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INDUSTRY ACCEPTED DESIGN: A CASE STUDY ON PRESCRIPTIVE VS. PERFORMANCE BASED DESIGN CRITERIA

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The building analysis discussed below was for the Culminating Project for the Fire Protection Engineering Master's degree from California Polytechnic State University, San Luis Obispo.

ABSTRACT

A prescriptive and performance based analysis has been conducted on a College Campus Building in Southern California. The building is proposed to be the center of operations as well as having administration facilities for the College. It will house an administrative office, production and support facilities. The project is three stories and includes a balcony that does not qualify as a story. The top floor is greater than 30 feet from grade and the largest floor has an area of approximately 12,500 square feet. The building is comprised of Group A and B occupancies in a separated mixed-use configuration. The building will be of Type II-B construction.

The prescriptive analysis has been evaluated based on the following systems:

- Egress Components
- Fire Rated Construction
- Fire Alarm System
- Fire Suppression System

The performance based analysis has been conducted for a number of fire scenarios using the following programs:

- Fire Dynamics Simulator (FDS)
- Simulation of Transient Evacuation and Pedestrian movementS (STEPS)

The required safe egress time (RSET) and available safe egress time (ASET) have been calculated and analyzed to determine if the fire and life safety goals have been achieved.

Based upon the performance-based analyses that were conducted for the building, it was evident that the performance-based design criteria applied to the analyses were more stringent than those inherent in the prescriptive design requirements. This paper will address the differences in industry-accepted design criteria for both prescriptive- and performance-based design solutions. Options for rectifying the difference in these criteria will also be presented.

PROJECT DESCRIPTION

The proposed project at a College Campus includes the new construction of a Media/Technology building. The building is proposed to be the center of radio station operations as well as having administration facilities for the College. It will house an administrative office, production and support facilities comprised of multiple control rooms, computer labs, and telecommunication studios. The project is three stories and includes a viewing balcony that does not qualify as a story. The top floor is greater than 30 feet from grade and the largest floor has an area of approximately 12,500 square feet. The building is comprised of Group A and B occupancies in a separated mixed-use configuration. Buildings B will be of Type II-B construction.

APPLICABLE CODES AND STANDARDS

- 2010 California Building Code (CBC)
- 2010 California Fire Code (CFC)
- 2010 California Electrical Code (CEC)
- 2010 California Mechanical Code (CMC)
- 2010 California Plumbing Code (CPC)
- NFPA Standards Including but not limited to NFPA 10,13,14, 20, 72, 72E, 75 and 2001
- CCR-Title 19: State Fire Marshal – Public Safety
- DSA – Plan Submittal Requirements for Fire Alarm and Detection Systems, Plan Submittal Requirements for Sprinkler Systems

KEY BUILDING FEATURES

Separated Mixed Use

A separated mixed use approach will be applied in the building. Rated separation will divide the structure into assembly (A-3) on Level 1 (including the Viewing Balcony located above Level 1) and the two B occupancy levels adjacent and above. The Figure below illustrates where the rated separation will be.

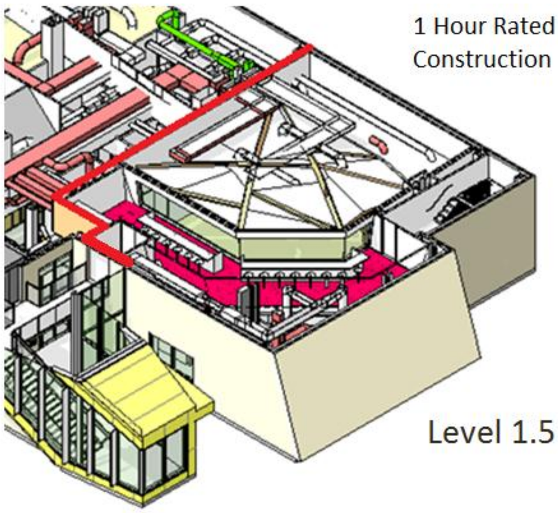


Figure 1: Separated Mixed Use Rated Construction

Atrium Requirements and Approaches

Open Stair

The building includes an atmospheric connection between three levels of the building. This condition is permissible without rated separation provided DSA and AHJ concurs that this non-egress stair is opening into the lowest level of the Atrium. This open stair is permitted to be unenclosed by CBC 708.2 Exception 2.1 when a smoke curtain assembly with closely spaced sprinklers is utilized to create this separation. This approach has been taken, and a draft curtain has been specified above the landing on Level 2 seen in the figure below.

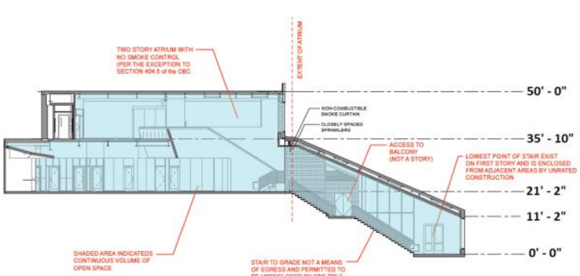


Figure 2: Section Views of Atrium and Open Stair

Atrium

The building includes an atmospheric connection between two levels that is classified as an atrium by the 2010 CBC 404. This condition is permissible without smoke control systems in accordance with the exception to Section 404.5 of the CBC. This condition is complicated by the presence of the entry stair described above but has been interpreted to comply based on the achieved separation with the application of sprinklers and a draft curtain.

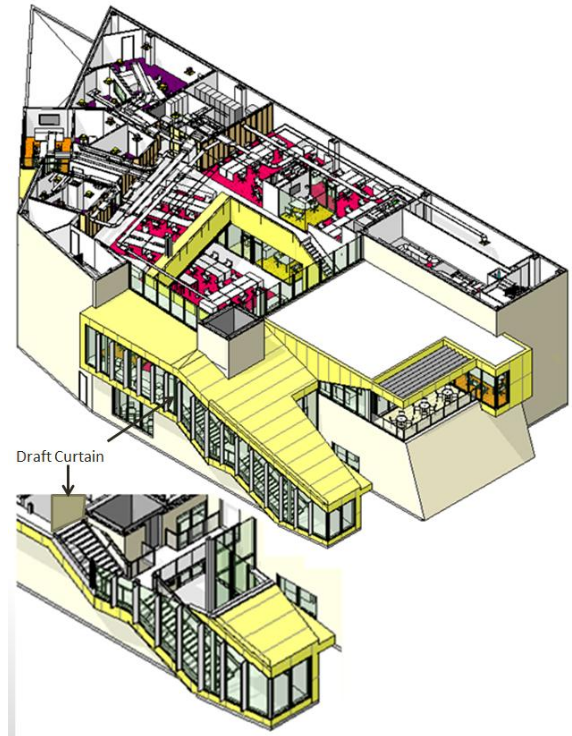


Figure 3: Open Stair Separation

EGRESS

Occupancy

The main uses of the building are administrative office, production and support facilities comprised of multiple control rooms, computer labs, and telecommunication studios. Media production facilities with no audience are classifies as Group B occupancies per Section 304 of the 2010 CBC. Radio stations specifically fall within this classification per the CBC. On the first level there is a 1050 square foot Performance Studio provided with a viewing balcony that will have an occupancy classification of Group A-1.

The color coded plans seen below represent the different occupancy classification uses of the building. The main uses are office, assembly, and accessory (storage, restrooms, etc.).

The exits per level are also noted. There are two stair enclosures. Exit Stair B can be accessed and serve all levels except the viewing balcony. Exit Stair C can be utilized by all occupants above level 1. There is no entrance for occupants on level 1 to enter the Exit C stair enclosure. Level one has access to three exits. Some rooms have additional exits directly to the exterior of the building but these were not included in the exit capacity calculation because they are not clearly accessible to the majority of the occupants.

In determining the required means of egress, the number of occupants utilizing the building will be based on the area of the space, the use of the space, and the occupant load factor. The following table summarizes the occupant load factors used in the analysis.

Table 1: Occupant Load Factors

Occupancy	Occupant Load Factors
Business (general office)	1 person per 100ft^2 gross
Business (conference/ meeting/assembly)	1 person per 15ft^2 gross
Assembly–Unconcentrated	1 person per 15ft^2 gross
Storage/Mechanical/ Utility	1 person per 300ft^2 gross

Figure 4: Level 1 Plan View

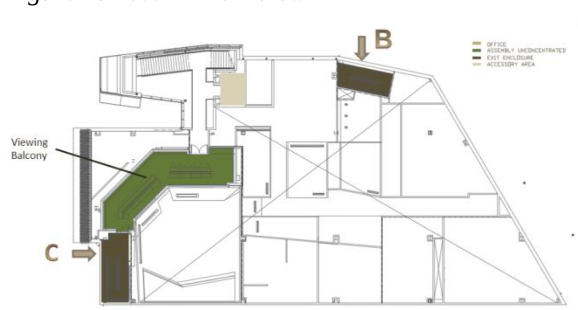


Figure 5: Level 1.5 Plan View

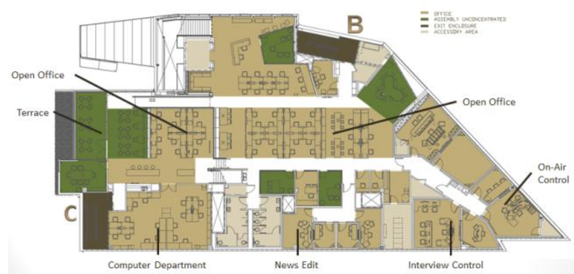


Figure 6: Level 2 Plan View

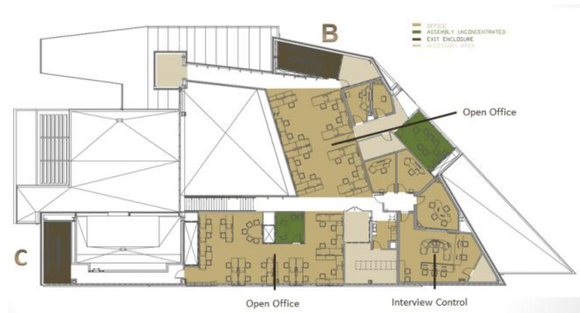


Figure 7: Level 3 Plan View

Means of Egress

The goal of the means of egress strategy is to allow the building occupants to move to an area of relative safety prior to interior conditions becoming untenable. This approach allows for a progression of increasing safety outspreading from occupiable spaces to the public way.

Key concepts incorporated in the methodology of egress from the building include the minimum number of exits based on occupant load and the maximum travel distance from a point within an occupied space to an exit based on occupancy classification.

Quantity of Required Means of Egress

The required number of means of egress is a function of occupancy classification, occupant load, and building geometry. The required number of means of egress for individual spaces within the project is listed below.

- One Exit
  - Storage – Fewer than 29
  - Busniess, Assembly Mechanical – Fewer than 49
- Two Exits
  - All Occupancies – Fewer than 500 (and not less than the maximum

allowable occupant for a single exit) but more than 40.

- Three Exits
    - All Occupancies – 501-1,000 Occupants

Where travel distances or common path of travel limitations are exceeded additional exits must be provided to serve areas surpassing the allowable distance.

The number of accessible means of egress per floor (described in 2010 CBC Section 1007) are required to be equal to the required number of general means of egress from that floor. Each required accessible means of egress will be continuous to a public way.

Egress Capacity

The components serving a required means of egress have a maximum allowable capacity based on their width. The component with the smallest capacity limits the number of allowable occupants where multiple egress components are present. For this building, the clear width factors per occupant for Groups A, B, M, or S can be seen below:

- Stairs: 0.3
- Doors, Corridors, and Ramps: 0.2

All occupant loads and egress exit capacity is shown in the table below, isolated by level. The capacity table show the limit based on the most restricting egress component (door, stair, and corridor). The actual usage is the number of occupants using that exit for egress purposes. Since no stair is converging, the stair capacity is not based on an accumulative load.

Table 2: Egress Capacities by Level

Level 1 Capacities		
ID	Limit Capacity	Actual Usage (Occ Load)
A	340	62
B	170	57
E	340	79
Total	850	199
Level 1.5 Capacities		
ID	Limit Capacity	Actual Usage (Occ Load)
C	160	40
Total	160	40
Level 2.0 Capacities		
ID	Limit Capacity	Actual Usage (Occ Load)
B	160	111
C	160	76
Total	320	187
Level 3.0 Capacities		
ID	Limit Capacity	Actual Usage (Occ Load)
B	160	47
C	160	21
Total	320	68

Based on the occupant loading of individual rooms to the occupant load factors which the space is used, there is sufficient egress capacity for all occupants to safely egress per the CBC.

PASSIVE SYSTEMS

The required fire performance of building elements is primarily a function of construction type and fire separation distance. The compartmentation strategy appraises the fire performance requirements for interior walls.

Construction Type

Buildings B will be of Type II-B construction. The building will be equipped with an automatic sprinkler system designed in accordance with DSA. The design for the building height and areas per CBC Table 503 would be restricted by the Group A-1 requirements of 2 stories and a building area limitation of 8,500 square feet. The installation of sprinklers allows for an additional story increase, per CBC 504.2 as well as the building area limitation to be increased by an additional 200 percent per CBC 506.3. The building would also be allowed a frontage increase, however, with the allotment of the sprinkler increase in the building area per story met the 12,500 square feet needed for the building area per story design. Therefore, this construction type is appropriate for the height and area of the structures as currently designed.

Fire Resistance Strategy

Structural Elements

The fire rating requirements for structural elements of the building vary based on construction type. All penetrations through fire rated construction are required to be protected. The building is designed to ensure both its stability in a fire event and also to make certain that the structure has the ability to limit fire spread between difference compartments. Fire resistance requirements are to comply with CBC Table 601 requirements.

Exterior Walls

The fire rating requirements for exterior walls of the building vary based on construction type, occupancy classification, and separation distance. Fire prescriptive requirements including the maximum permissible quantity of openings in exterior walls and the separation distance are to comply with CBC Table 602 and CBC Table 705.8.

Separation Strategy

The separation strategy is intended to prevent fire and smoke from spreading from the zone of fire origin to the surrounding areas. This is important for means of egress components. All exit enclosures in the building are required to have one hour fire resistance ratings per CBC 1022.1. Shaft enclosures are required to have a fire-resistance rating of not less than 2 hours where connecting four stories or more, and not less than 1 hour where connecting less than four stories per CBC 708.4. The separation between Group A and Group B occupancies are required to have a fire resistance rate of not less than 1 hour in a sprinklered building per CBC Table 508.4. Any room being protected by a clean agent system will also have a fire resistance rating of one hour.

Interior Finish Requirements

Interior finishes for walls, ceilings, and floors will be provided in accordance with the requirements of 2010 CBC Chapter 8. 2010 CBC Sections 803.1.1 and 804.2 provides the minimum fire resistance classifications of interior finish at walls, ceilings and floors. These requirements vary by occupancy classification per 2010 CBC 803.9.

ACTIVE SYSTEMS

Fire Alarm Strategy

A fully automatic power-limited fire alarm and detection system will be provided in the building in accordance with the requirements of Title 19, 24, NFPA 13, NFPA 72 and the Division of the State Architect (DSA).

The system will be comprised primarily of strobes, combination horn/strobes, smoke/heat detectors, duct detectors, and will monitor waterflow and tamper switches via addressable modules; microprocessor based main fire alarm panel, sub-panels, and associated accessories. Wiring is to comply with the requirements of NFPA 72.

Fire alarm notification systems are required by CBC Section 907.2.1 for Group A occupancies with an occupant load of 1,000 or more. The total occupant load of the building is less than 500 thus voice alarm notification is not required the by the code, however, the guidelines of the College campus require Public Address systems for emergency evacuation provided in all classrooms and public areas. The emergency voice/alarm communication system will be in compliance with NFPA 72. It is intended that after the initiation of the fire alarm, the building and possibly surrounding buildings would be notified and be evacuated simultaneously.

Speakers or signaling devices used to sound the voice or fire alarm are to be located to provide audibility on the floor where activated and as required by the local authorities. The operation of any automatic fire detector, sprinkler or water-flow device will automatically sound an alert tone subsequently voice instructions giving applicable information and direction on a general or selective basis. As a minimum, paging zones will be provided at the elevator, exit stair enclosures, each floor, and areas of refuge.

A manual override for emergency voice communication is to be provided for all paging zones, as well as be capable of broadcasting live voice messages, on a selective and all-call basis.

Fire Sprinkler Strategy

A non-separated mixed-use approach for separating different occupancies is being utilized, and as such, sprinklers are provided throughout implementing the respective hazard rating for each room. The system will meet requirements from NFPA 13 Figure 11.2.3.1.1, Table 8.12.2.2.1 and Table 11.2.3.1.2.

Manual wet Class I standpipes (combined sprinkler riser/standpipe) will be provided in each required exit enclosure of the building (per Exception 1 to 2010

CBC Section 905.3.1). Where required standpipes will be installed accordance with NFPA 14.

PERFORMANCED BASED ANALYSIS

Egress analysis encompasses multiple factors including, occupant characteristics, age, mobility, patience,, as well as pre-movement times and walking speeds influencing their travel time. All of these factors are used to calculate and determine what the required safe egress time (RSET) is for the building.

Occupant Characteristics

Occupants using this building are going to be both staff and students to the college. The building function is for the media and technology department and is the hub for the college radio stations. Occupants will be conducting live interviews, be on-air disk jockeys, and be reaching various topics and writing article pieces to be aired at a later date.

The demographics of the media/technology department could not be found. However, the entire campus demographics are as follows:

- Population: 34,000
- Female: 53%
- Male: 47%
- Average Age: 24 years

The building is designed as an open office area with various interview rooms, control rooms and new edit rooms for on each level. Level one has a larger performance studio approximately 1050 square feet with a viewing balcony. Most occupants should be familiar the building since they are there on a regular basis. New students, persons being interviewed and other performers may be initially unfamiliar with their surroundings; however, they will most likely be accompanied by someone who is familiar with the building.

Pre-Movement Time

Time to alarm may vary based on location of occupants and occupant awareness with respect to the fire location. It is assumed that occupants become aware of the fire through visual cues, smell of smoke, or the initiation of the fire alarm system whether it be from smoke/heat detection or a sprinkler water flow sensor.

After an alarm has been monitored, a pre-recorded voice announcement will direct the occupants to begin exiting. It is likely that the occupants near the fire origin will begin exiting before the audible alarm.

Guylene Proulx's work in the SFPE Handbook on evacuation time states that live directions using a voice communication system, along with trained staff, result in movement delays less than two minutes for assembly areas where occupants may be unfamiliar with the building (Performance Studio). Where occupants are familiar with their surroundings the delay stated in the SFPE handbook is less than one minute.

HAND CALCULATIONS

Hand Calculations

There are many factors that are incorporated in the calculation of the egress time. Some of these factors include the effective width of exit route elements (corridor, doorway, stairs, etc), travel speed of occupants, and flow of occupants through exit elements. The effective width of an exit path is the effect of the boundary layer on clear width of a path. The boundary used in the hand calculations is 6 in for doorways and stairs (per SFPE Handbook Table 3-14.1). The maximum specific flow used in the SFPE calculations is based on the most restricting egress element, the doors, found in Table 3-14.5.

Building Assumptions

- Three levels with a viewing balcony observing Level 1
- Level 1 exits directly to the public way
- Number of Exits
  - Level 3 has two exits
  - Level 2 has two exits
  - Level 1.5 (Viewing balcony) has one exit
  - Level 1 had three exits with multiple rooms having direct access to the outside.
- Exit Width
  - Exit Stairs are 48", with handrails
  - Exit Enclosure doors are 34"
  - Main Exits on Level 1 are both 68"

- Minimum corridor is 68”
- Occupant Load
  - Level 3 : 68 persons
  - Level 2: 187 persons
  - Level 1.5: 40 persons
  - Level 1: 199 persons
- Occupants will distribute evenly to the available exits
- Most occupants are free of disabilities that would hinder their own or other occupants travel time

Scenario 1:

Evacuation of the entire building using all viable exits (does not include open stair).

Scenario 2:

Evacuation when all stairs are available, including the open stair.

Table 3: Summary of Hand Calculations

Scenario	Pauls Method	SFPE Method (Total)	SFPE Method (Phased Level 3)	SFPE Method (Phased Level 2)
1	3.89 minutes	3.4 minutes	0.78 minutes	2.14 minutes
2	1.14 minutes	1.69 minutes	0.78 minutes	1.07 minutes

STEPS EVACUATION SIMULATION

STEPS Evacuation Simulation

STEPS (Simulation of Transient Evacuation and Pedestrian movementS) is a computer optimization evacuation model for building evacuation. Ordinary pedestrian movement and evacuation scenarios can be modeled using STEPS. The model supports travel through a variety of egress routes generated within the model as specified by the modeler. Simulated occupants have the ability to choose various egress paths, different egress scenarios can be readily simulated to quantitatively differentiate between egress scenarios. This program allows for modeling phased evacuation scenarios and other more complex egress strategies, effectively revealing locations where queuing or choked flow may occur.

STEPS is a grid-based evacuation model where simulated occupants are placed individually on floor planes within the program. Walls, columns, and furniture also occupy portions of a grid and are interpreted as blockages. Occupants view blockages at not accessible and have to use other cells to travel around the blockages.

Total Evacuation Simulation

A STEPS analysis was conducted that simulates a complete evacuation of the building. The building is fully occupied as described in Section **Error! Reference source not found.** and all viable exits and stairways are available for use as defined per scenario.

Grid Size and Travel Speed

Within the STEPS model the simulated occupants are assigned various sizes and travel speeds, which affect their movement. A person is assigned a travel speed and will remain at predetermined distances from any other simulated occupants or obstruction. Occupants travel on planes that are subdivided into a grid of squares cells and only one occupant and can occupy a single cell. The physical size of the occupants was set as the default for STEPS, with dimensions of 0.32m x 0.5m on the floor, which is an estimate of the shoulder width of the occupants. Height of the occupants does not influence the egress calculations for this analysis.

Both grid-size and travel speed are user-defined settings within STEPS. Travel speed varies based on both the type of individual and the type of walking surface. Effective travel speeds are reduced due to crowding and queuing. The inputs that will be applied to this modeled simulation are summarized below.

Demographics and Walking Speed

Demographics influence the evacuation model because the horizontal and vertical travel speeds for occupants are dependent on the age and mobility of the occupant. The table below indicates the values that were used in the model for walking speeds of the occupants. An additional consideration related to demographics is the patience parameter. Each occupant in the model will continuously assess which exit is available. The patience parameter controls the commitment to an exit for each occupant. For example, once an occupant chooses an exit and travels towards that exit, a low level of patience is where the occupant will immediately change directions if another exit is perceived as providing a faster evacuation. A high patience parameter will have the occupant stay in at the exit, no matter if they see the other exit moving faster. For this analysis, the patience parameter was set to average and the walking speed was based on a young occupant type as average college aged student for this campus is 24.

Table 4: Occupant Walking Speeds

Occupant Type	**Walking Speeds**	
	Horizontal Speed	**Vertical Speed**
Child (<18)	4.27ft/sec (1.3m/s)	2.62t/sec (0.8m/s)
Young (18-29)	4.27ft/sec (1.3m/s)	2.62ft/sec (0.8m/s)
Middle (30-50)	3.94ft/sec (1.2m/s)	2.30ft/sec (0.7m/s)
Old (>50)	3.28ft/sec (1.0m/s)	1.96ft/sec (0.6m/s)
Disabled	1.64ft/sec (0.5m/s)	0.89ft/sec (0.27m/s)

Occupant Load and Usage Assumptions

The following occupant load and usage assumptions have been made in the context of the STEPS analyses. Office spaces, conference rooms, MEP rooms, and storage rooms are occupied by the number of persons determined as the occupant load of the space per the requirements of the 2010 CBC Table 1004.1.1 (1 person per 100 ft^2 of area, 1 person 15 ft^2 of area respectively, and 1 person 300 ft^2 of area respectively).

The total number of occupants present in the model is 494 persons. This figure reflects the occupants throughout the entire building. STEPS found the evacuation time to be 2.22 for scenario 1 no use of the open stair, and 1.49 minutes for scenario 2 use of all exits and stairs. Detailed results and images can be seen in the section below.

<u>STEPS Results</u>

Using the occupant loads calculated from occupancy egress section above and inserting the appropriate people in their respective locations the model was generated. The snap shots below show how the occupants would evacuate the building.

Scenario 1

In this model there is no implemented pre-movement times and occupants were not allowed to use the open stair resulting in values close to the hand calculations based on the SFPE method where occupants are considered safe when they reach a stair enclosure.

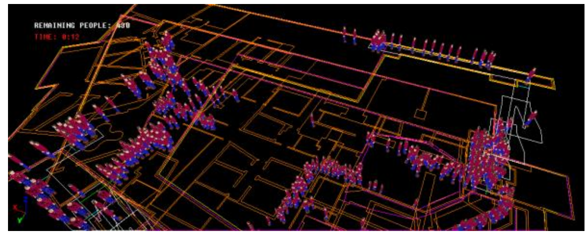


Figure 8: Scenario 1, Time 12 seconds

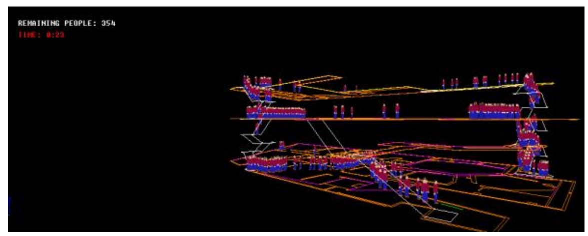


Figure 9: Scenario 1, Time 23 seconds

The following image shows a detailed view of Exit B. This shows that occupants on the first level trying to exit through the stair result in queuing.

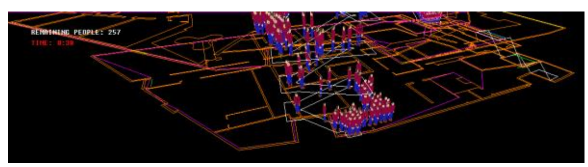


Figure 10: Scenario 1, Time 38 seconds

The figure below is a detailed view of both Exit B (closer stair) and Exit C (further stair on right). This shows queuing on the landing as well as the stair to exit to the exterior after 1 minute has passed since the start of the evacuation.

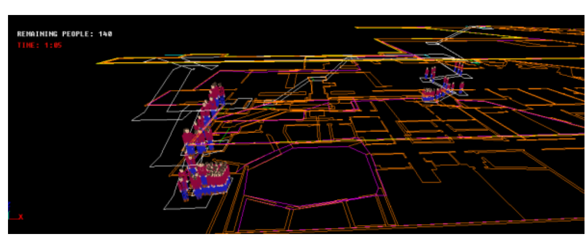


Figure 11: Scenario 1, Time 1 minute 5 seconds

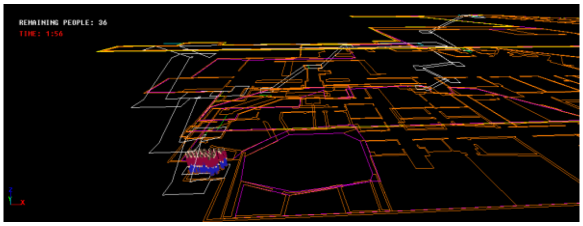


Figure 12: Scenario 1, Time 1 minute 56 seconds

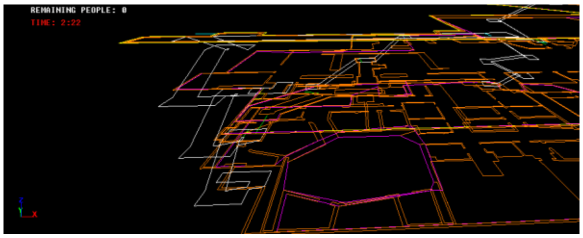


Figure 13: Scenario 1, Time 1 minutes 22 seconds

Scenario 2

In this last scenario there is no time delay associated with the total time for evacuation and occupants were free to leave from the open stair resulting in a total evacuation time of 1.49 minutes.

Figure 14: Scenario 2, Time 0 seconds with 494 Occupants in the Building

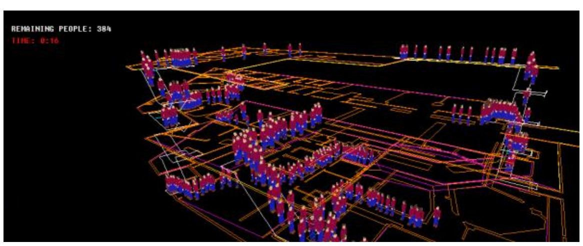


Figure 15: Scenario 2, Time 16 seconds with 384 Occupants in the Building

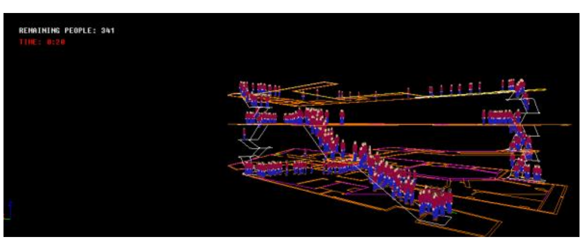


Figure 16: Scenario 2, Time 20 seconds with 341 Occupants in the Building

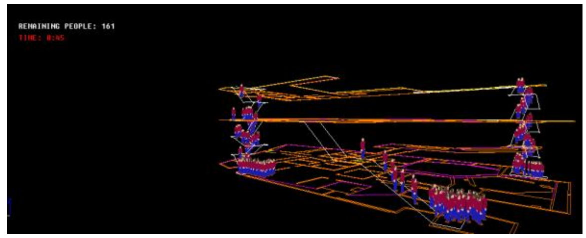


Figure 17: Scenario 2, Time 45 seconds with 161 Occupants in the Building

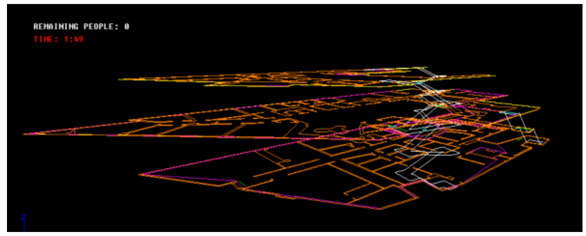


Figure 18: Scenario 2, Time 1 minute 49 seconds with NO Occupants in the Building

Table 5: STEPS Egress Results Summary

Scenario	Evacuation Time
1	2.22 minutes
2	1.49 minutes

Further analysis would incorporate appropriate time delays associated with the response of fire alarms and sprinklers that would initiate that action is require, time for occupants to react and pre-movement delays such as saving work done, shutting down computers, packing personal items, etc. Reviewing the occupant demographics for the building and incorporating multiple ages and mobility travel speeds will influence the evacuations times as well.

PERFORMANCE CRITERIA

Fire Safety Objectives

The primary focus and goal of the rational analysis is the life safety of the occupants in the building. In the design of the building, several objectives are directly or indirectly considered with regard to the fire and life safety of the system:

- Fire Prevention – to identify fire risks and to implement policies that will lead to the reduction of these risks.
- Fire Protection – to install suitable systems for the detection and suppression of fires, incorporating active and passive measures to separate smoke and fire from people.

- Fire Planning – to recommend that procedures are developed and enforced to provide for safe evacuation of people and facilitation of fire department operations.
- Fire Fighting – to provide suitable systems to assist the fire department, as well as protect the lives of emergency personnel.

Tenability Requirements

Visibility

The minimum visibility criterion chosen for occupants moderately familiar with the open office to egress safely is 6 meters. In the SFPE Handbook, Jin's work suggests that an allowable visibility for occupants unfamiliar with their surroundings is 13 m (42 feet) and for occupants familiar with their surroundings is 4 m (13 feet).

Rasbash's fire research found that the extinction coefficient of 0.2. Using a visibility coefficient of 2 allows a visibility distance of 10m (10m = 3/0.2) Research has asserted that occupants familiar with their surroundings can escape in environments where smoke density is under 0.5 m^{-1}, which corresponds to visibility to a light reflecting sign of 6 meters. Based on these limits the scale used in evaluating visibility or wayfinding ability range from 6 m and 10 m.

Carbon Monoxide Dosing

To some extent carbon monoxide is always present in fires. When carbon monoxide (CO) is inhaled there is a steady increase of carboxyhemoglobin in the blood. When exposed for an extended period of time above certain concentrations may lead to hypoxemia and tissue hypoxia.

Hadjisophocleous in "Literature Review of Performance-Based Fire Codes and Design Environment" in the Journal of FPE 9 suggests a CO tenability of 1400 ppm causing incapacitation in 30 minutes. Occupants exposed to a 1,200ppm concentration for 30 minutes (10-13% COHb production) will likely experience slight headaches (10-20% COHb) and COHb of 11-13% will have no effect on hand and foot reaction time, hand steadiness, or coordination. NFPA 101 specifies a CO limit as an integrated dose of 30,000ppm-min, resulting in a concentration of 1,500ppm for a 20 minute exposure. The tenability limit chosen for carbon monoxide is 1,400ppm.

Temperature

Heat generated by a fire can affect occupants by means of hyperthermia, body surface burns, or respiratory tract burns. The SFPE Handbook states that 60C (140F) is the highest temperature saturated air can be breathed for prolonged exposures. NFPA 101 Handbook discusses tenable conditions are met if smoke 60 inches (5 feet) above the floor is 93C (200F). At six feet above the highest walking surface these will be the lower and upper limits of the scale for evaluating the model.

FIRE DYNAMICS SIMULATOR

A computational fluid dynamics analysis of the building was conducted to assess the performance of the proposed building design. Fire Dynamics Simulator V.5.3.1 (FDS) was used for this analysis. FDS was developed and is maintained by the National Institute of Standards and Technology (NIST). In addition, calculation methods from established fire protection handbooks and other relevant methods have been considered and applied as appropriate.

Fire Growth Rate

Heat release rate characterized by a fire growth rate and can be determined by experimental fire tests on various items of fuels and combustibles. Fire growth rates are often specified as slow, medium, fast or ultra-fast, based upon on how quickly an item burns, in relation to other items. The figure below compares various standard fire growth rates.

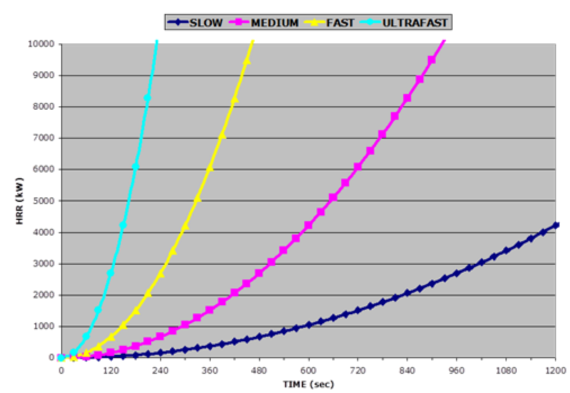


Figure 19: Typical fire growth rates

Fuel Properties and Smoke Development

The fuel package and its combustion characteristics, along with the size of the fire, determine the rate at which a fire releases combustion products including heat, soot, and carbon monoxide, among others.

For the design fire within the office, the fuel was assumed to be a 50/50 mass weighted mix of cellulosic (paper and wood) and plastic materials. The "average" fuel properties of such a mixture used in the modeling are as follows:

Heat of combustion (ΔH_c):	8500 Btu/lb (19,826 kJ/kg)
Soot or Particulate Yield (y_s):	0.10 lb/lb
CO Yield (y_{co}):	0.04 lb/lb

Model Parameters

Grid Resolution and Size: X = 0.2 m, Y = 0.2 m, Z = 0.2 m, totaling 1,166,400 million cells.

Simulation Time:	1200 seconds.
Ambient Temperature:	68°F
Ambient Pressure:	101,325 Pa

Material Properties: Solid boundaries (obstructions) other than the fire source were given material properties corresponding to *gypsum*, or *concrete*.

Table 6: Model Material Thermal Properties

Material	Specific Heat [kJ/kgK]	Conductivity [W/mK]	Density [kg/m^3]
Concrete	1.04	1.80	2280
Gypsum	1.09	0.17	930

Exit Paths: Egress doors were assumed to be closed and not contribute to make-up air, and thus were not modeled as openings.

Sprinkler Effect: (cooling, spray momentum) not explicitly modeled

Design Fire Scenario

A fire scenario represents a possible set of fire conditions that may be threatening to a building, its occupants, and/or the contents. Three design fires were considered in the evaluation of the tenability of the building during a fire event. Two were assumed to be sprinkler controlled and the other was assumed to be fuel-controlled fire involving typical workstation furniture for the office. However, only one will be discussed in this paper.

The design fires were assumed to be accidental and as such did not involve the use of accelerants. The fire scenario locations were evaluated independently and assumed to not occur simultaneously. The suppression systems and detection and notification systems are assumed to be in working condition and operate according to their design. These scenarios are justified based upon the Life Safety Code (LSC) Section 5.5.3 Scenario 1 and Scenario 8. The scenarios are described by the LSC is as follows:

- It is an occupancy-specific fire representative of a typical fire for the occupancy.
- It explicitly accounts for the following:
    - Occupant activities
    - Number and location
    - Room size
    - Furnishings and contents
    - Fuel properties and ignition sources
    - Identification of the first item ignited and its location

DF Scenario 1

The design fire was assumed to follow a medium t^2 growth rate where the heat release rate (HRR) is proportional to a coefficient multiplied by time squared. A medium growth rate fire is defined as a fire that grows to 1,000BTU/s (1,055kW) within 300 seconds which yields a growth factor α of 0.01172kW/s^2. Test data detailing fire growth rates and peak HRR For various material and fuel packages are detailed in Section 3 Chapter 1 of the SFPE Handbook.

Experimental work carried out by NIST in conjunction with the World Trade Center investigation characterized the burning of generic workstations. The NIST experiments indicated a characteristic growth rate similar to a generic medium growth rate, see the figure below. For the furniture found in an office cubicle, an overall medium growth rate fire is considered an appropriate representation.

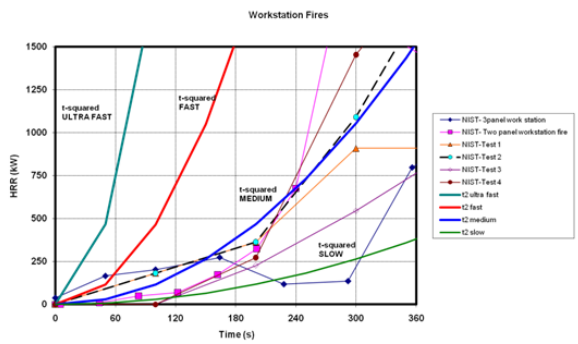


Figure 20: NIST Workstation Fire Testing Growth Rate

The building will be protected by an automatic sprinkler system, thus the design fire heat release rate is assumed to be sprinkler controlled. The plan view of the fire location as well as the modeled location can be seen in the figures below.

Figure 21: Design Fire Scenario 1 Location

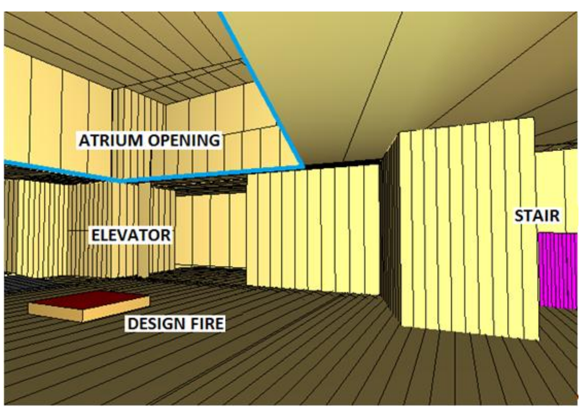


Figure 22: Model Design Fire Scenario 1 Location

The open office area is considered a light hazard occupancy in NFPA 13. The maximum designed sprinkler spacing is approximately 12 feet (3.66 meters). The time to sprinkler activation was estimated using the method developed by Beyler based on the Heskestad and Delichatsios ceiling jet correlations. It was assumed that sprinklers were of the quick-response type, rated at 165°F (74°C), with a response time index (RTI) of 50 m1/2s1/2. In the heat release rate calculation, centerline of the fire plume is assumed to be centered between four sprinklers. The ceiling height of the space is approximately 28.9 feet (8.8 meters).

At the time of sprinkler activation, it was assumed that the fire growth is halted and a constant heat release rate is maintained. The sprinkler water spray was assumed to not reduce the fire heat release rate or to extinguish the fire.

The peak design fire HRR reaches 2298kW .with sprinkler activation at 442.8 seconds, and is maintained for the duration of the simulation. The HRR output can be seen in the figure below.

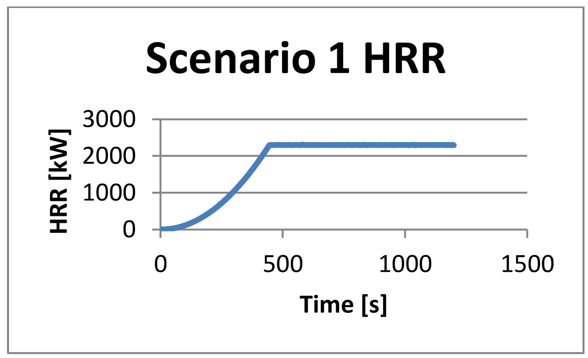
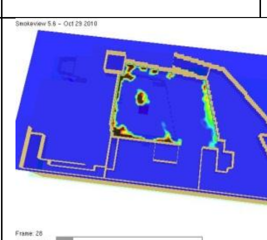
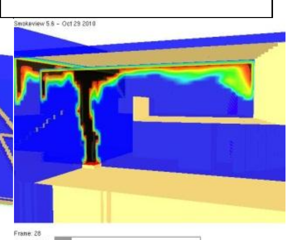


Figure 23: Design Fire Scenario 1 HRR

Fire Scenario 1 FDS Results

The tables below provide visibility and temperature information in plan view 6 feet above the walking surface of the third level and a visibility section view. The table of CO results table show slices in plan view 6 feet above the walking surface of the third and second floors. The first criterion to fail (black image coloring) is visibility on the third level.

Table 7: Design Fire 1 Visibility Results

T [s]	Visibility [m]	Visibility [m]
140		

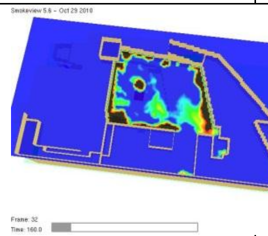
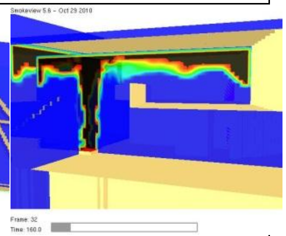
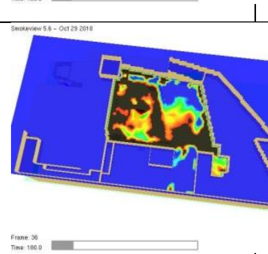
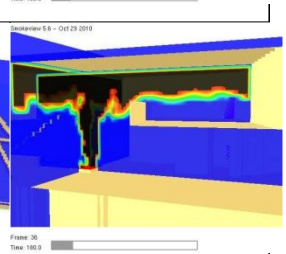
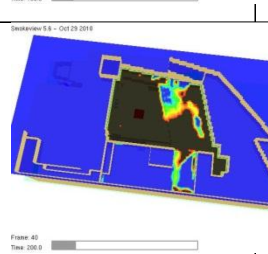
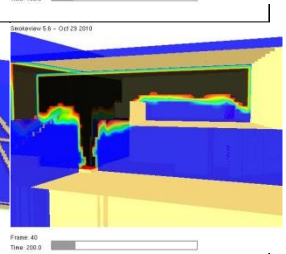
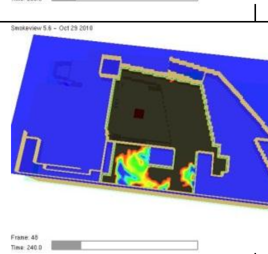
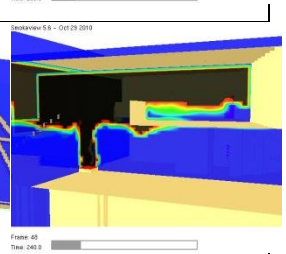
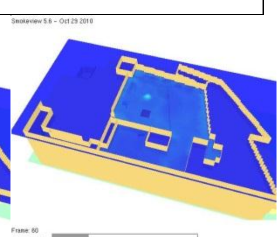
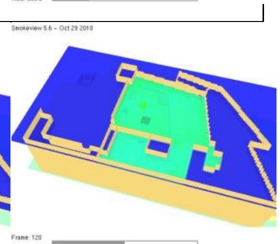
T [s]	Visibility [m]	Visibility [m]
160		
180		
200		
240		

Table 8: Design Fire 1 CO Results

Time [s]	PPM (10^6 mol/mol) Level 2	PPM (10^6 mol/mol) Level 3
300		
600		

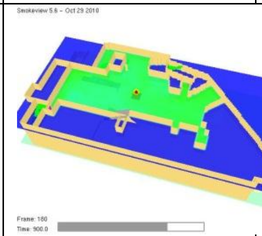
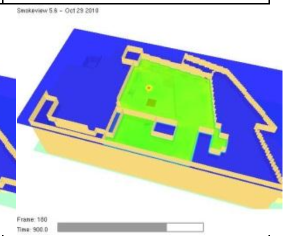
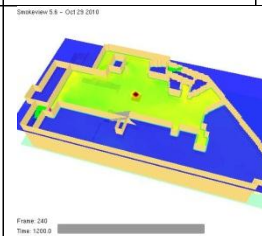
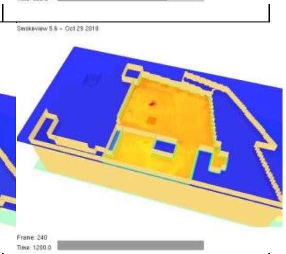
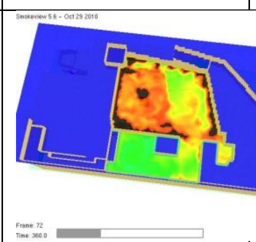
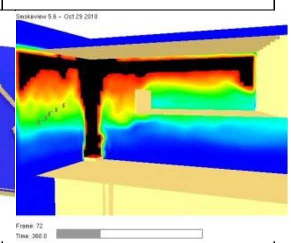
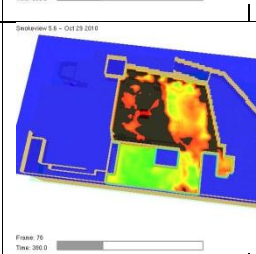
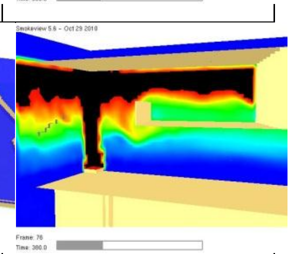
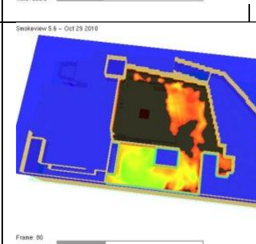
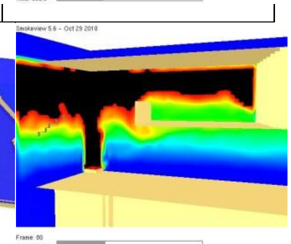
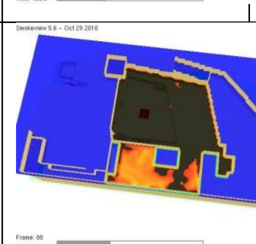
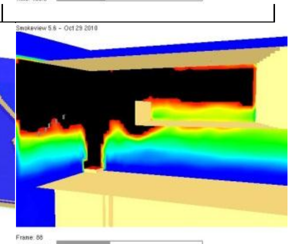
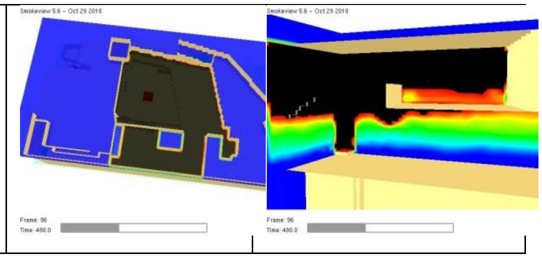
Time [s]	PPM (10^6 mol/mol) Level 2	PPM (10^6 mol/mol) Level 3
900		
1200		

Table 9: Design Fire 1 Temperature Results

T [s]	Temperature [°C]	Temperature [°C]
360		
380		
400		
440		

480



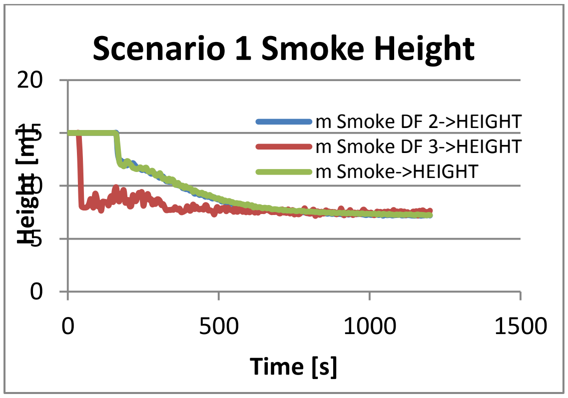


Figure 24: Design Fire 1 Smoke Height

REQUIRED SAFE EGRESS TIME (RSET)

The calculated RSET consists of many variables. These variables include time to alarm, pre-movement time, and travel time. The time to alarm is determined by the time to detect the fire and initiate an alarm. The pre-movement time consists of the time to recognize the notification as an alarm and the occupants' response time. The occupant's response time may include shutting down computers, gathering their belongings, notifying other building occupants, etc. The travel time of the occupants is based on the width of egress components and the occupant's walking speed. The RSET is the sum of the time for the all of these factors to subsequently occur as seen in the Figure below (SFPE Handbook Figure 3-12.1 Egress time model)

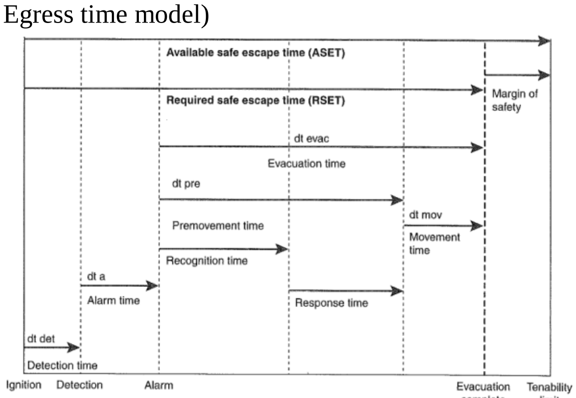


Figure 25: ASET and RSET Components.

AVAILABLE SAFE EGRESS TIME (ASET)

The ASET was determined by results from the design fire scenarios implemented in FDS. FDS was used as a tool to provide information about a fire scenario and not exact solutions or results. The criteria used for the ASET tenability limitation were visibility, temperature, and CO production.

Table 10: ASET Component Summary

Criteria Limit	Scenario 1 [s]	Scenario 2 [s]	Scenario 3 [s]
Visibility – 6m	180	240	340
Temp – 60°C	360	660	580
CO –1,400 ppm	1200	1200	1200

RSET VS. ASET

Design Fire 1

The fire specified for Design Scenario 1 is a medium t-squared fire consuming multiple workstations under the atrium opening. The detection time calculated for a detector to activate was over two minutes for a medium growth fire. This is considered high for a normally occupied space and was assumed that Level 2 occupants would sound the alarm via pull station within 45 seconds. The pre-movement time chosen is one minute as discussed by Proulx referenced earlier. The egress times are based on the hand calculations found in the STEPS results section.

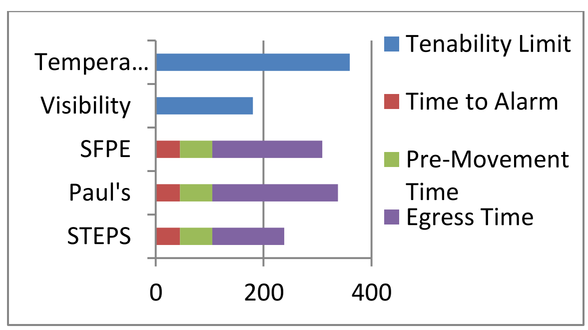


Figure 26: Design Fire 1 ASET vs. RSET Total Evacuation

These results show that for this fire scenario tenable conditions are not maintained for a sufficient time to allow all occupants to safely egress for total evacuation. Additional analysis was conducted to determine if phased evacuation, level by level analysis, would be a viable egress strategy based on the configuration of the space and loading of the building.

-

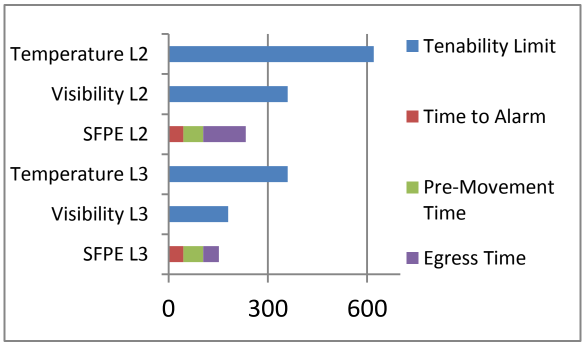


Figure 27: Design Fire 1 ASET vs. RSET Phased Evacuation

PERFROMANCE RECOMMENDATIONS

For Performance Based Analysis to Comply

There are limited applications that can be applied to assist the current fire protection systems. There is no application that can completely eradicate the risk of life safety and other damages related to a fire event, but there are prospects to diminish the risk. There are four recommendations that will be discussed but there are other feasible options that will not be addressed.

Phased Evacuation

As discussed in the ASET vs. RSET sections above, utilizing a phased evacuation strategy would allow appropriate time for occupants to safely egress the building in tenable conditions. Voice notification is to be used in the design required by the campus codes and various commands can prompt the appropriate level(s) to evacuate.

Enclosing the Open Stair

By enclosing the open stair, the stair would be permitted to be used for egress. Having an additional egress stair will allow the evacuation times to be reduced and possibly. A modification may be submitted to only require fire rated doors with hold opening hardware at the top of the stairs because the current adjacent walls are currently rated. The exterior wall is 1 hour rated due to separation distance from the property line and the elevator hoistway is on the opposite side. Further analysis would be required to understand if this option is viable.

Smoke Control

Through various code exceptions the building does not prescribe a smoke control system. When analyzing the results of a fire event and the rapid loss of tenability, it is strongly recommended and encouraged that the College Campus installs a mechanical smoke control system.

The benefit of incorporating a smoke control system will increase the time available for occupants to safely egress the building. This is done by extracting the smoke at high levels, removing the hazardous smoke, and reducing the rate of smoke dissension. Additional analysis will be required to determine how much exhaust would be required to maintain tenable conditions.

Reduce Fuel Load

The current floor plan of the building shows many workstations below the opening of the atrium. The large fuel load of this area coupled with the elevation to the ceiling causes the reduced detection time and an increased notification time. It is recommended that either the fuel load of this area be reduced (less workstations spaced farther apart) or the materials of the workstation be further considered and more appropriate material property data be obtained (have a reduced soot yield and CO yield).

SUMMARY

Prescriptively, the atrium in this building is compliant by the regulating codes. However, performance based analysis shows that the current design will not permit occupants to egress in tenable conditions without modifications to the building, evacuation methods, or controlled furnishings as mentioned in the section above.

Possible modification to the performance based design:

- Tenability criteria values
- Elevation which tenability criteria are to be maintained.

This disconnect between acceptable designs allows for freedom for the design engineer. The SFPE Handbook Performance Based Design chapter states it well, prescriptive based design is intended to have a “safe” building, where “safe” is not defined. Performance based design is intended to show how a building will perform during a fire.

As a fire protection engineer it is important be aware of the difference and to notify clients and architects of the potential risks associated to these types of design decisions.

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