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ESCAPE ROUTES DESIGN SPECIFICATION ANALYSIS FOR OPTIMUM EVACUATION OF 200 PEOPLE IN HIGH-RISE BUILDING

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ABSTRACT: *Current issues in evacuation from the high-rise buildings, i.e. to either evacuate using staircase or elevator, the condition of escape routes provided in high-rise residential buildings, and people's attitude toward fire safety, are still being debated by many parties. Escape routes in high-rise residential buildings is an important element for emergency escape. In this paper analysis of the specification of staircase, fire door and corridor will be carried out by simulating a number of people evacuating buildings of different layouts identified in the observation study.*

Keywords: *Fire safety, evacuation, staircase design and specification, evacuation*

Introduction

Evacuation from building fire is essential and has to be initiated as soon as the fire alarm is sounded or fire cues have been detected. When evacuation is in progress, two important elements have a strong influence on the evacuation time i.e. Occupants' characteristics and building characteristics. Purser (2004) mentioned that the behaviour of occupants escaping from fire depends on a range of factors including building characteristics i.e. occupancy types, method for detection and the provision of warnings, fire safety management systems and building layout. Other equally important building characteristics are spatial complexity of the buildings, travel distances, and escape route and final exit. However, occupant characteristics themselves also have a large influence on the evacuation time i.e. occupant numbers, state of alertness, whether they are awake or asleep, familiarity with the building environment, experience of fire drill, and physical abilities.

Purser, (2004), explains that the prescriptive approach concentrates on the structural aspects of means of escape and acknowledges only in a general sense the point that fire hazard and safe escape are basically time dependent. It does not consider occupant behaviour in emergencies and the time required for occupant responses. Best practice for structural design in relation to fire safety therefore takes into account the needs of building occupants for structural performance. This can be achieved by means of a performance-based Fire Safety Engineering approach. However Rasbash *et al* (2004) mentions that the consequences of inadequate means of escape have been highlighted in a number of incidents in which the absence of properly designed escape routes, inadequate protection, failure of alarm or warning systems, or some other shortcoming, has resulted in serious loss of lives.

Research Methods

SIMULEX is an evacuation tool which specialises in modelling the physical aspects of evacuation movement, and is widely used as a consultancy and analysis tool around the world. Simulex enable the user to simulate occupant behaviour in the event of a building evacuation, identify potential problems and find solutions. It uses a series of 2D floor plans, with exits and staircases linked together. Each floor plan and staircase is displayed in its own simulation window so that every event in Simulex environment can be viewed simultaneously (Thompson, IES 03/2008). Further application of the Simulex programme can be found in Thompson and Marchant (1995a, 1995b, 1996) and validation references can be referred to Olsson and Regan (1998) and Thompson and Marchant (1995c).

Models were designed using CAD software and saved in a dxf file. If more than one floor needs to be analysed, dxf files have to be uploaded as many times as desired and the floor then named accordingly. All floors have to be connected to each other by using staircases designed in the SIMULEX environment.

Pre-designed models were then uploaded into Simulex and named accordingly to indicate the appropriate floor level they represent. Staircases are then designed according to the width and length of staircases to test. In general, the simulation procedures were as follows;

(i) Add floor; by clicking ‘Building’ button, floor plan can be added. Dxf file saved in appropriate folder can be imported and named accordingly i.e. ground floor.

(ii) Procedure (i) can be repeated to add other floor plans i.e. Floor 1, 2, 3 etc. The number of floor plans to be added depends on the number of floors we wanted to investigate.

(iii) Add staircases i.e. staircase 1, 2, 3, 4, etc by putting in the staircase specification e.g. staircase width as in table 4.9 and name them accordingly.

(iv) Add links to every staircase designed to the floor level i.e. link 1 is to link staircase 1 to the ground floor plan, link 2 is to link staircase 1 to the 1st floor, link 3 is to link staircase 2 to the 1st floor, link 4 to link staircase 2 to the landing floor, link 5 to link staircase 3 to the landing floor, link 6 to link staircase 3 to the 2nd floor and so on. All links widths have to be the same width as the staircase designed.

(v) Add 2 metres exit to indicate the normal main entrance width at the ground floor which is normally uses by the occupants to enter and leave the building. It is placed opposite to the link 1 made in procedure (iv).

(vi) Add people into all models by dividing equally into every chamber available in the study models. People characteristics are then set; in the analysis of the models the same typical distribution of people is used in each model tested to reflect the normal occupancy type of people in residential buildings, i.e. male, female, children and elderly.

(vii) Calculate the distance maps by clicking ‘DistMap’ button and then click ‘Calculate All’.

(viii) Run the simulation by click 'Simulation' and then click 'Begin'. The simulation can be recorded and saved in an appropriate folder under an appropriate name.

(ix) After the simulation has been completed a popup window will show the simulation time. Click 'Yes' and another popup window will tell the time taken by all people who have reached the exit.

(x) Note down the evacuation time in table for further analysis.

Figure 1 shows one of the models that have been simulated in Simulex.

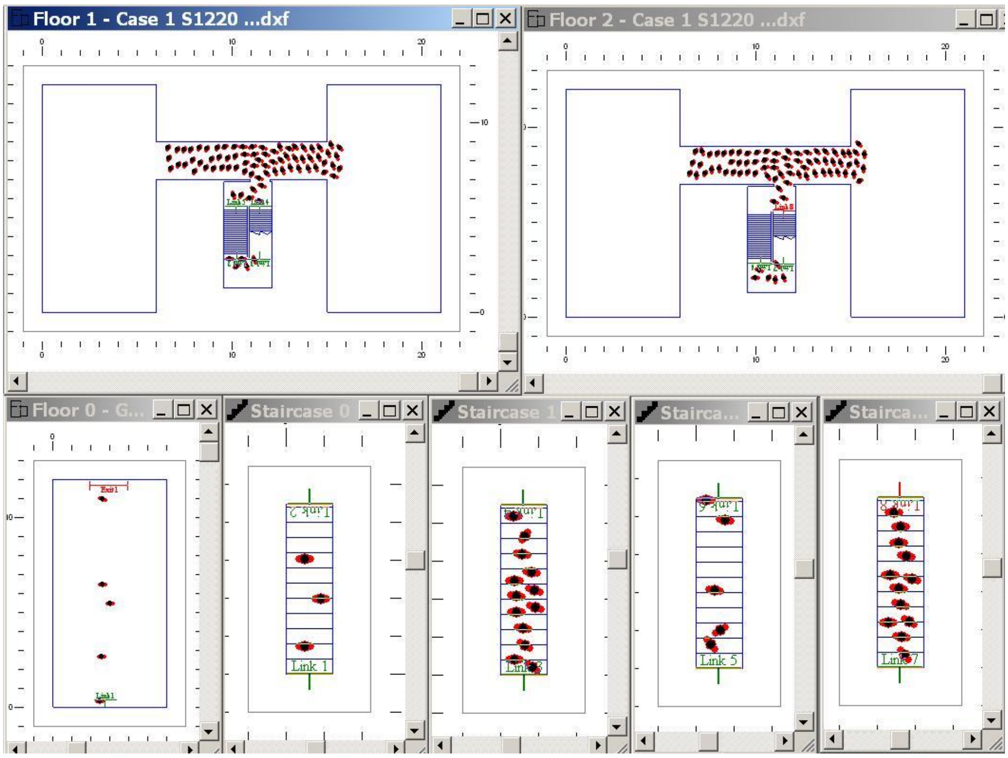

Figure 1: Example of simulation process

Result and Discussion

There are eight scenarios of evacuation patterns all together that were developed based on the observation of the high-rise residential buildings in Malaysia. The vast majority of high-rise residential buildings observed had emergency staircases, parallel, vertical, or straight with the corridor, or staircase without corridor that served the cluster flats. Those scenarios come with or without a fire door. The philosophy adopted here is *the faster is the safer*[1]. The purpose of this study is;

[1] *The faster means that in all models simulated, evacuation time will be compared and the shorten time taken by occupants to evacuate the studies models is consider the safest one.*

(1) To know at what point the design of staircase, fire door and corridor in the high-rise building provides an optimum safe route to be used by occupants.
(2) To test the popular assumption that wider staircase and corridor are better for evacuation process and the bigger space provided the better for the people to evacuate.

Analysis on the study models is important because technical solutions need to be determined, hopefully to reduce the risks to the building occupants by helping them in the evacuation process. It is difficult to change human behaviour but the building specifications can be changed more easily. From the opinion survey 72.6% of the occupants had no formal training or courses in fire safety and 77.4% had no experience of involvement in building fires. Even though 57.4% of them had experienced a fire drill, none of them had experienced a fire drill in their own residential building (Yatim and Harris, 2007). In this regard, the building element best known as escape route, that is escape stairs, corridors and fire doors, should be designed and constructed to serve the occupants the best they can by not allowing any further delay in the evacuation process. The design and construction of escape routes needs to consider not only the evacuation time but also the construction time, economics, construction method and space utilization factors. The objective of this section is to analyse the optimum staircase width, corridor width, and fire door width. Table 4.9 show the staircase, fire door and corridor sizes that have been selected to be used for further analysis in SIMULEX software.

Time is the determining factor for analysing the staircase specification.. In this sub-chapter, discussion will be centred on the travel time taken by 200 occupants evacuating the pre-designed model through the specific staircase dimension, fire door and corridor width. From 200 people, 100 people will be placed at the 1st floor and another 100 at the 2nd floor. The number of people on each floor will be divided equally i.e. if the study model has two chambers, 50 people will be placed in each of the chambers. 260 models have been tested and the test results can be found in figure 7.8 to figure 7.15 below. 200 occupants were chosen based on the assumption of high occupancy i.e. 4 persons per room for a three bedroom flat. From the observation of high-rise residential buildings in Kuala Lumpur and Penang, the number of flats per floor level ranges from 6 to 16 flats with the majority having 8 flats per floor. Therefore; 4 persons/room x 3 bedrooms/flat x 8 flats/floor = 96 people. The nearest round figure to 96 is 100, therefore 100 people per floor level had been chosen for the simulation because in the seventh schedule of the UBBL says that the capacity in a number of persons of a unit of exit width (i.e. staircase width) varies from 30 persons per unit of exit width to 100 persons per unit of exit width for travel in horizontal direction. (Refer to Table 2.0 in Chapter 2 for example showing the maximum number of people per given staircase width). In engineering terms designing any building elements, for the safety of people, the extreme condition has to be considered. We do not have to worry about the lower cases if we have considered the extreme condition. For example when designing a building column, the maximum load that could be carried by the column has to be considered. On top of that it is commonly practice that 5% – 10% of the safety factors are added to accommodate the unforeseen circumstances of possibly the building is overloaded in the future especially when dealing with the live load i.e. people and movable equipment. The optimum dimensions derived below are for overcrowded conditions and for lower populations the optimum dimensions may be different.

(i) Model one

Figure 2 shows the graph of evacuation time versus fire door width for model one. This scenario has a staircase with a fire door and not parallel with the corridor. This model is named “Opposite Direction with Fire Door”. There are five sizes of staircase from the minimum width 914 mm to the maximum width 1524 mm. Every staircase is designed with one fire door in the range 762 mm (2 ft 6 inch) to 1524 mm (5 ft), taking the evacuation times of 200 occupants.

Overall analysis of the test result of 200 occupants evacuating the study model showed a difference of 84 sec between the shortest and longest of the staircase design tested. The shortest time taken was 225.0 sec for the 1372mm staircase with 838 mm fire door width. The longest time taken was 309.3 sec for the 914mm staircase with 914 mm fire door width.

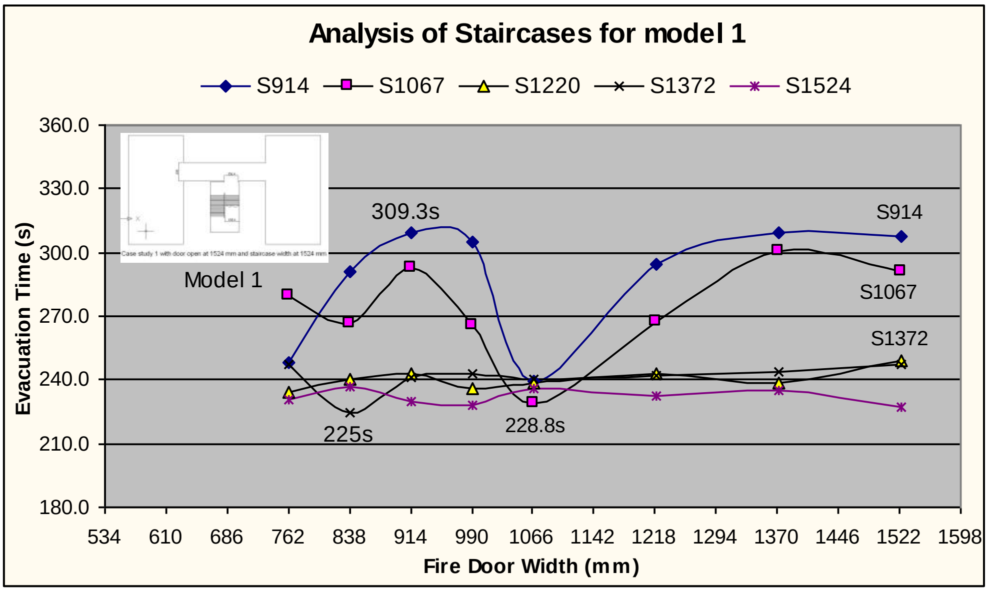

Figure 2: Evacuation Time Vs Fire Door; Model 1 i.e. Opposite directions with fire door.

The staircases of width 914 mm and 1067 mm show the same pattern of evacuation time i.e. time increased when the fire door width increased. Fire door size 914mm (3 ft) has the longest time taken for all occupants to evacuate the model. The total evacuation time is slightly improved when the fire door width is increased to 990 mm (3ft 6inches). The shortest time taken recorded was when the fire door width was 1067mm (3.5 ft). The time is then increased again when the fire door width is increased to 1220mm (4ft) and 1370 mm (4.5ft) and remains about the same when the fire door width is further increased to 1524mm (5ft). Test results for staircases

1220 mm, 1372 mm and 1254 mm wide show that this has no significant effect on evacuation time even after the fire door sizes changed. This suggests that there is no significant correlation between the evacuation time and the fire door width if the staircase width is wider than 1220 mm for the number of people tested. There is significant evidence that traffic is not congested either if the staircase designed is wider than 1220 mm. For the same staircase orientation, a test is needed to determine the effect of corridor width on the evacuation time. In this regard, model two has been developed and tested.

(ii) Model two

The second test has been carried out on model two, which has been slightly modified from model one i.e. without fire door increased corridor width. Corridor widths ranged from 1220 mm (4 ft) to 2440 mm (8 ft). This model is named as "Opposite Directions without Fire Door". The result of the test is in figure 3 i.e. evacuation time versus corridor width. The purpose of this analysis is to examine the corridor specification against the staircase width.

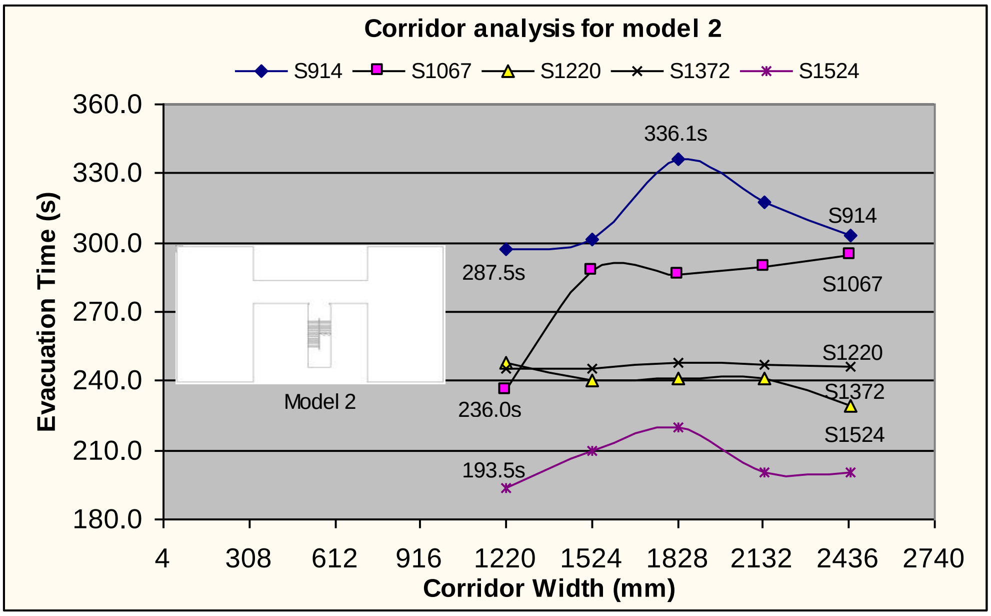

Figure 3: Graph Evacuation time Vs Corridor width, Model 2 i.e. opposite direction without fire door

The test results show that the time taken for the staircase 914mm wide is slightly higher than model one. The shortest time taken is 287.5 sec at corridor width 1220 mm and the highest time taken is 336.1 sec at corridor width 1828 mm. The time taken seems to improve when the staircase width increases. However, there is no significant difference between staircases 1220 and 1372 wide, as for both models the time taken is around 4 minutes even though the corridor width has been increased. There is a significant time reduction in staircase 1524 that is around 30 sec faster than the time taken in model one. However, the time is seen to steadily increase when the corridor width increases from 1220 to 1524 and 1828mm. The evacuation time then decreases when the corridor width is further increased to 2134 and remains about the same after it is further increased to 2440mm.

The phenomenon in staircase 1067 is similar in that the evacuation time increases when the corridor width increases. Staircase 1067mm has the best evacuation time when the corridor width is 1220 mm (4ft) i.e. 236.0 sec. The evacuation time increases when the corridor width increases to 1524 mm (5 ft) and remains about the same even after the corridor width is further increased to 1828 mm. The evacuation time then increases again approaching the 300 sec when the corridor width is increased to 2440 mm (8 ft).

However, this phenomenon does not happen to staircases 1220mm (4 ft) and 1372mm (4 ft 6 inch) where the evacuation time is recorded steady throughout the test and shows no significant changes even after the corridor width has been changed. This suggests that the wider corridor does not contribute to improving the evacuation process in high-rise residential buildings if the staircase width does not increase.

The results suggest that in staircases 914mm and 1067mm wide congestion is likely to happen because the evacuation time for both staircases, if corridor width is increased, was nearly 300 sec (5 minutes). For the staircase 914mm wide it is worst, when all cases were above 300 sec except for the corridor width 1220mm i.e. 287.5 sec. An anomalous result appeared for staircase 914mm when the corridor width was 1828 mm (6 ft) i.e. the evacuation time increased very significantly to 336.1 seconds. At the beginning, it seems that congestion at the staircase might have caused this phenomenon but the evacuation time reduced when the corridor width was increased to 2134mm.

It can be concluded that:

(1) The fire door can contribute to minimise traffic congestion in staircases if staircases are designed as in model one.
(2) A wider staircase can improve the evacuation time provided that wider openings are designed to replace the fire door.
(3) A staircase width between 1220mm to 1372mm inclusive is the best dimension where it can be substituted at any fire door or corridor width.
(4) There is no significant evidence that increases in the corridor width will improve the travel time.

Further analysis will be carried out on other types of model to test the effect of corridor, fire door and staircase width on the different orientation and staircase layouts. Tests on model three have been carried out and the test result is as in figure 7.10 i.e. evacuation time Vs Fire doors, Model 3 i.e. One direction ‘L’ shape with fire door.

(iii) Model three

Model three is designed with ‘L’ shaped corridor and fire door attached t. The fire door has the same width as the corridor. Therefore in figure 4, only the corridor width is shown in the graph of evacuation time verses corridor width. The overall result shows that increasing the staircase width will improve the travel time. However, there is insufficient evidence to prove that increasing the corridor width will contribute to the decrease in travel time. The difference in travel time between the widest staircase i.e. 1524mm and the narrowest staircase i.e. 914mm is about 1½ to 2 minutes. Meanwhile, travel time differences among the staircases e.g. staircase 914 to 1067, staircase 1067 to 1220 and so on are within 20 to 30 sec. Analysis on every staircase shows that increasing the corridor width does not improve the travel time. The travel time remains about the same even though the corridor width is increased up to 2440mm.

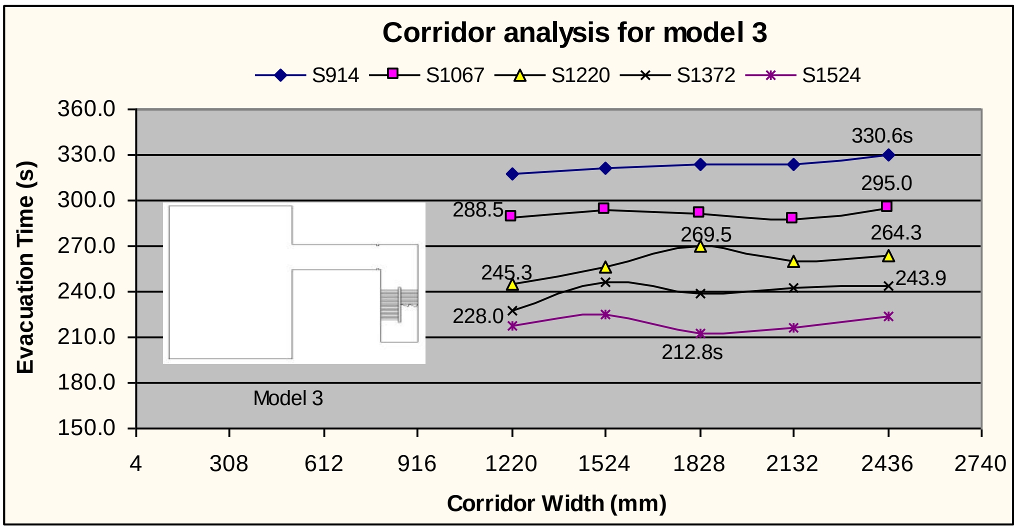

Figure 4: Graph evacuation time Vs corridor or fire doors width for Model 3

It can be concluded that:

(1) Wider is not necessarily better for the corridor design.

(2) The wider the staircase the shorter the evacuation time recorded.

(3) The main attribute that can cause the increase of evacuation time is the number of people occupying the building. The evacuation time can increase by about 160% to 200% if the number of people occupying the building is multiplied i.e. doubling the occupant numbers.

(4) In terms of staircase orientation and layout as in model three, there is no correlation between evacuation time and width of corridor. Therefore a corridor width between 1220mm to 1524mm is sufficient for high-rise residential buildings.

However, further tests on the corridor orientation with staircase designed straight with fire door needed to be done to test this correlation. Tests on the model have been carried out and the test results are as in figure 5. This model is known as model 4 i.e. straight direction with fire door. The fire door and corridor are the same width.

(iv) Model four

Model four is designed with the staircase attached at the end of the corridor. The corridor is fitted with fire doors having the same width as the corridor. The test results in figure 5 show that there is not a significant difference in terms of marginal differences of evacuation time recorded on the same staircase when the corridor width increases compared to the test results on model three. The tests on model four show about the same pattern as in model three. The difference in evacuation time between the widest and the narrowest staircase is nearly double i.e. 2 ½ to 3 minutes. However, the evacuation time for staircases 1607, 1220 and 1372mmwide are within 30 sec to 60 sec. The evacuation time for the staircase 1067 and 1372 mm wide is slightly increased when the corridor width is increased. The difference between model three and model four in terms of the total evacuation time recorded i.e. model four recorded higher total evacuation time for the same width of staircase e.g. staircase 914 mm gives 320 – 330 seconds but model four gives over 510 seconds because the corridor length in model four is nearly 2/3 longer than the corridor length in model three. The emphasis of the analysis is on the increase or decrease margin of evacuation time when the corridor width increases.

It can be concluded that:

(1) There is significant evidence that corridor width does not have much influence on the evacuation time but staircase width does.

(2) However staircases of width 1067mm and 1372mm show a slightly different pattern compared with the rest of the staircases. These staircases show that travel time is slightly increased when corridor width increases from1524 mm up to 2440mm. The increase of travel time occurs gradually and up to about 30 sec difference (depending on the number of occupants).

(3) A positive correlation of the staircases widths 1067mm, 1220mm, and 1372mm show that by increasing the corridor width, the evacuation time is slightly increased. It seems that the wider corridor does not necessarily give the better evacuation time.

(4) The others staircase test results show that there is no correlation between the corridor width and evacuation time. It is about the same pattern as the model three test results.

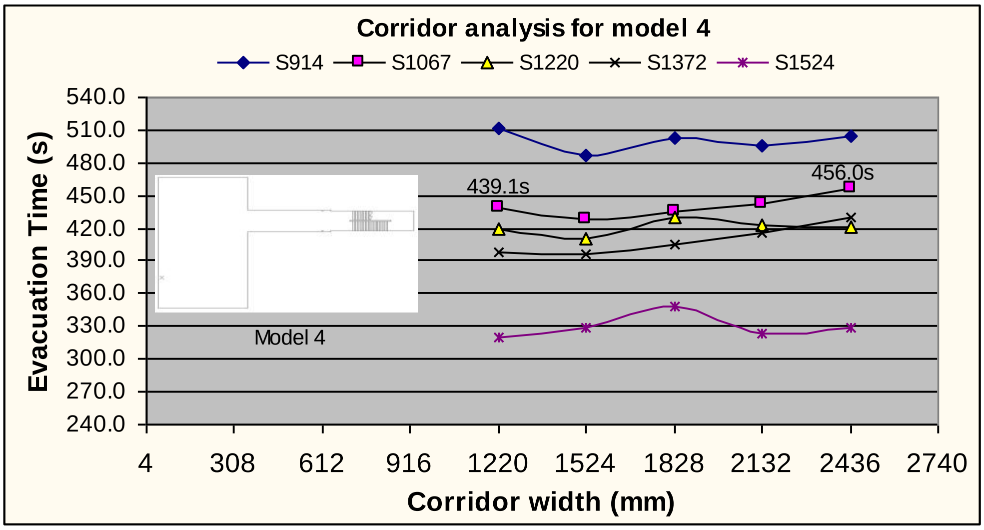

Figure 5: Evacuation time Vs corridor width for model 4 i.e. Straight direction with fire door. Fire door width is the same as the corridor

However, further tests are needed to understand the effect of the different design of the staircase layout. Tests on model five i.e. horizontal opposite direction with fire door have been carried out and the results are as in figure 6.

(v) *Model five*

Model five is designed with the fire door orientation parallel with the corridor. The occupants have to go through the fire door located at the side of the staircase shaft. Figure 6 shows the test results and small plan of model five. The test results from five different staircase widths i.e. 914mm to 1524mm show that staircase 914mm takes the longest time to evacuate. It shows that evacuation time increases when the fire door width increases.

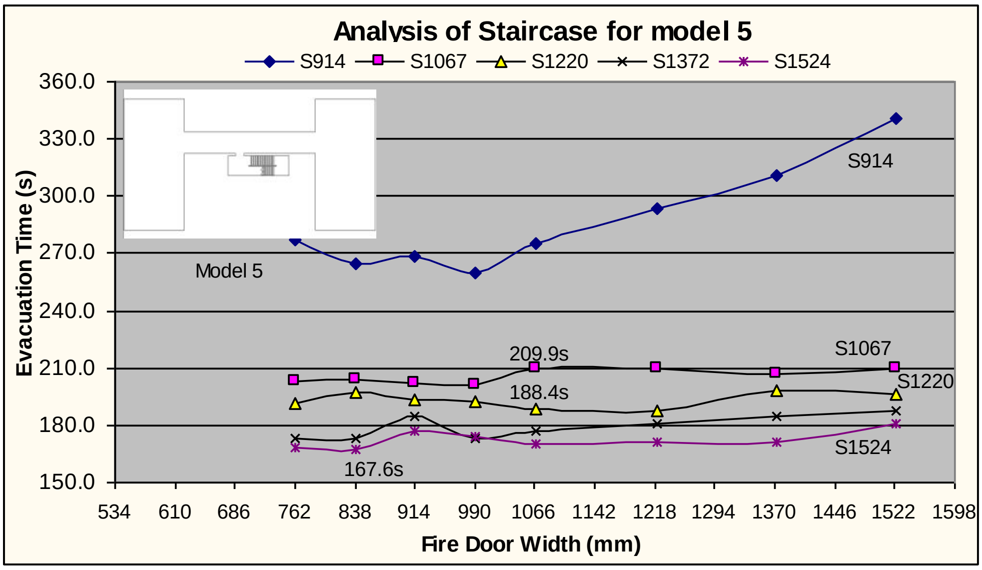

Figure 6: Evacuation time VS fire doors; Model 5 i.e. Opposite directions horizontal with fire door

Test results on the other model shows that staircase of width 914mm takes the longest time to evacuate. Therefore, there is significant evidence to say that staircase 914mm is not viable to be used in high-rise building because;

(1) It would not permit the occupants to exit from the building fast enough. However it depends on the number of occupants i.e. high occupancy. It would be no problem for the low occupancy.

(2) Traffic congestion is likely to happen in a staircase 914mm wide even though the fire door and corridor width increase, because the evacuation time increases when fire door widths increase.

(3) It only permits traffic to move in one direction, while in the real world rescuers may need to use the same staircase to enter the building while the occupants are moving out from the affected building.

The other staircases are seen to have quite steady recorded evacuation time. The test shows that the fire door widths do not make any significant difference even if they are wider. The evacuation time seems to fluctuate within 20sec for staircase width 1067mm to 1524mm. However, evacuation from the staircase 1220mm wide takes slightly above 3 minutes and staircase 1372mm about 3 minutes. This is significant evidence that staircase widths 1220mm and 1372mm are viable for high-rise buildings. However further tests need to be carried out to confirm this finding. Tests on model six, that is modified from model five by removing the fire door are carried out and the results are as in figure 7.

(vi) Model six

The outcome of the test results on model six are not significantly different from model five in that the 914mm staircase takes the longest time to evacuate. The rest of the staircases show a roughly steady evacuation time except for staircase 1524mm which shows the evacuation time is slightly increased when the corridor width is increased. Staircase 1220mm and 1372mm indicated that they can let people out of the building within 3 minutes. This result was in line with the test result in model five.

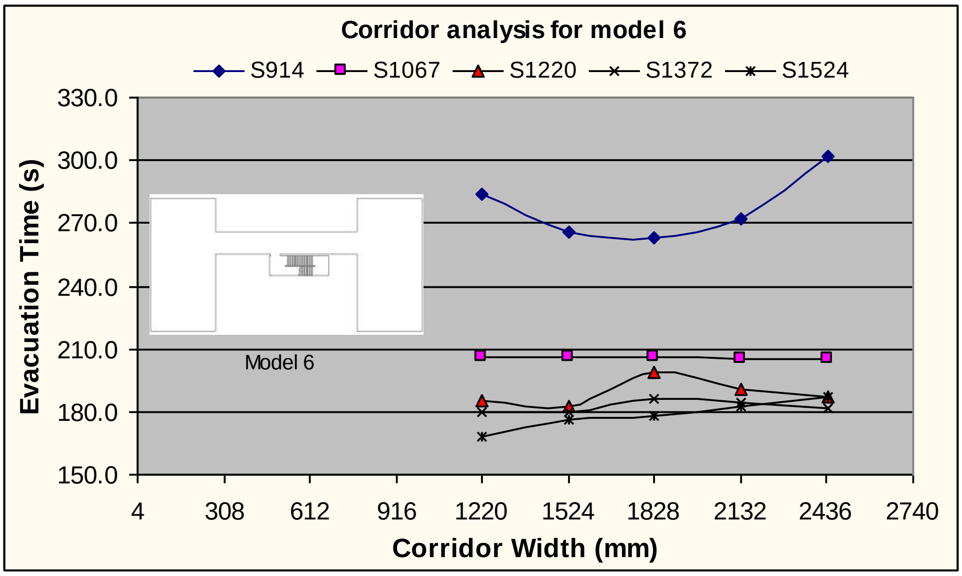

Figure 7: Graph evacuation time Vs corridor width for model 6 i.e. Opposite directions horizontal without fire door

The test results from the other models show that staircase 1220mm and 1372mm have no significance difference in evacuation time taken in the various fire door widths tested. It is significant evidence that these staircases are viable. It is evident that these staircases can be used as a benchmark to further analyse the fire door and corridor specification.

However, tests on model seven and eight are necessary to confirm this finding. Models seven and eight have a different staircase orientation and layout compared to the rest of the models described.

(vii) Model seven

Model seven is designed to enable the occupants to move in one direction to the staircase. Staircase orientation is horizontal with a fire door. The occupants have to make a ‘U’-turn at the landing floor before they can reach the escape stair. The test results on model seven are in figure 8. Staircase 1220mm, 1372mm and 1524mm wide show about the same pattern in evacuation time taken i.e. evacuation time decreases when the fire door width increases from 762mm to 990mm and remains about the same when the fire door widths are further increased. Whereas, staircase 914mm and 1967mm show a unique evacuation time taken where evacuation time decreased, increased, then decreased again to form a 'S' curve graph when fire door width increased.

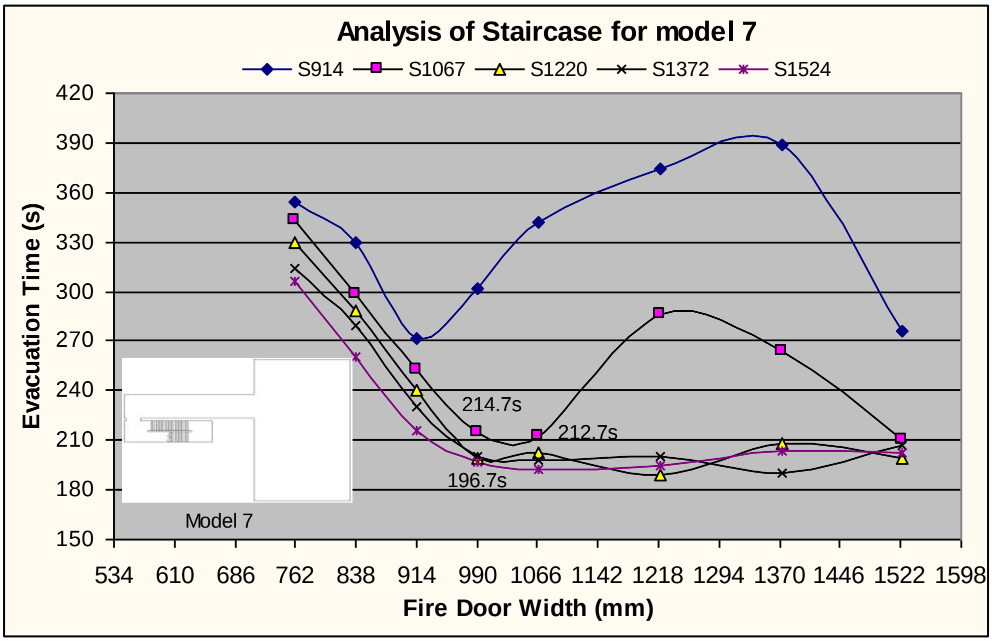

Figure 8: Evacuation time Vs corridor width for model 7 i.e. One direction horizontal with fire door

The evacuation time for staircase 914mm decreased from 354.6 sec to 271.3 sec when the fire door width increased from 762mm to 914mm respectively. The time is then gradually increased until it reaches the maximum of 388.6 sec when the fire door width is further increased up to 1372mm. It then sharply decreases when the fire door width further increases to 1524mm.

Staircase 1067mm follows approximately the same pattern but the evacuation time is further decreased when the fire door width increases to 990mm and 1067mm at 214.7 sec and 212.7 sec respectively and increases again to 285.8. It then gradually decreases to 206.9 sec when the fire door width further increases.

The graph in figure 8 shows that the best evacuation time recorded was when the fire door width was 990mm i.e. 196.7 sec. That was for staircases 1220, 1372 and 1524mm wide. The evacuation time remained about the same after the fire door width was further increased and recorded no significant changes throughout the test. Therefore, there is sound evidence to suggest that a fire door designed in high-rise building should be between 990mm and l067mm inclusive. There is no point in designing fire door wider than 1067mm because it will not improve the evacuation time, instead it will increase if the staircase is smaller than 1067mm.

As discussed in the previous test models, there is sound evidence that staircase widths 1220mm and 1372mm are the best staircase widths for high rise buildings. However, this finding needs to be tested on model eight which has a slight difference in terms of building internal circulation. Model eight is designed such that all residential flats are scattered and located near to the escape stair.

(viii) Model eight

In model eight, the best travel time recorded was when the staircase width is 1524mm and fire door width 1372mm (see figure 9). The worst travel time recorded was for staircase width 914mm when fire door width is 1524mm. The evacuation time recorded for staircase 914 mm was approximately the same pattern as in model 5. The evacuation time decreased at the beginning when the fire door width increased from 762mm to 914mm, then it gradually increased when the fire door width further increased.

Traffic congestion at the staircase could have caused this pattern when the fire door width increased. Staircase 1067mm shows that the evacuation time fluctuated i.e. increased slightly before decreasing, and increased again when the fire door width further increased. Staircase 1220mm has about the same pattern as the staircase 914mm, in that the evacuation time decreased when the fire door width increased from 762mm to 914mm, and then gently increased when the fire door width further increased.

Staircases 1372mm and 1524mm wide follow about the same pattern as the 1220mm staircase. The evacuation time started to increase when the fire door width increased from 990mm to 1067mm. The evacuation time then remains about the same without any significant changes even after the fire door width has been increased. It can be concluded, from the overall observations of the evacuation time versus fire door width, there is a small correlation between them. To some extent, it has a negative correlation i.e. when fire door increased from 762mm to 990mm. It has a positive correlation when fire door is further increased i.e. from 1067mm to 1524mm.

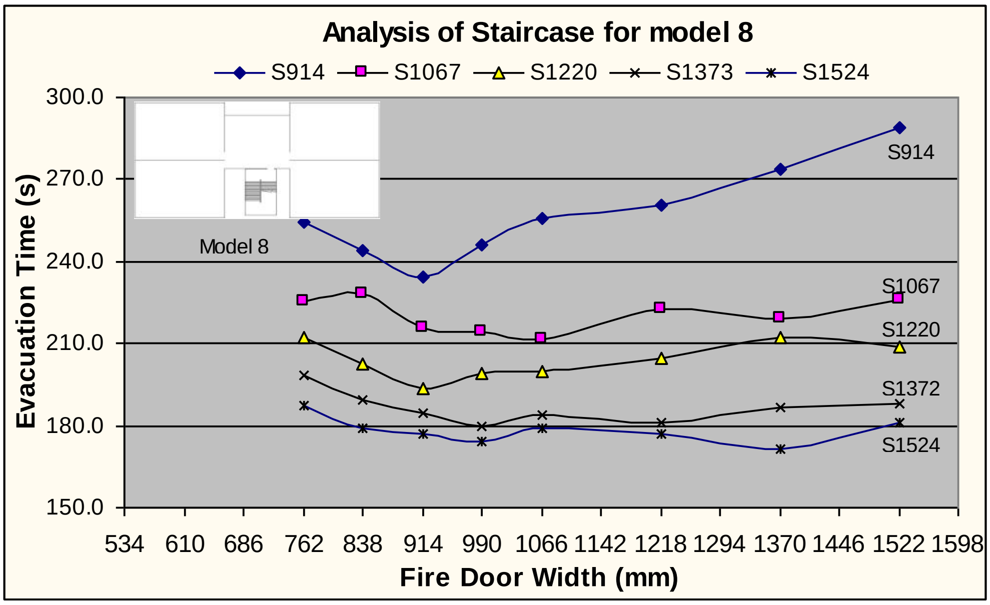

Figure 9: Evacuation time Vs corridor width for model 8 i.e. Cluster types with one staircase

Conclusions

Figure 10 is summarising of the staircase, fire door and corridor widths from the models studied. The analysis was made based on the assumption that if the evacuation time recorded fell within 30 seconds, it was considered as being of no significance. Therefore the staircase, fire door and corridor are assumed to offer the same efficiency i.e. able to allow people to evacuate the building safely. The assumption made is based on 30 seconds response time allowance for the occupants to start their evacuation once a fire alarm goes off.

Model	Staircase Width (mm)	Fire Door Width (mm)	Corridor Width (mm)
1	**1220, 1372**, and 1524	914, **990, 1067, 1220**	-
2	**1220, 1372**, and 1524	-	**1220, 1524**, 1828
3	**1220, 1372**, and 1524	-	**1220, 1524**
4	1067, **1220**, and **1372**	-	**1220, 1524**, 1828
5	1067,**1220, 1372**, and 1524	914, **990, 1067, 1220**, 1372, 1524	-
6	**1220, 1372**, and 1524	-	**1220, 1524**, 1828, 1232 2436
7	**1220 , 1372**, and 1524	**990. 1067, 1220**, 1524	-
8	**1220, 1372**, and 1524	914, **990, 1067, 1220**	-

Figure 10: Optimum specifications suggested resulting from the models studied based on the evacuation time recorded.

For the optimum width, more staircases recorded within 30 seconds differences of evacuation time on any fire door or corridor width in any models are assumed as an optimum width. Optimum means that consideration is not only given to the minimum evacuation time recorded but at what fire door or corridor width is the most staircases recorded the evacuation time close together within 30 seconds differences. For example if there are three staircases recorded evacuation time within 30 seconds differences at fire door width 1067mm but evacuation time recorded says 180 seconds, even though the minimum evacuation time recorded was 160 second but only confers to one staircase at fire door width says 914mm, therefore fire door width 1067mm considered as the optimum one.

The second analysis is what staircase, fire door and corridor width conform to the majority of the models tested. For example, staircase 1220mm and 1372mm conform to all models, therefore staircase widths 1220mm and 1372mm are considered as an optimum dimension for the staircase. Meanwhile, the optimum fire door width is 990mm, 1067mm and 1220mm, and optimum corridor width is 1220mm and 1524mm. These optimum specifications relate to the specific number of people simulated, i.e overcrowded situation. For different occupancy levels the optimum specification may be different.

References

IES (2008). http://www.iesve.com/content/mediaassets/pdf/simulex.PDF - (19.03.08)

Marchant, E.W. (1976), Some aspects of human behaviour and escape route design. *5th International Fire Protection Seminar, Karlsruhe,* Sept 1976

Olsson, P.A., and Regan, M.A. (1998), A comparison between actual and predicted evacuation times, *1st International Symposium on Human Behaviour in Fire*, University of Ulster.

Thompson (a), P.A. and Marchant, E.W. (1995), A computer model for the evacuation of large building populations, *Fire Safety Journal* **24,** pp. 131–148.

Thompson (b), P.A. and Marchant, E.W. (1995), Computer and fluid modelling of evacuation*. Safety Sciences Journal* **18,** pp. 277–289.

Thompson (c), P.A. and Marchant, E.W. (1995), Testing and application of the computer model SIMULEX. *Fire Safety Journal* **24** pp., 149–166.

Thompson, P.A., and Marchant, E.W. (1996), Modelling Evacuation in Multi-Storey Buildings with SIMULEX, *Fire Engineering Journal*, 56 (185), Pg. 6-11.

Yatim, Y.M. and Harris, D.J. (2007), Human Behaviour Response Issues in High-Rise Residential Building in Malaysia, *The International Journal of Interdisciplinary Social Sciences*, Common Grounds Publisher, Australia, Vol.2, No. 3, pp. 277 - 289, http://www.SocialSciences-Journal.com