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Case Study for Performance-Based Design in Hong Kong

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Abstract

This is a performance-based design on the designated project by following practices in Hong Kong. The leading author has served the government assessment party for 6 years since the fire engineering approach for passive protection on construction elements was implemented in 1998. The other four authors have working experience on fire safety from 11 to 31 years.

1. Introduction

As designated, the objective of this case study is to undertake a performance-based fire safety analysis and design for a senior living facility. The performance-based fire safety analysis and design should meet the following fire and life safety goals as specified in the project brief:

- Safeguard occupants from injury due to fire until they reach a safe place.
- Safeguard fire fighters while performing rescue operations or attacking the fire.
- Avoid collapse of all or part of the structure in the event of a fire.

The project would be designed by following Hong Kong practices [1-4]. However, fire safety objectives for each type of building are not yet spelled out clearly. The objectives for fire services installation [4] are:

- Extinguishing, attacking, preventing or limiting a fire.
- Giving warning of a fire.
- Providing access to any premises or place for the purpose of extinguishing, attacking, preventing or limiting a fire.

The design principles for the proposed senior living accommodation [5] should include the following:

- Evacuation will not be conducted unless there is an imminent need.
- If considered necessary, phase evacuation will be executed.
- Since evacuation is not desired, in case of fire, the fire should be confined in the cubicle with appropriate fire rated door and building materials.
- All the cubicles on each floor will be divided into two portions with proper separations by a common lobby. In case of fire and if evacuation is necessary, patrons from the affected portion will be temporarily moved to the unaffected portion of the same floor for temporary stay and pending for rescue.
- Refuge floors at an interval of ten floors to be provided for temporary stay of the evacuees and rescuers in case of emergency.
- From the given layout plan, since there are two dead-ends on each floor, lobby approach is suggested at both ends in order to shorten the escape distance from each cubicle to the staircases.

For those projects having difficulties in complying with the prescriptive fire codes on passive fire safety designs [1-3] in Hong Kong, “Fire Engineering Approach FEA” [6,7] is accepted by the authority since 1998.

The fire safety objectives can be summarized as:

- Confine the fire in a crucible, if happens.
- Separation by fire-resisting walls into different zones.
- Provide alternative exit routes.
- Provide sufficient fire service installations.

2. Regulations in Hong Kong

Fire regulations in Hong Kong was briefly summarized by Chow [8] in another paper of this conference. A summary is presented:

The fire codes in Hong Kong are basically prescriptive following those developed decades ago in the UK with some slight modifications. Approval of fire safety designs and inspection of the buildings upon completion are held responsible by two government departments. The building design shall be submitted to the BD to check against all fire aspects for approval. The requirements and installation of fire protection systems are monitored by the Fire Services Department FSD. A pictorial presentation of the application procedure is shown in Figure 1.

Codes on passive building construction [1-3] are:

- Code of Practice for Fire Resisting Construction (FRC code)
- Code of Practice for Provisions of Means of Access for Firefighting and Rescue Purposes (MoA code)
- Code of Practice for Provisions of Means of Escape in case of Fire and Allied Requirements (MoE code)

Code on active fire protection system or fire services installation (FSI) [4] is:

- Code of Practice for Minimum Fire Service Installations and Equipment and Inspection and Testing and Maintenance of Installations and Equipment (FSI code)

This is not yet Engineering Performance-Based Fire Codes (EPBFC) as implemented in places elsewhere. For those buildings having difficulties in complying with the prescriptive fire safety codes, FEA as shown in Figure 1 will be accepted by BD since 1998. Implementation of FEA will be discussed in the next section. FE is similar to performance-based design (PBD).

A Fire Safety Committee (FSC) was set up by BD in 1998 to consider fire safety designs with FEA when necessary. This committee is chaired by an Assistant Director. Members include the Chief Building Surveyor responsible for fire, other Chief Building Surveyors, Chief Structural Engineers, a representative officer from FSD, and two experts in fire engineering who are not government officers.

There are not yet standard methods for assessing those designs. Approaches to PBD used overseas were applied. But in most of the submitted reports, the parts deviated from the prescriptive codes would be assessed. Non-compliance with FRC code for glazing walls in a double-skin façade is an example. In fact, application of the FEA for most projects is to demonstrate the equivalency to prescriptive codes.

3. Active Protection Systems

Active protection systems or fire services installations (FSI) required are specified in Codes of Practice (COP) by Fire Services Department (FSD) [4], known as the FSI code.

The building in this project is regarded as a high rise institutional building and the following are the units required stated in the FSI code [4]:

- Audio/Visual Advisory Systems
- Automatic Actuating Devices
- Automatic Fixed Installations Other than Water
- Emergency Generators
- Emergency Lighting
- Exit Signs
- Fire Alarm Systems
- Fire Control Centre
- Fire Detection Systems
- Fire Hydrant/Hose Reel Systems
- Fireman's Lifts
- Portable Hand-operated Approved Appliances
- Pressurization of Staircases
- Sprinkler Systems
- Ventilation/Air Conditioning Control Systems

Detailed information on this particular case is:

- Audio/Visual Advisory System
  For audio alarm system, there should be a Public Address System to guide the staff and occupants how to react in emergency conditions besides alarm bells.

- Automatic Actuating Devices
  There are some installations involved like fire shutters, fire stop doors, fire dampers, fire curtains and smoke vents, etc. In this case, fire dampers would be required to install in ventilation air ducts.

- Automatic Fixed Installations other than Water
  It can generally be regarded as gaseous extinguishing systems such as carbon dioxide, nitrogen or clean agent heptafluoropropane FM200. Since there may be some oxygen

containers for those requiring special medical care, it is necessary to provide this system to prevent any explosion of the container room.

- Emergency Generator
  It is required to sustain the full load power for not less than 6 hours for all installations stated in this report.

- Emergency Lighting
  This system is designed according to BS5266:Part 1 [9] except exit signs to provide sufficient lumination for evacuation within the building.

- Exit Signs
  Some modifications are made in applying BS 5266:Part 1 [9] in order to suit local situations while the directional signs would follow BS5499:Part 1. All signs are to help those occupants escape in emergency.

- Fire Alarm System
  Manual fire alarm system should follow BS5839:Part 1 [10] with alarm gongs installed at all hose reel points and main exits of the premise for the people to notify others in the building. Visual fire alarm should conform to Clause 6-4 of NFPA 72 [11] which would also be actuated to inform the deaf.

- Fire Control Centre
  A location placed at ground floor near the main entrances to house the equipments of fire services systems to be inspected and used by fire bridges for their ease to understand the situations of all installations and prepare fire fighting and evacuation process.

- Fire Detection Systems
  It is necessary to install heat or smoke detectors throughout the building for early detection of any fire in accordance to FOC Rules 12 [12].

- Fire Hydrant/Hose Reel Systems
  Fire hydrant is designed with reference to BS5041:Part 1 [13] to equip fire bridges for fire fighting progress while hose reel is installed every 30 m to let the people have a hands-on means in fire control.

- Fireman’s Lifts
  Based on the occupancy loading, fireman lifts would reach each floor. Firemen would use them to evacuate the people inside the building and arrive at their desired location to fight against the fire.

- Portable Hand-operated Approved Appliances
  Various types of hand-operated fire extinguishers would be placed inside each plant room and every convenience location for them to carry out first round fire fighting.

- Staircase Pressurization
  Staircases are used as means of escape for the occupants and means of access for firemen. It is designed in accordance to BS5588:Part 4 with some amendments made to suit local situation. Pressurization can enhance the safety for the people using the staircases.

- Sprinkler Systems
  Requirements on sprinkler system would be referred to Loss Prevention Council Rules for Automatic Sprinkler Installation and alternations are stated in FSD Circular Letter No. 2/94 [14].

- Ventilation/Air Conditioning Control Systems
  Air flow introduced by ventilation would help the spraying of toxic gas and fire to other compartments. Also, air jet from air conditioning system would disturb the stability of smoke layer and enhance the entrainment of ceiling jet. Therefore, the ventilation/air conditioning would be cut off partially or wholly subjected to the severity of the fire.

4. Means of Escape and Means of Access

Since means of escape and means of access were stated in the given drawings, the layout was changed to include the lifts and escape routes for daily operation and emergency conditions as in Figure 2.

There are four staircases (each 2 m wide structurally) with two for normal operation and two for emergency connecting to each floor, four lifts (two 2 x 2 m and two 4 x 2 m) and escape ram for 2nd floor, 3 m in width with slope about 1:20. Such staircases design is to avoid dead-end effect of the corridor.

Maximum number of residents is only 812 for the whole building. According to the local MoE code [1], the number of staircases, the width of each staircase and the total width of staircases comply with statutory requirements for the discharge rate of 1000 persons per floor. Normally, it is not the case to gather all of them on the same floor in daily operation. However, the travel distance of evacuation for most rooms is far longer than 30 m under this design. This does not comply with the local MoE code and will be discussed in a later section.

In order to provide evacuation design for occupants in buildings in the case of fire, two design approaches of evacuation design are reviewed. This included the use of traditional prescriptive approach as stipulated in the local code of practice and the use of fire engineering approach. From current review, it showed that there is a large variation of design parameters considerations when fire engineering approach is adopted.

5. Additional Points

Since the headroom is taller than 3 m, there is sufficient clearance to facilitate the smoke traps or smoke extraction system at high level. Calculation can be based on the largest fire load of the floor. The total fire load on each floor will be the total fire load of combustibles on the floor. For simplicity, each floor is assumed to be identical as the building is an elderly home. When considering the total fire load on each floor, the normal type of conbustibles as listed in Chapter 7 of the Code of Practice for Residential Care Homes [5] is assumed.

Each compartment should be fire rated in order to make some refuge area and the roof can be used as a refuge floor. Each floor will be partitioned into portions with lobby, common area and recess area such that it will be easier to carry out evacuation for the patrons within available resources and manpower.

Total evacuation in such building will take a considerable time. If evacuation is absolutely necessary, evacuation by phase will be more appropriate.

Like other types of buildings in Hong Kong, refuge floor for such building has to be provided. It is suggested preferably to be provided at intervals of every ten floors.

Since management forms the core part of the performance-based design, apart from ensuring the effectiveness of the passive and active fire protection systems, routine management in the building is also very important. These include staff training on fire safety and regular fire talks and drills to the patrons; conduct joint exercises with local fire department and other local authorities; control to limit the amount of combustibles on each floor.

Combustibles such as polyurethane foam (PUF) mattress and upholstery should comply with BS7176 [15] and BS7177 [16]. Only safe fuel, such as town gas, piped LPG system and electricity will be used.

All these are shown in Figures 3 and 4.

6. Performance-Based Design

In Hong Kong, escape routes of a building can be designed based on prescriptive approach and fire engineering approach. With prescriptive approach, the designers or architects would follow the guidelines laid down in the codes of practice, practice notes for authorized persons, circular letters, etc. For most buildings in Hong Kong, the escape routes design are still based on these codes of practice to obtain the "deem to satisfy" provision. The three codes of practices issued by the Buildings Department and one code of practice issued by the Fire Services Department have to be complied with in designing escape route.

In following MoE code [1], prescribed figures are specified for the building designer to determine the occupant density of the building, number of staircases in both sprinklered and non-sprinklered buildings, discharge values, travel distance and staircase width, etc. As stated in this code of practice, the evacuation time for each storey to a protected area (e.g. the staircase leading to the exit) should be within a notional period of 2.5 minutes (150 s) for non-sprinklered buildings. While in the FRC code [3], the provisions for protection of the building and escape route using suitable non-combustible materials which possess a specified fire resistance period for different construction elements and resisting the action of fire are described. It also stipulates the integrity, stability and insulation requirements for the building elements.

Design following these codes of practice is presumed to provide sufficient protection to the occupants and the building in the case of fire. Under the prescriptive approach, designers or engineers will design the escape route based the requirements stated in the code of practice without questioning the actual performance of these escape routes and its interaction with the occupants and other building features.

However, for buildings with special features such as this example, the escape route is not designed by following the requirements prescribed in the codes of practice. FEA has to be adopted to design the escape route. Under the fire engineering approach, there are no standard figures for the design of escape route. A common practice is the timeline approach to estimate the evacuation time of the building occupants.

In such an approach, fire engineers will normally study the probable fire scenarios by reviewing the features, function of the building and the characteristics of the occupancy. The compliancy of active fire service installation design will also be checked against the existing code of practice. The fire engineers will then determine the design population and the proposed means of escape.

The worst credible fire scenarios and fire location will be determined (have to convince the Authority later in presentation) by considering the function and operation of the building. After choosing the fire location for the study, a design fire size will be determined. The determination of a suitable design fire size always leads to vigorous arguments between relevant parties. Fire engineers will usually refer to the NFPA, CIBSE and journal papers for the rationale of design fire determination. Wind and stack effects affecting the fire development and smoke movement will also be considered. All factors concerned will be used as input parameters for fire and smoke spread calculation. The calculation may rely on empirical equations provided in the standard and design guides such as CIBSE TM19 or CIBSE Guide E [17]. Some engineers may prefer to use zone models such as CFAST [18] or field models such fire dynamics simulator (FDS) [19] to estimate the tenability conditions of the building in the case of fire. The untenable conditions might be determined by the smoke layer clear height, thermal radiation from fire and enclosure temperature. The time from ignition to the occurrence of untenable conditions will be estimated and taken to be the available safe egress time (ASET) for the building occupants.

In estimating the evacuation time of the occupants, designers or engineers will first determine the ultimate place of safety. They will normally use empirical equations from the Handbook of Society of Fire Protection Engineers (SFPE) or evacuation software such as SIMULEX, STEPS and EXODUS to calculate the total evacuation time (traveling time) of the occupants. Congested areas, dead-ends and extended traveling time of the occupants are identified. The difference of ASET and the required safe egress (escape) time (RSET) of the occupants will then be calculated. If the value of ASET is larger than the value of RSET, the escape route design will be considered as appropriate. One of the comprehensive documents available for providing a systematic approach to the calculation of escape time is BS7974:2002 [20].

The following formula is proposed in BS7974:2002 [20].

$$RSET = \Delta t_{det} + \Delta t_{alarm} + \left(\Delta t_{pre} + \Delta t_{trav}\right)$$

where $\Delta t_{\det}$ is the time from ignition to detection determined from engineering tool such as the empirical model by Alpert, Δt_{alarm} is the time from detection to a general alarm, Δt_{pre} is the pre-movement time for the building occupants and the Δt_{trav} is the travel time of the building occupants which is determined from the evacuation software such as SIMULEX, STEPS.

After estimating REST, the difference of ASET and RSET will be used as one of the acceptance criteria for the fire safety design. After the calculation, the results will be submitted to the Buildings Department and related authorities for discussion and approval.

Based on the above formula, it is apparent that a great delay in initiating evacuation (i.e. large value of Δt_{pre}) would lead to a considerable vulnerability of the occupants. Behavioral response of the occupants is one of the important factors affecting the evacuation time in the case of fire and would be dictated by their physical and psychological states at the time of fire awareness, e.g. whether they were asleep, just awake and not dressed, or dressed and awake, the severity of threat posed by fire, the building design and the fire protection devices installed. The reaction of occupants after the perception of fire would be affected by their perception of the seriousness of the fire. Before egress, many people tend to take preservative action, such as collecting important or valuable items. In estimating Δt_{pre}, the cognitive functioning ability of the occupants is very important. Some people would treat the audible fire alarm sound as a warning and wait for further information, e.g. notified by neighbor, clarified with management personnel via phone calls before starting to evacuate. Therefore, in using this fire engineering approach for escape route design, it is important to understand the behavior of the occupants in the case of fire emergency such that Δt_{pre} can be determined and included in the egress time calculations. However, the value of Δt_{pre} varied with considerable uncertainty and it is important to obtain accurate information of occupants. The determination of Δt_{pre} always leads to vigorous arguments between the designers or engineers and the authority.

Physical conditions, occupant distribution, gender, age, etc. are very important input parameters for the estimation of Δt_{trav}. However, in the existing fire engineering approach design, no universal guideline was developed in the determination of these input parameters This again leads to arguments between the designers or engineers and the approving authority.

7. Evacuation Simulation

Only 1 floor with one 2 m exit is considered in the simulation by Simulex [21]. Total number of occupants on floor 1 is 39. The simulation setup is shown in Figure 5. During the simulation, the response time of the occupants is based on random distribution with mean value equal to 1 min/s.

Two occupant types are considered: office staff and the elderly. For the office staff, the total evacuation time is 46 s. For the elderly, the total evacuation time is 63 s. This shows that by simply changing the occupant type, the simulated evacuation time is doubled. The evacuation pattern is shown in Figure 6 which illustrated the time required for the occupants to pass through the exit on floor 1.

The values are less than the MoE code specification of 150 s. Although the travel distance is longer than the specified value, the evacuation time is still satisfied.

8. Conclusions

The assigned case study using fire engineering approach [6,7] in Hong Kong was outlined. However, it is difficult to convince the Authority to accept an elderly house design without following the prescriptive codes [1-5]. Hazard assessment with only fire models [e.g. 18,19] and evacuation simulations [e.g. 21] are always judged to be not convincing in many FEA projects since 1998. Whenever performance-based design is adopted on such building use, full-scale burning tests [8] might be required to support the argument.

About the Authors

Professor W.K. Chow is the Chair Professor of Architectural Science and Fire Engineering; Principal Investigator, Areas of Strength: Fire and Safety Engineering; and Director, Research Centre for Fire Engineering at The Hong Kong Polytechnic University. He was a non-official member of the Fire Safety Committee of Buildings Department of the Special Administrative Region Government for six years since the implementation of fire engineering approach for passive building design in 1998. He is the Founding President, Hong Kong Chapter of the Society of Fire Protection Engineers. He has published over 600 research papers (over 300 in SCI/EI journals) and is active in consultancy projects in the Far East since the budget cut in fire engineering in 2003.

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Mr. Edgar C.L. Pang graduated from The Hong Kong Polytechnic University (PolyU) with a BEng(Hon) degree in Mechanical Engineering in 1995, and a Master of Science in Fire and Safety Engineering in 2005. He is a practical fire engineer for over 10 years and is carrying out part-time research in fire engineering with Professor Chow.

Mr. Fred K.W. Lau is a retired Fire Officer serving the Hong Kong Fire Services Department for 31 years. He had taken up different leading posts in fire safety design; fire safety certificate approvals related to commercial premises and activities, schools and other approvals of active fire protection systems in buildings and licensing in the control of hazardous materials for 14 years; and fire fighting operation experience as an officer-in-charge for 17 years. Currently, he is the technical adviser of a fire consultant/contractor company. He graduated from the PolyU with a Master of Science in Fire and Safety Engineering degree in 2005 and is a part-time researcher with Professor Chow.

Mr. Kenny S.M. Kong joined DCL Consultants Limited in 1996 and has been appointed as Executive Director. He was qualified as a Chartered Surveyor in 1990, and being a Member of the Hong Kong Institute of Surveyors, a Member of the Chartered Institute of Arbitrators and a Member of Australian Institute of Building Surveyors. He is an Authorized Person under Buildings Ordinance in Hong Kong, and now a part-time PhD student working on fire safety of institutional buildings with Professor Chow.

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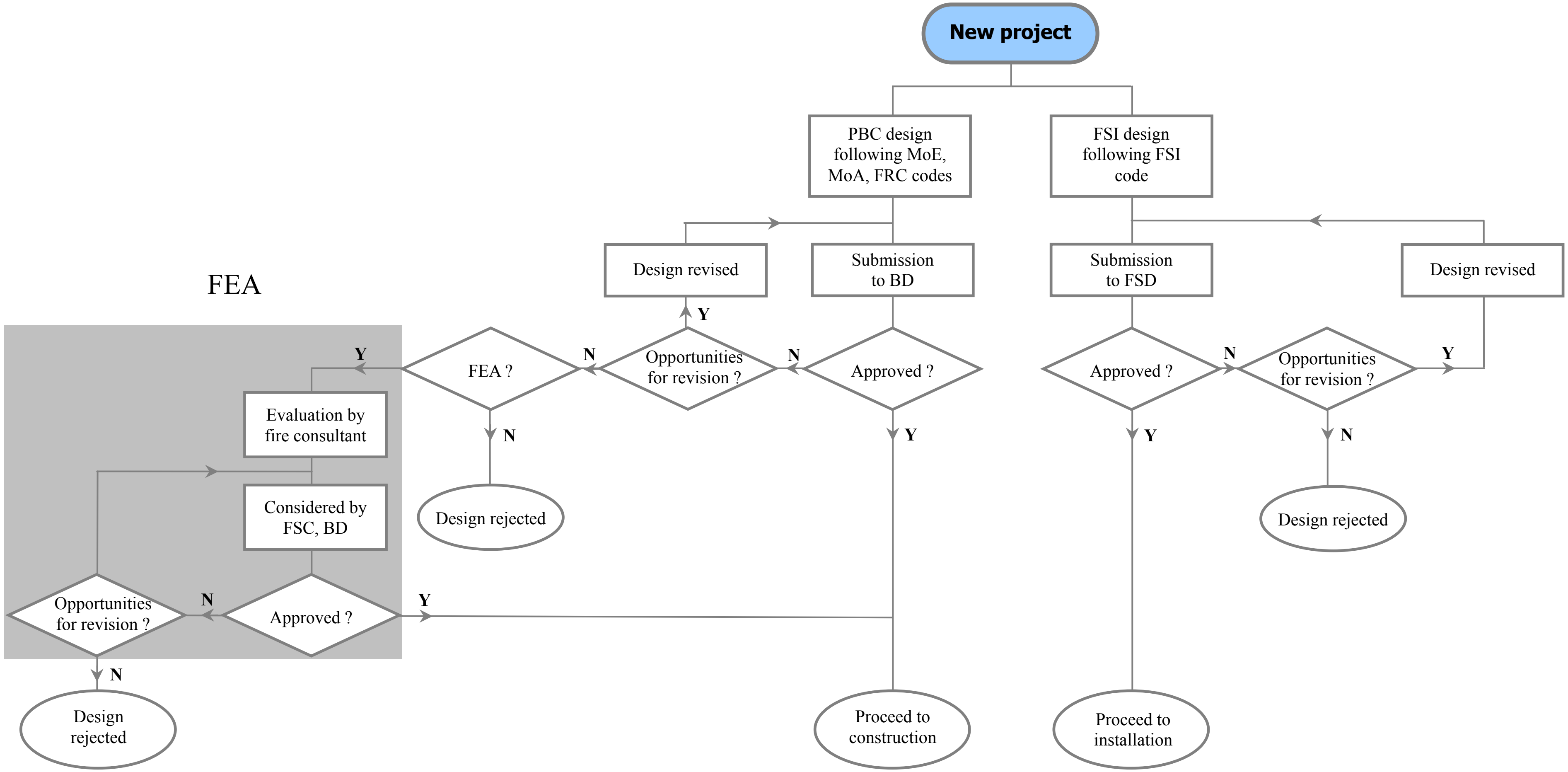

Figure 1: Process for approving fire safety designs

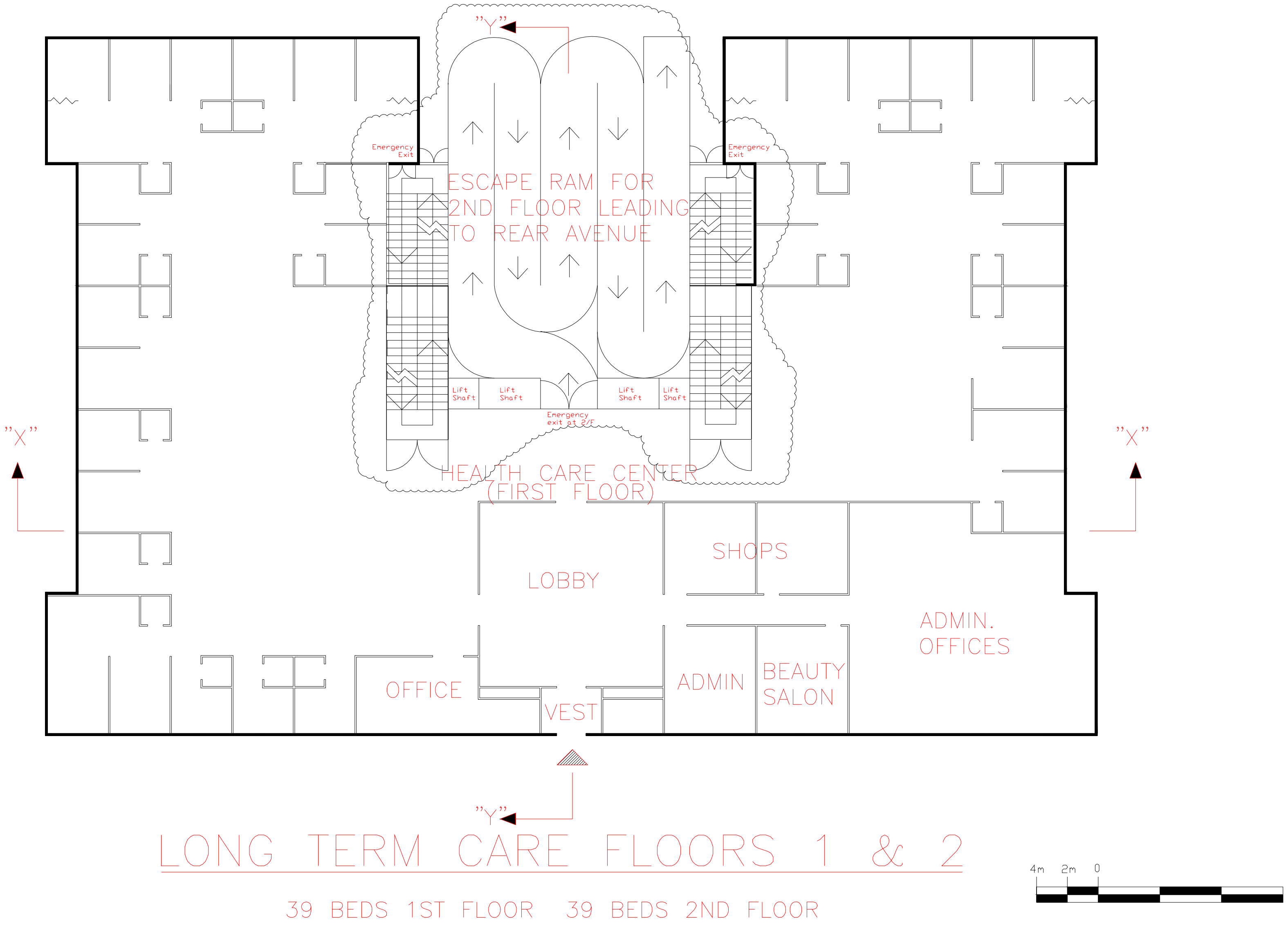

Figure 2: Long term care floors 1 & 2

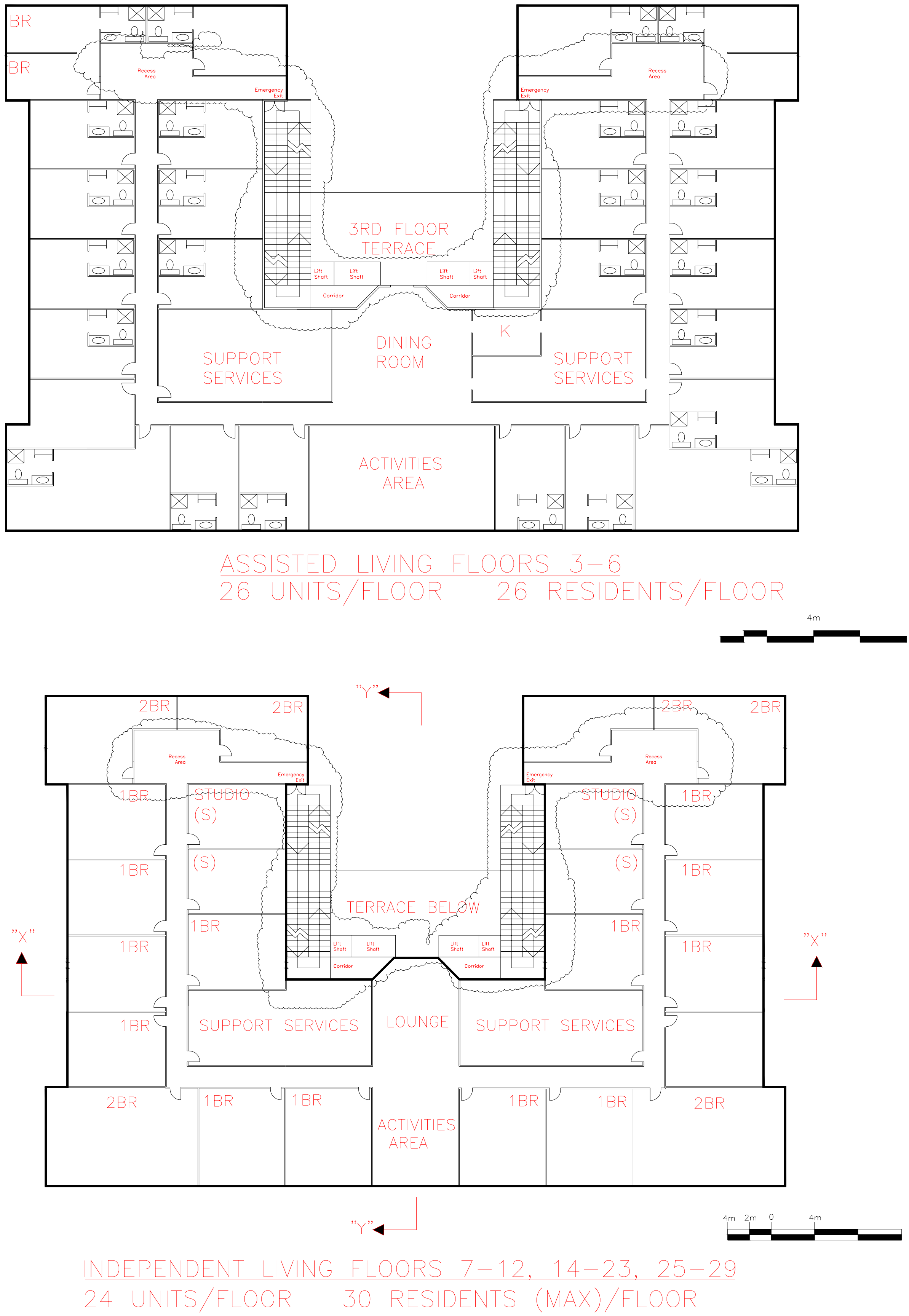

Figure 3: Modifications suggested

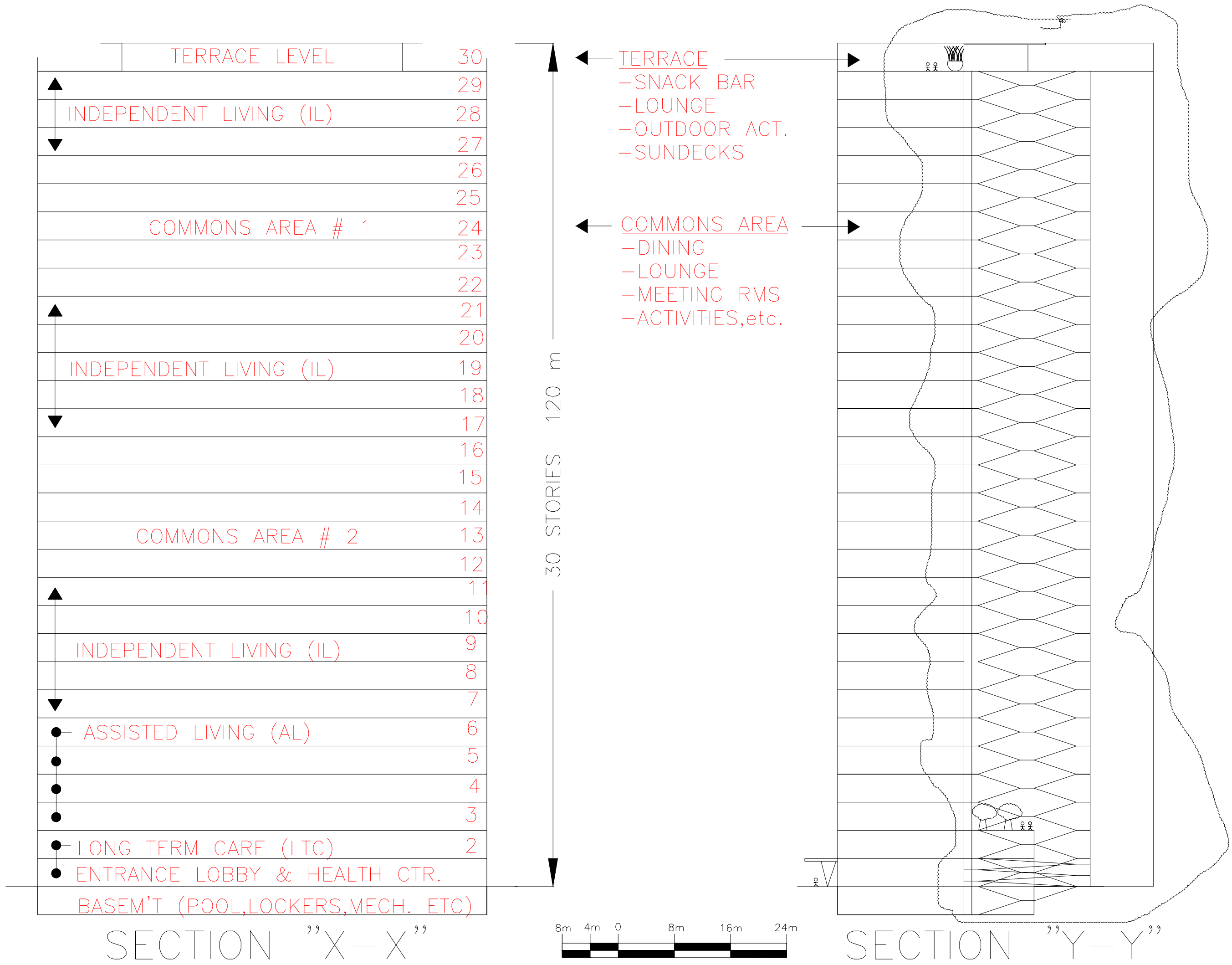

Figure 4: Evacuation

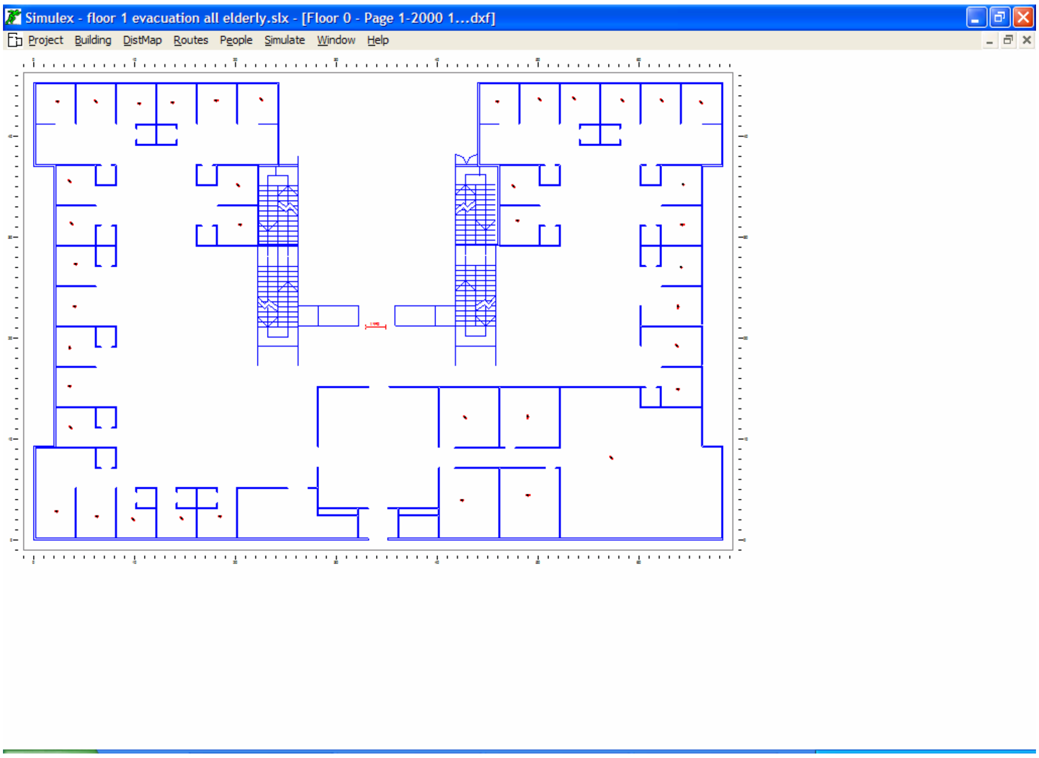

Figure 5: Layout and occupant distribution in floor 1

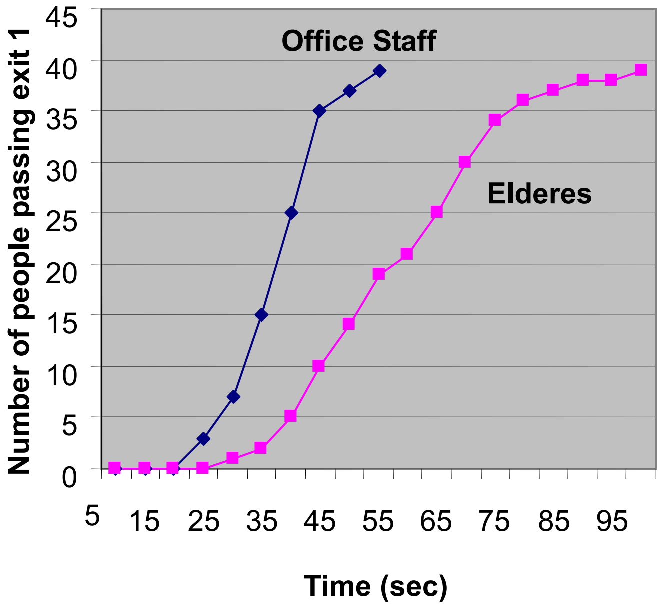

Figure 6: Evacuation time estimation of floor 1 with single exit (2 m wide) using Simulex