

THE HOT AREA EVACUATION MODEL APPLICATION IN LARGE SCALE GYMNASIUMS

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Abstract. Execution difficulties and financial constraints are encountered when conducting experiments of full scale evacuation exercises in large scale building. This study focuses on large gymnasiums. The concept of “Hot Area” is proposed by focus groups of fire experts. The most dangerous spot in a building, Hot Area, is selected and analyzed based on the ranking method. Then, a Hot Area evacuation exercise is carried out to replace a full-scale evacuation exercise. In addition to simulating the Hot Area evacuation in Taipei Arena with Exodus software, an observation of a real life exiting of 2089 people is also conducted. Next, the observation result is compared with the software-simulated result. Finally, suggestions are made to provide a set of reference criteria for inspecting the same type of buildings when their construction works are completed.

Keywords: hot area, evacuation simulation, evacuation exercise, large scale gymnasium, emergency management, fire safety.

1. Introduction

The time taken to evacuate space inside a building (required time for evacuation) must be shorter than the time for the environment in that space to become life threatening. The time after which environment conditions of the building become critical is a fire-safety benchmark (Konecki and Pólka 2009; Chow and Chow 2009). Hence, whether a building’s evacuation facilities are well designed has a great impact on public safety. Historically, a great deal of disasters occurred during emergency evacuation of crowds, such as 120 died in the 2001 stampede incident in the Soccer Stadium in Ghana Africa; 21 children died and 47 people were injured in a power failure at a school in China in 2002; 21 died in a nightclub incident in Chicago, Illinois in 2003; 602 people were trampled to death in Chicago’s Iroquois Theater fire in 1903; at the 1981 Hillsborough English FA Cup Stampede, 95 people died and 400 were injured (Pan *et al.* 2006). As these incidents often occurred in the buildings located in densely populated cities, the issues of fire safety are particularly important. As a result, the design and inspection of large scale building are of crucial im-

portance. Unforeseeable calamities may happen if governments fail to screen out the poorly-designed evacuation facilities. This study originated from the author’s observation over the public fire department’s inspection of the performance of the evacuation design of Taipei Arena (with a capacity of 15 000 people). It is found that although the project design team evaluate the evacuation function with the commonly-used software, comparison between analyses conducted by different software is made difficult by financial constraints. Moreover, few similar cases can be found to compare and evaluate the analysis reliability of the software’s analysis result. In a search of international journals, no similar research models were found for comparison, hence this case study can be seen as a reference point for inspecting this type of buildings during their design or construction-completed stages.

Although it is possible to observe realistic evacuation behavior with an unannounced evacuation exercise, due to the safety concern and the general public’s disapproval of “human demonstrations,” the public sector would not easily use unannounced evacuation exercises as a way to perform research or evaluations. In order to

overcome this research restraint, this study uses government resources to study large gymnasiums, and bring up the concept of “replacing full-scale exercises with Hot Area exercises” for simulation. Based on the results found through focus groups composed by fire experts and the ranking method analysis, Hot Areas are selected and evaluated. The “Hot Area criteria” are composed by three key factors: “largest travel distance”, “capacity of exit”, “density of occupants”. Besides using Exodus software to simulate the Hot Area evacuation in Taipei Arena, the real life exiting of 2089 people in the Hot Area of Taipei Arena is recorded and analyzed based on the argument, brought up by Arthur and Passini (1992), that real life evacuation results are similar to exiting. Then, the observation result of real life exiting is compared with the software simulation result. Finally, suggestions are made to provide a set of reference criteria for inspecting the same type of buildings when their construction works are completed.

2. Problem Statement

When architects are designing a building, they must consider the issue that how to guarantee that users can be evacuated in a safe and efficient fashion to safe areas during a fire emergency. Traditionally, two techniques have been used to meet these needs: 1) full-scale evacuation demonstration, and 2) the adherence to prescriptive building codes (Gwynne *et al.* 1999). However, issues of morality and financial constraints make full-scale evacuation demonstrations difficult to carry out. On the other hand, designs which only meet the requirements of prescriptive building codes may not fully guarantee the safe evacuation. A better compromise for solving the problems of morality issues and financial constraints is to adopt performance-based designs and follow the software-simulated solutions as the standards for designing evacuation facilities (Still 1993). Even though the large scale building nowadays generally follows the model of performance-based design, the complexity and funding constraints involved with full-scale evacuation exercises, the morality issues of human demonstration, and the insufficient attention on software analyses are still the major problems encountered when designing a safe evacuation plan for fire emergencies.

2.1. Studies on Performance-Based Designs of Large Scale Building

At present, most studies adopt the concept of performance-based designs, particularly on the part of large scale building. In view of the execution difficulty lying in full-scale evacuation exercises, these studies chose simulation analyses as an alternative to them. The software used for simulation can be divided into self-developed and commercial one. For example, Jing and Yang (2005) used evacuation models they created to test the effect of exit locations in Olympic game gymnasiums and the movement flow of workers on evacuation, and to create an improved plan if an exit causes an evacuation bottleneck. Liu *et al.* (2005) also used their own model to analyze

evacuation efficiency of Olympic game gymnasiums. Zhang *et al.* (2007) used self-designed SCM (stranded-crowd model) model to study the number of crowds which can be accommodated by exits of different width in a gymnasium to find the most economically viable exit width. Xie *et al.* (2005) used STEP evacuation software to evaluate travel time in stadiums and gymnasiums that can accommodate 100 000 people. The same authors in 2006 used manual calculation and STEP evacuation simulation software to analyze evacuation safety in Beijing national stadium, Beijing national swimming center and Tianjin Olympic aquatic center. Weiguo *et al.* (2005) applied Simulex software to a large shopping mall to test their self-developed CAFÉ evacuation model. Pelechano and Malkawi (2008) focused on describing the main challenges and limitation of these commercial tools (STEPS and EXODUS) for high rise building evacuation simulation, in addition to explaining the importance of incorporating human psychological and physiological factors into the models. They think that these commercial tools still need to develop models that can closely simulate human behavior (physical interactions between individuals, physiological, psychological, communication between agents, etc.) As to studies applying evacuation software to evacuation analysis on gymnasiums, Graat *et al.* (1999) studied the effect of the slope of the seated area in a sports stadium on an evacuation. Nicholson (1999) used Exodus software to demonstrate the smoke ventilation and evacuation design of the Millennium Dome that can accommodate 37 000 people. Although studies of performance-based design may be able to avoid morality issues involved with full-scale evacuation exercises, if results simulated by these studies cannot be compared with observation of real life evacuation or exiting, further researches are still required to verify whether the simulation results can closely represent the real evacuation scenarios in large scale building.

2.2. Limitations of Full-Scale Evacuation Exercise

The reliability of replacing full-scale evacuation exercises with performance-based design studies still needs further investigation. Therefore, some researchers also tried to compare the results of simulation analyses with real-life simulations or even with unannounced evacuation exercises. For example, Ashe and Shields (1999) carried out unannounced evacuation exercises in two large retail stores with 616 people and 1848 people respectively, then compared the results to 11 different situations in Simulex. Although deviation was existed in some situations, it was in an acceptable range. Weckman *et al.* (1999) studied a theater which can hold 750 people and compared the results of an unannounced exercise, manual calculation and four simulation software (Simulex, Exodus, ASERI, and EVACNET). They found that: with different numbers of people taken into account, ASERI and EVACNET simulated travel times differed by 44 seconds, while simulated results of Simulex and Exodus software are very similar, with only a 6 second difference. Olsson and Regan (2001) conducted three real-life simulations in a theater, a law building and a commerce building with

633 746, and 1216 participants each to compare the difference between Simulex and real-life simulations. Their findings show that the travel time calculated by Simulex and the travel time in real-life simulations are very close. Wang (2001) held a real life simulated evacuation exercise with 136 in a large commerce building, compared the result with software simulation by FEgress, finding that the travel time simulated by FEgress was longer than the real life exercise; this was because participants were notified in advance and were familiar with the environment. Furthermore, Papinigis *et al.* (2010) also estimated and compared the time needed for occupants to evacuate from rooms or buildings with the methods of simple calculation and FDS + Evac. As seen in the above literature review, although the four papers conducted real-life exercises in a large retail store, a law building, a commerce building and a large shopping mall, there is no research looking into evacuation exercises in large gymnasiums. Great variance also exists in the basic features of each study, such as the types of building studied, the software used for their analyses, whether the exercise is announced, the number of participants, and the difference between software and real-life simulations. Furthermore, no evacuation simulation of more than 2000 participants in large scale building has been conducted. This study observes the real-life exiting of 2089 people and compares the result with the software analysis. For analyzing evacuation in large gymnasiums, the research method designed by this study is quite unique.

As to the number of people can be accommodated by the large scale building, particularly in the evacuation analysis of large gymnasiums, the number of evacuees should be much more than other types of buildings. Also, among all the types of large scale building, the characteristics of large scale building are very different from other commonly-seen large buildings or shopping malls. However, an evacuation exercise without previous notice may cause morality and safety concerns, which are more pronounced for the evacuation studies of large scale building. Since the large scale building usually can hold more than tens of thousands people, an unannounced exercise could result in casualties. These concerns are the major constraints of conducting a real-life evacuation experiment in large scale building. The theater evacuation exercise conducted by Weckman *et al.* (1999) is an example. Working with the fire department and insurance company, the unannounced evacuation exercise of 612 participants was held at a theater in the City of Tampere. The fire alarm was activated to make a fire alert before the performance ended and a pre-recorded evacuation notice was played by the PA system. All the actors and audience were evacuated to the exits following the standard evacuation procedure. No smoke was released and the whole process was recorded by two video cameras. During the evacuation process, evacuees were given instructions by personnel based on the standard evacuation procedure, and they were evacuated from the theater calmly and smoothly. If the same evacuation exercise were carried out in Taiwan, it would stir up great controversy among the media and the public. If civil servants

conduct an unannounced evacuation exercise to inspect or study a building's evacuation plan, it is highly likely they would be punished heavily because of pressure from the public's opinions or people's representatives.

3. Design of Hot Area Research Method

This study focuses on Taipei Arena. The concept of "Hot Area" simulation is formed by focus group interviews of fire experts. Then, the Hot Area is selected and analyzed based on the ranking method, and evacuation simulations are carried out in partial scale with the method of Hot Area testing. In addition to simulating the Hot Area evacuation in Taipei Arena with Exodus software, an observation of a real life exiting of 2089 people is also conducted. The observation result in turn is compared with the software-simulated result. Finally, suggestions are made to provide a set of reference criteria for inspecting the same type of buildings when their construction works are completed.

3.1. Focus Groups for Hot Area

The reliability of replacing full-scale evacuation exercises with performance-based design studies still needs further investigation. However, moral and financial constraints arise with human demonstrations in large scale building. If real-life evacuation simulations are indeed closer to actual situations than software simulations, then how to avoid the moral risk and decrease the financial cost of human demonstrations is an issue which should be explored and investigated further. After attending several discussion panels and review conferences, the authors concluded that a practicable solution may be able to be found through consulting and brainstorming with experts of related fields. Hence, this study chose the research method of focus groups and invited 9 experts to join a 2 hours' focus group interview. Of the 9 experts, 3 have experience in designing fire evacuation plan of large scale building, 3 are reviewers, and 3 are experts or scholars in the field of emergency evacuation. The second author of this paper was the moderator of the focus group discussion. The research method of focus group is a cost-efficient tool for exploration into a subject. It is not a spontaneous dialogue between group members. The talk focuses on a specified topic, following a well-defined agenda, and conducted in the way of small group interview (or discussion). The small group is composed by 8 to 12 people. A focus group interview lasts for around 2 hours. The group must be homogeneous, and members must have similar experience to the same question in order to avoid a clash of opinions. During the interview, the moderator leads the discussion and asks questions to help the group members drop their guard so that they can engage in the discussion and contribute their opinions. The guiding techniques of brainstorming and synectics method are used to stimulate the participants to come up with new ideas by embellishing, improving and modifying other participants' ideas (Stewart and Shamdasani 1990).

Full-scale evacuation exercises measure the time it takes for a number of people to escape to exits, however,

ethical, practicality and economic issues may limit their feasibility (Wong and Cheung 2006). Almost all large scale gymnasium was designed with the aid of evacuation simulation software instead of being tested by real life evacuation exercises, since full scale evacuation exercises in large scale gymnasium are especially difficult. Fortunately, after conducting the said focus group interview, the experts and scholars suggested the concept of “Hot Area” as an experiment method and assessment criteria to replace a full-scale evacuation exercise in the hope that the financial cost and moral risk of real-life evacuation exercises can be reduced and the result can serve as a reference for governments to inspect evacuation plans of large scale building.

3.2. Criteria of Hot Area

During the focus group interviews, the experts look at examples in other countries and discuss the factors considered when assessing a building’s evacuation safety. It was found that the evacuation safety evaluation centers on the value of “total evacuation time”. Besides taking a building’s type of use into account, and the value is calculated based on the following criteria: 1) Floor area; 2) Floor height; 3) Largest travel distance; 4) Number of exits; 5) Layout of exits; 6) Exit width; 7) Capacity of exit; 8) Number of occupants; 9) Density of occupants (person/m²); 10) Travel speeds; 11) Flow rate. Hence, at the end of the interview, it was concluded that general factors formed by Hot Area criteria in evacuation analysis can be simplified into three key factors – “largest travel distance”, “capacity of exit”, and “density of occupants” – as the basis of assessment (Fig. 1). The concept of Hot Area derives from eleven criteria related to total evacuation time, and the eleven criteria can be divided into three categories: “structure factor,” “exit characteristics factor”, and “occupant characteristics factor”. The reasons why “3) Largest travel distance”; “7) Capacity of exit”; and “9) Density of occupants” were chosen from each category are explained below.

The criterion, “3) Largest travel distance”, was selected by the focus group experts because the three criteria under the category of the structure factor (Fig. 1) are all highly positively correlated with the evacuation time. When the floor area and floor height of one building increases, the distance that its occupants walk from their original location to a safe area during a fire emergency will increase proportionally, which means floor area and floor height are also highly positively correlated with the largest travel distance.

“7) Capacity of exit” was picked out to be the second Hot Area criteria from exit characteristics factors. Because when “4) Number of exits”, “5) Layout of exits”, “6) Exit width” on the building floor plan are evaluated independently without looking at the number of people, there would be insufficient evidence to verify whether the number of people in the crowd is overload and therefore dangerous. But if “7) Capacity of exit” is considered as a Hot Area criterion, then it becomes possible to analyze more directly the “largest number of people in the crowd” at different exits. Furthermore, the capacity of exit is based on the number of occupants, and usually if a great number of people are crowded at an exit, this is because the capacity of exit has not been effectively managed and controlled. Also, many disaster evaluations show a lot of tragedies have been the result of too many people overcrowding an exit. Therefore, the capacity of exit is a key factor in a successful evacuation. “9) Density of occupants” was chosen as the third Hot Area criterion for the fact that “occupant characteristics factor” includes “8) Number of occupants”, “9) Density of occupants”, “10) Travel speeds” and “11) Flow rate”. Because different areas have different usages when a building is planned, there is rarely a uniform density of occupants (person/m²), so just looking at the number of occupants as a Hot Area criterion is insufficient to reflect the danger, and travel speed is also affected in each area by the density of occupants – the higher the density the lower the travel speed and flow rate, and the longer the evacuation takes; in other words, the more danger is involved. Also, in the evacuation process, “11) Flow rate” is often an important item to be assessed for building evacuation

General evaluated factors in evacuation analysis		
Structure factors	Exit characteristics factors	Occupant characteristics factors
1. Floor area 2. Floor height 3. Largest travel distance (m)	4. Number of exits 5. Layout of exits 6. Width of exit 7. Capacity of exit (person/s)	8. Number of occupants 9. Density of occupants (person/m²) 10. Travel speeds (m/s) 11. Flow rate (person/s)



Fig. 1. Hot Area criteria form general evaluated factor in evacuation analysis

evaluation and has a negative correlation with “total evacuation time” and “largest number of people in the crowd”. The higher the flow rate, the lower the “number of people in the crowd” and “total evacuation time”, which means the safer the occupants are (they arrive at the safety area faster.)

3.3. The Evaluation Method for Hot Area Selection

The ranking method is commonly used for the decision process of selection. A ranking method gives the highest ranking depending on the importance of each evaluated factor (1 is the highest ranking, followed by 2, 3, 4, 5, 6, etc.). When using the ranking method for the purpose of selecting a Hot Area, the higher the ranking the harder the area is to evacuate and the more dangerous it is. After ranking assessment by experts, the lower the total score, the more dangerous an area is, so the selection of the Hot Area is dependant on the lowest total score. The selection of the Hot Area uses the most dangerous area to represent the whole in a real life simulation exercise, to lower the moral and labor cost risk of a full-scale real life exercise. For example, Taipei Arena floors and seating areas are divided into three areas: B1F, 1F–2F and 3F–5F with a capacity of 1 500 people, 8 000 people, and 5 500 people each. If this rough division were used and 1F~2F (with a capacity of 8 000 people) and 3F~5F (with a capacity of 5 500 people) were selected as the Hot Areas for conducting real life simulation exercises, the execution of the exercises would be difficult due to the large number of

evacuees involved. Therefore, the focus group experts suggested that the three large floor seating areas should be divided further into eleven small seating areas for evaluation. The eleven small areas are ranked according to the three Hot Area criteria – “largest travel distance”, “capacity of exit”, and “density of occupants”. Table 1 below shows the ranking given by experts. Results show that No. 9 area has the lowest total score (5) hence No. 9 is the Hot Area. No. 9~ 11 are both part of the floor seating area on 3F~5F, which can accommodate 5,500 people. No. 10 and No. 11 are booth seats on 3F and 4F.

4. Result of Hot Area Exercise

4.1. Brief of Exercise Case

Taipei Arena is located in Taipei, Taiwan’s capital city. It was designed as a multifunctional gymnasium. In addition to sports events, it is a venue where Taipei citizens visit frequently for large performances, and it can also be used for election campaigns, concerts, and large exhibitions. Its building foundation is 114 522 m²; building height is 44 m; and total floor area is 88 401 m² (see Fig. 2). Taipei Arena is a steel reinforced concrete (SRC) building which has two basement floors, five stories above ground. The use of each floor is as followings: B2F is a parking lot; B1F to 5F holds walkways, seating areas and other facilities with a capacity of 15 000 people; and B1F~5F is the seating areas of the main auditorium (see Fig. 3).

Table 1. The priority analysis of Hot Area in Taipei Arena

Floor seating area	Seating areas	1. Largest travel distance to safe area (m)	2. Capacity of exit (person/s)	3. Density of occupants (person /m ²)	HOT AREA determination (□ the chosen lowest score item)
3F~5F (5500 people)	No. 11	1	4	4	9
	No. 10	2	4	4	10
	No. 9	3	1	1	5 (□)
1F~2F (8000 people)	No. 8	5	2	2	9
	No. 7	6	2	2	10
	No. 6	5	2	2	9
	No. 5	6	2	2	10
B1F (1500 people)	No. 4	4	3	3	10
	No. 3	4	3	3	10
	No. 2	4	3	3	10
	No. 1	4	3	3	10

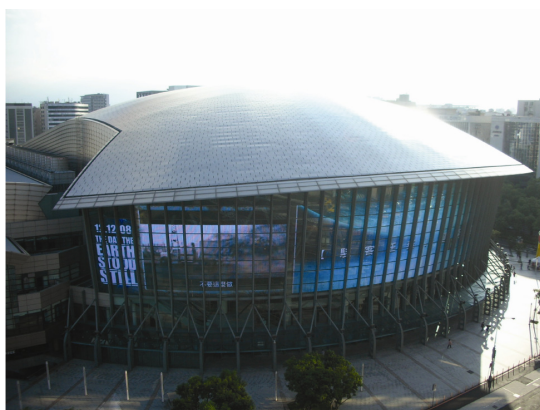


Fig. 2. Taipei Arena

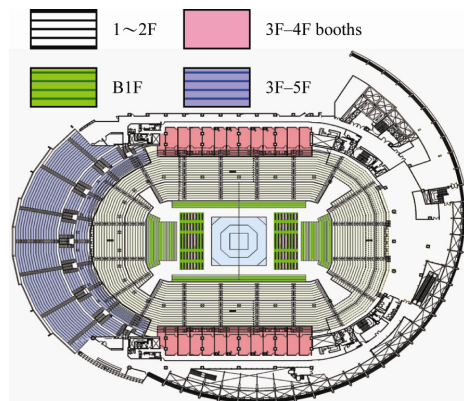


Fig. 3. Taipei Arena B1F~5F Audience Seats

For evacuation, there are two staircases on both sides of the entrance, four exits leading to the emergency shelter on B1F, 1–2F seating areas have 20 exits that lead to the 2F walkways, 3–5 F seating areas have 9 exits that lead to the 3F walkways, 2F and 3F walkways each have access to 3 stairs that lead directly to safe areas. The interior is constructed with fireproof material and building smoke control which includes passive and active smoke control systems.

4.2. Hot Area Exercise Planning

P. Arthur and R. Passini argued that real life evacuation results are the same as exiting results. Based on this argument, gymnasium evacuation study of Graat *et al.* (1999) investigated the effect of 30 degrees and 38 degree slant on exit speed. Hence, upon the development of the Hot Area concept, with the moral risk being taken into account, this study attempts to test the argument that real life evacuation is equal to exiting on a Taipei Arena evacuation exercise by recording and analyzing a real life Hot Area evacuation in the Taipei Arena, then comparing it to Exodus software results. Taipei Arena's Hot Area is designated as the seating area on 3–5F, where the seats of the "whole area" can accommodate 5500 people (including 48 booths in the No. 10 area on 3F and in the No. 11 area on 4F), and since the entire 3–5 F seating areas are symmetrical, in order to save on the labor cost, the real-life exiting observation is performed on a "half area" of 2170 seats (not including 48 booths). On the day of the observation, 2089 people occupied the seats, and the total attendance rate was 96%. Fourteen people were used in this study to carry out the observation – 1 director, 1 camera man in the grounds, 1 to support communication and 11 camera men with handheld cameras. The 11 cameramen wearing red fireman uniforms were standing on chairs placed at the height of 2.1 meter to record the evacuation process. During the evacuation, video cameras record the process for calculation of people and time after the experiment. The cameras were placed at locations which did not affect the movement of the evacuating crowd (see Fig. 4 for the positions of the 11 cameramen).

No. 1 ~ 5 cameras, covering the exits of the 5 seating areas to the 3F walkway, were installed at the 3F walkway to record the characteristics of exiting audience, their travel speed at each exit, and the number of audience at each exit. No. 6 camera filmed 3F walkway to re-

cord the travel speed of the audience on the horizontal surface. Located on the 2F stairs landing, No. 7 camera filmed the crowds on the stairs descending from 3F to 2F to record the speed of audience descending the stairs. Installed on 1F, No. 8 and No. 9 cameras filmed the crowd walking down from 2F to 1F stairs to record their speed of descending the stairs. No. 10 camera, installed on the 1F lobby, filmed the crowd walking through the lobby to the security check points at the Arena's exit so that the travel speed of the crowd toward the exit could be recorded. No. 11 camera, installed outdoors, filmed the crowd walking from indoors to outdoors on 1F to record their travel speed around the Arena's exit. Hence, No. 1~11 cameras were positioned to record the evacuation process in the area from 3F seating area to the outdoor. The recordings made by the eleven cameras provide data for analyzing the exiting observation experiment. See Fig. 5 for the photos taken by No. 11 camera.

4.3. Analysis of the Hot Area Exiting Observation Result

During the demonstration, actual exiting is observed on half of the Hot Area. No. 1–5 camera were installed along the wall in the 3 F to monitor 5 exits (Exit A~Exit E) in the 3F Hot Area and 3F walkway (see Fig. 4 for the positions of the cameras.) There are 2170 seats in the area of Exit A~Exit E. With 2089 seats being taken during the observation, the area was 96% full, very close to a full



Fig. 5. Picture taken by No.11 camera at the Arena's Exit

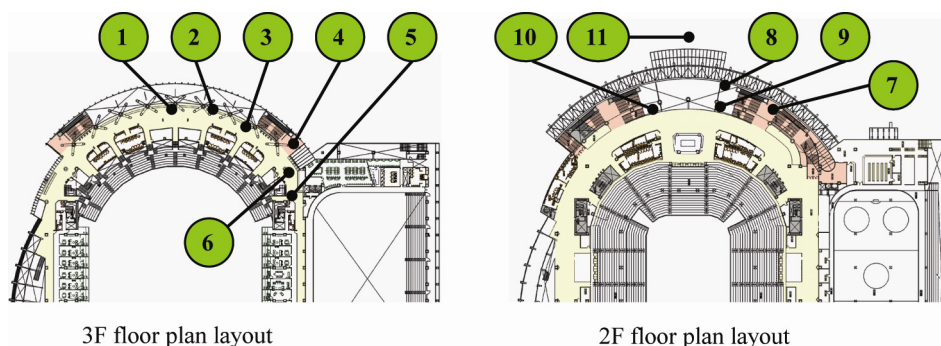


Fig. 4. Camera positions for exit observation experiment on 1F~3F

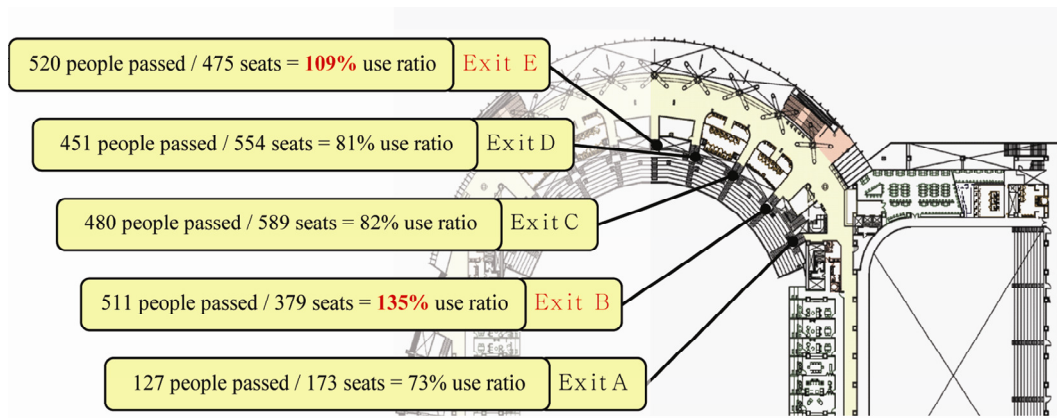


Fig. 6. Exits of seating areas on 3F Hot Area and the use ratio of each exit

house. After analyzing the recordings, it is found the number of exiting audience use Exit B and Exit E were more concentrated. There are 379 seats in the area of Exit B while 511 people took this exit. The use rate of Exit B was 135%. There are 475 seats in the area of Exit E while 520 people used this exit. The use rate of Exit E was 109%. On the other hand, the use ratio of Exit A, Exit C and Exit D were only 73%, 82% and 81% (see Fig. 6).

The study finds that the travel speed varied in different location, which is shown as follows: the exits of each floor (0.84 m/s) > the walkways (0.64 m/s) > descending the stairs (0.46 m/s). It can be explained that the audience at the exits of the five floors must leave through walkways, and the crowds from different floors tend to converge. In addition, the width of each floor's exit is 8.25 m while the width of each walkway is only 5 m. The staircase is even narrower with the width of 4.8 m. Therefore, when the audience was exiting the Arena, the narrowing width of the passages tended to cause "the bottle neck" (BN) effect. For evacuation simulation of the gymnasium, the travel speed of descending the stairs inputted into the simulation software is 0.4 m/s–0.85 m/s, which is very close to the observation experiment's finding, 0.46 m/s. After further analysis, the study finds that when the ratio of the floor exit width to the stairs width (the ratio of Bottle Neck Rate (BNR) = 8.25/4.8) is 1.7, the observed speed of descending the stairs is close to the minimum limit of the speed inputted in the simulation software. The result shows that the travel speed during an actual evacuation is not the same as the input value of the software simulation. The actual speed is apparently much slower, which means that high risk still exists.

Architects designed the floor exits for two purposes: exiting and evacuation. Each floor exit is planned to evacuating the occupants evenly, but the exit observation shows that the use ratios of Exit B and Exit E exceeded the number of seats they contains. At the Exit A, Exit C, and Exit D, the exiting audience diverged or moved to other exits (their use ratios were between 73–82%). However, diverging or moving to other exits may increase the travel distance to safe area. The exiting or evacuation behavior is based on rational and irrational judgment. The rational judgment is affected by implicit and

explicit reasons. Implicit reasons refer to that evacuees choose a floor exit based on their subjective decisions, which matches the characteristic of evacuation behavior – "gravitation toward the closer route". Irrational judgment leads the evacuees to run around aimlessly or follow someone else, which matches the characteristic of evacuation behavior – "follow-the-crowd". The two characteristics were seen at Exit B and Exit E.

4.4. Analysis of Hot Area Simulation Result

This study conducts a simulation analysis with the evacuation software and observes the exiting of 2089 people after a sold-out musical performance. After taking the cost into account, Exodus (Version 4.0a) software, commonly used internationally as well as in Taiwan for evacuation simulation, was used and compared in this article. Exodus was developed by the Fire Safety Engineering Group of Greenwich University. Written in C++, it can run on a personal computer or workstation, and is commonly used to simulate evacuation processes in large spaces and spaces that accommodate large crowds.

As Exodus only has built-in settings for offices, stations, marketplaces and schools, other venues must be set separately. The simulated scenario designed in this study specifies 2089 people in the half area of 3F~5F. Based on the recordings of the exiting, the composition of the crowds was inputted into the Exodus software. The occupant characteristics are set as Average 30%, Male 20%, Female 30%, Child 20%. Another hypothesis is that everyone can rely on himself to be evacuated and will not need the assistance of other people or equipment; the movement speed of the occupants is relative to the density of occupants, and when the distance between people becomes smaller than 0.3 m, the travel speed is zero, which means they are stranded. If the distance between people is larger than 1.4 m, all occupants will move forward at an unobstructed regular travel speed. Travel speeds differ according to each occupant's characteristic – normal travel speed is 0–1.4 m/s, ascending stairs is 0.35 times that, and descending stairs is 0.5 times. The initial direction each occupant begins with is set randomly, and the evacuation location is the safe or relatively safe area in the building. Because the facilities of the researched large scale gymnasium are complicated

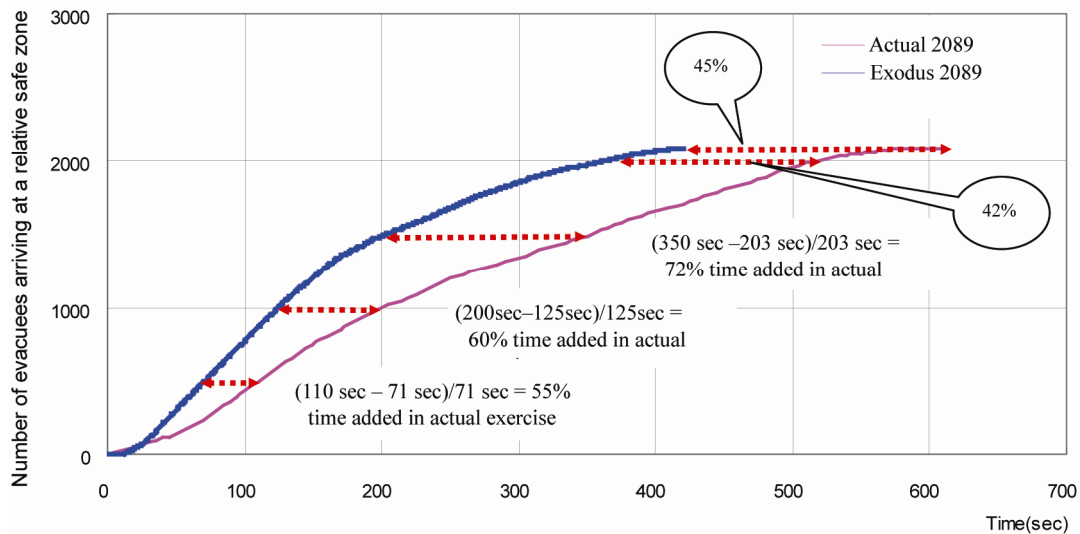


Fig. 7. Actual and Exodus evacuation simulation comparison

and varied, in this case escalators are set as immobile and seen as stairs, with the width calculated collectively with stairs. Whether each occupant's travel speed on an escalator is unequal to the speed on stairs is another research topic, and will be disregarded and assumed as equal in this study. This study mainly quantifies travel time which does not include pre-movement time between the beginning of the fire and the beginning of the evacuation.

The study finds that Exodus software evacuation simulation time was 420 seconds, while real life exiting observed time was 610 seconds – a 190 second difference. The final time shows that real life exiting was slower than software simulation by 45%. In comparison with the exiting observation results of 500 people, 1000 people, 1500 people and 2000 people, the study finds that the real life exiting takes more time than the simulation results of Exodus software. The evacuation time needed in real life exiting is 55% more for 500 people; 60% more for 1,000 people; 72% more for 1,500 people; and 42% more for 2000 people (see Fig. 7). On average, the real life exiting time is 57% more than the software simulates. For the purpose of government's inspection, in order to safeguard building users' lives and avoid possible risks, the inspection must be carried out in the most cautious way. While the full scale evacuation exercise at the stage of inspection and acceptance can be replaced by the concept of Hot Area exercise, it is suggested the inspectors should multiply the software-simulated evacuation time by 1.57 (safety ratio) at the stage of architecture plan review.

5. Conclusions and Suggestions

After making the above empirical analysis and discussion, the authors reach the following conclusion and raise a few suggestions.

5.1. Conclusions

1. This study uses focus groups to come up with the "Hot Area" simulation concept, and Hot Area criteria comprises three key factors: "largest travel distance," "capacity of exit," "density of occupants." A ranking

method is adopted to determine the most dangerous "Hot Area" in the building. Then, real life exiting observation and Hot Area simulation are conducted to replace full-scale simulations in a large scale building in order to avoid the high moral risk and labor and economic cost involved with a full-scale real life simulation. While an unannounced evacuation can allow observation of true evacuation behavior, considering democratic rights, moral risk, and safety and labor cost issues, there is great difficulty in carrying out this kind of study, studies of large scale building in particular.

2. This study uses low cost concept of Hot Area simulation and use 14 firemen and 11 cameras to observe a real-life exiting of 2089 people. After empirical analysis of the observation result and comparison between the simulation result made by the Exodus software, the study finds that the actual exiting time and evacuation time of a large crowd (2089 people) are indeed different from the result of software simulation. The comparison shows that real life exiting was slower than software simulation by 45%. While the full scale evacuation exercise carried out at the stage of inspection and acceptance can be replaced by the concept of Hot Area exercise, it is suggested the inspectors should multiply the software-simulated evacuation time by 1.57 (safety ratio) at the stage of architecture plan review.

3. Furthermore, from the observation of the exiting in the Hot Area, the study finds that while the use ratios of both Exit B and Exit E exceeded the planned number of seats (the use ratios of the two exits reached 109~135%), the audience belonging to the areas of Exit A, Exit C, or Exit D diverged or moved to other exits (the use ratios of these exits were only 73~82%). The problems of "gravitation toward the closer route" and "follow-the-crowd" were also shown during the process of exiting. To solve these problems, the study suggests architects to take the Hot Area concept into consideration and avoid the two problems of the evacuation behavior as much as possible when designing the exits and walkways in this most dangerous area.

4. The three hot area criteria are important factors affecting evacuation process. While drawing up a building plan, large building designers should try to minimize the “largest travel distance to safer area” (Criterion 1) and maximize the width of exits (Criterion 2). Furthermore, as indicated by the Criterion 3 – “Density of occupants” the designers must keep in mind that evacuation safety will be compromised if there is no limit to the number of occupants in a building.

5.2. Suggestions

1. Information Communication and Technology (ICT) advances quickly. As the future studies will focus on the results of unannounced real-life evacuation exercises, Closed Circuit Television (CCTV) installed in large scale building can be used for constant long-distance monitoring and recording to gather analysis data. Hence, this study suggests that government units use their administration authority to install CCTVs along the evacuation paths in large scale gymnasium as well as long-distance monitoring and backup systems. These will aid security on a regular basis, and serve as a record for real evacuation behavior during a disaster, which will aid in evaluating the difference between software simulation and real life evacuation in large scale gymnasium, making it possible to find a more close-to-reality safety ratio for software simulation results.

2. As there is a difference of 57% between the evacuation time calculated by Actual 2089 and Exodus 2089, the authors suggest setting the safety ratio at 1.57. The cause of the difference can be explained by the audience’s exit behavior. Although most audience walked to the exits right after the end of performance, some audience remained in their seats because the exits were crowded with people and they preferred to wait until the crowd dispersed. This may be one reason that the real life exiting took longer time than the scenario simulated by Exodus. Therefore, the argument that exiting time equals evacuation time, proposed by the past studies, is proved inapplicable to large-scale performance venues like Taipei Arena. More studies should be done to test this argument in the future. It is suggested more similar comparative researches (including sensitivity tests and real life exercises) should be conducted to evaluate what affects the evacuation time (such as building use types, occupancy capacity, performance forms or composition of the crowd) and verify whether the exiting time “does not” equal to the evacuation time as shown by this study.

3. Also, the study recommends that after considering the different scenario of each case, the value which correlates with the danger during emergency evacuation, the BNR (BottleNeck effect Ratio), should be researched and analyzed further to help the design of evacuation plan more practical. The BNR model discussed in the paper is not fully matured yet and further research work for improvement is still being carried out.

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EVAKUACIJOS IŠ KARŠTOSIOS ZONOS MODELIO TAIKYMAS DIDELĖMS GIMNAZIJOMS

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Santrauka

Evakuacijos iš didelių pastatų eksperimentai yra sunkiai atliekami ir brangūs. Straipsnyje nagrinėjama evakuacija iš didelių gimnazijos pastatų. Tyrimas grindžiamas karštosios zonos sąvoka, pasiūlyta gaisrinės saugos ekspertų grupės. Karštoji zona yra pavojingiausia vieta pastate. Straipsnyje ši zona parenkama ir analizuojama taikant rikiavimo metodą. Parinkus pavojingąją zoną, evakuacijos eksperimentas atliekamas iš jos, o ne iš viso pastato. Evakuacija modeliuota Taipėjaus arenos pastate taikant *Exodus* programą, modeliavimo rezultatai lyginti su tikrąja 2009 žmonių evakuacija. Remiantis tyrimo rezultatais pasiūlyta keletas kriterijų, panašių pastatų inspekcijai atlikti baigus jų statybą.

Reikšminiai žodžiai: karštoji zona, evakuacijos modeliavimas, didelė gimnazija, kritinių situacijų valdymas, gaisras.

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