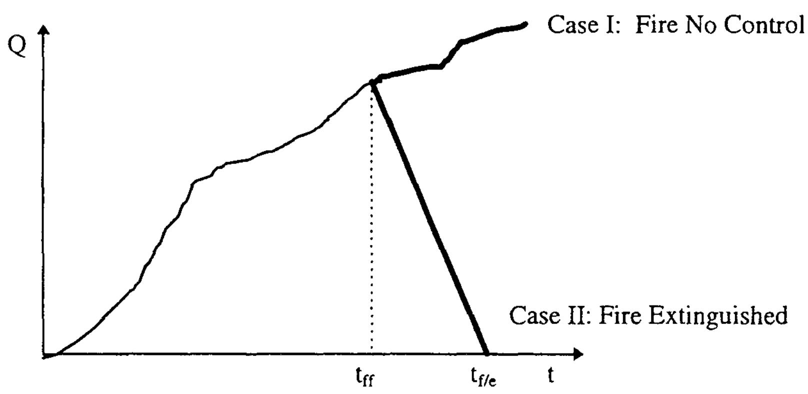

Figure 6: Two possible outcomes due to fire brigade intervention

The theoretical water cooling capacity is estimated to be 3.5 MW per l/s water. For extinction of diffusion flames, this theoretical absorption capacity should be multiplied by a factor of 3 because it is sufficient to only remove 30 to 35% of the released energy from diffusion flames to gain extinguishment. Thus the theoretical extinguishing capacity for per l/s water is a fire size of 10.5 MW.

The actual delivered water rate depends on the fire fighting equipment and available resources for fire fighting. For simplicity, it is assumed that the number of hose lines is the same as the number trucks. For internal fire fighting, the minimum water rate is 5 l/s per hose line, and for external fire fighting, 10 l/s per hose line.

For practical purposes, not all water applied have an effect on the fire. The efficiency of water applied varies significantly with fire fighting skills, equipment type, fire size, enclosure dimensions and water droplet size. For simplicity, an efficiency of 15% is chosen for internal fire fighting, and 5% for external fire fighting. The applied water extinguishing capacity is thus:

- 15% x 10.5 = 1.58 MW per l/s water for internal fire fighting, and
- 5% x 10.5 = 0.53 MW per l/s water for external fire fighting.

If the conditions in the corridor become untenable for the fire fighter, that is, the temperature is greater than 250 ^{0}C, the fire fighter can not stay in the corridor, and external fire fighting will be used. Otherwise, internal fire fighting is always the preferred option.

Case 1: Fire Not under Control

If the fire size (heat release rate) is greater than the applied water extinguishing capacity, then the fire is not under control. In such cases, the fire is assumed to continue to grow as if there is no fire brigade intervention. The fire may eventually extinguished if more fire brigade resources are available or not sufficient fuel is left. If the fire spread beyond the apartment of fire origin, it is assumed that the fire is not under control and non-time dependent models are used.

Case 2: Fire Extinguished

If the fire size (heat release rate) is smaller than the applied water extinguishing capacity, then the fire is extinguished. The time to extinguish a fire is to be determined.

(b) Search and Rescue

After the equipment setup, the fire brigade is assumed to enter the building with one hose line. If search and rescue is required, it will be started immediately after they enter the building. The search and rescue strategy is assumed to be in the following sequence [3]:

- level of fire origin
- level above and below the fire origin
- other levels above the fire origin

The number of occupants rescued by the fire brigade depends on many factors. For simplicity, it is assumed that these factors are

- the time available for fire brigade to rescue the occupants,
- the number of residual occupants in each location (further classified as mobile and non-mobile which will be detailed later) and
- fire brigade rescue resources.

The fire brigade rescue can only take place before the untenable conditions for the fire brigade occur to avoid harm to the fire brigade. The untenable conditions for fire brigade is different from for occupants because fire fighter have protection clothes. The untenable conditions for fire fighters is defined to occur at 250 ^{0}C. After the time of untenable conditions, the fire fighters can not do search and rescue. Therefore, the fire brigade search and rescue is different for each location because the condition at different location is different. There are two types of searches:

- primary search which is a quick initial attempt to gain an idea of the possibility that any occupants are in the immediate vicinity of the fire.
- secondary search which is a through investigation of each compartment in the general area of the fire where occupants could require rescue or assistance.

Search and Rescue Strategy

- first searching level = level of fire origin
- second searching level = level above the fire floor
- third searching level = level below the fire floor
- fourth searching level = two levels above the fire floor
- other searching levels = other levels above the fire floor.

Time Required to Search and Rescue

The total time required for search and rescue is the sum of the time required for search and the time required for rescue.

There are two types of searches: primary search and secondary search. A primary search is a quick initial attempt to gain an idea of the possibility that any occupants are in the immediate vicinity of the fire. This generally occurs in compartments with a small size. A secondary search is a thorough investigation of every compartment which is generally conducted by a search team rather than an individual fire fighter. In case of residential buildings, primary search is usually used. The primary search speed is estimated to be 1.3 m/s, and the secondary search speed is 0.16 m^2/s. Thus the total time to search is

$$dt_s^i = \frac{D_i}{S_p} \quad \text{for primary search} \tag{7a}$$

$$dt_s^i = \frac{A_i}{S_c} \quad \text{for secondary search} \tag{7b}$$

where dt_s is the time required to search enclosure i, D_i is the search distance for the enclosure which is the sum of the enclosure length and width, Ai is the floor area of the enclosure, S_p is the primary search speed, and S_c is the secondary search speed.

The required time for rescuing n_{nm} non-mobile occupants by n_{fbr} fire fighters in one location (AFO, ANFO, or any other levels where rescue is required) is estimated by the search time given by equation (7) plus the time to carry the occupant to the exit plus the time to return to the same location; that is,

$$dt_r = \frac{n_{nm}}{n_{fbr}} \times \left[\frac{(W+L)/2 + Lc/2 + Ds}{S_r} + \frac{(W+L)/2 + Lc/2 + Ds}{S_s}\right] \tag{8}$$

where dtr is the time required to rescue all non-mobile occupants at one level, n_{nm} is the total number of non-mobile occupants, n_{fbr} is the number of fire brigade doing search and rescue. W and L are the enclosure width and length, L_c is the length of the corridor, D_s is the travel distance in stair, S_r is the rescue speed which is 0.05 m/s and S_s is the fire brigade returning speed which is assumed to be 1.0 m/s.

Time to Start and Finish Search and Rescue in Each Location

According to the fire brigade strategy, the time of fire brigade starting to search and rescue in the apartment of fire origin is the time of fire brigade arrival at the fire scene (kerb-side) plus the time used for preparation stage, that is,

$$t_{rAFO} = t_{fba} + dt_p \quad (9)$$

where t_{rAFO} is the time of fire brigade starting to rescue people in the apartment of fire origin. t_{fba} is the time of fire brigade arrival, and dt_p is the time required to reach the apartment of fire origin. t_{rAFO} is also the same as t_{ff}.

The time of fire brigade starting to rescue people in the apartment of non-fire origin is the time of fire brigade complete the rescue in the apartment of fire origin; that is, t_{rAFO} plus the time required to complete the rescue for the occupants at the apartment of fire origin; which is,

$$t_{rANFO} = t_{rAFO} + dt_s + dt_r \quad (10)$$

where t_{rANFO} is the time of fire brigade starting to rescue people in the apartment of non-fire origin, and dt_r is the time required to search and rescue the people in the apartment of fire origin.

The time of fire brigade rescue at any other enclosure is the time when the fire brigade complete the search and rescue at the previous enclosure (according to the rescue strategy) plus the time required to travel from the previous enclosure, which can be expressed as

$$t_r^i = t_r^{i-1} + dt_r^{i-1} + dt_s^{i-1} + dt_t^{i-1} \quad (10)$$

where t_r^i is the time of fire brigade starting to search and rescue at enclosure i, dt_r^{i-1} is the time required to rescue people at enclosure (i-1), dt_s^{i-1} is the time required to search enclosure (i-1), and dt_t^i is the time required to travel from enclosure (i-1) to enclosure i.

Impact on the Occupants Conditions

At the time of fire brigade rescue, there are two types of occupants, namely, mobile occupants and non-mobile occupants. The mobile occupants are the occupants who can move without any assistance from the fire brigade, while the non-mobile occupants are the occupants who are incapacitated or who are fatalities or are disabled occupants. For the mobile occupants, the fire brigade may need to give instruction or accompany them to the exit, and for the non-mobile occupants, the fire brigade will have to carry them to a safe place. It is assumed that the fire brigade are not able to discriminate those occupants who are incapacitated or who are fatalities.

Since the fire brigade may give some help to the occupants, such as providing oxygen to the occupants, it is assumed that if the occupant is a mobile occupant at the time of fire brigade rescue, the occupant is safe. For the non-mobile occupants, from the time of fire brigade rescue, they will have the same speed as the fire brigade rescue speed. It should be noted that the fire brigade rescue speed is the speed when the fire brigade carry a non-mobile occupant, which is 0.05 m/s with standard deviation of 0.03 m/s. The thermal and toxic doses will be accumulated until the non-mobile occupants are rescued to the exit to determine their final fate.

CONCLUSION

A fire brigade intervention model for residential buildings in Australia has been developed. This model is being incorporated into the overall risk assessment model. Variation in the time of fire brigade arrival is considered via the use of the three-realisation method.

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