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Exit Width Provisions for Emergency Egress

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Preface

This is a report prepared from a literature search into the changing demographics of the human population. The report shows the increase in the size and mobility of people is causing concerns about the egress provisions in existing and new buildings which may not be able to cope with the current and future populations.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for:

- The Department of Building and Housing as a technical basis for reviewing and /or updating provisions contained within their approved documents

Exit Width Provisions for Emergency Egress

BRANZ Study Report SR 193

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Reference

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Abstract

This study has demonstrated that with the changed demographics of the worldwide population, people have increased in size considerably in the period since provisions for egress and minimum exit widths were implemented for buildings and assembly areas on the basis of contemporary population mobility studies. The current situation is that the existing egress provisions are unlikely to deliver the evacuation times required by fire safety designs. Suggested means of correcting this potentially serious shortfall in egress capacity go beyond the obvious solution of simply increasing exit widths which, apart from new buildings, would be considered uneconomic and impractical. Other solutions suggested range from increasing fire protection to allowing longer times for safe evacuation and reducing occupant numbers. More radical solutions suggest the previously forbidden practice of using elevators for the evacuation of people with disabilities and limited mobility. In advocating the use of elevators, strategies for staged evacuations are suggested where the most at-risk areas are cleared first. The concept of safe or refuge areas within buildings is also promoted where occupants may simply wait to be rescued.

Keywords

Egress, mobility, exit width, overweight, demographics, obesity, stairway, elevator, fire safety.

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1. INTRODUCTION

This study reviews the existing minimum exit width requirements in the New Zealand Building Code (NZBC) Compliance Document C/AS1 (DBH 2005) prompted by a recent paper by Fruin and Pauls (2007) expressing concern about current practices. The study focuses on cultural, anthropometric and mobility differences internationally, and with time the impact on the specification of minimum exit widths needed for emergency egress. The overall strategy of emergency egress and the use of elevators for evacuation (as well as emergency services) are also considered.

1.1 Background

Fruin and Pauls (2007) presented a paper at the 2007 World Safety Conference & Exposition in June reviewing the history, current practice and implications for the future in relation to the design of means of escape. Fruin and Pauls are long-standing authorities in traffic engineering and people movement. Their earlier research involved data collected in the 1960s and 1970s on flow rates and walking speeds for people individually and in crowds, and is used today by fire safety engineers for egress calculations and simulation. The original data for people movement were generally obtained from observation of pedestrian commuter traffic flows in cities such as New York, London and Ottawa.

In their paper, the validity of the data as it is used today applied to emergency egress calculations for building designs was questioned for two main reasons:

- Anthropometrics have changed significantly since the 1960s – human body mass and size have increased. In the USA obesity rates have doubled in that time.
- Movement characteristics of people in New York, London and Ottawa commuters may not reflect emergency egress characteristics of the current general population (who may in general be less physically capable).

There now exists the unprecedented situation of two of the leading producers of pedestrian movement technology recommending withdrawing their own work from the design handbooks that fire safety engineers have relied on for two decades or more, and strongly advocating that new studies be undertaken. They also strongly advocate that the increase of the currently required minimum stairway width to a minimum of 1220 mm between handrails (1420 mm wall-to-wall) across the board from 1120 mm.

The minimum exit width in the NZBC compliance document C/AS1 (DBH 2005) is currently 1000 mm for 'safe paths'. This is significantly less than the 1420 mm recommended by Fruin and Pauls (2007). In New Zealand, exit width is calculated according to 9 mm per person for stairs and 7 mm per person horizontal travel based on the occupant load served, but not less than 1000 mm for safe paths.

The current practice by engineers when calculating evacuation times is to separately determine a pre-movement time (accommodating any behavioural or other factors that delay the commencement of evacuation) and a travel time (based on walking speeds and flows for a given density of people/m^2 and escape route width) (Buchanan 2001). The travel time component is therefore affected by the exit width and this is the emphasis of this project. Timed evacuation trials were not particularly useful for this study, unless they included detailed observation of the density and flow of occupants at various points within the path of travel, which is rarely recorded/reported. Measurements of overall evacuation times can be useful for validating calculations of total evacuation time.

1.2 Project objectives

The objective of this paper is to examine the exit width provisions in New Zealand and internationally and compare with data, publications and other studies relating to the increasing size of people. After establishing that there is a problem in New Zealand some egress modelling confirms the impact on occupant evacuations.

2. LITERATURE SEARCH

Fruin and Pauls (2007) draw attention to concerns about current practices and methods of calculating egress capacity. In particular, they suggested that recent and ongoing demographic changes in the population warrant reconsideration of the long accepted and established beliefs, data and formulae that are the basis for design requirements in codes, standards and handbooks which are used for performance predictions affecting life safety in existing and proposed facilities.

The basis of the established calculation methods subject to change are:

- Human body mass and sizes have increased significantly since the 1960s.
- The original basis used for determining the movement characteristics of the general population is not universally applicable. Studies of the movement of relatively fit commuter people that were used to measure egress characteristics may not be applicable to the general population who may not, on average, be so physically able.

Recommendations were offered on what should be done immediately, with what is currently known, and what must be done in the near future e.g. research to understand and cope with future challenges. Implications for regulators and other safety professionals include:

1. Paying much closer attention to actual people movement, as opposed to undue reliance on traditional code rules, handbook formulae and computer simulations.
2. Refining certain long-standing code requirements (e.g. minimum exit stairway width as discussed by Pauls, Fruin and Zupan 2007).
3. Reducing expectations of egress flow, speed, plus evacuation time.
4. Re-conceptualising the role of evacuation generally as the most traditional response to emergencies.

The authors recommend that the USA standard (minimum) 1120 mm width for exitways be increased to 1420 mm across the board immediately. Furthermore, the authors were recommending withdrawing their own work from the *SFPE Handbook,* in particular the chapter that details methods for calculating egress capacities (Nelson and McLennan 2002).

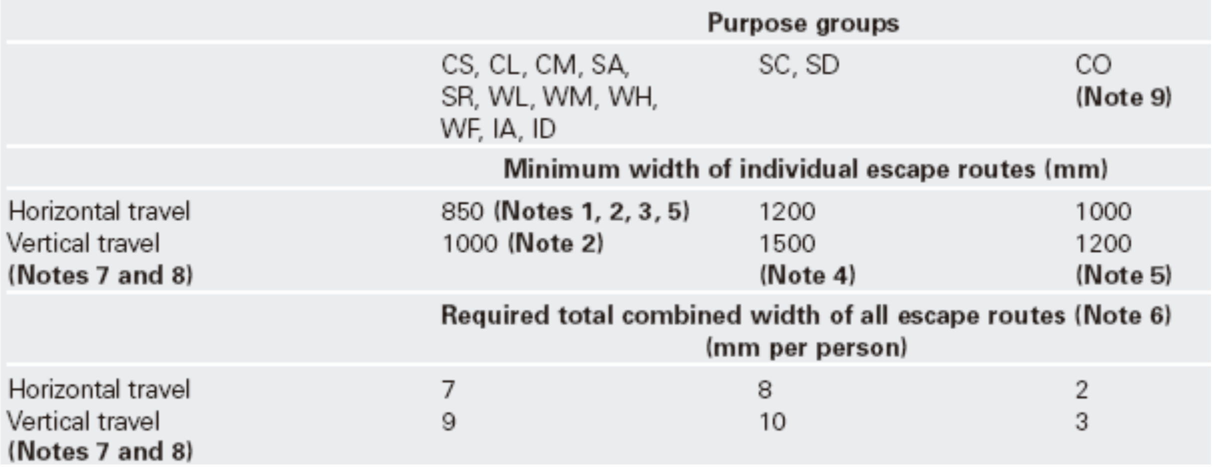
Just how much the exit width needs to be increased to take into account the effect of the people being bigger (increased Body Mass Index (BMI) and disability), and how this affects mobility and what can be done to address it, is the question.

In New Zealand BRANZ *Technical Recommendation 11* 'Method for Determining the Minimum with of Exitways in Means of Escape' (Wade 1992 and 1991) and the *Fire Engineering Design Guide* (Buchanan 2001) minimum exit widths are based on the original egress design data and methods of Fruin (1971) and Pauls (1980). Therefore these are equally out of date if the current population data in New Zealand has followed the same international trends.

2.1 Egress provisions in New Zealand

The required widths of escape routes in New Zealand are presented in Table 1 as listed in NZBC Compliance Document C/AS1 (DBH 2005) which is included as Table 3.2 in Appendix 1., minimum exit widths depend on whether travel is horizontal or vertical (down stairs) and on the purpose group served. The exit widths are also calculated on the basis of the occupant load and should this exceed the minimum then that width applies. In general, the required exit widths (see Table 1) fall below the recommendations (old and new) being proposed in the USA of 1120 mm increased to 1420 mm. New Zealand is perhaps facing the same challenge to revise exit widths assuming the same trends as shown for other countries.

Table 1: Current exit widths in New Zealand (refer to Table 3.2 in Appendix 1) (DBH 2005)



	Purpose groups		
	CS, CL, CM, SA, SR, WL, WM, WH, WF, IA, ID	SC, SD	CO **(Note 9)**
	Minimum width of individual escape routes (mm)		
Horizontal travel	850 **(Notes 1, 2, 3, 5)**	1200	1000
Vertical travel **(Notes 7 and 8)**	1000 **(Note 2)**	1500 **(Note 4)**	1200 **(Note 5)**
	Required total combined width of all escape routes (Note 6) (mm per person)		
Horizontal travel	7	8	2
Vertical travel **(Notes 7 and 8)**	9	10	3

2.2 International egress width provisions

The requirements for exit widths in Australia (ABCB 2006) are similar to New Zealand, but there are variations in occupancy classifications. In facilities where patient or aged care is the building purpose, passageways and exit widths are similarly increased. In cases where egress is primarily by independently mobile occupants the required widths are essentially the same as New Zealand.

A summary of common stair width requirements is presented in Table 2. The minimum requirements are fairly consistent, and it is apparent that with increased body size and reduced mobility these provisions may be significantly below the capacities required for safe egress. Proposals in the USA to increase minimum stairway width are particularly being prompted by the egress requirements of tall buildings (Puchovsky 2007, Shimshoni 2007). Otherwise the minimum stair width requirements are very similar, with the exception of Japan where the minimum width was increased to 1200 mm at the beginning of 2000.

Table 2: Summary of stairway width requirements internationally*

Code	Minimum stair width mm	Comments
NZ, C/AS1	1000	1500 mm in SC and SD purpose groups and 1200 in CO (DBH 2005)
Australia	1000	
USA	1100	Proposal to increase to 1420 mm and perhaps 1725 mm (NFPA 2007)
UK	1000	
Spain	1000	
Hong Kong	1050	
China	1100	
Japan	1200	
Canada	1000	

* (Bukowski 2008)

Hansen (1984) comments that by increasing corridor widths in a building about to be constructed there would probably be no additional cost except for the possible loss of rentable space. In existing construction, however, the cost would include the demolition and reconstruction of the partition. Although the benefits are presumably the same in both cases, the cost may be justified in the former, but not for the latter.

2.3 Size of people

Although the majority of research and publications relating to increases in body size are motivated by medical reasons and relate to health issues, the statistics relating to the increasing size of people are useful for the purposes of ambulation and mobility relating to egress from buildings. Worldwide increases in the average size of people are occurring across developed and developing countries alike. Table 3 presents a study (Popkin 2000) of the upward trend on a country-by-country basis of overweight and obese people.

Table 3: Country-by-country population overweight or obese adapted from (Popkin 2000)

Country	**Percentage of adults who are overweight or obese**								
Year	1975	1977	1991	1997	1998	2000	2003	2004	2006
Brazil	20	–	–	36.7	–	–	–	–	–
Egypt	–	–	–	–	59.1	–	–	–	–
Mexico	–	–	–	–	–	61.9	–	–	69.3
China	–	–	12.9	–	–	–	–	27.3	–
New Zealand*	–	43.9	–	–	–	–	55.9	–	–

* New Zealand statistics added from MOH (2004) data below.

Note: overweight is taken as a BMI >27 and obese BMI >30 where definition of BMI = weight (kg)/(height(m^2).

A New Zealand study (White H 2005) reported on increasing obesity and diabetes trends. Since 1982 men increased their BMI by 6% and women by 9%. This is consistent with Ministry of Health findings (MOH 2004) where between the years 1977 to 2003 those considered obese (BMI >30) increased from 9% to 20% for males and 11% to 22% for females as shown in Table 4.

Table 4: New Zealand population overweight or obese (MOH 2004)

	Males			**Females**		
	1977	**2003**	**AAPC(%) ***	**1977**	**2003**	**AAPC(%) ***
Mean BMI	25.5	26.9	0.20	24.5	26.4	0.28
Median BMI	25.1	26.3	0.18	23.8	25.2	0.23
Overweight (%)	41.5	42.1	0.05	26.1	27.7	0.23
Obese (%)	9.4	19.9	2.93	10.8	22.1	2.79

*Average annual percentage change: assumes linearity.

Combining the overweight and obese figures in Table 4, and assuming a 50/50 split between male and female, the change in overweight and obese people from 1977 to 2003 in New Zealand is in the range 43.9% to 55.9%. This data has been included in Table 3 above.

Another New Zealand study (White J 2007) compared advertising food versus obesity country-by-country and reported that results indicated a correlation. The undeniable finding supported the general trend that obesity (and people size) is increasing.

Considering the more global perspective the percentage obese where BMI >30 is shown in Figure 1 and Figure 2, it is necessary to differentiate between ‘obese’ and ‘overweight or obese’ as shown in Table 3. Some European countries, Japan and Korea do not show high levels of obesity. But New Zealand at 20.9%, and other countries of interest in this study such as Australia, United Kingdom and Unites States, are higher which is where the issue is being addressed.

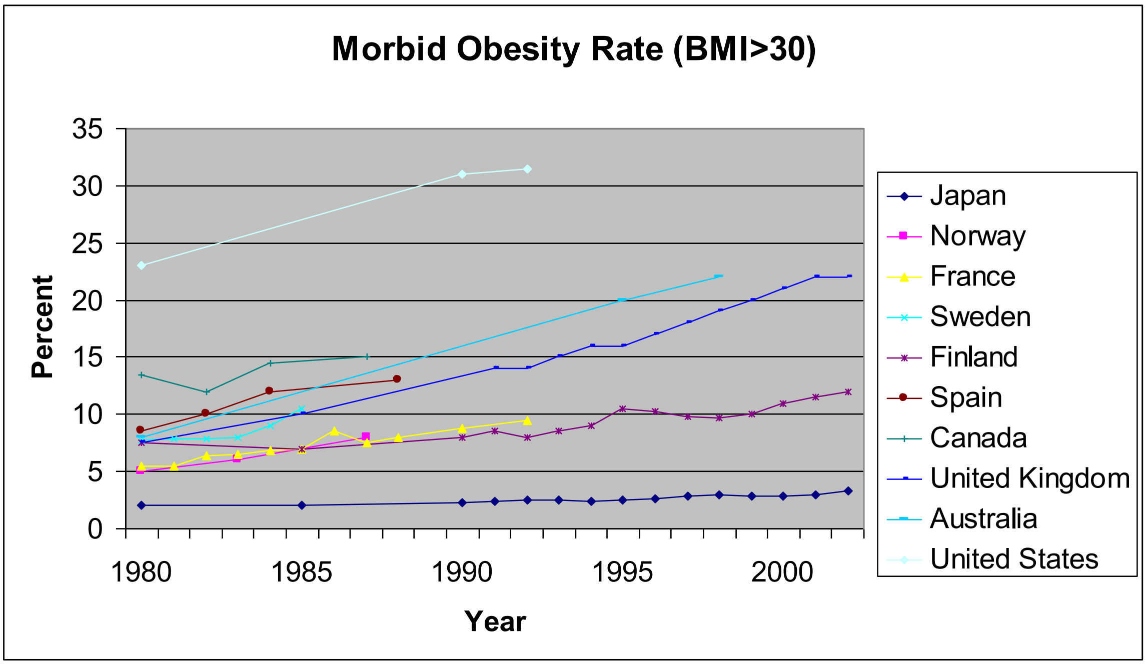


Figure 1: Obesity rates by country data: International Obesity Task Force (IOTF), EU Briefing paper 2005 (Bukowski 2008)

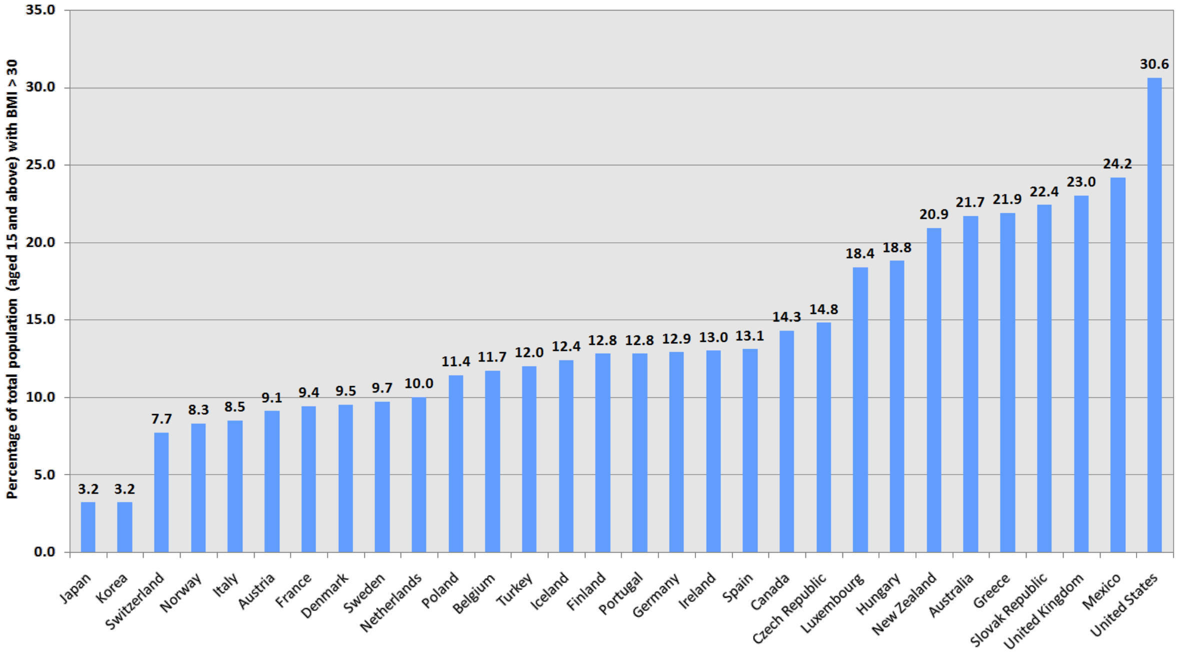


Figure 2: Obesity prevalence worldwide (OECD 2005)

2.3.1 Projected people size in the future

Looking into the future, the upward trend will continue according to the International Obesity Task Force (IOTF 2001). This is indicated in Figure 4 which shows the trend of increasing obesity projected forward to 2025.

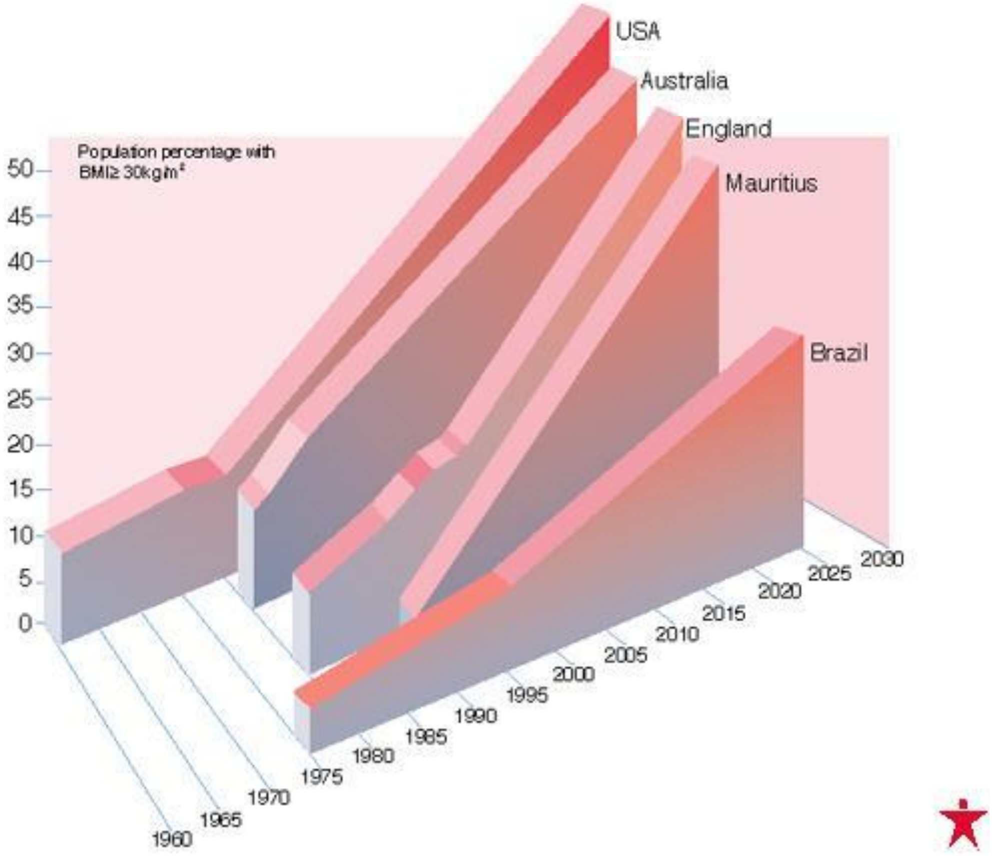


Figure 3: Growth of obesity projected to 2025 (extracted from IOTF 2001)

2.3.2 Conclusion on trends

All of the statistical data reviewed supports the common trend that people are getting bigger. Although there are quite wide variations between countries, there are also quite serious implications for the safety of populations in general when emergency evacuations from buildings are required.

The mechanism by which the population size data may be applied to existing egress modelling is the subject of section 3. It may evolve that several different, but complementary, approaches to the problem end up providing a satisfactory solution.

2.4 Reduction of mobility

No references in the literature search specifically examined the influence of obesity on travel speeds. However, a *Draft Technical Report ISO/DTR 16738* (ISO 2007) does address the effect of impaired mobility on travel speed, but does not account for the changing demographics of populations and increasing size of people. It is also noted that the inclusion of persons with restricted mobility may be important, as is including the movement of a family group that is likely to be determined by the slowest member, or the speed of movement of a person who walks with a cane.

A number of factors have an impact on the speed of movement, including the characteristics of the occupants, such as:

- age
- gender
- grouping
- clothing
- physical ability.

The environmental conditions are also important, such as the presence of a crowd, smoke or emergency lighting. The stairwell or corridor design, dimensions and covering can also play an important role in the speed of movement. The presence of fire effluent is also likely to affect movement speed as discussed. All these factors are rarely considered in evacuation models.

Boyce Shields and Silcock (1999a, b) studied travel speeds of mobility impaired populations and provided adjustments compared with maximum unimpeded speeds of walking. The data was presented as a distribution between a minimum and maximum with mean and quartiles indicating a wide variation that is likely to result in an equally wide range of evacuation times depending on how it is applied. The travel speed data is presented in Table 6 in Appendix 1.

2.5 Evolution of egress designs to account for increased size of people

Accepting that population demographics have changed means the problem of the resultant reduced exitway capacity must be addressed urgently. The relationship between demographics and exitway capacity needs to be determined.

Skill (2000) investigated body dimensions and anthropometric sizes of the world population. Results showed that:

- shapes vary both within countries and between countries; and
- that breadth (across shoulders) and depth (chest to back) and overall cross-sectional area determine how closely people can pack together (density = people/m^2) and influence people movement.

It was suggested that increasing people size does not make a significant difference to the speed of people movement. There was a relationship between density ρ (people/m^2) and speed in the form of a walking velocity $(V) = V_0\rho^{-0.8}$, but it was assumed that the relationship was independent of people size.

This may be true to a certain extent, but there must be a level above which it does make a difference purely on the basis that the flow will become choked. People become so closely packed together that movement is impeded shown by Fruin (1971) to the point where movement is reduced to near impossibility. It thus follows that if people are bigger then that level is reached with fewer people per m^2. As a result, Fruin and Pauls (2007) acknowledge the prospect that current evacuation flow assumptions may have to be halved to maintain the levels of evacuation safety originally intended.

2.5.1 Increasing width of exitways

Exit stairways wider than both the required 1120 mm and 1420 mm proposed for the NFPA documents are already being designed into major high-rise buildings (Shimshoni 2007). Designers are cautioned however, not to make the clear width between handrails larger than 1525 mm as extensive crowd use puts people in the middle of the stair beyond the reach of a handrail. Thus, 1725 mm is the largest nominal width recommended for exit stairways. Wide stairs of 1725 mm provide more people flow per width than narrower stairs. For example, a 1420 mm nominal width stair performs about 38% more effectively – for flow – than a traditional 1120 mm nominal width stair even though the former is only 27% wider.

The data collected by NIST investigations (Averill 2005) into the World Trade Centre (WTC) collapse enable the flow rate in the stairways to be estimated. It was found that for WTC 1, the egress flow decreased by about 80% in the last 20 minutes before collapse, indicating that the majority escaped in an 82 minute period before that. On that basis the egress flow rate was estimated as 16 people per unit exit width (22 inches) per minute. These estimates support the argument that current flow rates may be significantly less than the rate suggested by Pauls (1974) and Togawa (1976) in the 1970s and one-third of the rates proposed in 1914.

2.5.2 Use of elevators for evacuation

Puchovsky (2007) wrote in response to the potential need for more timely evacuation of occupants in tall buildings that new provisions allowing the use of elevators in certain situations prior to Phase I Emergency Recall Operation (as mandated by the Firefighters Emergency Operation provision of ASME A17.1 *Safety Code for Elevators and Escalators*) be put forward. Elevators remain usable after initiation of the building fire alarm system, provided that the elevators have not been recalled upon detection of smoke in the elevator lobbies, machine room or hoistways. In such situations the elevators remain operable and are available for occupant evacuation.

The new provision paves the way for a broader concept currently being explored, which would allow the use of elevators as a component of the means of egress. As currently written, the proposal only allows elevators to be used for evacuation, and does not permit the elevators to satisfy the requirements for the number, capacity or arrangement of means of egress. Even so, the proposal introduces a major shift in the traditional way in which elevators have been considered for use in emergency situations, as building occupants have usually been instructed not to use elevators in fire and similar emergencies. Because of this, the proposal includes details about occupant information features and training as well as additional details about associated detection, alarm and communication equipment, sprinkler systems, elevator components, electrical power and wiring, and the concept of an occupant evacuation shaft system.

Similarly a new standard is proposed (ISO 2006) that suggests new technologies – and strategies for evacuations using elevators coupled with means of providing information to people (evacuees) to make correct decisions in their use.

2.5.3 Other egress provisions

Bukowski (2008) promotes alternative egress strategies which may negate the adverse impact of exitways that are of insufficient width, such as:

- Stairways that as well as a means of egress are also designated protected zones where the occupants can wait and be protected until rescued.
- Protected lobbies for elevators with protected elevator shafts and doors (already regulated in New Zealand (DBH 2005))
- Exit width may not be so problematic if the pressure (shortfall in capacity) is relieved by balancing of people flow to avoid bottle necks (choking) by matching flow through doors to stairs. In other words, manage the evacuation process.
- Refuge floors in tall buildings to provide a protected area for occupants to rest temporarily on their journey downstairs. Also intended as protected space in which people with disabilities can await rescue by the fire department.
- Provision of assistance for disabled occupants down stairs.

3. MODELLING EGRESS – ADAPTING FOR LARGER BODY SIZES AND REDUCED MOBILITY

Assuming that an individual's speed of movement is slowed by their increased size, the specific flow (people/sec/m) is similarly reduced due to the dual effects of reduced speed and reduced density because more space is required per person. So it logically follows that egress times will increase because people are bigger.

To obtain a measure of the likely effect of reduced mobility on the egress from buildings some analysis using first principles is proposed. The work in the *SFPE Handbook* by Nelson and Mowrer (2002) uses the following calculation method to determine emergency movement and evacuation time. By making assumptions and adapting the formulae by factoring in slower movement speeds for people of reduced fitness, and making an adjustment for people density on the basis that bigger people take up more space, some reductions in travel speed and increases in egress time can be estimated.

It should be noted that the above assumptions are not supported by contemporary data on the flow rates and walking speeds of people that would reflect present day conditions. The following is presented as an indication of the likely effect of the impact of larger body sizes and reduced mobility, and not as a substitute for collection of actual data.

The length of travel L_t is related to the travel speed S and traversal time t_{tr} by:

$$L_t = S \times t_{tr}$$

Equation 1

Speed of travel depends on the occupant density, age and mobility, where mobility is also now considered to perhaps be dependent on body size.

Speed – movement velocity of exiting individuals, S is governed by:

$$\begin{aligned} &S = k - akD \\ &where: \\ &S = speed\,along\,the\,line\,of\,travel, m/s \\ &D = density\,in\,persons, persons/m^2 \\ &k = constant \\ &a = 0.266 \end{aligned}$$

Equation 2

The constant *k* is 1.4 for horizontal travel and ranges from 1 to 1.26 for stairs depending on the gradient. This is all based on people of standard size, implying that some adjustments to the constants 'a' and 'k' may be all that is required to account for larger people.

For the purposes of this study an adjustment for the increased size of people is incorporated into the preceding equations as follows:

$$\begin{aligned} &a = a_o \times Os \\ &k = k_o / Os \\ &Os = oversize\,factor\ (10\%\ oversize => 1.1) \end{aligned}$$

Equation 3

The *Os* factor is an arbitrary measure for the purposes of the following analysis to gauge the effect of increasing population size and is subject to verification by other means/research.

The reductions in movement speed in Figure 4 are due to bigger people moving slower on their own, and when sharing space with other similarly sized people the effects of density (close proximity of other people) are more acutely felt in slowing down movement speed *S*.

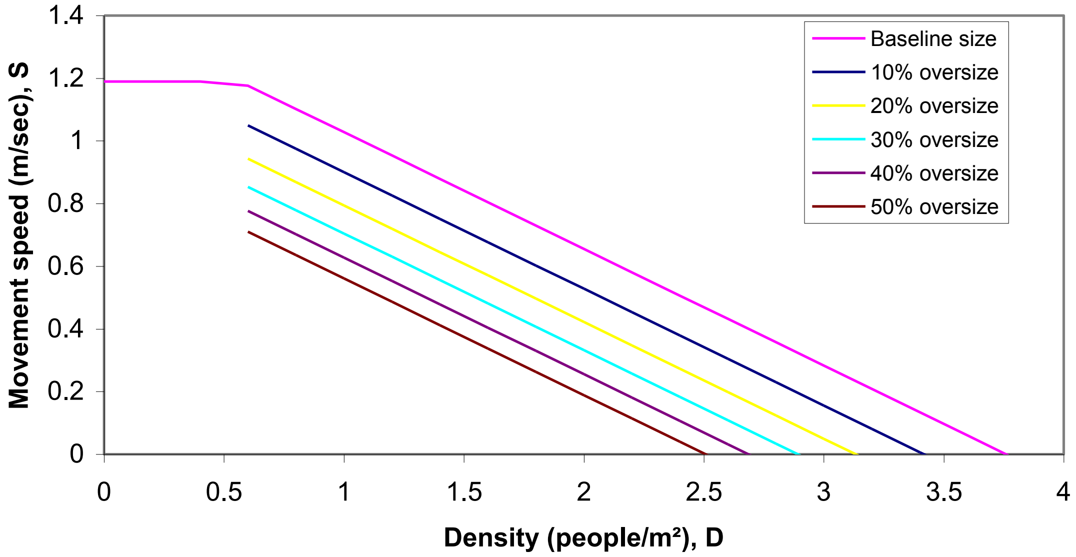


Figure 4: Evacuation speed as a function of density and people size

The specific flow F_s

$$F_s = (1 - aD)kD$$
$$F_s = kD - akD^2$$

Equation 4

Figure 6 also takes into account that for larger people it is difficult to fit them into the same size space and shows how the specific flow (persons/sec/m) is reduced.

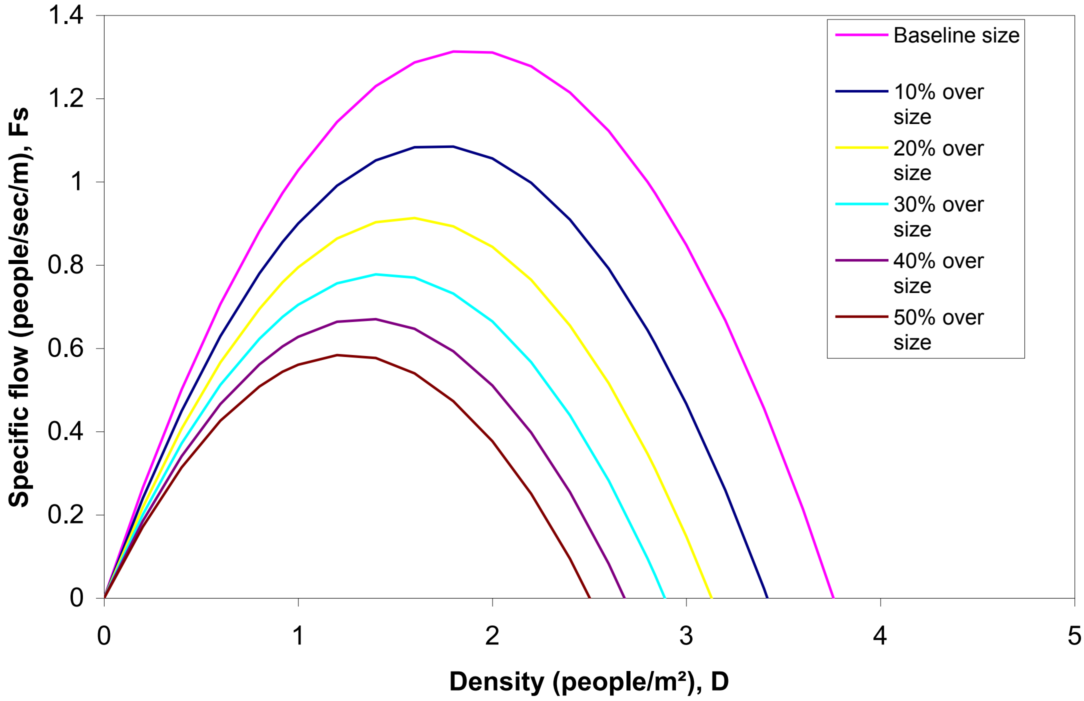


Figure 5: Specific flow as a function of density for increasing people size

The resulting increase in egress time is illustrated by reworking the example (see Appendix 2: Egress Design) in the *Fire Engineering Design Guide* (Buchanan 2001) for a range of increased people sizes to determine the effect.

The example is for a first floor level space measuring 10 x 10 m with an occupancy of 90 people, giving a density of 0.9 people/m^2. There is a single exit, 1000 mm wide, at one corner leading to a 1200 mm wide protected stairway, 10 m long (horizontally) with treads and risers of 280 and 180 mm respectively. The stairway exits to the outside through another 1000 mm wide exit.

Ignoring the detection, decision and investigation time (and considering only the evacuation time) it takes 3.1 minutes for the building to be evacuated.

3.1 Impact of increase in size of people

Based on the worked example above, a people oversize factor (Os) was introduced to account for increased people sizes and several assumptions are implicit in this exercise.

The relationship between changing people size and shape, where BMI is one possible measure, and how this relates to mobility is a key relationship in this study. So for the purposes of this exercise, a BMI-based oversize factor (Os) is used and applied as defined in equations 1 to 4. Whether the method is valid or not is a minor issue compared with the trends illustrated. Establishing a concept is required initially and calibrating and optimising the method (to actual data on oversize people movement) can follow later.

Three modelling trials were conducted to access the effect of varying people size on:

1. Evacuation time; and then
2. Reducing occupant number to maintain the same evacuation time;

3. Increasing exit widths to maintain the same evacuation time.

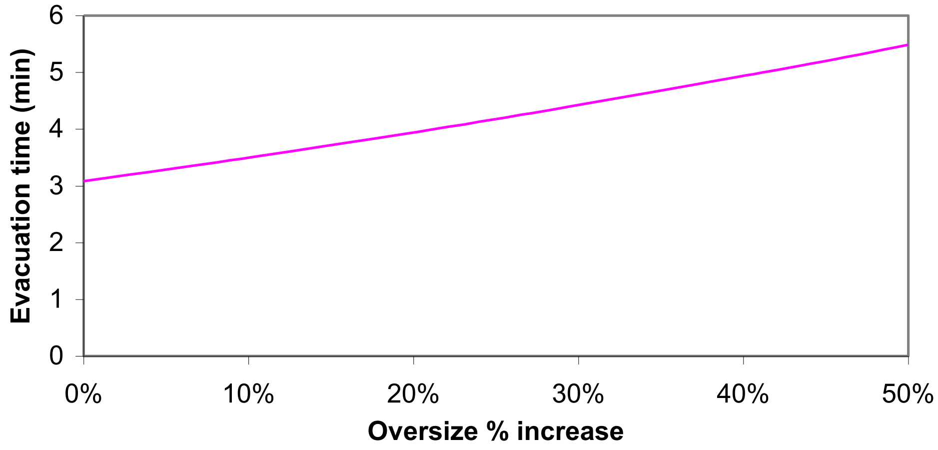


Figure 6: Effect of increasing people size on evacuation time

Increasing the size of the people increases the evacuation time as shown in Figure 7. The slope of the trend increases upwards (exponentially $3.1e^{1.15x}$) so that the evacuation time increases from 3.1 minutes to 4.2 minutes (25% oversize), which when added to the pre-movement time of 1.9 minutes is 6.1 minutes and when a safety margin of 6.1 is added to the design time is 12.2 minutes, originally 10 minutes.

This 22% increase in time may not be so significant for the small building in this example. However, it is likely to have a multiplying effect for more complex and large buildings where exitways merge and the original design assumed some exitways may have already been cleared before the next exiting group arrived at that point.

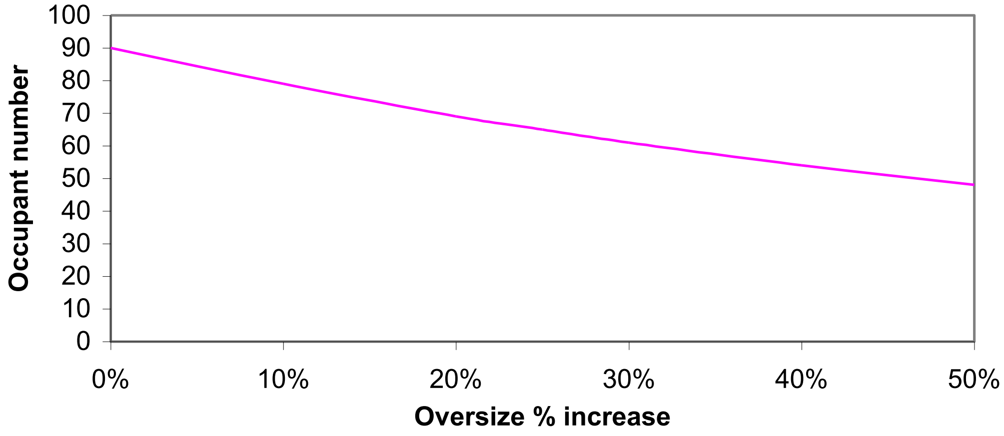


Figure 7: Reduction of occupant number to maintain evacuation time

If the evacuation time is required to remain the same, a reduction in the occupant capacity achieves this as shown in Figure 8. For a 25% increase in people size the occupant capacity is reduced from 90 to 64 people. However, this may not be a practical solution from a building use standpoint.

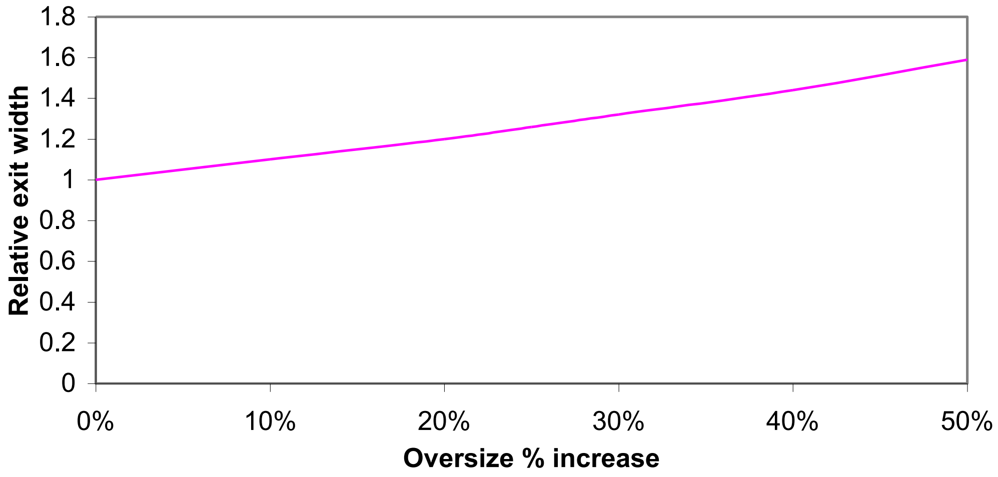


Figure 8: Exit width to maintain evacuation time

To maintain the evacuation time, the relative width of the exits is increased as illustrated in Figure 9. As applied to the worked example with current minimum acceptable widths of 1000 mm doors and 1200 mm for stairs, an oversize value of 25% from current values requires the relative widths to be increased by 25%, resulting in doors being 1250 mm wide and stairs being 1500 mm.

The egress modelling results are summarised in Table 5 indicating changes required to maintain the same level of egress safety as estimated for a BMI relative to 1970s values.

Table 5: Summary of egress parameters

BMI	0%	10%	20%	25%	30%	40%	50%
Evacuation time mins	3.1	3.5	3.9	4.2	4.4	4.9	5.5
Occupancy number	90	79	69	65	61	54	48
Exit width increase %	0%	10%	20%	26%	32%	44%	59%
Exit B mm	1000	1100	1200	1260	1320	1440	1590
Stair mm	1200	1320	1440	1512	1584	1728	1908
Exit C mm	1000	1100	1200	1260	1320	1440	1590

Furthermore, even if only some people are of increased size but move slower it is likely the whole occupancy will be slowed as a result, particularly if there is merging of flows.

3.2 Other modelling solutions

A survey of other egress modelling software was unable to find any programme that had people size or mobility as an input parameter. However, some models include inputs for walking speeds for different occupancy groups and for people with disabilities (suggested input data is included in Appendix 2: Egress Design).

This development with new questions raised about people mobility could spurn a next stage of development of egress models.

The EXIT89 (Fahy 1995) model can handle some of the most relevant components of evacuation scenarios of interest in the evaluation of engineered building designs from a fire safety standpoint. These include:

- Accounting for occupants with a range of mobility, including disabled occupants and young children.

- A choice of walking speeds that can reflect the difference between normal movement, what might be appropriate in a drill situation, and emergency movement which might be more appropriate for a population reacting with a sense of urgency.

Unfortunately EXIT89 and other models reviewed do not address the problem of mobility-impaired people, particularly due to their increased size. This would require modelling the associated changes in people density and the resultant choked flow scenarios, and would be dependent on supporting people movement data consistent with current population demographics.

4. FIXING EGRESS PROBLEMS

This study has established that there are very real concerns about the current ‘real’ capacity of emergency egress provisions and, in particular, the exit widths. To remedy the problems a review of NZBC Compliance Document C/AS1 (DBH 2005) for new and existing buildings in accordance with the following broad options is warranted.

Options

1. Increase exit widths.
2. Increase active protection – to increase permitted evacuation times.
3. Increase passive protection – to increase permitted evacuation times.
4. Reduce occupancy numbers.
5. Monitor ongoing international research.
6. Manage evacuations.

   Utilise staged evacuations in accordance with ISO/DTR 16738:2007E (ISO 2007) by clearing most at-risk floors in a building first.

   Allow use of elevators ISO/TR 25743:2006(E) (ISO 2006) where a strategy for determining use of lifts in emergency evacuations is presented. Useful for evacuating people with disabilities and limited mobility, and may add to egress capacity by taking the load off stairways that would otherwise be effectively reduced by slower moving people.

   Extensive flow charts are included in ISO/TR 25743:2006(E) that suggest a decision strategy based on several inputs from the building management system (BMS), which includes the hazards throughout the building such as smoke, flooding, temperatures and gas detection etc. The BMS can be programmed to make decisions and issue instructions to the occupants and manage the evacuation.
7. Evacuation plans tailored to the occupancy (type) and disabled requirements (if any) and to utilise the elevators if possible. Assign minders for people with special needs and take those people out of the able-bodied flow.
8. Verify evacuation data in terms of people movement for current population demographics.

4.1 Other factors affecting egress

While there may seem to be a case for making changes based on longer expected ‘travel times’, it needs to be considered in relation to other factors such as ‘pre-movement times’. If travel time is small compared to pre-movement time, then the overall impact may not be so great.

There is also uncertainty regarding the safety factors that are already included in the calculations, and therefore to what extent some of the ASET and pre-movement assumptions are conservative (or not).

5. CONCLUSIONS

Based on the literature review and basic egress modelling this study confirms that:

- The size of people has increased and is forecast to continue.
- Bigger people do slow down evacuation rates.
- As a result evacuation times increase.
- A few disabled people may slow the evacuation significantly.
- Wider exits will counter the increase in evacuation times.
- Reduced occupancy will counter the increase in evacuation times.
- Installing additional active/passive protection will accommodate longer evacuation times
- Use of elevators and staged evacuations with an effective management strategy will relieve pressure on traditional means and methods of egress.

It therefore follows that to address the safety concerns resulting from impeded evacuation the solution will be found from an effective combination of the above key findings.

Another essential parameter requiring review is the original data upon which the egress calculations are based.

6. RECOMMENDATIONS

For the exit width requirements in the NZBC Compliance Document C/AS1 (DBH 2005) in Table 1, there is a case for re-evaluating the current values. The pertinent question is by how much the exit widths need to be increased. On the basis of the simple modelling data presented in Table 5 there is a roughly linear relationship between increases in body size and the exit width required. So if, for instance, it could be confirmed that body sizes have increased by 25% then exit widths need to be 25% or 26% wider to maintain the same egress time.

Alternatives to increasing exit widths to achieve equivalent egress safety may include reducing occupant numbers or permitting egress times to be increased by the provision of additional active and passive protection, or re-evaluating egress strategies by including elevators and staged evacuations.

7. FUTURE WORK

Use distributions of BMI or otherwise incorporate variations in body anthropometrics and mobility into evacuation models.

Consider the influence of the distribution of body anthropometrics on the movement of a whole occupancy with a distribution of sizes and movement speeds and consider also that slim people could be on crutches or otherwise disabled. This may lead to the possible modification of evacuation software programmes to include that input, which would require data testing to support relationships between BMI, density, movement speed and flow.

A likely scenario is that for a particular building a distribution of evacuations times will be the output allowing the opportunity to take the 95% or 97.5% single-sided confidence limits of evacuation times to use in the design of the passive and active protection. If that is not practical, then staged or other evacuation strategies could be modelled to demonstrate the required level of performance which is likely to be achieved.

Central to all the above intentions is the necessity to confirm just how much the movement of people now differs from the original work of Fruin (1971) and Pauls (1974) and, in particular, how it applies to New Zealand conditions. Studies could be conducted, for instance, on people egress from stadia after major sporting or cultural events. Analysis of video taken at 100 frames per second is required to record essential body movements and is necessary to study in depth (Pauls 2008) how people interact. Such movement data will enable review of the people movement formulae used in this study.

In addition, future studies could focus on:

- improving the understanding of the contribution that the travel time makes to the overall evacuation time
- what safety factors really exist in calculations of ASET and RSET
- what the overall impact is on the evacuation time.

The issue of counterflows in stairways, where fire fighters are travelling up the stairs at the same time as people are travelling down, is a very valid reason for considering increasing stair widths. But just how the two opposing flows interact is worthy of study where a small increase in width may make the provision acceptable.

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9. APPENDIX 1: ACCEPTABLE SOLUTION C/AS1 (DBH, 2005)

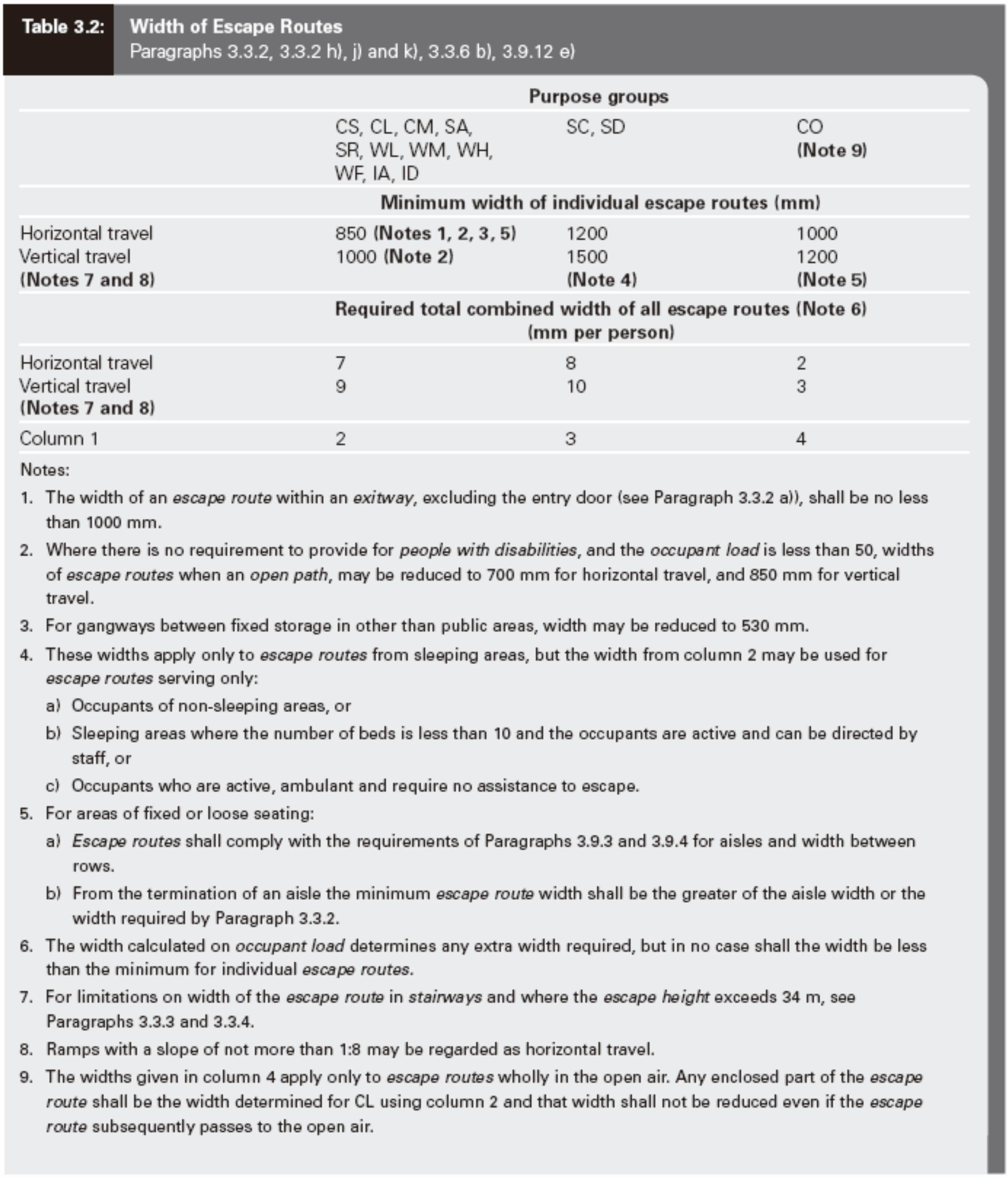


Table 3.2: **Width of Escape Routes**
Paragraphs 3.3.2, 3.3.2 h), j) and k), 3.3.6 b), 3.9.12 e)

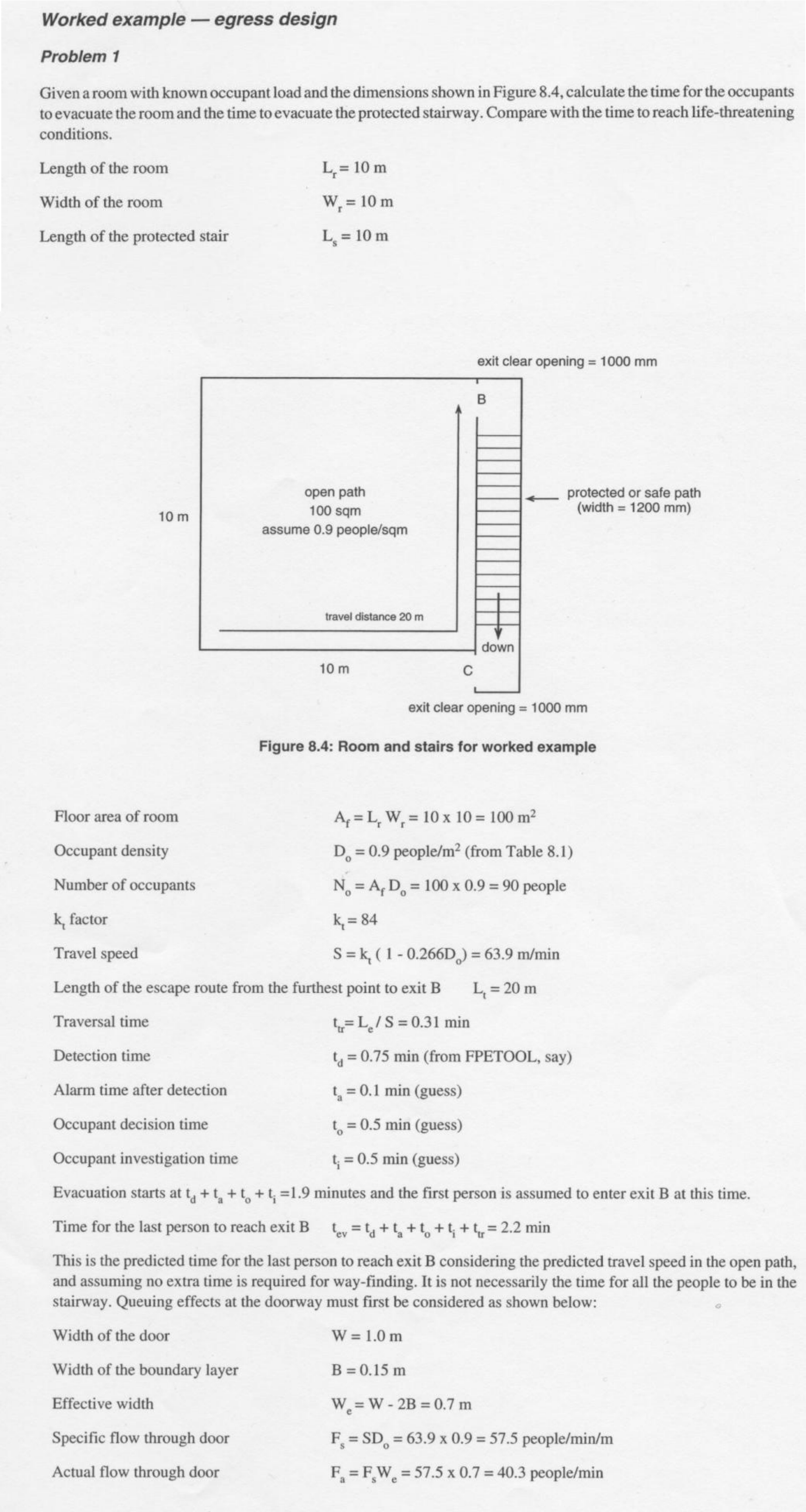
	Purpose groups		
	CS, CL, CM, SA, SR, WL, WM, WH, WF, IA, ID	SC, SD	CO **(Note 9)**
	Minimum width of individual escape routes (mm)		
Horizontal travel	850 **(Notes 1, 2, 3, 5)**	1200	1000
Vertical travel **(Notes 7 and 8)**	1000 **(Note 2)**	1500 **(Note 4)**	1200 **(Note 5)**
	Required total combined width of all escape routes (Note 6) (mm per person)		
Horizontal travel	7	8	2
Vertical travel **(Notes 7 and 8)**	9	10	3
Column 1	2	3	4

Notes:

1. The width of an *escape route* within an *exitway*, excluding the entry door (see Paragraph 3.3.2 a)), shall be no less than 1000 mm.
2. Where there is no requirement to provide for *people with disabilities*, and the *occupant load* is less than 50, widths of *escape routes* when an *open path*, may be reduced to 700 mm for horizontal travel, and 850 mm for vertical travel.
3. For gangways between fixed storage in other than public areas, width may be reduced to 530 mm.
4. These widths apply only to *escape routes* from sleeping areas, but the width from column 2 may be used for *escape routes* serving only:
   a) Occupants of non-sleeping areas, or
   b) Sleeping areas where the number of beds is less than 10 and the occupants are active and can be directed by staff, or
   c) Occupants who are active, ambulant and require no assistance to escape.
5. For areas of fixed or loose seating:
   a) *Escape routes* shall comply with the requirements of Paragraphs 3.9.3 and 3.9.4 for aisles and width between rows.
   b) From the termination of an aisle the minimum *escape route* width shall be the greater of the aisle width or the width required by Paragraph 3.3.2.
6. The width calculated on *occupant load* determines any extra width required, but in no case shall the width be less than the minimum for individual *escape routes*.
7. For limitations on width of the *escape route* in *stairways* and where the *escape height* exceeds 34 m, see Paragraphs 3.3.3 and 3.3.4.
8. Ramps with a slope of not more than 1:8 may be regarded as horizontal travel.
9. The widths given in column 4 apply only to *escape routes* wholly in the open air. Any enclosed part of the *escape route* shall be the width determined for CL using column 2 and that width shall not be reduced even if the *escape route* subsequently passes to the open air.

Figure 9: Acceptable Solution C/AS1 (DBH 2005)

10. APPENDIX 2: EGRESS DESIGN



Worked example — egress design

Problem 1

Given a room with known occupant load and the dimensions shown in Figure 8.4, calculate the time for the occupants to evacuate the room and the time to evacuate the protected stairway. Compare with the time to reach life-threatening conditions.

Length of the room	$L_r = 10$ m
Width of the room	$W_r = 10$ m
Length of the protected stair	$L_s = 10$ m

Figure 8.4: Room and stairs for worked example

Floor area of room	$A_f = L_r W_r = 10 \times 10 = 100$ m^2
Occupant density	$D_o = 0.9$ people/m^2 (from Table 8.1)
Number of occupants	$N_o = A_f D_o = 100 \times 0.9 = 90$ people
k_t factor	$k_t = 84$
Travel speed	$S = k_t (1 - 0.266D_o) = 63.9$ m/min

Length of the escape route from the furthest point to exit B $L_t = 20$ m

Traversal time	$t_{tr} = L_e / S = 0.31$ min
Detection time	$t_d = 0.75$ min (from FPETOOL, say)
Alarm time after detection	$t_a = 0.1$ min (guess)
Occupant decision time	$t_o = 0.5$ min (guess)
Occupant investigation time	$t_i = 0.5$ min (guess)

Evacuation starts at $t_d + t_a + t_o + t_i = 1.9$ minutes and the first person is assumed to enter exit B at this time.

Time for the last person to reach exit B $t_{ev} = t_d + t_a + t_o + t_i + t_{tr} = 2.2$ min

This is the predicted time for the last person to reach exit B considering the predicted travel speed in the open path, and assuming no extra time is required for way-finding. It is not necessarily the time for all the people to be in the stairway. Queuing effects at the doorway must first be considered as shown below:

Width of the door	$W = 1.0$ m
Width of the boundary layer	$B = 0.15$ m
Effective width	$W_e = W - 2B = 0.7$ m
Specific flow through door	$F_s = SD_o = 63.9 \times 0.9 = 57.5$ people/min/m
Actual flow through door	$F_a = F_s W_e = 57.5 \times 0.7 = 40.3$ people/min

Queuing time to travel through exit B $t_q = N / F_a = 90 / 40.3 = 2.2$ min

The last person enters exit B 2.2 min after the first person entered exit B, i.e. $t_t = 2.2$ min, hence evacuation time $t_{ev} = t_d + t_a + t_o + t_i + t_q = 1.9 + 2.2 = 4.1$ min. Take safety margin $t_s = 4.1$ min.

Design time to escape $t_d = t_{ev} + t_s = 4.1 + 4.1 = 8.2$ min

Design is OK if the design time is less than the time for untenable limits in the room to be exceeded.

Problem 2

Extend problem 1 to calculate the time for the occupants to evacuate the stairway.

Width of the stairs $W = 1.2$ m

Width of boundary layer $B = 0.15$ m

Effective width $W_e = W - 2B = 0.9$ m

Using the actual flow of people as they pass through exit B and the width of the space they enter, the specific flow in the stairway can be determined.

Specific flow $F_s = F_a / W_e = 40.3 / 0.9 = 44.8$ persons/min/m

Length of stair tread going $G = 280$ mm

Height of the stair riser $R = 180$ mm

k_t factor $k_t = 51.8(G/R_s)^{0.5} = 64.6$

The specific flow and people density can be related as follows to determine the density of people in the stair.

Density of occupants $S = k_t\,(1\text{-}0.266D_s)$ and $F_s = S\,D_s$

so $F_s = k_t D_s\,(1 - 0.266D_s)$

$$0.266\,k_t\,D_s^2 - k_t\,D_s + F_s = 0$$

This is a quadratic equation in the form $ax^2 + bx + c = 0$, where $a = 0.266\,k_t$, $b = -k_t$, $c = F_s$ and $x = D_s$. Solve for D_s.

$$D_S = \left[-b \pm \sqrt{\left(b^2 - 4ac\right)}\right]\Big/2a \quad = 0.92 \text{ or } 2.84 \text{ people/m}^2$$

Sensibly choose $D_s = 0.92$ people/m^2.

Travel speed in stair $S = k_t\,(1\text{-}0.266D_s) = 48.8$ m/min

Length of stair $L_s = 10.0$ m

Time to traverse the stairs $t_{ts} = L_s / S = 10 / 48.8 = 0.20$ min

The first person reaches and enters exit C at 1.9 + 0.2 = 2.1 minutes. The last person reaches exit C at 4.1 + 0.2 = 4.3 minutes.

Actual flow through exit C $F_a = F_s\,W_e = 44.8 \times 0.7 = 31.4$ people/min

Time to travel through exit C $t_{qc} = N / F_a = 90 / 31.4 = 2.9$ min

The last person enters exit C 2.9 minutes after the first person has entered exit C, therefore the stairway is clear and the evacuation time for the "building" is 2.1 + 2.9 = 5.0 minutes.

The design time for escape for the protected stairway is $t_d = t_{ev} + t_s = 5.0 + 5.0 = 10$ minutes.

This time should be compared with time for untenable conditions in the stairway.

A timeline for the escape design is shown overleaf.

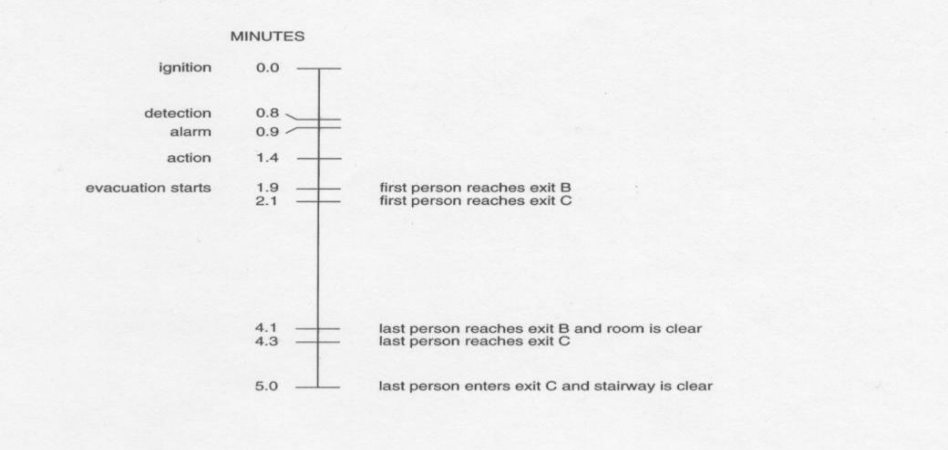


Figure 10: Worked example from *Fire Engineering Design Guide* (Buchanan 2001)

Table 6. Travel speeds reported in Boyce Shields and Silcock (1999a, b)

A. Where density was reportedly not a factor

Type of situation	Measured travel speeds				
Transport terminals[2]	265 ft/min on walkways (1.35 m/s)				
Average under "normal conditions"[3]	60 m/min (1.0 m/s)				
Experiment with disabled subjects[6]					
On horizontal (m/s)	*Min*	*1st Q*	*3rd Q*	*Max*	*Mean*
All disabled subjects	0.10	0.71	1.28	1.77	1.00
With locomotion disability	0.10	0.57	1.02	1.68	0.80
No aid	0.24	0.70	1.02	1.68	0.95
Crutches	0.63	0.67	1.24	1.35	0.94
Cane	0.26	0.49	1.08	1.60	0.81
Walker/rollator	0.10	0.34	0.83	1.02	0.57
Without locomotion disability	0.82	1.05	1.34	1.77	1.25
Unassisted wheelchair	0.85	--	--	0.93	0.89
Assisted ambulant	0.21	0.58	0.92	1.40	0.78
Assisted wheelchair	0.84	1.02	1.59	1.98	1.30
On upward incline					
All disabled subjects	0.21	0.42	0.74	1.32	0.62
With locomotion disability	0.21	0.42	0.72	1.08	0.59
No aid	0.30	0.48	0.87	1.08	0.68
Crutches	0.35	--	--	0.53	0.46
Cane	0.21	0.38	0.70	1.05	0.52
Walker/rollator	0.30	--	--	0.42	0.35
Without locomotion disability	0.70	--	--	1.32	1.01
Unassisted wheelchair	0.70	--	--	--	--
Assisted ambulant	0.23	0.42	0.70	0.72	0.53
Assisted wheelchair	0.53	0.70	1.05	1.05	0.89
On downward incline					
All disabled subjects	0.10	0.42	0.70	1.83	0.60
With locomotion disability	0.10	0.42	0.70	1.22	0.58
No aid	0.28	0.45	0.94	1.22	0.68
Crutches	0.42	--	--	0.53	0.47
Cane	0.18	0.35	0.70	1.04	0.51
Walker/rollator	0.10	--	--	0.52	0.36
Without locomotion disability	0.70	--	--	1.83	1.26
Unassisted wheelchair	1.05	--	--	--	--
Assisted ambulant	0.42	0.52	0.86	1.05	0.69
Assisted wheelchair	0.70	0.96	1.05	1.05	0.96

Table 6. continued

B. Where density was a factor

Location	Measured travel speeds					
Public places[2]	100-250 ft/min on walkways (0.51-1.27 m/s) 70-150 ft/min on stairs (0.36-0.76 m/s)					
Public places[3]	17 m/min minimum on horizontal (0.28 m/s) 11-16 m/min downstairs (0.18-0.27 m/s)					
Theatres and educational[3]	15-20 m/min (0.25-0.33 m/s) max 2.33 m/s					
Industrial buildings[3]	25-30 m/min (0.42-0.56 m/s) max 2.33 m/s					
Transport terminals[3]	20-25 m/min (0.33-0.83 m/s) max 2.10 m/s					
Descending stairs[3]	20-25 m/min (0.33-0.42 m/s) max 1.28 m/s					
High-rise office building drill[18]	*mean speed*			*density*		
stair with full lighting	0.61 m/s			1.30 p/m^2		
stair with reduced lighting	0.70 m/s			1.25 p/m^2		
stair with photo-luminescent material (PLM) installation and reduced lighting	0.72 m/s			1.00 p/m^2		
stair with PLM only	0.57 m/s			2.05 p/m^2		
Mid-rise office building drill[12]	0.78 m/s down stairs					
Mid-rise office building drill[12]	0.93 m/s down stairs					
Hotel exercise - along corridor (m/s) [9]						
Daytime scenario 1	*Min*	*1st Q*	Med	*3rd Q*	*Max*	*Mean*
able-bodied participants	0.6	1.1	1.3	1.8	4.0	1.5
wheelchair users	0.2	--	--	--	1.2	0.8
walking disabled	0.1	--	--	--	--	--
Daytime scenario 2						
able-bodied participants	0.3	0.9	1.1	1.3	1.6	1.1
wheelchair users	0.4	--	--	--	0.7	0.6
walking disabled	0.7	--	--	--	--	--
Night-time scenario						
able-bodied participants	0.5	1.1	1.3	1.7	3.8	1.5
wheelchair users	0.5	--	--	--	0.9	0.7
walking disabled	2.4*	--	--	--	--	--

* This person travelled at this speed for a distance of 4.9 metres