*International Journal on Engineering Performance-Based Fire Codes, Volume 1, Number 2, p.81-95, 1999*

# SOME DISCUSSIONS ON EGRESS CALCULATIONS - TIME TO MOVE

**R. Marchant**
Adelaide Fire Safety Research Unit, Department of Mechanical Engineering, University of Adelaide
Adelaide, SA 5000, Australia[#]

## ABSTRACT

In Australia, changes to the Building Code of Australia (BCA) have since 1996 allowed building designers to use alternative fire engineering solutions, in lieu of the traditional deemed to satisfy prescriptive building regulations. The alternative solution must achieve a performance which is equal to or better than that achieved by the deemed to satisfy prescription.

Occupant egress is a cornerstone of Building legislation throughout the world. In a performance-based fire engineering design, it is often necessary to calculate the time taken for occupants to escape. This must be complete, before the calculated conditions within the escape path become untenable.

This paper describes a conceptual hypothetical methodology for calculating the time before occupant movement is initiated, in response to different evacuation cues. This methodology was apparently developed by Jonathan Sime, for inclusion into the Draft British Standard Fire Engineering Code 1994. A description of the Occupant Avoidance Sub-system, SS5 in the Australian Fire Engineering Guidelines, March 1996, intended for use by Australian designers, is also described. The Australian methodology was allegedly prepared by Hamish MacLennan. A comparison of the results obtained by each of the two methodologies is then made.

It would appear that Sime's "time to move" hypothesis has been further elaborated by MacLennan and subdivided into "time to respond" and "coping time". Whilst it would be expected that the sum of "time to respond" and "coping time" would be similar to Sime's "time to move", this is not the case. The basic scoring system used by MacLennan for response time is to all intensive purposes the same as that Sime has used for his total occupant pre-movement time, except that multipliers have been introduced to the scores in MacLennan's system and his mathematical manipulation of the scoring system differs to that of Sime.

MacLennan's calculated "time to respond" is greater than Sime's calculated "time to move" and is further extended when "coping time" is added. A comparison of the two methodologies applied to typical building occupancies with typical AS 2220 systems reveals that the "time to move" generated by MacLennan's method is many times greater than that generated using Sime's conceptual method.

It would appear that if MacLennan's data employs a modified mathematical procedure as suggested in this paper, it can produces results comparable to Sime's original method. It is suggested that the proposed modified calculation procedure be adopted as an interim measure to facilitate acceptance of a worthy design methodology by the Australian fire engineering design community. This gives an added advantage that further reductions in the occupant coping time (hence total occupant pre movement time) will arise where effective in house management and training systems are in place. Further refinement and validation of the methodology is recommended.

## 1. AUSTRALIAN FIRE ENGINEERING PRACTICE

In Australia, changes to the Building Code of Australia (BCA) [1] have since 1996 permitted alternative fire engineering solutions to be used by building designers, in lieu of the traditional deemed to satisfy requirements of prescriptive building regulations, provided that the alternative solution has a performance which is equal to or better than that achieved by the deemed to satisfy prescription.

[#] Mr. Marchant is also a Fire Safety Engineer, South Australian Metropolitan Fire Service, Fire Safety Department, 99 Wakefield St., Adelaide, SA 5001, Australia. Tel: (618) 8204 3611 Fax: (618) 8204 3781 e-Mail: samfsrlm@senet.com.au in addition to Tel: (618) 8303 5020 Fax (618) 8339 8246 e-Mail afsru@senet.com.au.

A principal Australian document which provides guidance for engineers embarking upon a performance based design option is the *Fire Engineering Guidelines, March 1996* (FEG) [2] which was developed by the Fire Code Reform Centre (FCRC) [3] as part of Australian Microeconomic Reform strategies encouraged during the late 1980's and early 1990's.

Occupant egress is a cornerstone of Building legislation throughout the world. In a performance based fire engineering design, it is often necessary to calculate the time taken for occupants to escape before conditions within the building become untenable. The FEG describes the concepts of Available Safe Evacuation Time (ASET) which is dependent upon fire growth and its impact upon tenability time in the occupant escape routes and Required Safe Evacuation Time (RSET) which is dependent upon the alertness mobility and other factors influencing the time taken for occupants to leave the building. It is essential that ASET >= RSET. The FEG details a method for the calculation of occupant movement times to establish the RSET, however, Australian fire engineers have been extremely critical of the lengthy occupant pre-movement times yielded when the methodology is applied.

This paper describes a conceptual hypothetical methodology developed by Jonathan Sime in 1994 for calculating the time before occupants move as a response to different evacuation cues. This methodology was considered for inclusion in the Draft British Standard Fire Engineering Code 1994 [4]. A description of the FEG Occupant Avoidance Subsystem 5 (SS5), which was allegedly prepared by Hamish MacLennan is given. This appears to be closely aligned with the work of Sime. A comparison between Sime's and MacLennan's methodologies is made and some suggestions proposed which appear to better align the outcomes of the two methodologies.

## 2. OCCUPANT EVACUATION

### 2.1 Occupant Avoidance Subsystem

The FCRC FEG incorporates an Occupant Avoidance Subsystem (SS5) which utilises a subjective non dimensional scoring system, to calculate the hypothetical pre-movement time of building occupants. The total FEG occupant evacuation time has been broken down into 3 consecutive and cumulative processes which comprise:

1. Occupant "response time" to given cues, based upon such issues as alertness, mobility, social affiliation, role, position, commitment, focal point and familiarity. This is basically the time occupants take to recognise that a problem exists.

2. Occupant coping time is the time to address immediate issues prior to evacuating the building, this may involve collecting important personal possessions such as loved ones, handbag or getting dressed. This involves such issues as mobility, communication, social affiliation, role, commitment, decisiveness, position and familiarity. We must therefore add the response time to the coping time to obtain the occupant pre movement time.

3. The occupant movement time is the time taken for occupants to travel through the building via the exit system to a safe place. This involves such issues as familiarity, signage, complexity, population, mobility, safety, social affiliation and role. This aspect of occupant evacuation is outside the scope of this paper.

The total time for occupants to leave the building is referred to as the occupant evacuation/avoidance time (RSET) which is the sum of the calculated times 1, 2 and 3 above.

### 2.2 Simes Proposal for a Draft Fire Safety Engineering Code

A conceptual hypothetical methodology for calculating the time before occupants move as a response to different evacuation cues, was proposed by Jonathan Sime in 1994 for inclusion into the Draft British Standard Fire Engineering Code 1994.

Table 1 of this paper was produced by Sime for some typical occupancies and shows the scores nominated for different attributes relating to occupant avoidance.

**Table 1**

| Occupancy | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hospitals | *** | * | * | **** | **** | * | ** | * | ** | *** | ** | ** | * |
| Residential Buildings | * | *** | *** | * | * | ** | **** | * | ***** | * | **** | * | ***** |
| Nursing Homes | ** | ** | * | **** | *** | ** | **** | * | **** | ** | ** | * | *** |
| Hotels | ** | *** | **** | **** | *** | ** | **** | * | * | ** | ** | ** | **** |
| Places of Assembly | *** | ***** | **** | *** | ** | ** | * | ***** | ** | *** | **** | *** | **** |
| Sports Stadia | ***** | ***** | ***** | *** | ** | ** | * | **** | ** | ***** | *** | ***** | *** |
| Shopping Complexes | **** | ***** | **** | *** | *** | **** | *** | ** | * | **** | * | **** | * |
| Shops | ** | ***** | **** | *** | *** | *** | *** | *** | ** | *** | ** | ** | *** |
| Undergrnd Stations | **** | ***** | **** | **** | *** | ***** | ** | ** | ** | ***** | * | *** | * |
| Offices | ** | ***** | ***** | **** | ***** | ** | ** | ** | **** | ** | ** | ** | *** |

Where **A** = **Communications** - what kind of warning system is in place e.g. non directive bell to full directive system with closed circuit TV and public address system.
**B** = **Alertness** -likelihood of occupants being awake or asleep
**C** = **Mobility** - what are the sensory and mobility abilities of the occupants
**D** = **Social Affiliation** - are individuals alone or separated from their primary social group (e.g. family) when first alerted
**E** = **Role** - what is the ratio of public to staff in the establishment
**F** = **Position** - likelihood of lying down, sitting, standing or moving
**G** = **Commitment** - are occupants committed to finishing something, eg. queuing to obtain a ticket, waiting to collect property
**H** = **Focal Point** - to what degree does the setting influence the occupants attention to a focal point (to the exclusion of other influences) e.g. a theatre or cinema
**I** = **Familiarity** - how familiar are the majority of people with the building such as entry and exit routes
**J** = **Population Density** - what are the maximum numbers of people allowed in the setting and how are they distributed
**K** = **Visual Access** - how visually accessible are the alternative exit routes from the setting?
**L** = **Enclosure** - How enclosed or open is the setting?
**M**= **Complexity** - How complex or simple is the setting (in terms of numbers of rooms corridors, etc.)

It is important to note that the scores shown in Table 1 were provided by Sime for illustrative purposes only, (to the authors knowledge this methodology has not been validated). Each building design requires a subjective assessment of the relevant Table 1 score, applicable to each attribute. Table 1 attributes comprise:

**Column A** - Which describes the effectiveness of the alarm system. This has been used by MacLennan for the calculation of "coping time" but was not apparently used by Sime for his calculated "time to move"[5].

**Columns B to I** - Which describes the factors influencing the time to move. This being the central issue discussed in this paper.

**Columns J to M** - Which describes the factors influencing the direction of occupant movement, ie., which exits and exit paths they will choose and the rate of flow through these chosen paths. This will directly impact upon the time taken to exit once the occupants have started to move, and is outside the scope of this paper.

The asterisk weighting's given in Sime's Table 1 are scaled in accordance with Table 2.

**Table 2**

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no alarm | asleep | low | group | public | lying | high | none | unfamiliar | low | low | enclosed | Complex |
| alarm bell | * | * | * | * | * | * | * | * | * | * | * | * |
| | ** | ** | ** | ** | sitting | ** | ** | ** | ** | ** | ** | ** |
| non dir PA | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| | **** | **** | **** | **** | standing | **** | **** | **** | **** | **** | **** | **** |
| | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |
| PA and CC TV | awake | high | alone | staff | moving | low | focussed | familiar | high | high | open | simple |

## 2.3 Time to Move

Sime provided a matrix baseline of time estimates ($t_l$) before occupants start to move as shown in Table 3. There are 3 alarm cues types used ($w_1$, $w_2$, $w_3$) these being, a simple ringing bell, a pre recorded PA message and a live fully orchestrated evacuation, where the chief fire warden has the benefit of closed circuit TV and can tell occupants what to do over a public address system. Worst possible, average and best possible base times are given for these systems. These base times apparently reflect the outcome of research projects and other investigations undertaken by Sime.

**Table 3**

| Alarm type | Description | Best possible scenario (tl) | Average scenario (tl) | Worst possible scenario (tl) |
|---|---|---|---|---|
| $w_1$ | alarm bell | < 3 mins | 6 mins | > 9 mins |
| $w_2$ | non directive pre recorded PA and or informative fire warnings | < 2 mins | 4 mins | > 6 mins |
| $w_3$ | live directive PA with CCTV | < 1 min | 2 mins | > 3 mins |

These base times (*tl*) are then modified according to a weighting factor $W_{eff}$ obtained by using the scores given in Table 1, columns B - I.

The time to move for the different alarm stimuli $w_1$, $w_2$ or $w_3$ is $tl_{(adjusted)}$

where

$$tl_{(adjusted)} = w_{1,2\ or\ 3}\ x\ tl_{b.p.s,\ average\ or\ w.p.s}.\ x\ W_{eff}$$

and

$$W_{eff} = 5 \div Average\ columns\ B - I$$

There is a maximum score of 5 for each event in columns B - I, therefore, the best possible $W_{eff}$ will be 1. Hence, the base times given for $w_1$, $w_2$ or $w_3$, cannot be eroded. The worst possible $W_{eff}$ will be 5 and the maximum time to move will be 5 times the given base times.

The worst possible scenarios (w.p.s.), average (av) and best possible scenario (b.p.s.), for $w_1$, $w_2$ or $w_3$ give a *tl* range shown in Table 4. For a $W_{eff}$ value of between 1 and 5.

**Table 4**

| Alarm type | Best possible scenario *(tl)* | Average scenario (*tl*) | Worst possible scenario *(tl)* |
|---|---|---|---|
| $w_1$ | 3 - 15 mins | 6 - 30 mins | 9 - 45 mins |
| $w_2$ | 2 - 10 mins | 4 - 20 mins | 6 - 30 mins |
| $w_3$ | 1 -5 min | 2 - 10 mins | 3 - 15 mins |

If we look at the typical occupancies shown in Table 1, and accept the scores given, we can establish some typical $tl_{(adjusted)}$ values for the different alarm types $w_1$, $w_2$ or $w_3$, as shown in Table 5. For the purpose of this exercise only the b.p.s. time has been calculated, average and w.p.s. times can be calculated by modifying the times in proportion to the *tl* base times given in Table 3.

**Table 5**

| Values given in Table 1 | | | | b.p.s time to move minutes | | |
|---|---|---|---|---|---|---|
| | | | | *tl* for $w_1$ (alarm bell) | *tl* for $w_2$ (Non Dir PA) | *tl* for $w_3$ Directive PA |
| | | | | 3 | 2 | 1 |
| **Occupancy** | **Sum B - I** | **Ave B-I** | **Weff = (5/ave)** | $tl_{(adjusted)} = tl\ (b.p.s.) \times W_{eff}$ | | |
| Hospital | 16 | 2.0 | 2.5 | 7.5 | 5.0 | 2.5 |
| Residential Buildings | 20 | 2.5 | 2.0 | 6.0 | 4.0 | 2.0 |
| Nursing Homes | 21 | 2.6 | 1.9 | 5.7 | 3.8 | 1.9 |
| Hotels | 22 | 2.8 | 1.8 | 5.4 | 3.6 | 1.8 |
| Places of Assembly | 24 | 3.0 | 1.7 | 5.1 | 3.4 | 1.7 |
| Sports Stadia | 24 | 3.0 | 1.7 | 5.1 | 3.4 | 1.7 |
| Shopping Complexes | 25 | 3.1 | 1.6 | 4.8 | 3.2 | 1.6 |
| Shops | 26 | 3.3 | 1.5 | 4.5 | 3.0 | 1.5 |
| Underground Stations | 27 | 3.4 | 1.5 | 4.5 | 3.0 | 1.5 |
| Offices | 29 | 3.6 | 1.4 | 4.2 | 2.8 | 1.4 |

## 3. THE AUSTRALIAN FIRE ENGINEERING GUIDELINES

### 3.1 Occupant Avoidance Subsystem

It would appear that the methodology devised by Sime for the Draft British Standard Fire Safety Engineering Code 1994, forms the basis of the FEG SS5. Sime's time "*tl*" referred to as "the time to move" (time taken before occupants start to evacuate the building) has been subdivided in the FEG into "response time" *tr* and "coping time" *tc*, where, $tr + tc = tl$. Sime's system describes human attributes and other factors which are virtually the same as those adopted in the FEG.

### 3.2 Occupant Response Time

The FEG method of calculating occupant response time as allegedly prepared by MacLennan seems to be closely aligned with Sime's work. The scoring system shown in Table 1 is almost exactly the same as the scoring system of FEG Table 7.9A, however, the mathematical manipulation of these scores differs. Whilst Sime's $W_{eff}$ is the multiplier for the base times, MacLennan's $W_{eff}$ is a factor used to calculate *Rc*, which is then used to multiply the base times. Whilst Sime averages the table scores to calculate his $W_{eff}$, MacLennan weights the scores, with the 3 most important factors being multiplied by 2 and the remaining factors multiplied by 0.4 (shown with a tick).

Sime's $W_{eff}$ is calculated by dividing 5 by the average score.

MacLennan's *Rc* is calculated by subtracting the weighted result (his $W_{eff}$) from 6.

If Sime's and MacLennan's scores are the same, except for a best possible or worst possible score, the calculated response times will differ, simply because of the different mathematical procedures employed.

For a best possible score or a worst possible score, the calculated multiplier to be applied to the base time for both Sime's and MacLennan's methodologies will remain the same, as shown next.

Best possible score = 40, then:
MacLennan = 6 - (40/8) = 1
Sime = 5 / (40/8) = 1

Worst possible score = 8, then:
MacLennan = 6 - (8/8) = 5
Sime = 5 / (8/8) = 5

However due to the different mathematical structure of each model, scores between these two limits will yield different multipliers, as shown graphically in Fig. 1.

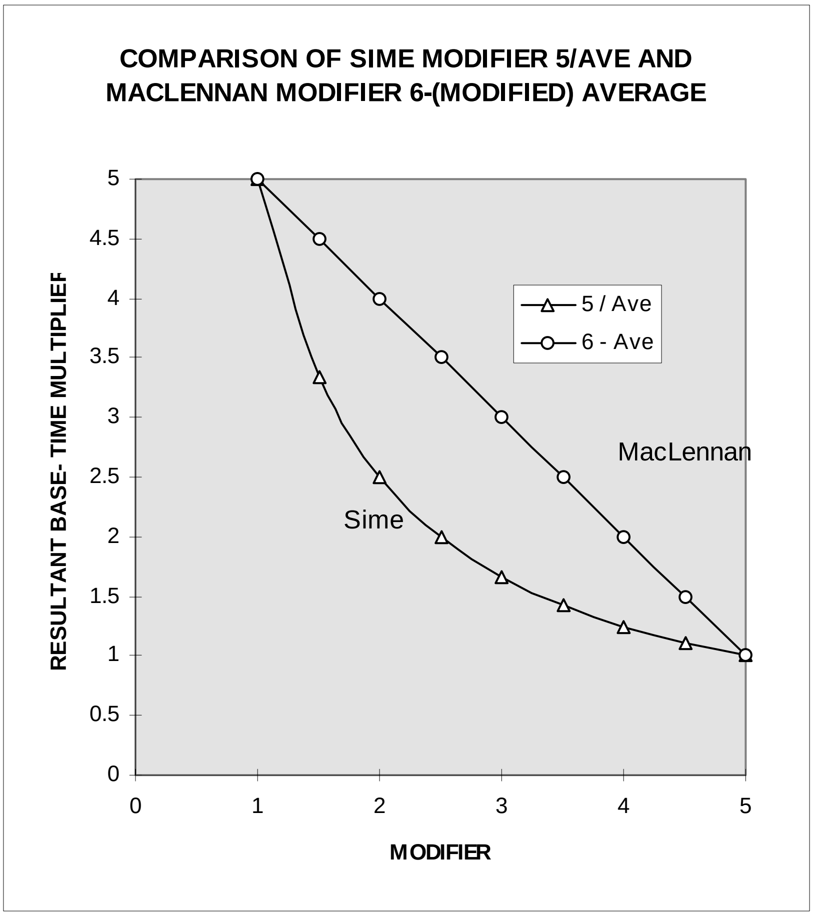


**Fig. 1**

A closer inspection reveals that this simple comparison is further complicated because of the weighting factors MacLennan's methodology employs when assessing the total score. For the same base scores, this may give an even greater variation than that shown in Fig. 1. Typical scores for response time calculations in typical occupancies are contained in the FEG Table 7.9A, essentially repeated in this paper as Table 6 (these compare with columns B - I in Sime's work as shown in Table 1).

The scores in Table 6 which reflect the least important issues of a particular occupancy type need to be multiplied by a weighting factor of 0.4 and are shown with a tick. The 3 remaining most important scores need to be multiplied by a weighting factor of 2.0.

**Table 6**

| FEG 7.9A Occupancy | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Hospitals | * ✓ | * | **** | **** ✓ | * | ** ✓ | * ✓ | ** ✓ |
| Apartments | ** | *** ✓ | * ✓ | * ✓ | ** ✓ | **** | * ✓ | **** |
| Hotels | ** | **** ✓ | **** ✓ | *** | ** ✓ | **** | * ✓ | * ✓ |
| Nursing Homes | ** | * | **** ✓ | *** ✓ | ** | **** ✓ | * ✓ | **** ✓ |
| Places of Assembly | ***** | **** ✓ | *** ✓ | ** ✓ | ** ✓ | * ✓ | ***** | ** |
| Sports Stadia | ***** ✓ | ***** ✓ | *** | ** ✓ | ** ✓ | * ✓ | **** | ** |
| Shops | ***** ✓ | **** ✓ | *** | *** ✓ | **** ✓ | *** | *** ✓ | ** |
| Offices | ***** ✓ | ***** ✓ | *** ✓ | ***** | ** ✓ | ** | ** | **** ✓ |
| Industrial | ***** | ***** | *** ✓ | ***** ✓ | **** ✓ | ** ✓ | * ✓ | ***** |

Where **A** = **Alertness** -likelihood of occupants being awake or asleep
**B** = **Mobility** - what are the sensory and mobility abilities of the occupants
**C** = **Social Affiliation** - are individuals alone or separated from their primary social group (e.g. family) when first alerted
**D** = **Role** - what is the ratio of public to staff in the establishment
**E** = **Position** - likelihood of lying down, sitting, standing or moving
**F** = **Commitment** - are occupants committed to finishing something, e.g. queuing to obtain a ticket, waiting to collect property
**G** = **Focal Point** - to what degree does the setting influence the occupants attention to a focal point (to the exclusion of other influences) e.g. a theatre or cinema
**H** = **Familiarity** - how familiar are the majority of people with the building such as entry and exit routes

There are some apparent anomalies with the FEG tables as some occupancies only have 4 ticks and others have six ticks (to maintain an ordered 8 column analysis, we require [5 *x* 0.4] + [3 *x* 2] = 8). For the purpose of this paper the anomalies have been subjectively corrected and are incorporated in Table 6.

The asterisk scores shown in Table 6 are scaled in accordance with FEG Table 12.5, reproduced in this paper as Table 7, which is virtually identical with Sime's original table as proposed for the total occupant pre movement time.

**Table 7**

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| asleep | impaired | group | public | lying | high/involved | none | unfamiliar |
| * | * | * | * | * | * | * | * |
| ** | ** | ** | ** | sitting | ** | ** | ** |
| *** | *** | *** | *** | *** | *** | *** | *** |
| **** | **** | **** | **** | standing | **** | **** | **** |
| ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |
| awake | high | alone | staff | moving | low | focussed | familiar |

The FEG matrix baseline time estimates for occupant response time is given in FEG Table 12.6 and is reproduced in this paper as Table 8. MacLennan employs four (4) alarm types rather than Sime's three (3), these being, a simple ringing bell, an AS 2220 signal [6] an AS 2220 signal with pre recorded information message and an AS 2220 system with pre recorded information message and chief fire warden who has the benefit of closed circuit TV and can tell occupants what to do over a public address system. MacLennan's worst, average and best possible base times for these systems are shown in Table 8.

**Table 8**

| Alarm type | Description | Best scenario effective training | Average scenario | Worst scenario no training/experience |
|---|---|---|---|---|
| A1 | alarm bell | < 4 mins | 7 mins | > 10 mins |
| A2 | sounder /horn with rise fall signature (AS 2220) | < 3 mins | 5 mins | > 7 mins |
| A3 | A2 plus an additional pre-recorded voice message and/or informative warning system | <2 | 3.5 | >5 |
| A4 | AS 2220 system incorporating rise fall signature and live directive PA with CCTV | < 1 min | 2 mins | > 3 mins |

Table 8 values can be directly compared with Sime's times shown in Table 3 because MacLennan's alarm type *A1* = Sime's type $w_1$, *A2* = $w_2$ and *A4* = $w_3$. MacLennan's b.p.s times range from 1 - 4 minutes whereas Sime's range from 1 - 3 minutes. MacLennan's w.p.s. base times range from 3 - 10 minutes whilst Sime's range from 3 - 9 minutes.

Taking the FEG values shown in Table 6 and employing the methodology given in the FEG yields the b.p.s. response times *tr* shown in Table 9 for the 4 alarm types considered.

**Table 9**

| Values calculated from Table 6 (FEG 7.9A) | | | | b.p.s. time to move minutes | | | |
|---|---|---|---|---|---|---|---|
| | | | | ***A1*** (alarm bell) | ***A2*** (2220 horn) | ***A3*** (Non Dir PA) | ***A4*** Directive PA |
| | | | | **4** | **3** | **2** | **1** |
| **Occupancy** | **Modified Sum A - H** | ***Weff* = Mod Sum /8** | ***Rc* = 6 - $W_{eff}$** | ***tr = tr(baseline) x Rc*** | | | |
| Hospital | 16 | 2 | 4 | 16 | 12 | 8 | 4 |
| Apartment | 23.2 | 2.9 | 3.1 | 12.4 | 9.3 | 6.2 | 3.1 |
| Hotels | 22.8 | 2.85 | 3.15 | 12.6 | 9.45 | 6.3 | 3.15 |
| Nursing Homes | 16 | 2 | 4 | 16 | 12 | 8 | 4 |
| Places of Assembly | 28.8 | 3.6 | 2.4 | 9.6 | 7.2 | 4.8 | 2.4 |
| Sports Stadia | 22 | 2.75 | 3.25 | 13 | 9.75 | 6.5 | 3.25 |
| Shops | 23.6 | 2.95 | 3.05 | 12.2 | 9.15 | 6.1 | 3.05 |
| Offices | 25.6 | 3.2 | 2.8 | 11.2 | 8.4 | 5.6 | 2.8 |
| Industry | 36 | 4.5 | 1.5 | 6 | 4.5 | 3 | 1.5 |

## 3.3 Coping Time

The FEG details a method to calculate the occupant coping time, an event which happens subsequent to the occupants responding to the alarm cue (at time *tr*) and prior to occupant movement towards an exit. This time (*tc*) can be deemed necessary by the occupant for activities ranging from the simple need of picking up a handbag to a more time consuming search for loved ones separated in a crowd. The methodology employed by MacLennan is exactly the same at that used to calculate his response time (*tr*). Table 10 shows the FEG Table 7.9B used to determine the weighted average $W_{eff}$.

**Table 10**

| FEG 7.9B Occupancy | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Hospitals | * | ** | **** ✓ | **** ✓ | * ✓ | *** ✓ | * | ** ✓ |
| Apartments | *** ✓ | ** | * | * | **** ✓ | ** ✓ | ** ✓ | **** ✓ |
| Hotels | *** ✓ | *** | **** | *** | *** ✓ | ** ✓ | ** ✓ | * ✓ |
| Nursing Homes | * | ** | **** ✓ | **** | *** ✓ | *** ✓ | * ✓ | *** ✓ |
| Places of Assembly | **** ✓ | *** | * ✓ | *** | * ✓ | * ✓ | ** ✓ | ** |
| Sports Stadia | **** ✓ | *** ✓ | ** ✓ | *** | ** | * | ** ✓ | ** ✓ |
| Shops | **** ✓ | *** | ** ✓ | *** | * | ** ✓ | **** ✓ | * ✓ |
| Offices | **** | *** ✓ | ** | **** ✓ | ** ✓ | ** | *** ✓ | * ✓ |
| Industrial | ***** | ** | **** ✓ | ***** ✓ | ** ✓ | *** ✓ | ***** ✓ | *** |

Where **A** = **Mobility** - what are the sensory and mobility abilities of the occupants
**B** = **Communication** -what kind of warning system is in place, eg. non directive bell or fully directive system with PA and closed circuit TV
**C** = **Social Affiliation** - are individuals alone or separated from their primary social group (eg. family) when first alerted
**D** = **Role** - what is the ratio of public to staff in the establishment
**E** = **Commitment** - are occupants committed to finishing something, eg. queuing to obtain a ticket, waiting to collect property
**F** = **Decisiveness** - can often include leadership, highly dependent upon training, are the occupants going to dither, not knowing what to do or make a quick decision?
**G** = **Position** - likelihood of lying down, sitting, standing or moving
**H** = **Familiarity** - how familiar are the majority of people with the building such as entry and exit routes

The asterisk scores given in Table 10 are scaled in accordance with Table 11 similar to Sime's original proposal for time to move (*tl*).

**Table 11**

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| impaired | ineffective | group | public | high | nil | lying | unfamiliar |
| * | * | * | * | * | * | * | * |
| ** | ** | ** | ** | sitting | ** | ** | ** |
| *** | *** | *** | *** | *** | *** | *** | *** |
| **** | **** | **** | **** | standing | **** | **** | **** |
| ***** | ***** | ***** | ***** | ***** | ***** | ***** | ***** |
| high | effective | alone | staff | nil | focussed | moving | familiar |

$W_{eff}$ is calculated by dividing the weighted scores (those with a tick multiply by 0.4, those without, multiply by 2.0) by the number of columns used (8). $C_c$ (rather than $R_c$) is obtained by subtracting Weff from 6 and is the multiplier for base times given in FEG Table 12.9. The resulting b.p.s. times are given in Table 12 for each of the categories contained in FEG Table 7.9 B for each of the three cue types presented in FEG Table 12.9.

**Table 12**

| **Values calculated from Table 10 (FEG Table 7.9B)** | | | | **b.p.s coping time minutes** | | |
|---|---|---|---|---|---|---|
| | | | | ***C1*** **no procedure or very complicated** | ***C2*** **procedure plus informative warning system** | ***C3*** **C2 plus CCTV PA and directive messages** |
| | | | | **4** | **2** | **1** |
| **Occupancy** | **Modified Sum A - H** | $W_{eff}$ **= Mod sum/8** | $C_c$ **=** $6 - W_{eff}$ | $tc = tc_{(base\ time)} \times C_c$ | | |
| Hospital | 14 | 1.75 | 4.25 | 17 | 8.5 | 4.25 |
| Apartment | 14 | 1.75 | 4.25 | 17 | 8.5 | 4.25 |
| Hotels | 24.4 | 3.05 | 2.95 | 11.8 | 5.9 | 2.95 |
| Nursing Homes | 20.4 | 2.55 | 3.45 | 13.8 | 6.9 | 3.45 |
| Places of Assembly | 19.6 | 2.45 | 3.55 | 14.2 | 7.1 | 3.55 |
| Sports Stadia | 17.2 | 2.15 | 3.85 | 15.4 | 7.7 | 3.85 |
| Shops | 19.2 | 2.4 | 3.6 | 14.4 | 7.2 | 3.6 |
| Offices | 22 | 2.75 | 3.25 | 13.0 | 6.5 | 3.25 |
| Industry | 27.6 | 3.45 | 2.55 | 10.2 | 5.1 | 2.55 |

## 4. A COMPARISON OF SIME'S AND MACLENNAN'S METHODOLOGIES AS APPLIED TO TABLE 7.9A OF THE FEG

The outcome of Sime's methodology for total occupant pre movement time (*tl*) as shown in Table 5 can be compared with MacLennan's response time (*tr*) shown in Table 9.

Because of the different mathematical procedures employed and the different weighting's imposed on the FEG scores (contained in FEG Table 7.9A as interpreted in Table 6 of this paper) it is of interest to compare the results when applying both Sime's and MacLennan's methods to the same data. To all effective purposes the data in FEG Table 7.9A is the same as that originally proposed by Sime, therefore, applying both methods to that table gives a representative comparison of the results yielded by the different methodologies.

Table 13 contains the results of that comparison.

Sime's total pre movement time (*tl*) and MacLennan's response time (*tr*) for alarm cues A1 and A4 as shown in Table 13 are graphically shown in Fig. 2. In every case, MacLennan's time is greater than Sime's.

**Table 13**

| **Values calculated from Table 6 (FEG 7.9A)** | | | | | **b.p.s time to move minutes** | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | ***A1* (alarm bell)** | ***A2* (2220 horn)** | ***A3* (Non Dir PA)** | ***A4* Directive PA** |
| | | | | | **4** | **3** | **2** | **1** |
| **Occupancy** | **Mac L *Weff*** | **Mac L *Rc*** | **Avrage A-H** | **Sime $W_{eff}$ (=McL *Rc*)** | **MacLennan *tr* compared with (Sime *tl*)** | | | |
| Hospital | 2 | 4 | 2 | 2.5 | 16 (10) | 12 (7.5) | 8 (5) | 4 (2.5) |
| Apartment | 2.9 | 3.1 | 2.25 | 2.22 | 12.4 (8.88) | 9.3 (6.66) | 6.2 (4.44) | 3.1 (2.22) |
| Hotels | 2.85 | 3.15 | 2.63 | 1.9 | 12.6 (7.6) | 9.45 (5.7) | 6.3 (3.8) | 3.15 (1.9) |
| Nursing Homes | 2 | 4 | 2.63 | 1.9 | 16 (7.6) | 12 (5.7) | 8 (3.8) | 4 (1.9) |
| Places of Assembly | 3.6 | 2.4 | 3 | 1.67 | 9.6 (6.68) | 7.2 (5.01) | 4.8 (3.34) | 2.4 (1.67) |
| Sports Stadia | 2.75 | 3.25 | 3.0 | 1.67 | 13 (6.68) | 9.75 (5.01) | 6.5 (3.34) | 3.25 (1.67) |
| Shops | 2.95 | 3.05 | 3.38 | 1.48 | 12.2 (5.92) | 9.15 (4.44) | 6.1 (2.96) | 3.05 1.48) |
| Offices | 3.2 | 2.8 | 3.5 | 1.43 | 11.2 (5.72) | 8.4 (4.29) | 5.6 (2.86) | 2.8 (1.43) |
| Industry | 4.5 | 1.5 | 3.75 | 1.33 | 6 (5.32) | 4.5 (3.99) | 3 (2.66) | 1.5 (1.33) |

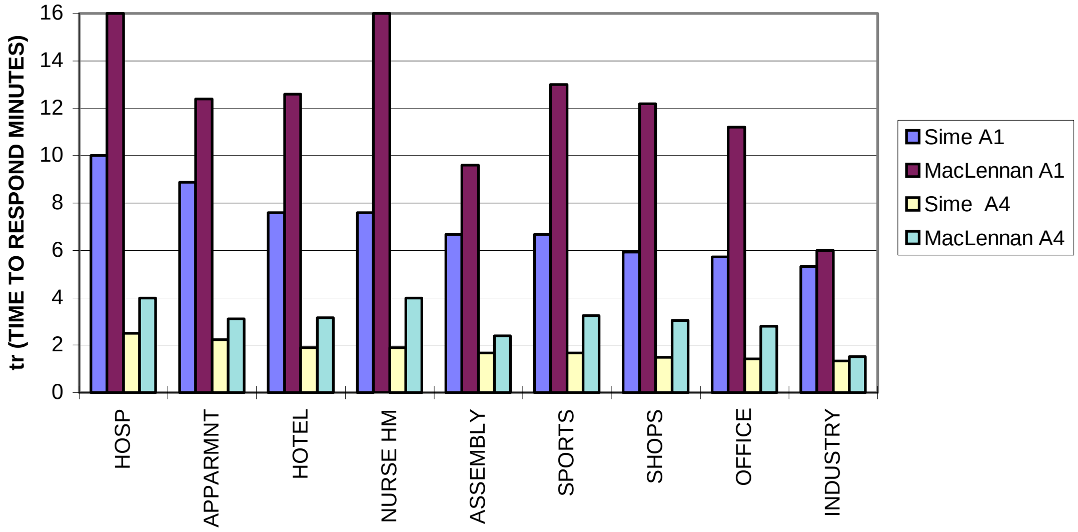


**Fig. 2: Calculated times (tr) using Simes and Maclennans methods**

The resultant sum of MacLennan's response and coping times (*tr* + *tc*) compared with Sime's time to move (*tl*) is given in Table 14 for a typical Australian occupant evacuation warning system where usual OH&S [7] occupant fire safety procedures and training are in place. Theoretically these times should be similar, however that is not so. MacLennan's times are far greater (as shown in Fig. 2 *tr* alone exceeds *tl*). The percentage variation between the two methods for total occupant pre-movement time is shown graphically in Fig. 3.

**Table 14**

| BUILDING WITH AS 2220 SYSTEM AND OH&S i.e. C2 EVACUATION PROCEDURE AND COMMUNICATIONS SYSTEM USING AN A2 WARNING SYSTEM | | | | | |
|---|---|---|---|---|---|
| **Occupancy** | ***tr*** | ***tc*** | ***tr+tc*** | ***Tl*** | **% variation** |
| Hospital | 12 | 8.5 | 20.5 | 7.5 | 273 |
| Apartment | 9.3 | 8.5 | 17.8 | 6.66 | 267 |
| Hotels | 9.45 | 5.9 | 15.35 | 5.7 | 269 |
| Nursing Homes | 12 | 6.9 | 18.9 | 5.7 | 332 |
| Places of Assembly | 7.2 | 7.1 | 14.3 | 5.01 | 285 |
| Sports Stadia | 9.75 | 7.7 | 17.45 | 5.01 | 285 |
| Shops | 9.15 | 7.2 | 16.35 | 4.44 | 368 |
| Offices | 8.4 | 6.5 | 14.9 | 4.29 | 347 |
| Industry | 4.5 | 5.1 | 9.6 | 3.99 | 240 |

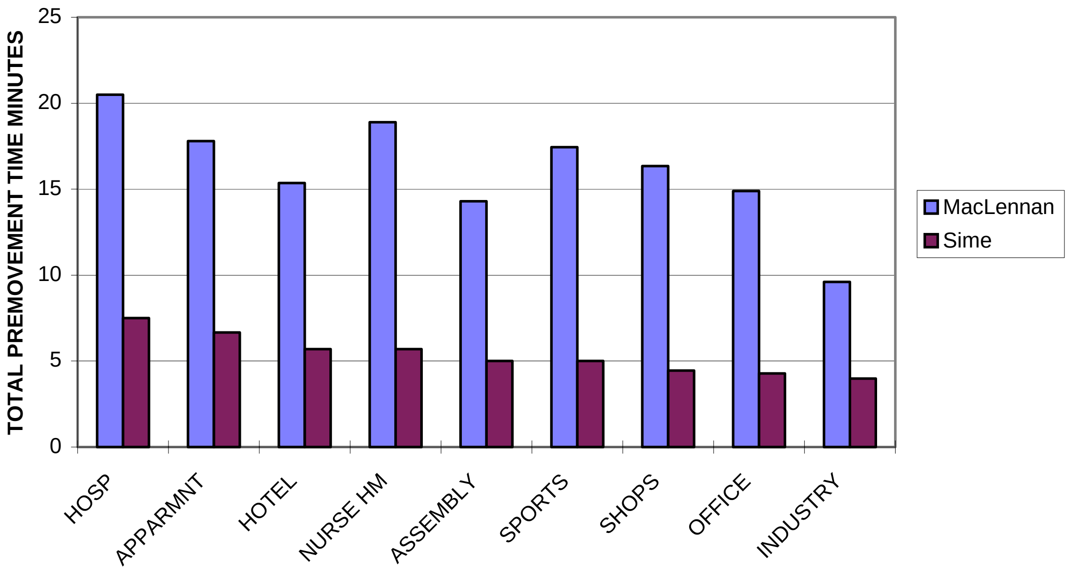


**Fig. 3: Comparison of Sime and Maclennan occupant pre movement times**

## 5. DISCUSSION

It must be remembered that both Sime's and MacLennan's methodologies, when applied to a particular design, requires an individual assessment of each risk. Each occupant attribute is reviewed for a particular building and subjectively assigned a value of between 1 & 5. The scores given in FEG Tables 7.9 A & B are examples only, in many buildings, the scores will vary from those given. This paper has utilised the scores shown in the FEG tables for the purpose of comparison between Sime's and MacLennan's methodologies, because these scores appear to have been derived from Sime's original work.

The variation in total occupant pre-movement time resulting from application of the two methodologies could be the result of different research, or simply the outcome of different mathematical manipulation of the data. It is important to note that Sime's work is for "time to move" and includes any coping time, whereas MacLennan adds additional coping time *tc* to *tr*.

This yields times to move substantially greater than those proposed by Sime.
The scores used for "response time" calculations by MacLennan in FEG Table 7.9A are virtually identical to the scores proposed by Sime for his time to move *tl* (columns B-I Table 1 this paper). Whilst it could be argued that the "coping times" calculated may complement the work of Proulx and Fahy for worst case scenarios [8], where apparently no occupant fire safety procedures or training existed (a design parameter we should not be using) generally, MacLennan's results do not appear to correspond with the times expected in the workplace.

Where a typical AS 2220 system is installed and the building owner complies with OH &S legislative requirements in relation to fire safety training and procedures, MacLennan's results are seen by most Australian fire engineers to be excessively conservative. In all cases, the results of Sime's original hypothesis will be the preferred option of both methodologies.

Australian fire engineers perceive the times generated by the FEG methodology to be excessive. In general, they appear to avoid its use, preferring other methods where occupant pre-movement time is not defined, hence, subjective (usually minimal) pre movement times can be employed. Such an approach potentially reduces project costs because expensive systems required to maintain tenability can either have a reduced capacity or be totally eliminated. The author of this paper is of the opinion that the basic concept of the methodologies of Sime and MacLennan have merit and should be an integral part of a fire safety design.

If we wish to break down the "time to move" into response and coping phases, it is interesting to apply Sime's original mathematical procedure to the unweighted columns given in MacLennan, (Table 7.9A and 7.9B) in each case, the total of *tr* and *tc* will better match the results of Sime's procedure for calculating *tl*.

i.e. time to move $tm = tr + tc$

where $tr = W_{eff}\_r$ x base time
$tc = W_{eff}\_c$ x base time

and $W_{eff}\_r$ = 2.5/Average Response Score (FEG Table 7.9A)

and $W_{eff}\_c$ = 2.5/Average Coping Score (FEG Table 7.9B)

on the basis that Simes $W_{eff}$ = 5.0/Average occupant pre-movement score.

The result of applying these equations is shown in Table 15.

**Table 15**

| BUILDING WITH AS 2220 SYSTEM AND OH&S i.e. C2 EVACUATION PROCEDURE AND COMMUNICATIONS SYSTEM USING AN A2 WARNING SYSTEM | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Occupancy | Ave Response =A | Ave Coping =B | *Weff_r*= 2.5/A | *Weff_c*= 25/B | tr | *tc* | *tr+tc* | *tl* |
| Hospital | 2.00 | 2.38 | 1.25 | 1.05 | 3.75 | 3.16 | 6.91 | 7.5 |
| Apartment | 2.25 | 2.38 | 1.11 | 1.05 | 3.33 | 3.16 | 6.49 | 6.66 |
| Hotels | 2.63 | 2.63 | 0.95 | 0.95 | 2.86 | 2.86 | 5.71 | 5.7 |
| Nursing Homes | 2.63 | 2.88 | 0.95 | 0.87 | 2.86 | 2.61 | 5.47 | 5.7 |
| Places of Assembly | 3.00 | 2.13 | 0.83 | 1.18 | 2.5 | 3.53 | 6.03 | 5.01 |
| Sports Stadia | 3.00 | 2.38 | 0.83 | 1.05 | 2.5 | 3.16 | 5.66 | 5.01 |
| Shops | 3.38 | 2.50 | 0.74 | 1.00 | 2.22 | 3.00 | 5.22 | 4.44 |
| Offices | 3.5 | 2.88 | 0.71 | 0.87 | 2.14 | 2.61 | 4.75 | 4.29 |
| Industry | 3.75 | 3.63 | 0.67 | 0.69 | 2.00 | 2.07 | 4.07 | 3.99 |

It must be stressed that this is purely a mathematical manipulation of the data presented in the Fire engineering Guidelines. Whilst the results of this proposed mathematical manipulation appear to yield results which will likely be more acceptable to the Australian fire engineering community, they may not in any way reflect what will happen during a real fire scenario.

The benefit of MacLennans method is that designs can be graded relative to each other in a transparent way taking into account two aspects of occupant pre movement behaviour, each separately analysed.

The suggested mathematical manipulation of MacLennans method has the potential to reduce the times generated by Sime, where is can be demonstrated that there is little or no coping time involved, due to management systems and occupant training procedures in place.

Further refinement of the methodology seems appropriate. A sensitivity analysis should be undertaken to assess the merit of retaining the weighting factors currently used in the FEG.

## 6. CONCLUSION

The design methodology used in the FEG appear to be closely aligned with Sime's early hypothetical conceptual model, as proposed for the Draft British Standard Fire Engineering Code 1994.

MacLennan's apparent manipulation of the original data and the extension of Sime's methodology to include coping time seems to generate results which are not acceptable to most Australian fire engineers for use in a fire engineering design. Whilst the results could reflect worst possible case scenarios, these appear unacceptable for design purposes.

It would appear that MacLennan's concept of response and coping time can be effectively employed by extending Sime's original mathematical methodology. The suggested mathematical manipulation appears to provide times comparable with Sime's original methodology and has the advantage that because the time to move is split into response and coping times, the effect of good management procedures and staff training is better reflected in the occupant pre movement time.

It is suggested that the proposed mathematical manipulation of MacLennans data be utilised as an interim measure, to encourage the use of a worthy methodology by Australian fire engineers. Further refinement of the methodology should take place and the merit of retaining MacLennan's weighting of scores should be further assessed.

## REFERENCES


1. Building Code of Australia, Vol. 1, Class 2 to Class 9 Buildings, Commonwealth and States and Territories of Australia, Australian Building Codes Board, GPO Box 9839, ACT 2601, Australia (1996).
2. Fire Engineering Guidelines, 1st edition, Published by Fire Code Reform Centre Ltd, Australia, Printed and distributed by Standards Australia, March (1996).
3. Fire Code Reform Centre Ltd, 4th floor, 50 King Street, Sydney, NSW 2000 Australia. A non-profit Approved Research Institute, directing a defined research program to facilitate regulatory reform undertaken by the Australian Building Codes board.
4. Draft British Standard Code of Practice for the Application of Fire Safety Engineering Principles to Fire Safety in Buildings, BSI document 94/340340 DC, Ref. 36, p. 190, British Standards Institution, 2 Park Street, London W1A 2BS, Great Britain, 3 June (1994).
5. J. Sime, "Assessing occupant response time", Presentation and workshop at "Respond and Escape! The Seminar", CSIRO DBCE, North Ryde, NSW Australia, December (1994).
6. AS 2220.1 - 1989, Emergency warning and intercommunication systems in buildings: Equipment design and manufacture; AS 2220.2 - 1989, Emergency warning and intercommunication systems in buildings: System design installation and commissioning, Standards Australia, 80 Arthur Street, North Sydney, NSW 2060, Australia (1989).
7. Occupational Health Safety and Welfare Regulations 1995, Part 2, General Workplaces, Division 2.6 - Emergency facilities and procedures, Government of South Australia. This document is typical of Australian States and Territories legislation which is based upon national standards developed by Worksafe Australia (1995).
8. G. Proulx and R. Fahy, "The time delay to start evacuation: review of five case studies", Fifth International Symposium on Fire Safety Science, Melbourne, Australia (1997).