Fire & Life Safety Analysis

Orfalea College of Business

Cal Poly State University
1 Grand Avenue, San Luis Obispo, CA 93407

Prepared By: Napoleon E. Nino
Fire Protection Engineering Department
California Polytechnic State University
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Keywords: California Building Code (CBC), RSET, Performance Based Design, Pyrosim, ASET

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Abstract

This report details the prescriptive and performance based analyses performed on the Orfalea College of Business building, located on the Cal Poly San Luis Obispo campus. Designed in accordance with the 1985 Uniform Building Code (UBC), this building is evaluated for compliance with the requirements prescribed under relevant codes in place as of 2016. The main function of this building is to serve both academic and administrative purposes, including classrooms and staff offices.

Aspects of the building analyzed include:

- Egress Systems
- Structural Fire Protection
- Smoke Management
- Fire Detection
- Fire Notification
- Fire Suppression

The prescriptive analysis demonstrates the lack of compliance in two general areas: egress systems and passive fire protection. Obstructions in corridors will impede egress travel, while propped open doors compromise the designed passive fire protection. The rest of the building features were deemed compliant based on the 2013 CBC.

A performance based analysis was performed on the building using tenability criteria justified by relevant scientific research. Thresholds for visibility, temperature, and toxicity were considered in determining the Available Safe Egress Time (ASET). This analysis intended to evaluate the building based on Method 2 found in the 2015 Life Safety Code (LSC), where ASET must be greater than the Required Safe Egress Time (RSET). The results of the analysis revealed that both temperature and toxicity were not a concern for a fire scenario in what is deemed one of the most potentially hazardous areas in the building. Visibility, however, would drop below its minimum threshold at 300 seconds after fire ignition. The RSET was determined using justified pre-movement times and calculated egress times. The RSET proved to be 444 seconds, which is more than 2 minutes greater than the ASET. Thus, the performance criterion is not met.

The building will maintain an acceptable level of protection if obstructions are removed from paths of egress and all fire and smoke doors are maintained in their proper position. The installation of sprinklers would greatly reduce the impact of a hazardous scenario, as it is nearly impossible to ensure that all doors required to be closed are closed due to the nature of the building.

Scope of Report

The intent of this report is to provide a full fire and life safety analysis, entailing both detailed prescriptive and performance based analyses, on the Orfalea College of Business building. The features analyzed include egress, structural fire protection, fire detection, fire suppression, fire notification, smoke management, and tenability under a designed fire scenario. Results of the analyses and recommendations for the maintenance of an acceptable degree of life safety will be provided in the conclusion of this report.

Applicable codes, standards, and handbooks are as follows:

- California Building Code (CBC), 2013 Edition
- California Fire Code (CFC), 2013 Edition
- Life Safety Code (LSC) 2015
- NFPA 72, National Fire Alarm and Signaling Code, 2016
- NFPA 13, Automatic Sprinkler System Handbook, 2013
- Fire Protection Handbook, Twentieth Edition, NFPA
- SFPE Handbook of Fire Protection Engineering, Fifth Edition, SFPE

General Building Description

Found on the west side of the California Polytechnic University campus in San Luis Obispo, California, the Orfalea College of Business building was originally conceived to house the University's pre-existing College of Business. Refer to Figures 1, 2, and 3 for graphic representations of the structure.

Figure 1. Scenic View of the Orfalea College of Business.

The building is named after Paul Orfalea, founder of FedEx Office which was formerly known as Kinko's, who donated $15 million to the College of Business [1]. This building will be alternatively referred to as the Business Building for the remainder of this report. Designed in 1989 under the 1985 Uniform Building Code (UBC), construction of the building was completed in 1992, and subsequently opened the same year.

Figure 2. Business Building Location on Campus Map.

This 75,975 ft^2 building has four stories with the top of structure reaching 69.5 ft. Although the structure was built on a slope, all four level are above grade. The building is believed to be a nonseparated, mixed occupancy building, containing predominantly Business (B) and Assembly (A-3) occupancies with minor accessory occupancies. The total occupant load is calculated to be around 1400 occupants. Floor plans emphasizing different aspects of the egress system in the building can be found in Appendix A.

The full extent of the exterior of the Business Building can be seen in Figure 3. Adjacent to the building are two structures: a silo and the Cotchette Education Building.

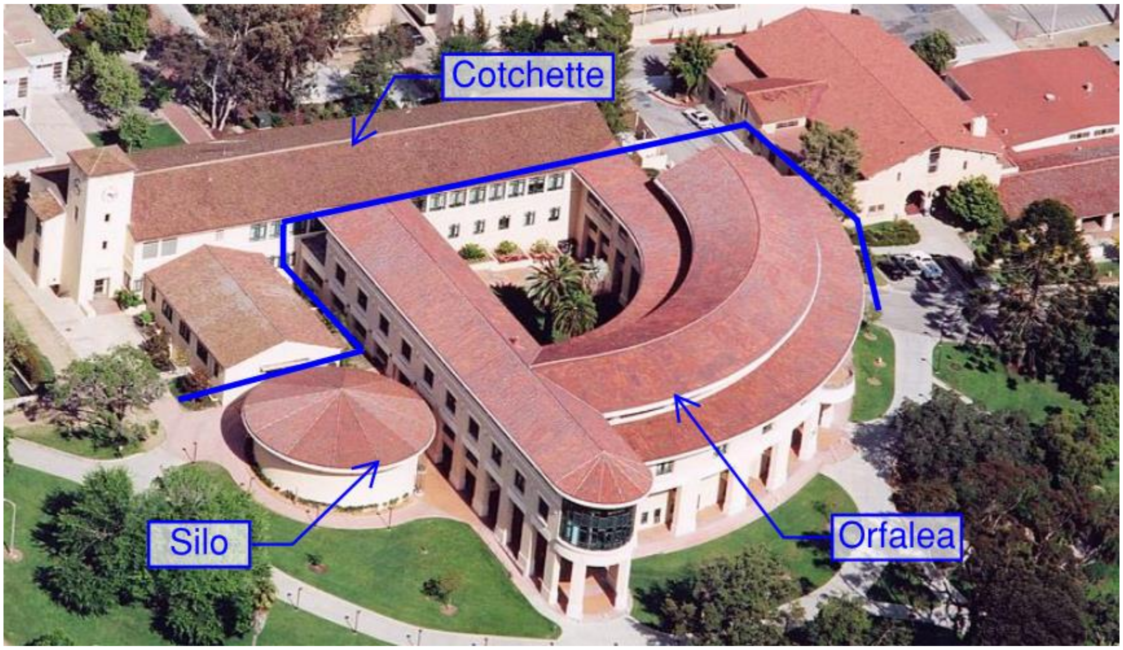

Figure 3. Orfalea College of Business, Silo, and Cotchette Education Buildings.

The building serves both academic and administrative purposes. In general, the bottom two floors serve academic purposes, with most of the occupiable space being used for classrooms and lecture halls. On the third floor, computer labs, study rooms, student and teacher lounges, and offices are found. Staff offices occupy much of the fourth floor.

An exterior courtyard is in the center of the building, as seen in Figure 4, and has large-tread stairs adjacent to both sides of the courtyard.

Figure 4. Courtyard.

Coming from both the west and south sides of the building, the stairs both lead into the Cotchette Education building. These stairs are represented in Figures 5, 6, and 7. The bottom of the stair traversing the east-west direction is located at the point of entrance into the first floor of the Business Building, and is considered a split-level entrance into the Cotchette Education building.

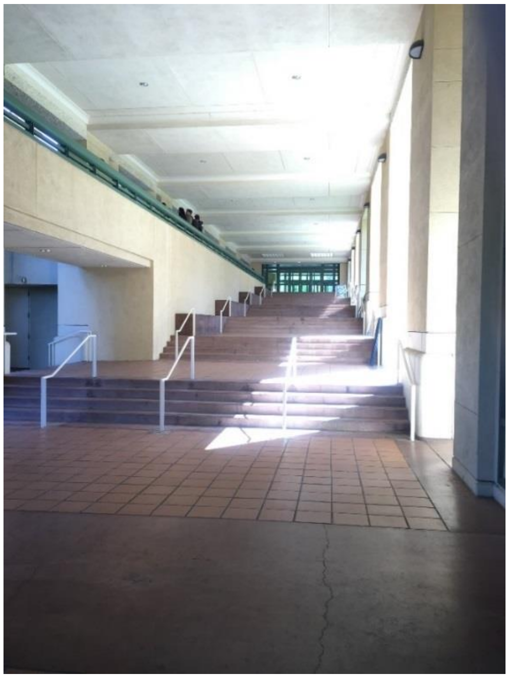

Figure 5. Split-level Entrance

Figure 6. Entrance into Cotchette Education Building.

Figure 7. Stairs Adjacent to Courtyard

Along with the split-level entrance into the Cotchette Education building, there is an open-air pathway that runs from the second floor of the Business Building to both the entrance of the Education Building and the entrance to the silo, as seen in Figure 8. In Figure 8, the location of the crowd indicates the opening of the pathway to the entrance of the silo.

Figure 8. Open-Air Pathway to Silo and Education Building.

The silo, considered in the scope of this report, is a standalone two-level lecture hall on the same lot as the Business Building. With around 230 fixed seats, the silo is a cylindrical tower typically used for academic lectures. Interior and exterior views of the silo can be seen in Figures 9 and 10.

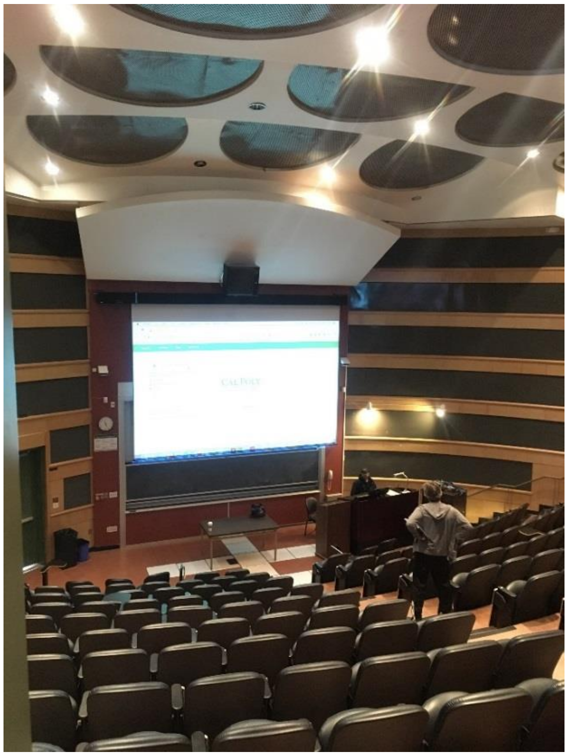

Figure 9. Inside View of Silo.

Figure 10. Entrance View of Silo

The Cotchette Education building, located on the east side of the Business Building, is not in the scope of this report. It is important to note, however, that the Education building has horizontal exits that lead into the Business building, and vice versa.

The remainder of this report will be dedicated to both prescriptive and performance based analyses performed on the Orfalea College of Business building, using the 2013 edition of the California Building Code (CBC) and related NFPA and International Code Council (ICC) Codes. As stated in the Scope of Report, the prescriptive analysis will entail an evaluation of the fire notification, suppression, detection, smoke management, and egress systems. The performance based analysis will use performance criteria found in the 2015 edition of the Life Safety Code (LSC) and evaluate a possible fire scenario. Subsequently, the determined required safe egress time (RSET) will be compared to the determined available safe egress time (ASET).

Prescriptive Analysis

Egress System

The analysis performed on the egress system is separated into various important aspects regarding occupant egress. Characteristics of the egress system addressed include occupancy classification, means of egress, occupant load, exit capacity, exit arrangement, and exit signage.

Occupancy Classification

To familiarize the reader of this report with the layout of each floor, the building floor plan has been provided below in Figures 11-14. The occupancy classifications are emphasized on these floor plans.

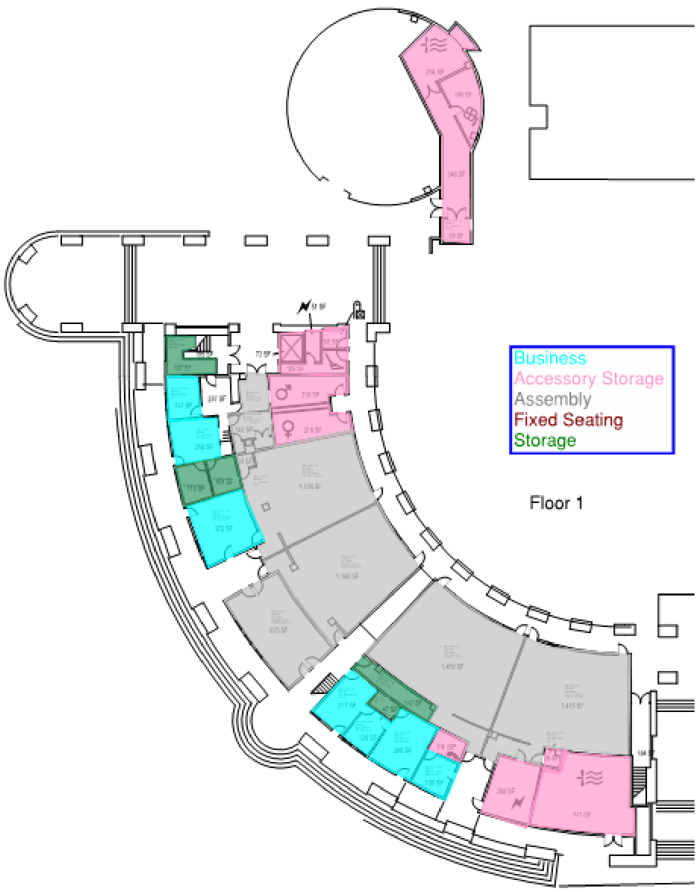

Figure 11. First Floor Classified by Occupancy

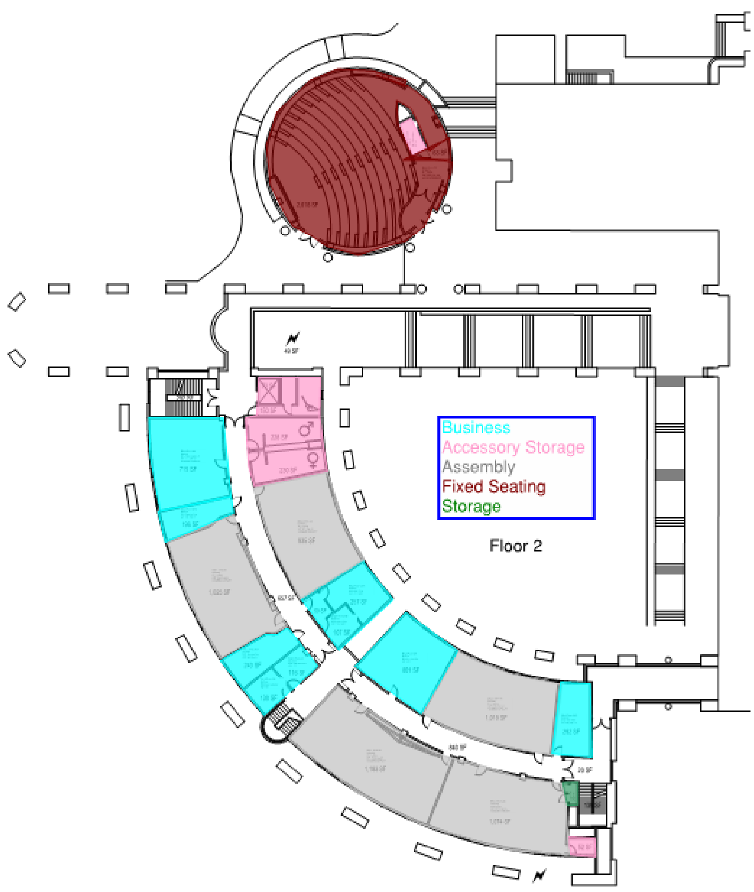

Figure 12. Second Floor Classified by Occupancy

The first two floors, seen in Figures 11 and 12, are generally comprised of rooms considered lecture halls and are categorized as Assembly Group A-3 under CBC Section 303.4. Business Group B (CBC Section 304), Storage Group S-2 (CBC Section 311.3), and Accessory (CBC Section 508.2) are found on the floors as well.

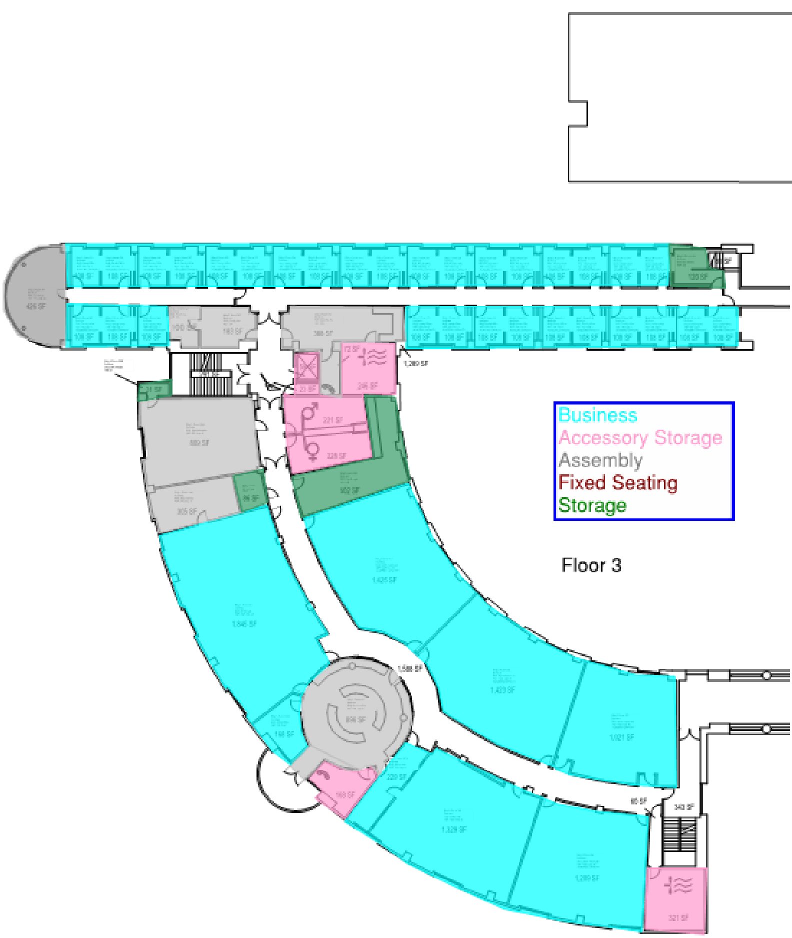

Figure 13. Third Floor Classified by Occupancy Type

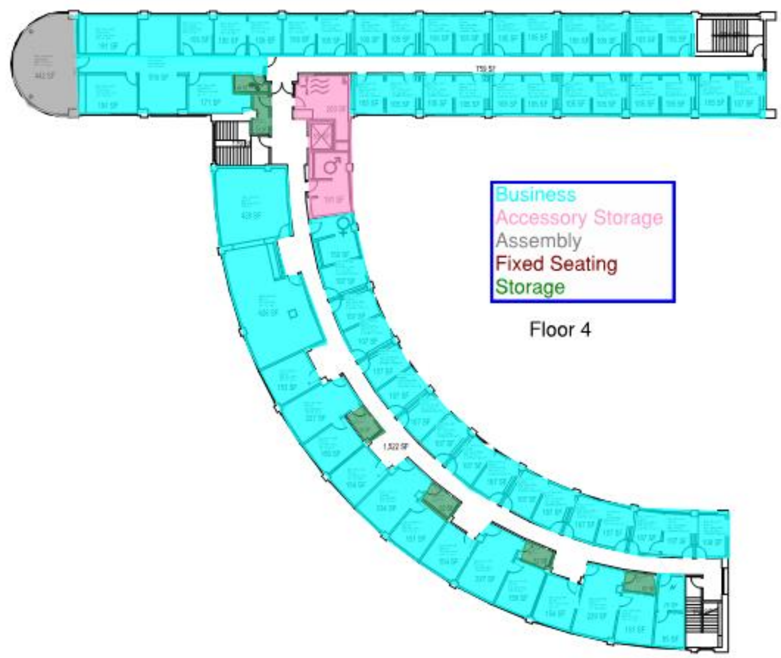

Figure 14 . Fourth Floor Classified by Occupancy Type

The third and fourth floors, seen in Figures 13 and 14, comprise of rooms generally classified as Group B, such as computer labs and staff offices. Although a classification for Educational Occupancies exists (Group E), classrooms in this building not considered lecture halls are classified as Group B per CBC Section 304.1, which states that Educational occupancies for students above the 12^{th} grade are classified as Group B.

The spaces considered accessory occupancies encompass less than 10% of the total area per floor, which is in accordance with CBC Section 508.2.1. The accessory occupancies in this building encompass less than 10% of the total area per floor, and thus fire resistance rated separation is not required between these accessory occupancies and adjacent rooms. Because this building is considered a nonseparated occupancy, the most restrictive requirements regarding the fire protection features found in Chapter 9 of the CBC should be implemented. The most restrictive occupancy classification in the Business Building is the Group A-3 Occupancy, and therefore the fire protection features should be designed for the whole building as if the entirety of the building is a Group A-3 occupancy. The related fire protection requirements will be discussed in later sections of this report.

Means of Egress

A means of egress is defined by the CBC as *continuous and unobstructed path of vertical and horizontal egress travel from any occupied portion of a building or structure to a public way.* In the Business Building, the means of egress includes both vertical and horizontal egress travel. Three enclosed stairs exist, two of which extend from the first floor to the fourth floor. One of these enclosed stairs can be seen in Figure 15.

Figure 15. Enclosed Stair.

The other enclosed stair extends from the third floor to the fourth floor, and leads egressing occupants from the fourth floor into an enclosed horizontal exit on the third floor, which leads to the Cotchette Education Building.

An open stairway also exists, extending from the first to the second floor. This open stairway, seen in Figure 16, is accessed by egressing through a fire rated door that leads to a corridor which is open to the environment. It is important to note that this stair is unenclosed, and thus the stairway does not directly provide occupant fire protection. The protection is provided by the separation of the open stairway from the rest of the building by the fire rated doors.

Figure 16. Open Stair.

An open-air corridor, seen previously in Figure 8, extends from the west entrance of the Business Building to the silo and Education Building. This open-air corridor can be used as a horizontal means of egress for people escaping fire from the second floor.

Multiple horizontal exits exist connecting the Business Building to the Education Building. However, only one of these horizontal exits are meant to be used as a means of egress for occupants attempting to escape from the Business Building. The rest are used for egress starting from the Education Building to the Business Building.

The Silo has two double-door exits that discharge into pathways that lead to the public way. Please see Figures 17, 18, 19, and 20 for the locations of the means of egress.

Occupant Load

To properly analyze the means of egress and their ability to adequately serve the building at full capacity, the occupant load must be known. To calculate the occupant load, the area of each occupancy type must be divided by their respective occupant load factors (OLF). The OLF for each occupancy type is found in CBC Table 1004.1.2 and is the basis for the sizing of the egress system.

Table 1. Areas per Floor Categorized by Occupancy Type.

Occupancy	OLF (ft²/person)	Area (ft²)				
		Floor 1	Floor 2	Floor 3	Floor 4	Total
Business	100.0	1524.0	2424.0	12213.0	8920.0	25081.0
Storage	500.0	331.0	20.0	708.0	307.0	1366.0
Accesory	300.0	2669.0	844.0	1152.0	600.0	5265.0
Assembly	15.0	6143.0	5235.0	3109.0	442.0	14929.0
Fixed Seating	# of fixed seats	0.0	2616.0	0.0	0.0	2616.0
Total	-	10667.0	11139.0	17182.0	10269.0	49257.0

The area of each occupancy type on each floor is tabulated in Table 1, along with the OLF for each occupancy classification.

$$Occupant\ Load\ (persons) = \frac{Area\ (ft^2)}{OLF\ (\frac{ft^2}{persons})}$$

Table 2 reveals the occupant load for each floor, as well as the total occupant load for each occupancy. To be conservative, the occupant load for each floor is rounded up.

Table 2. Occupant Load Analysis.

Occupant Load (Persons)						Occupancy
Floor 1	Floor 2	Floor 3	Floor 4	Total	Total (Rounded)	
15.2	24.2	122.1	89.2	250.8	251.0	Business
0.7	0.0	1.4	0.6	2.7	3.0	Storage
8.9	2.8	3.8	2.0	17.6	18.0	Accesory
409.5	349.0	207.3	29.5	995.3	996.0	Assembly
0.0	230.0	0.0	0.0	230.0	230.0	Fixed Seating
434.3	606.1	334.7	121.3	1496.4	1498.0	Total
435.0	607.0	335.0	122.0		Floor Total (Rounded)	

Exit Capacity

Exit capacity is the number of occupants that can egress through a specific exit component. The exit capacity of each floor is based on both the floor's door and stair widths. The CBC ascribes specific exit capacity factors to both stairs (0.3 inch per occupant) and doors (0.2 inch per occupant). Although an automatic sprinkler system is not present in this building, it is important to note that if a sprinkler system were installed, the capacity factors would be reduced allowing a larger occupant load. The total exit capacity is not a sum of the individual exit capacities for each door and stair. It is the sum of the limiting exit components for each means of egress. For example, take 6' double doors that lead into a 5' stairway. The double doors would have an exit capacity of 360 occupants and the stairway would have an exit capacity of 200 occupants. The total exit capacity for this means of egress is 200 occupants, as the stairway is the limiting component.

Table 3. Exit Capacity per Floor.

	Floor 1	Floor 2	Floor 3	Floor 4	Silo
Exit Component Width (in)	720.0	153.0	166.0	108.0	144.0
Required Exit Width (in)	87.0	113.1	100.5	36.6	46.0
Calculated Exit Capacity (Persons)	3600.0	550.0	580.0	540.0	720.0

As seen in Table 3, the limiting exit component widths are greater than the required exit widths which are based on the occupant load. Figures 17-20 are floor plans with the means of egress identified and the exit components used to calculate the exit capacity boxed in blue.

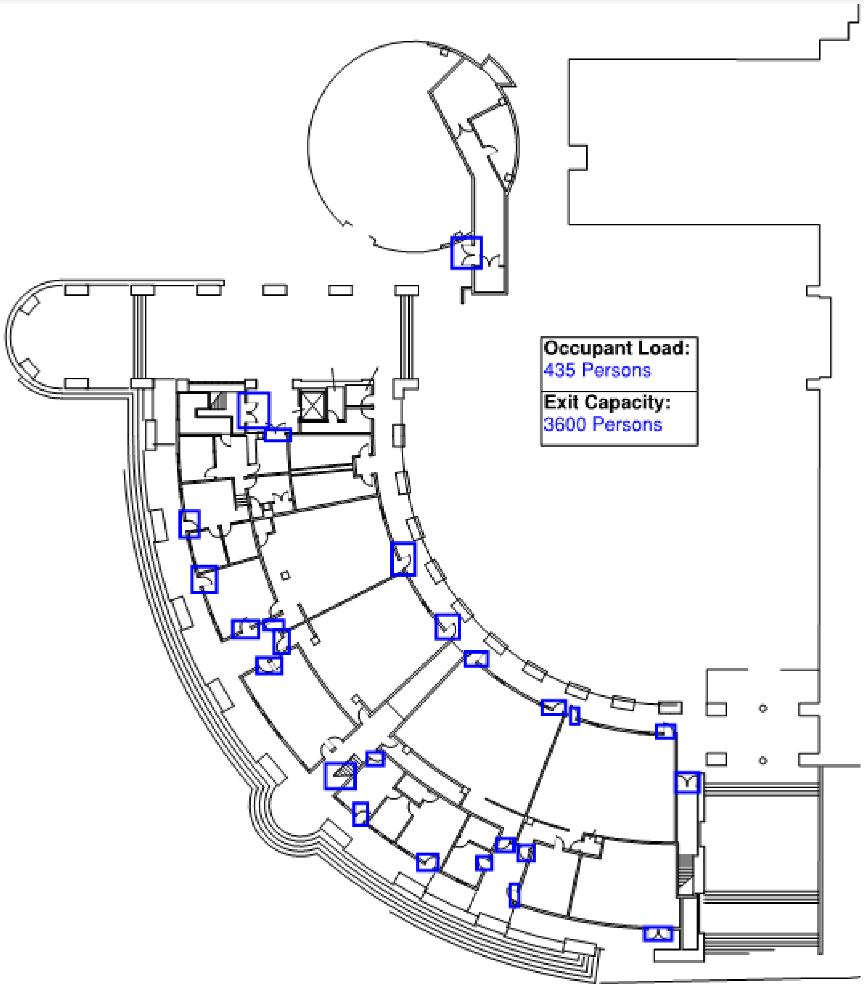

Figure 17. First Floor Exit Capacity.

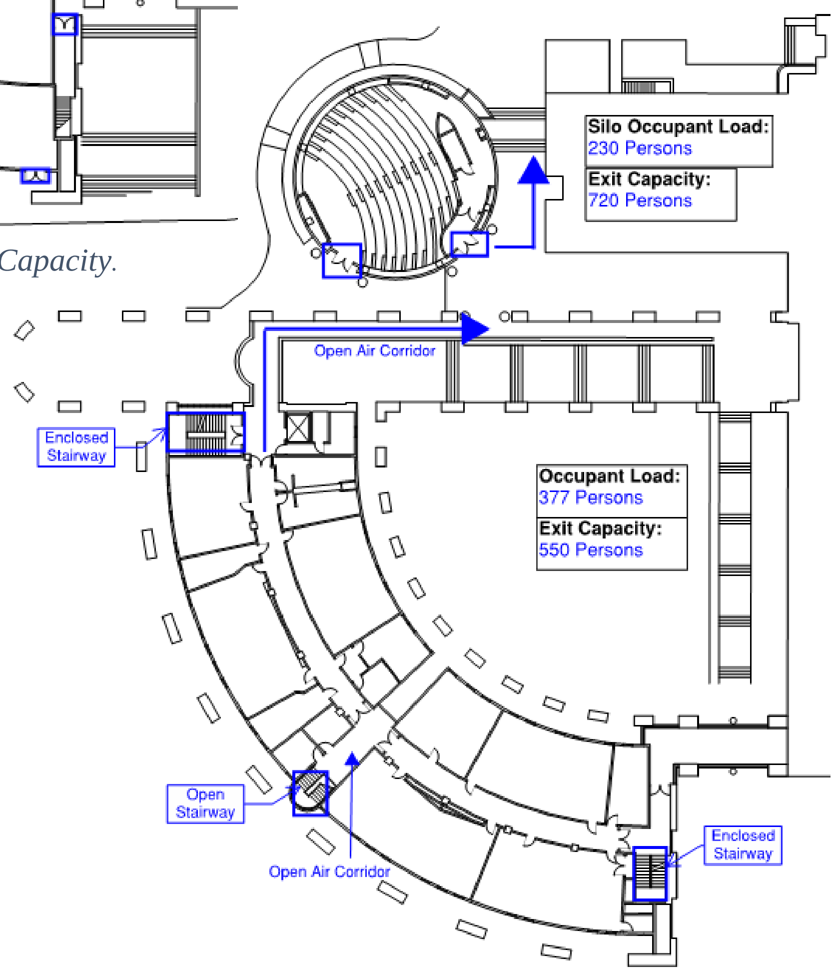

Figure 18. Second Floor Exit Capacity.

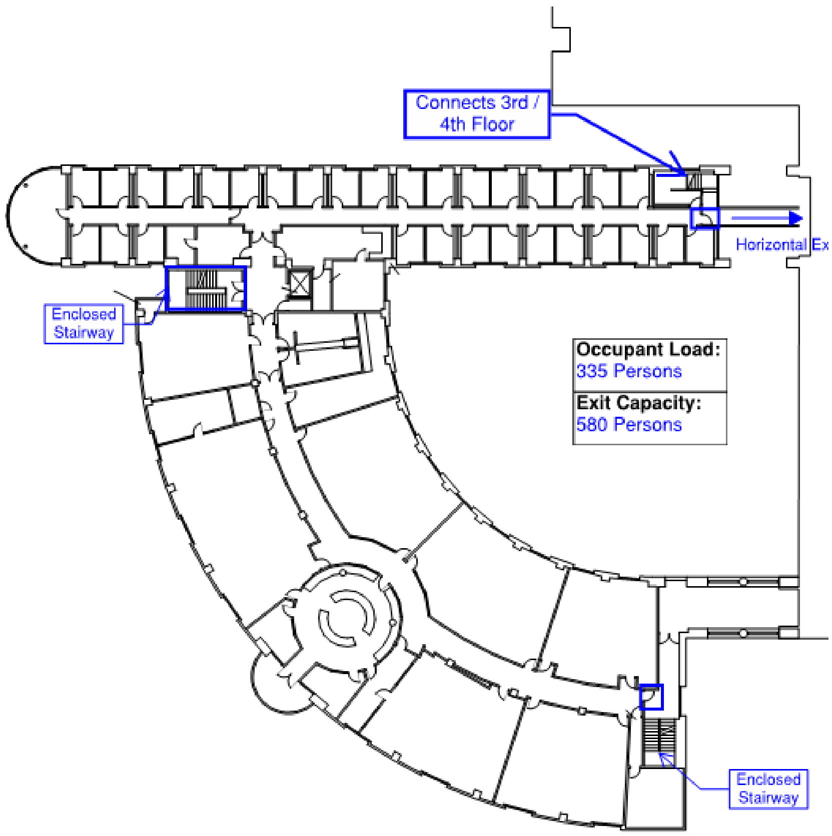

Figure 19. Third Floor Exit Capacity.

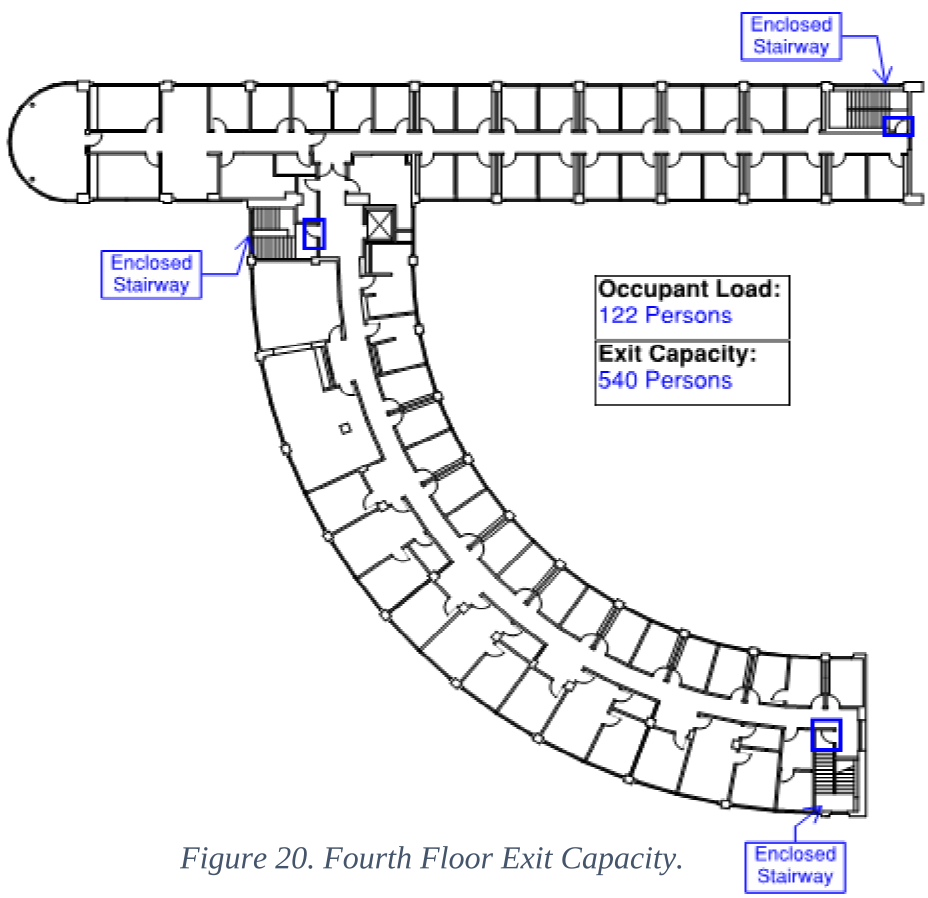

Figure 20. Fourth Floor Exit Capacity.

The means of egress and exit capacity in this building are sufficient for the occupant load. The arrangement of the exits are also important aspects of the egress system that must be considered.

Exit Arrangement

Exit remoteness, travel distance, common path of travel distance, number of exits, and path of egress width are analyzed in this section.

CBC Sections 1051.2.1 and 1051.2.2 require exits on each floor to be not less than one-half the length of the maximum overall diagonal dimension of the building or area to be served.

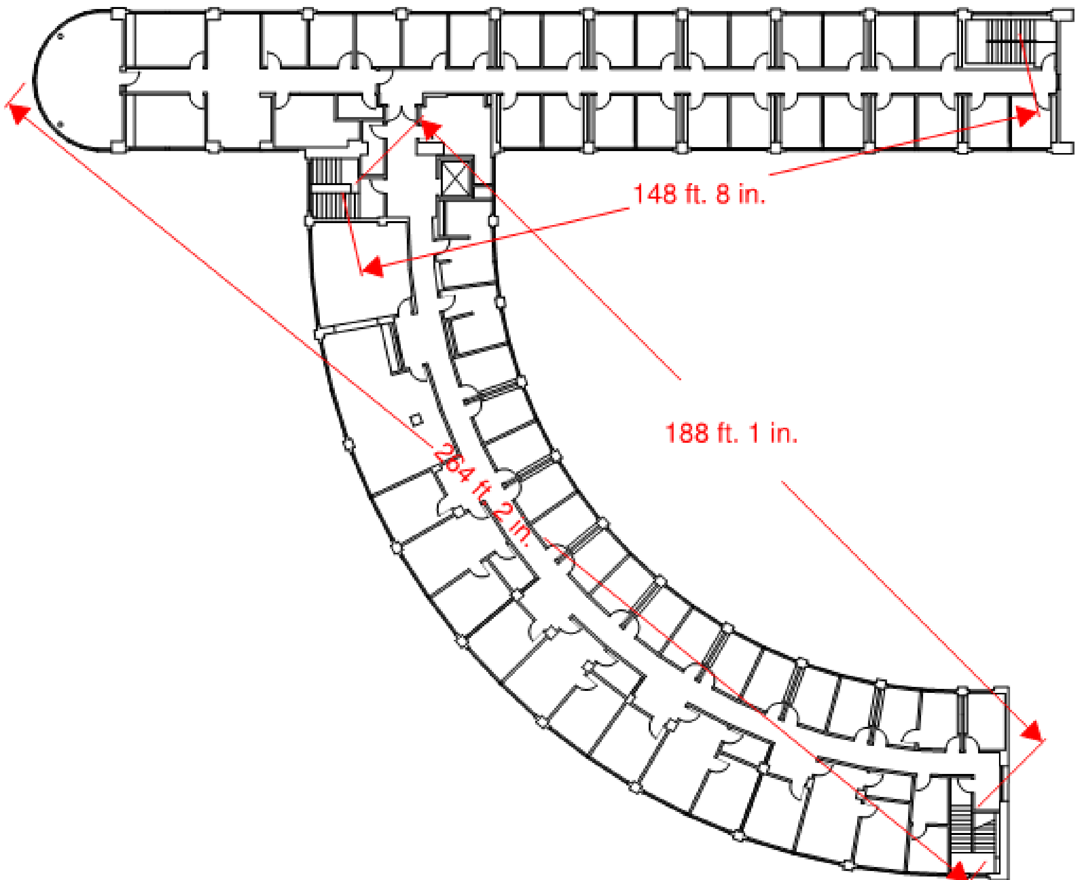

Figure 21. Exit Remoteness.

Figures 21 demonstrates that the remoteness of the exits are sufficient for the arrangement.

CBC Sections 1015.1 and 1015.1.1 require two exits from any space with more than 50 occupants, and three when the occupant load exceeds 500. All spaces of the building meet these requirements.

Tables 1014.3 and 1016.2 of the CBC, seen as Tables 4 and 5, exhibit the maximum requirements for both the distance an occupant must travel to reach an exit (Exit Access Travel

Distance) and the distance an occupant must travel before reaching a point where two separate and distinct paths of egress travel to two exits are available (Common Path of Egress Travel).

Table 4. Exit Access Travel.

OCCUPANCY	WITHOUT SPRINKLER SYSTEM (feet)	WITH SPRINKLER SYSTEM (feet)
A, E, F-1, M, R, S-1	200	250^{b}
R-2.1	Not Permitted	250^{c}
B	200	300^{c}
F-2, S-2, U	300	400^{c}
H-1	Not Permitted	75^{c}
H-2	Not Permitted	100^{c}
H-3	Not Permitted	150^{c}
H-4	Not Permitted	175^{c}
H-5	Not Permitted	200^{c}
I-2, *I-2.1*, I-3[d], I-4	Not Permitted	200^{c}
L	*Not Permitted*	200^{c}

Table 5. Common Path of Egress.

OCCUPANCY	WITHOUT SPRINKLER SYSTEM (feet) Occupant Load ≤ 30	WITHOUT SPRINKLER SYSTEM (feet) Occupant Load > 30	WITH SPRINKLER SYSTEM (feet)
B, S[d]	100	75	100^{a}
U	100	75	75^{a}
F	75	75	100^{a}
H-1, H-2, H-3	Not Permitted	Not Permitted	2^{a}
R-2	75	75	125^{b}
R-3[e]	75	75	125^{b}
I-3	100	100	100^{a}
All others[c, f]	75	75	75^{a}

Figures 22 and 23 demonstrate that the most remote areas of the building meet both distance requirements.

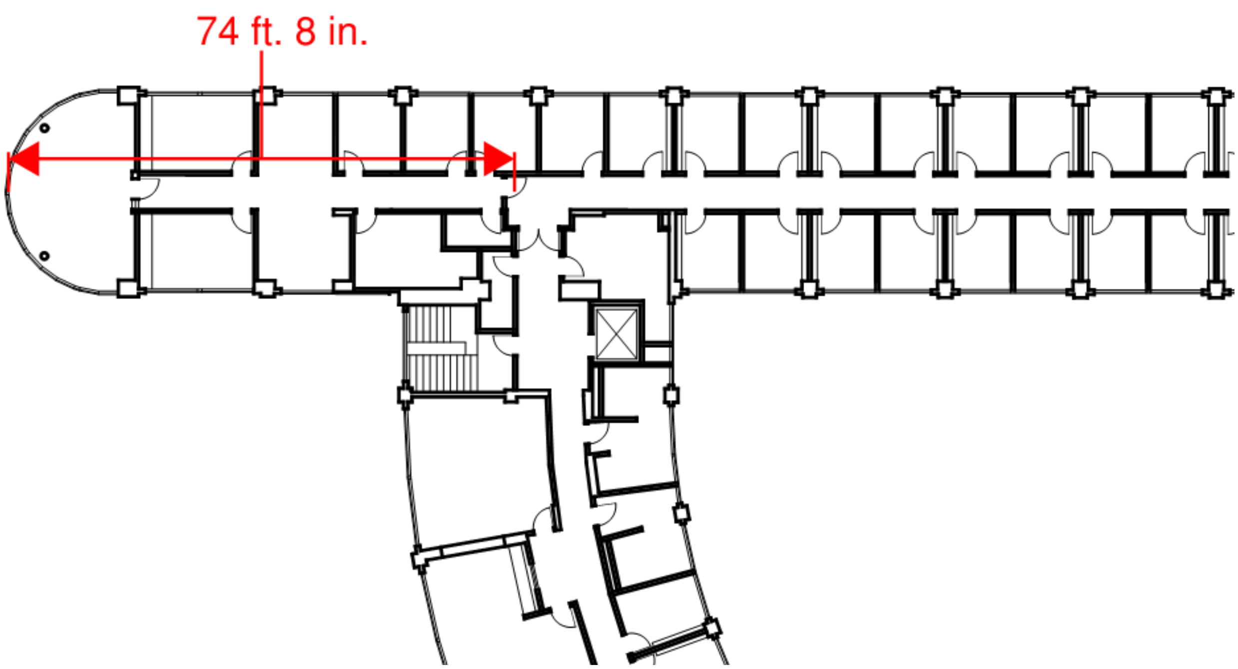

Figure 22. Level 3 - Most Demanding Common Path of Egress Travel.

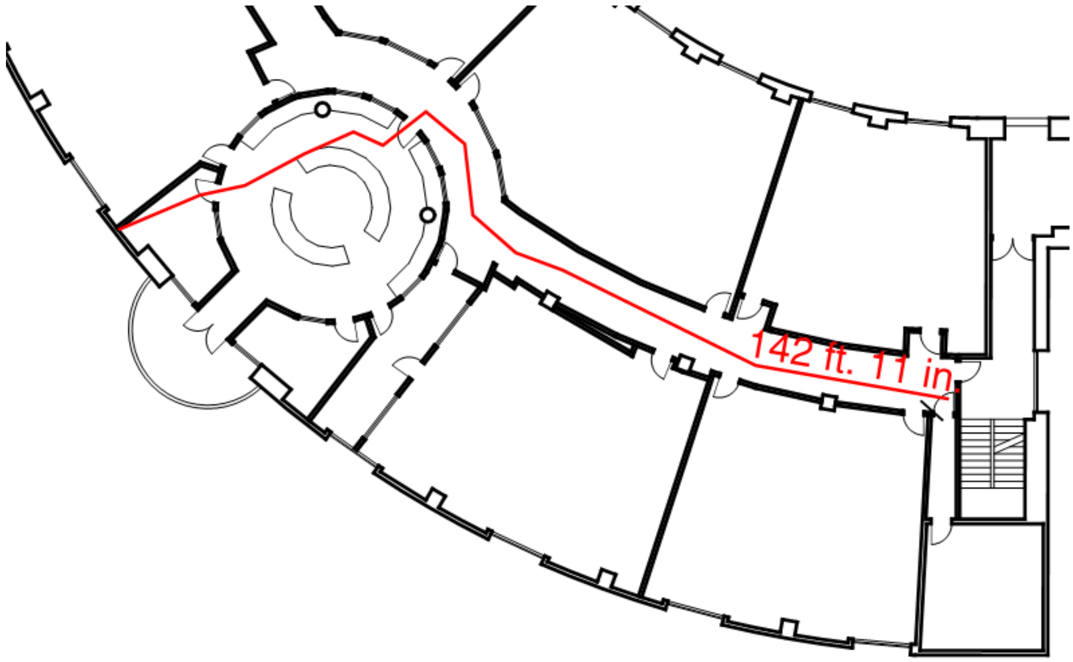

Figure 23. Level 3 - Most Demanding Exit Access Travel Distance.

Corridors are required to be at least 44" wide per CBC Section 1018.2. As seen in Figure 24, the corridors of the building comply with this requirement.

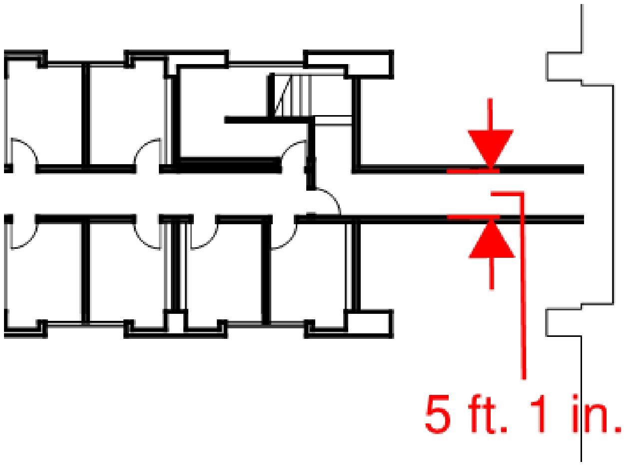

Figure 24. Most Restrictive Corridor Width.

The requirements for exit signs were compared to the existing condition. Per CBC Section 1011.1, exit signs are required at all exits and exit access doors, and shall be placed such that no point in an exit access corridor or exit passageway is more than 100 feet from the nearest visible exit sign.

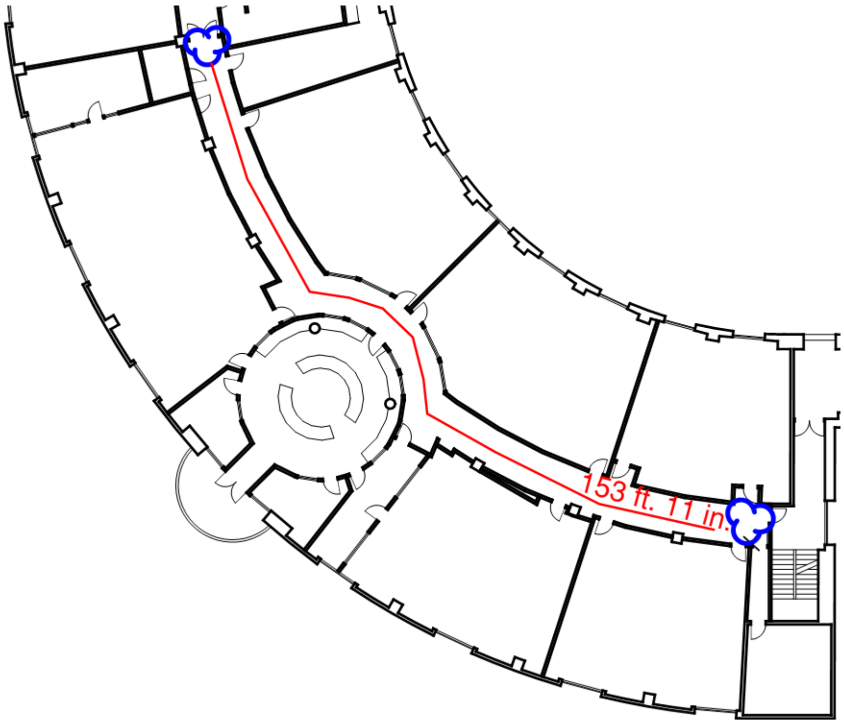

Figure 25. Exit Signage Distance.

In Figure 25, exit signs are indicated as blue clouds. As seen, the distance between the two exit signs exceeds the requirement put forth in the CBC.

Along with violations regarding placement distance, exit signs were found throughout the building without illumination, as seen in Figures 26 and 27.

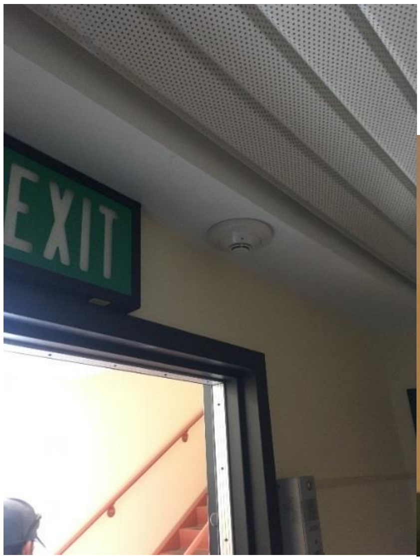

Figure 26. Darkened Exit Sign in Front of Stairway.

Figure 27. Exit Sign without Illumination.

This lack of exit sign illumination is in direct violation of CBC Sections 1011.5 and 1011.6, which permanently require the illumination of exit signs. Violations regarding other aspects of the egress system is found in the following section.

Issues

Obstructions in the pathway to the exit in the Silo, as seen in Figures 28 and 29, reduces the egress width below the minimum allowable width, per CBC Section 1003.6.

Figure 28. Obstructions in the Silo.

Figure 29. Obstructions in the Path of Egress in the Silo.

Conclusion

In general, the Business Building meets most the requirements listed in CBC Chapter 10, regarding the egress system. The exit capacity is sufficient for the designed occupant load, and the exit remoteness, number of exits, and exit arrangement are code compliant.

All unpowered exit signs must be illuminated and obstructions removed from paths of egress immediately, as these two issues can contribute to life loss if a fire event took place inside the Business Building.

For the egress system to function properly, adequate structural fire protection is required throughout, especially for the paths of egress leading to exit discharge.

Structural Fire Protection

Many factors play a role in providing satisfactory structural fire protection in a building. One of the more dominant contributors is the materials of construction.

Construction Type

The original construction documents of this building list the construction type as Type II-FR (Fire Resistive). Also, included in the original construction documents are the fire resistance ratings of various building elements:

Structural Frame: 2 HR.
Shaft Enclosures: 2 HR.
Floors: 2 HR.
Roof: 2 HR.

These values match the building element fire resistance ratings for a Type II Fire-Resistive Construction listed in the UBC, as seen in Table 6 below.

Table 6. Fire-Resistance Rating Requirements for Building Element (Hours) in 1985 UBC.

	TYPE I	TYPE II		
	NONCOMBUSTIBLE			
BUILDING ELEMENT	Fire-resistive	Fire-resistive	1-Hr.	N
Exterior Bearing Walls	4 Sec. 1803 (a)	4 1903 (a)	1	N
Interior Bearing Walls	3	2	1	N
Exterior Nonbearing Walls	4 Sec. 1803 (a)	4 1903 (a)	1 1903 (a)	N
Structural Frame[1]	3	2	1	N
Partitions—Permanent	1[2]	1[2]	1[2]	N
Shaft Enclosures	2	2	1	1
Floors-Ceilings/Floors	2	2	1	N
Roofs-Ceilings/Roofs	2 Sec. 1806	1 1906	1 1906	N
Exterior Doors and Windows	Sec. 1803 (b)	1903 (b)	1903 (b)	1903 (b)

Comparing the fire resistance ratings of the Business Building to Table 601 of the CBC (Table 7):

Table 7. Table 601 of the CBC – Fire-Resistance Rating Requirements for Building Element (Hours).

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior			See Table 602						
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and associated secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and associated secondary members (see Section 202)	$1\frac{1}{2}$[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

Type II-FR and Type I-B are nearly identical, except for the exterior wall requirements of the UBC. However, referencing Section 1803 (a) of the UBC, a 1-hour fire resistance rated wall is allowed in other than Group H occupancies, where openings are permitted. Thus, because the Business Building is primarily a Group B and A-3 building, and openings are permitted (as will be discussed in a subsequent section), the exterior wall is 1-hour rated. This building can be considered a Type I-B building.

To discuss the permitted openings, the fire separation distance must also be analyzed.

Fire Separation Distance

The fire separation distance is the distance measured from the building face to either the closest interior lot line, the centerline of a street, alley or public way, or to an imaginary line between two buildings on the property. In this case, the fire separation distance is measured as half the distance between the Education Building and both the Silo and the Business Building.

The exterior wall requirements of both the CBC are based on the fire separation distance. The larger the fire separation distance, the less fire protection required. Table 602 of the CBC (Table 8) reveals the exterior wall fire resistance rating requirement based on fire separation distance, occupancy type, and construction type.

Table 8. Table 602 of the CBC – Fire-Resistance Rating Requirements for Exterior Walls Based on Fire Separation Distance.

FIRE SEPARATION DISTANCE = X (feet)	TYPE OF CONSTRUCTION	OCCUPANCY GROUP H^f, L	OCCUPANCY GROUP F-1, M, $S-1^g$	OCCUPANCY GROUP A, B, E, F-2, I, $R^{h,i}$, $S-2^g$, $U^{b,h,i}$
$x < 5^c$	All	3	2	1
$5 \le x < 10$	IA Others	3 2	2 1	1 1
$10 \le x < 30$	IA, IB IIB, VB Others	2 1 1	1 0 1	1^d 0 1^d
$X \ge 30$	All	0	0	0

The fire separation distance between the silo and the Education Building can be seen in Figure 30. Using the 8’ distance and using Table 8, the required exterior wall rating is 1 hour.

Figure 30. Fire Separation Distance – Silo and Education Building.

Figure 31. Fire Separation Distance.

The same process can be used for the fire separation distance between the Education Building and the Business Building. As seen in Figure 32, the fire separation distance between the two buildings are about 10’. Using Table 8 once more, it is concluded that a 1-hour exterior wall rating is sufficient for this building.

Figure 32. Fire Separation Distance – Business and Education Building.

Figure 33. Fire Separation Distance.

It is important to note that the fire separation distance between the two buildings should be clear of any combustibles. As seen in Figure 33, foliage exists between the Education and Business Buildings, which defeats the purpose of the reduction in fire resistance ratings of the exterior walls based on fire separation distance.

Exterior Wall Openings

As stated previously, permitted openings in the exterior walls are dependent upon the fire separation distance. Table 705.8 of the CBC (Table 9) shows the allowable area of openings. Allowable area also can increase if sprinkler protection is allowed, as well as if the openings are protected.

Table 9. Table 705.8 of the CBC – Allowable Area of Exterior Openings.

FIRE SEPARATION DISTANCE (feet)	DEGREE OF OPENING PROTECTION	ALLOWABLE AREA[a]
0 to less than 3[b, c]	Unprotected, Nonsprinklered (UP, NS)	Not Permitted
	Unprotected, Sprinklered (UP, S)[i]	Not Permitted
	Protected (P)	Not Permitted
3 to less than 5[d, e]	Unprotected, Nonsprinklered (UP, NS)	Not Permitted
	Unprotected, Sprinklered (UP, S)[i]	15%
	Protected (P)	15%
5 to less than 10[e, f, j]	Unprotected, Nonsprinklered (UP, NS)	10%[h]
	Unprotected, Sprinklered (UP, S)[i]	25%
	Protected (P)	25%
10 to less than 15[e, f, g]	Unprotected, Nonsprinklered (UP, NS)	15%[h]
	Unprotected, Sprinklered (UP, S)[i]	45%
	Protected (P)	45%
15 to less than 20[f, g]	Unprotected, Nonsprinklered (UP, NS)	25%
	Unprotected, Sprinklered (UP, S)[i]	75%
	Protected (P)	75%
20 to less than 25[f, g]	Unprotected, Nonsprinklered (UP, NS)	45%
	Unprotected, Sprinklered (UP, S)[i]	No Limit
	Protected (P)	No Limit
25 to less than 30[f, g]	Unprotected, Nonsprinklered (UP, NS)	70%
	Unprotected, Sprinklered (UP, S)[i]	No Limit
	Protected (P)	No Limit
30 or greater	Unprotected, Nonsprinklered (UP, NS)	No Limit
	Unprotected, Sprinklered (UP, S)[i]	Not Required
	Protected (P)	Not Required

Utilizing the fire separation distance values provided earlier and Table 9, the silo can have 10% of the total area be unprotected openings, and the Business Building can have a maximum of 15% unprotected openings. The silo does not have any exterior openings aside from the two double doors used to enter and exit, and thus it meets the opening requirements. The Business Building, however, has an unprotected opened area that exceeds 15%, as can be easily deduced by Figures 32 and 33. Although this is allowable in the 1985 UBC, it no longer can be considered code compliant with regards to the 2013 CBC.

Fire Resistance Ratings

The stairways, shafts, corridor walls, and horizontal exits all provide a certain level of fire protection. Gypsum Wall Board is used in providing much of the interior fire protection. Below are the fire resistance ratings of each component:

Stairway Enclosure: 2 HR.
Shaft Enclosures: 2 HR.
Corridor Walls: 1 HR.
Horizontal Exit: 2 HR.

CBC Sections 1022 and 1025 state that both horizontal exits and interior exit stairways must have fire resistance ratings of 2 hours. Table 1018.1 of the CBC requires that buildings without sprinkler systems have a 1-hour rated corridor in both Assembly and Business occupancies. The fire resistance ratings of the existing construction meet the requirements of these codes.

Corridor doors and exit doors also have fire resistance ratings. The corridor doors have a 20-minute fire resistance rating, while the exit doors have 1.5-hour fire resistance ratings. The UL listing label for a corridor door can be seen in Figure 34.

Figure 34. Fire Separation Distance.

Table 716.5 of the CBC (Table 10) requires a minimum fire door rating of 1.5 hours in fire barriers with a 2-hour fire resistance rating. Therefore, doors leading into the horizontal exit, as well as the doors leading into the enclosed exit stairways must have a fire resistance rating of 1.5 hours. Doors in corridor walls are required to have 20 minute ratings per the same table. Thus, the door ratings in this building are compliant with the current code. The required ratings are boxed in Table 10.

Table 10. Table 716.5 of the CBC – Opening Fire Protection Assemblies, Ratings and Markings.

TYPE OF ASSEMBLY	REQUIRED WALL ASSEMBLY RATING (hours)	MINIMUM FIRE DOOR AND FIRE SHUTTER ASSEMBLY RATING (hours)	DOOR VISION PANEL SIZE	FIRE RATED GLAZING MARKING DOOR VISION PANEL[e]	MINIMUM SIDELIGHT/ TRANSOM ASSEMBLY RATING (hours)		FIRE-RATED GLAZING MARKING SIDELITE/TRANSOM PANEL	
					Fire protection	Fire resistance	Fire protection	Fire resistance
Fire walls and fire barriers having a required fire-resistance rating greater than 1 hour	4	3	Not Permitted	Not Permitted	Not Permitted	4	Not Permitted	W-240
	3	3[a]	Not Permitted	Not Permitted	Not Permitted	3	Not Permitted	W-180
	2	1 1/2	100 sq. in.[c]	≤100 sq.in. = D-H-90 >100 sq.in.= D-H-W-90	Not Permitted	2	Not Permitted	W-120
	1 1/2	1 1/2	100 sq. in.[c]	≤100 sq.in. = D-H-90 >100 sq.in.= D-H-W-90	Not Permitted	1 1/2	Not Permitted	W-90
Shaft, exit enclosures and exit passageway walls	2	1 1/2	100 sq. in.[c, d]	≤100 sq.in. = D-H-90 > 100 sq.in.= D-H-T-or D-H-T-W-90	Not Permitted	2	Not Permitted	W-120
Fire barriers having a required fire-resistance rating of 1 hour: Enclosures for shafts, exit access stairways, exit access ramps, interior exit stairways, interior exit ramps and exit passageway walls	1	1	100 sq. in.[c, d]	≤100 sq.in. = D-H-60 >100 sq.in.= D-H-T-60 or D-H-T-W-60	Not Permitted	1	Not Permitted	W-60
					Fire protection			
Other fire barriers	1	3/4	Maximum size tested	D-H-NT-45	3/4		D-H-NT-45	
Fire partitions: Corridor walls	1	1/3[b]	Maximum size tested	D-20	3/4[b]		D-H-OH-45	
	0.5	1/3[b]	Maximum size tested	D-20	1/3		D-H-OH-20	
Other fire partitions	1	3/4	Maximum size tested	D-H-45	3/4		D-H-45	
	0.5	1/3	Maximum size tested	D-H-20	1/3		D-H-20	

Conclusion

As described, the Business Building meets the Type I-B Construction requirements listed in the CBC. The fire separation distances between the silo, Business Building, and Education Building are sufficient for the fire resistance rating of the exterior wall. However, the openings on the floor adjacent to the Education Building far exceed what is allowable by the CBC. The fire resistance ratings of building components including means of egress and doors comply with the current edition of the CBC. Fire doors typically have a fire resistance rating to prevent fire spread, but also to prevent smoke spread. These doors play a large role in the containment of smoke, as will be seen in the next section.

Smoke Management System

An active smoke control system does not exist in the Business Building. Smoke management in this building functions passively. Smoke can be contained in certain areas of the building by means of fire resistance rated separations, including walls, doors, and dampers.

System Activation

In the building's Heating Ventilation and Air Conditioning (HVAC) system lies fire dampers and duct detectors. A description of the duct detectors will be discussed in a subsequent section. 28 fire dampers exist throughout the building on multiple floors, and these dampers close when the fusible link holding the damper open melts from a fire. A breakdown of the components of the fire damper can be seen in Figure 35, where the fusible link is indicated as a "Thermal sensor".

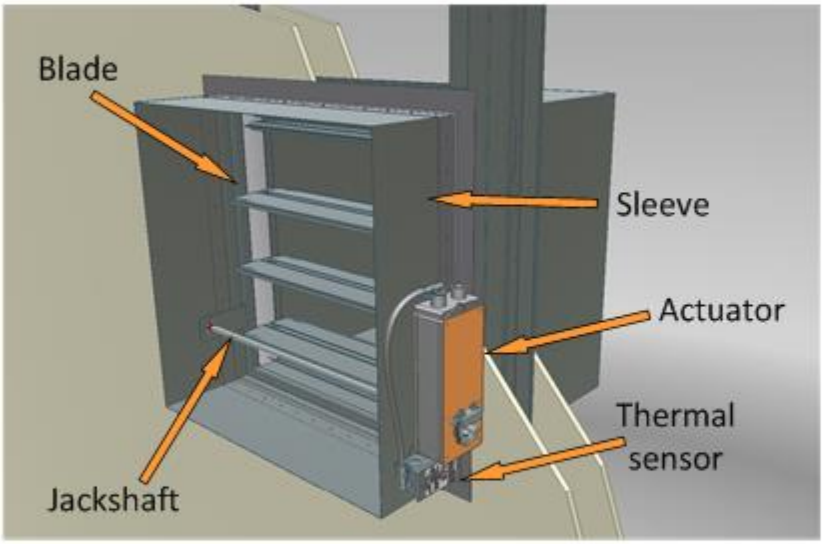

Figure 35. Fire Damper Components.

Activation of the smoke management system occurs when either the duct detector or waterflow switch is activated, if the dampers closer, or if any of the manual pull stations located throughout the building are initiated. Activation of any of these devices also triggers the fire alarm system, which will be discussed in an ensuing section.

System Response

When any of the activation devices are initiated, any fan programmed to be associated with the specific activation device shuts down. This shutdown is to limit smoke spread through the HVAC system. The activation devices also release doors held open by magnetic door holders, which are placed primarily on doors leading to exits. See Figures 36 and 37 for doors held open by magnetic door holders.

Figure 37. Doors Kept Open by Magnetic Door Holders.

Figure 36. Magnetic Door Holder.

When these magnetic door holders are deenergized by the activation of the smoke management system, the doors are released from the magnetic door holders. All doors that are required to have fire-resistance ratings must also be self or automatic-closing in accordance with the California Fire Code (CFC) Section 715.4.8. When these doors close, they should also latch shut so that a smoke seal is created between the two sections of the building the fire doors are separating. An "S" rating on a UL listing label indicates that the door is rated for smoke protection, as seen in Figure 38. Thus, when the doors close, passive fire barriers are created throughout the building.

Figure 38. "S" Rating on a Fire Rated Door.

Issues

Passive fire protection, when implemented according the CBC, is an effective method of preventing smoke and fire spread and life loss. However, this building contains far too many issues relating to the passive fire protection system to be deemed safe. Much of the concern derives from the overwhelming amount of self-closing fire doors being propped open by wedges and door stops. The collage seen in Figure 39 is just a fraction of the total number of fire doors found propped open in the Business Building.

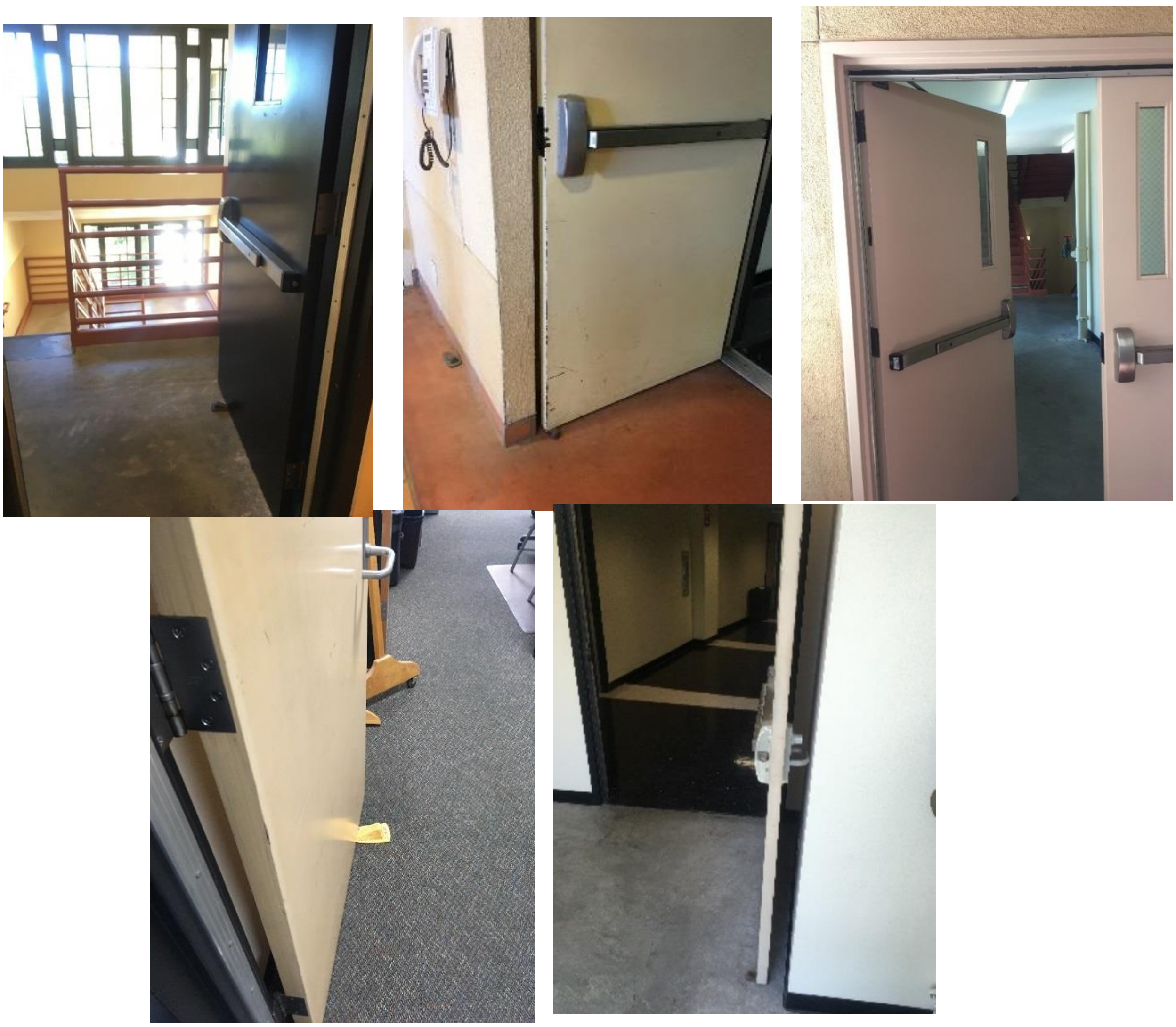

Figure 39. Multiple Propped-Open Fire Doors in the Business Building.

Some of these doors lead into classrooms directly adjacent to the corridor and some lead into the enclosed stairway. As stated previously, if a stairway is used as an exit stairway, it requires a 2-hour fire rating. These propped doors into fire rated areas compromise the rating and compromise the safety of the occupants on the floors containing propped fire doors. Because of

the amount of concern these propped doors cause, a performance based analysis discussed later in this report takes these doors into account. This issue needs to be dealt with without delay, for if a fire event takes place, the results could be catastrophic.

Another issue of great importance is the fact that many self-closing doors do not latch, which essentially means that there is no smoke seal created between the areas separated by the fire doors. Smoke could then pour in through these gaps, reduce occupant visibility during a fire, and impede occupant egress.

Finally, any dysfunctional magnetic door holders, like the one depicted in Figure 40, must be replaced immediately. In this case, the door is propped open and leads into a stairway, which is cause for concern. The consequences of propped open fire doors will be discussed in the performance based analysis.

Figure 40. Propped Door with Broken Magnetic Door Holder.

Conclusion

The Business Building contains a passive smoke management system, where the fire barriers are expected to limit the fire and smoke spread and provide adequate conditions for safe occupant egress. The smoke management system activates by means of duct detection, the closing of fire dampers, and the activation of the waterflow switch or any manual pull station. The smoke management system will then shut off running fans and release fire doors held open by magnetic door holders. Ideally, the passive smoke management system will function by closing off

different areas of the building to limit fire and smoke spread by means of dampers and fire doors. However, the existing condition is *much* less than ideal. Many of the fire doors are propped open, and many of those that do self-close do not latch shut. The issues regarding the passive smoke management system is a deal of great importance and must be resolved immediately. The fire alarm system in the Business Building is intertwined with the smoke management system and will be discussed thoroughly in the following section.

Fire Alarm System

When an alarm, detector, etc. is triggered in the Business Building, a signal is sent to a continuously supervised remote location that then notifies the local fire department. Thus, the fire alarm system is classified as a Proprietary Supervisory Station Alarm System. A description of such a system can be read below, according to Underwriters Laboratory.

Systems operate by detecting existence of heat, fire, smoke or other emergencies, annunciating off-normal conditions locally, and transmitting signals off premise to a remote, continuously attended supervising station. Supervising station personnel take action in response to signals as required by NFPA 72. A proprietary supervising station serves properties under a single ownership. Personnel take action in response to signals as required by NFPA 72. [2]

The alarm system includes the fire alarm control unit (FACU), all detection devices and all notification appliances. The Business Building is equipped with a Notifier FACU, multiple smoke, heat, and duct detectors, and horn strobes throughout the building. The fire alarm system has been upgraded since original construction.

Fire Alarm Control Unit

Original construction documents show that this building was initially installed with a Simplex 4002 Series FACU (Figure 41). However, an updated fire alarm system was added almost two decades later as a result of Cal Poly's transition to a single homologous system for the entire campus. Notifier's NFS2-640 (Figure 42) was selected as the building's fire alarm system. The Notifier System is located on the first floor on the southwest side of the building.

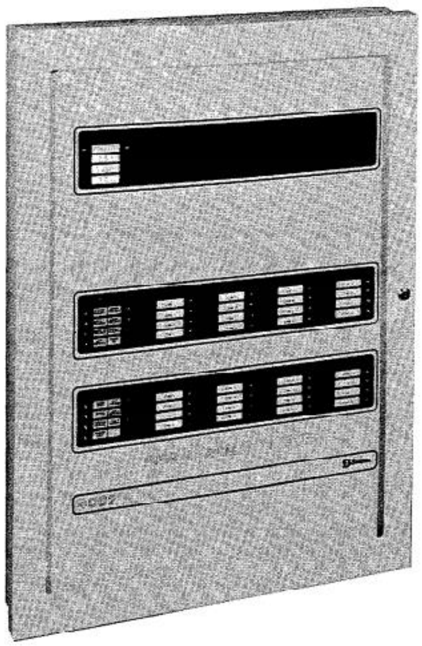

Figure 42. Simplex 4002 Series.

Figure 41. Notifier NFS2-640.

Appendix B contains catalog information for the NFS2-640 and floor plans identifying the location of FACU as well as the locations of the other features of the fire alarm system.

Fire Detection

The fire detection system only provides partial coverage for the Business Building, where selected areas of coverage include corridors, mechanical rooms, and some classrooms. There are two categories of detectors installed in the building: smoke detectors and heat detectors. The building utilizes intelligent detectors that contain both heat and smoke detection capabilities. These devices are all spot-type. One heat detector, 5 duct detectors, and 20 smoke detectors exist in the Business Building.

Heat detectors are best suited for fire detection in small spaces where high-heat-output fires are expected, where other fire detection devices could not be used because of surrounding environmental conditions, or where immediate notification of fire is not mandatory. These devices are normally located near ceilings or are ceiling-mounted and typically respond to the thermal energy of fire transported by means of convection. Actuation of these detectors occurs when a built-in detecting element reaches a specified temperature or when the device notes a listed rate of temperature change (rate-of-rise). [3]

One model of heat detector is utilized in the Business Building. There is only one heat detector found on the fire alarm plan: a System Sensor 5251p Fixed Temperature Sensor. This sensor is used in the room containing the Fire Alarm Control Unit (FACU). The 5251p, seen in Figure 43, operates solely when its detecting element reaches a fixed temperature. The rest of the detectors in the building have smoke detecting capabilities.

Figure 43. 5251p Heat Detector.

Smoke detectors function by picking up products of combustion. There are 4 categories of smoke detectors: Spot-type, beam, air-sampling, and video. Spot-type detectors have two subcategories: ionization and photoelectric. In this report, photoelectric spot-type detectors and air duct smoke detectors are the only smoke detectors used and thus will be the only non-combination smoke detectors discussed.

Photoelectric spot-type smoke detectors function off of a light-scattering principle. When smoke occupies a room, light starts to reflect off of this smoke and into the light-sensitive smoke detector, which then actuates. Air duct smoke detectors are, as stated in the name, mounted in the air ducts of the building. This device has a metal sampling tube that sends the smoke through a detecting element inside the detector, which monitors the smoke content in the flowing air. Air flow is required for this detector to operate as intended.

Simplex's 4098-9755 TrueAlarm Photoelectric Sensors are the air duct detectors used in the ducts of the Business Building. This model has seven standard levels of sensor sensitivity, ranging from 0.2% to 3.7% per foot of smoke obscuration. The sensitivity is controlled and monitored at the fire alarm control panel. This sensor functions as both an air sampling detector as well as a spot-type photoelectric sensor.

Notifier's FSP-851 Intelligent Plug-In Photoelectric Smoke Detectors, seen in Figure 44, were utilized as a thermal and smoke detector combination and are located in the corridors of the building. These detectors operate when the temperature reaches 135 °F or when obscuration reaches the specified amount, ranging from 0.5% to 2.35% per foot obscuration.

Figure 44. FSP-851 Smoke Detector.

Product data sheets and the locations of these devices on floor plans can be found in the Appendix B.

As previously stated, the fire alarm system provides partial coverage. According to NFPA 72 Section A.17.5.3.2, the intent of partial coverage is to address a specific hazard only. Where a specific area is to be protected, all points within that area should be within 0.7 times the detector spacing for spot type detectors. Thus, all areas intentionally covered by heat or smoke detectors should meet this distance requirement, as outlined in NFPA 72 Sections 17.6.3.1.1 and 17.7.3.2.3.1 (2). In this building, the corridors are considered the intentionally covered areas and should meet the stated requirements. Floors 2 and 3, as seen in the Fire Alarm Device Plans in Appendix B, lack corridor smoke detection and is a point of concern.

Notifier's FSP-851 Detectors have a maximum spacing of 30' for ceiling heights of 10', but for irregular spacing, the maximum spacing from any one point to another should not exceed 21'. Analyzing the locations of detectors on the floor plans proves there is a violation of the recommended maximum spacing in the corridors. System Sensor's 5251P Detector in the FACU room provides adequate coverage, as the detectors provide 50' spacing capabilities. No detectors were noted to violate ceiling distance requirements per NFPA 72 Sections 17.6.3.1.3.1, 17.7.3.2.1. As stated in NFPA 72 Section 17.5.2.1, air duct detectors shall not be used as substitution for open area protection. A clear violation of this requirement is observed as there is a lack of smoke detectors in areas where duct detectors are located.

DETACT Model

An example fire scenario is selected for the Business Building in accordance with NFPA 72 Section B.2.3.2. Factors taken into consideration for developing the design fire include type of fuel, ceiling height, and distance from smoke detector.

The fire is designed as a wastebasket fire taking place on the second floor where the waste basket was found holding a door open as seen in Figure 45. The location on the floor plan is seen in Figure 46. The nearest detector from the fire location is 65' away.

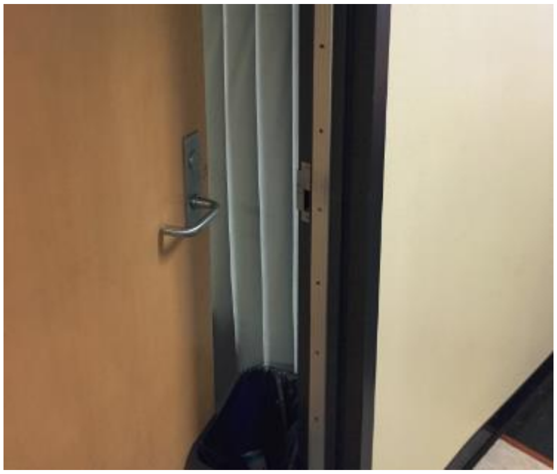

Figure 46. Door Propped by Trash Can.

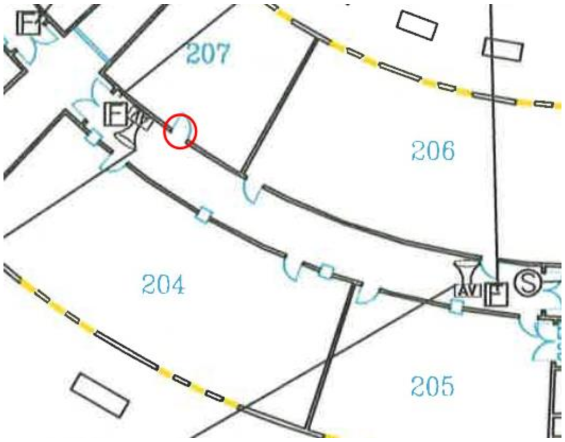

Figure 45. Fire Origin Location.

The fire scenario is as follows: a college student is leaving class and is headed home for the day. A smoker, he pulls out a box of matches and strikes one to light his cigarette on his way out of the building. He throws the match in the waste basket, thinking that had been extinguished. The waste basket contains paper and other combustibles. The combustibles catch fire, and the fire grows as a fast t-squared fire. It is assumed that the fire grows and spreads at a steady rate.

The response from the Intelligent Photoelectric Smoke Detector is analyzed using the DETACT (Detector Actuation) model. Two DETACT models are expressed in Figure 47 and Figure 48. Figure 47 represents a DETACT model in which the heat detecting capabilities of the selected Detector is analyzed, and Figure 48 represents a model in which the smoke detected capabilities were analyzed. The advantage of using this combination detector is that the shorter response time between the two models will be the time that the detector actuates.

The ceiling height of the floor is 10’, but the waste basket fire is 1.5’ above ground, and thus the input for the ceiling height is 8.5’ converted into meters. Distance from fire to detector is 65’. Ambient temperature is assumed to be 20 degrees Celsius. For the smoke model, an RTI value of 2 is used and an actuation temperature of 41.1 degrees Celsius is used. This value is derived from NFPA 72 Table B.4.7.5.3 (Table 11), which provides temperature rises for smoke detectors.

Table 11. Table B.4.7.5.3 of NFPA 72 – Temperature Rise for Detector Response.

	Ionization Temperature Rise		*Scattering Temperature Rise*	
Material	*°C*	*°F*	*°C*	*°F*
Wood	13.9	25	41.7	75
Cotton	1.7	3	27.8	50
Polyurethane	7.2	13	7.2	13
PVC	7.2	13	7.2	13
Average	7.8	14	21.1	38

Because information for a waste basket is not provided, the average value was used. Thus, actuation temperature = ambient temperature + temperature rise. For the heat model, an assigned 55 RTI value is used, and an actuation temperature of 135 degrees F is used and converted into Celsius. Both values are information given by manufacturer.

INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	2.5908	m	R/H	7.372
Radial distance (R)	19.1	m	dT(cj)/dT(pl)	0.079
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.038
Actuation temperature (Td)	57.22	C	Rep. t2 coeff.	k
Response time index (RTI)	55	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.047	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp
0	0.0	20.0	0.00	20.00
2	0.2	20.1	0.02	20.00
4	0.8	20.2	0.03	20.00
6	1.7	20.4	0.03	20.00
8	3.0	20.6	0.04	20.00
10	4.7	20.8	0.05	20.01
12	6.8	21.0	0.05	20.01
14	9.2	21.2	0.06	20.02
16	12.0	21.4	0.06	20.03
18	15.2	21.7	0.07	20.05
20	18.8	21.9	0.07	20.06
22	22.7	22.2	0.08	20.08
24	27.1	22.5	0.08	20.10

Actuation time (s)	HRR (kW)	Gas temp	Gas velocity	Det temp	dT/dt
266	3325.5	81.0	0.41	57.26	0.2770

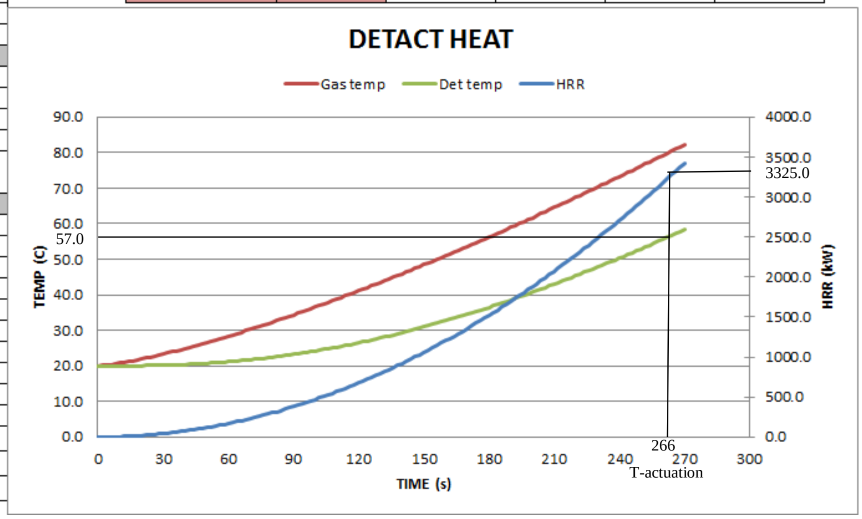

Figure 47. DETACT Model for Heat Detection.

With solely heat detecting properties, the detector would begin actuation at 266 seconds after ignition, with a heat release rate of 3325 kilowatts. The smoke detecting properties cause the detector to actuate at 120 seconds, when the fire has a heat release rate of 676.8 kilowatts. Because of the smoke detecting properties, the fire is detected when it is releasing a heat release rate of a magnitude of 5 less than what would be caused if it continued to grow until a heat detector activated. When the detector is activated, the alarm will sound. If occupants have not begun egress already, egress should ensue at 120 seconds after ignition.

INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	2.5908	m	R/H	7.372
Radial distance (R)	19.1	m	dT(cj)/dT(pl)	0.079
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.038
Actuation temperature (Td)	41.1	C	Rep. t2 coeff.	k
Response time index (RTI)	2	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.047	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp
0	0.0	20.0	0.00	20.00
2	0.2	20.1	0.02	20.00
4	0.8	20.2	0.03	20.01
6	1.7	20.4	0.03	20.05
8	3.0	20.6	0.04	20.11
10	4.7	20.8	0.05	20.20
12	6.8	21.0	0.05	20.32
14	9.2	21.2	0.06	20.47
16	12.0	21.4	0.06	20.65
18	15.2	21.7	0.07	20.85
20	18.8	21.9	0.07	21.07
22	22.7	22.2	0.08	21.30
24	27.1	22.5	0.08	21.55

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp	dT/dt
120	676.8	41.11180631	0.24193902	40.1552656	0.23524826

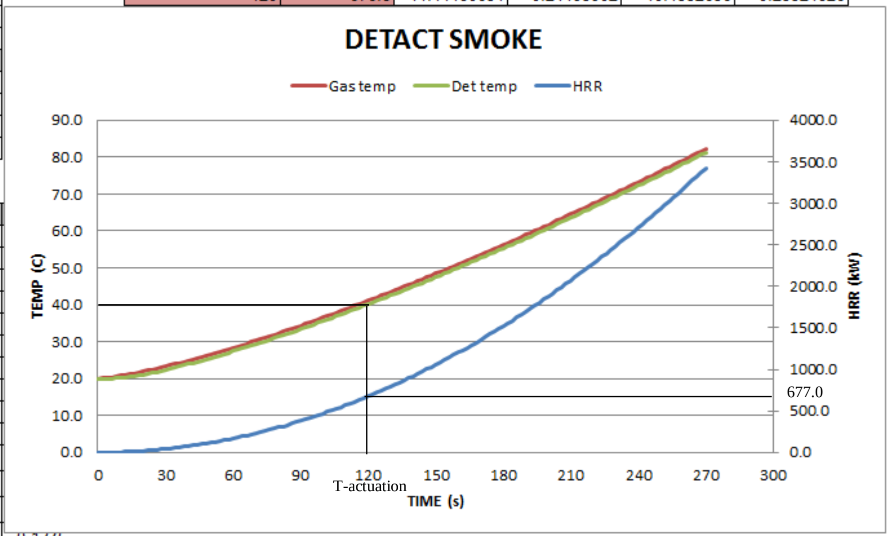

Figure 48. DETACT Model for Smoke Detection.

Once detection is activated, the notification appliances are triggered to alert the occupants of impending danger.

Alarm Notification

All notification appliances in this building are combination audible and visible appliances. Gentex's GEC3 Selectable Candela Evacuation Signals, seen in Figure 49, are the only audible/visible appliance used in the Business Building. These devices offer a range of tamperproof field selectable candela options from 30 candela (cd) to 110 cd intensity. The horns of these devices offer selectable tones as well, producing a sound pressure level of up to 82 dBA. The catalog datasheets for this device can be found in Appendix B. These appliances are located throughout the building, and the locations can also be found in the Appendix B. 24 horn strobes exist throughout the building.

Figure 49. GEC3 Horn Strobe found in the Business Building.

NFPA 72 Section 18.4.8.3 states that Section 18.5.5 (Visible Appliance Location) may be used for location requirements for combination audible visible appliances. Following the requirements for visible appliances from NFPA 72, Table 18.5.5.4.1(a) (Table 12) is used to determine if the spacing of the GEC3's is compliant.

Table 12. Table 18.5.5.4.1 (a) of NFPA 72.

Table 18.5.5.4.1(a) Room Spacing for Wall-Mounted Visible Appliances

Maximum Room Size		Minimum Required Light Output [Effective Intensity (cd)]	
ft	m	One Light per Room	Four Lights per Room (One Light per Wall)
20 × 20	6.10 × 6.10	15	NA
28 × 28	8.53 × 8.53	30	NA
30 × 30	9.14 × 9.14	34	NA
40 × 40	12.2 × 12.2	60	15
45 × 45	13.7 × 13.7	75	19
50 × 50	15.2 × 15.2	94	30
54 × 54	16.5 × 16.5	110	30
55 × 55	16.8 × 16.8	115	30
60 × 60	18.3 × 18.3	135	30
63 × 63	19.2 × 19.2	150	37
68 × 68	20.7 × 20.7	177	43
70 × 70	21.3 × 21.3	184	60
80 × 80	24.4 × 24.4	240	60
90 × 90	27.4 × 27.4	304	95
100 × 100	30.5 × 30.5	375	95
110 × 110	33.5 × 33.5	455	135
120 × 120	36.6 × 36.6	540	135
130 × 130	39.6 × 39.6	635	185

NA: Not allowable.

The light outputs of the GEC3's in the Business Building are on the 75 cd selection. Thus, a maximum spacing of 45' x 45' is allowable for the light intensity setting. However, there were rooms larger than this spacing that only contained one GEC3 such as room 300 on the third floor as seen on the floor plan, and thus did not meet the requirement. Also, there were rooms that did not contain any sort of visible signaling. Because these areas are occupiable spaces, the lack of visible notification appliances violates NFPA 72 Section 18.5.1.2. The corridors were noted to also exceed the spacing listed in the table above. However, Section 18.5.5.5.1 in conjunction with Section 18.5.5.5.5 allows notification appliances in corridors to be spaced no more than 15' from the end of the corridor and not more than 100' apart. After analyzing notification appliance distances on the floor plan, the corridor spacing for all four floors is deemed code compliant.

Although spacing for the audible aspect of the GEC3 appliances follows the Visible Appliance Location requirements, an analysis is performed to ensure that sound pressure levels would remain above the minimum required, per Section 18.4.3.1, which states that audible appliance signals must have a sound level of at least 15 dB above the average ambient sound level or 5 dB above maximum sound level having a duration of at least 60 seconds. Table A.18.4.3 (Table 13) provides average ambient sound levels, of which educational occupancies is selected with a value of 45 dBA.

Table 13. Table A.18.4.3 of NFPA 72.

Table A.18.4.3 Average Ambient Sound Level According to Location

Location	Average Ambient Sound Level (dBA)
Business occupancies	55
Educational occupancies	45
Industrial occupancies	80
Institutional occupancies	50
Mercantile occupancies	40
Mechanical rooms	85
Piers and water-surrounded structures	40
Places of assembly	55
Residential occupancies	35
Storage occupancies	30
Thoroughfares, high-density urban	70
Thoroughfares, medium-density urban	55
Thoroughfares, rural and suburban	40
Tower occupancies	35
Underground structures and windowless buildings	40
Vehicles and vessels	50

Thus, the sound level of every notification appliance must be equal to or exceed 60 dBA **at every location in the building**. The GEC3 appliances are currently set to 82 dBA at 10' away from the alarm. The maximum distance away from a horn is 35'. 6 dBA can be assumed to be lost every time the distance away from the source is doubled. At 35', about 13 dBA is lost, and thus has a sound pressure level of 69 dBA, which exceeds the minimum requirement.

To solve the visible requirement issues, at least one GEC3 should be placed in all occupiable areas, with varying strobe intensities to accommodate the room area along with minimizing current requirements.

Secondary Power Supply

A secondary power supply is necessary for the Fire Alarm System in case of emergency situations where the primary power supply is no longer functioning. The existing secondary power supply consists of a sealed lead acid battery, and original facility calculations state that the battery has a 10 Amp-Hours (Ah) capacity. Manual calculations of the required capacity of the secondary battery were executed to ensure the supply exceeds the current demand. The annunciator and relays were not considered in the battery calculations.

Battery calculations are provided below, where total required operating time is 24 hours in standby mode plus 5 minutes in alarm mode, per NFPA 72 10.6.7.2.1. Standby and alarm currents for each device and appliance were obtained from the catalog cut sheets provided in Appendix B.

ITEM	DESCRIPTION	STANDBY CURRENT PER UNIT (AMPS)		QTY		TOTAL STANDBY CURRENT (AMPS)	TOTAL ALARM CURRENT PER UNIT (AMPS)		QTY		TOTAL SYSTEM ALARM CURRENT (AMPS)
A	FACU + 4 NACS	0.39	X	1	=	0.39	0.39	X	1	=	0.39
B	DUCT DET	0.003	X	5	=	0.015	0.015	X	5	=	0.075
C	INTELLIGENT SMOKE DET	0.0003	X	20	=	0.006	0.0065	X	20	=	0.13
D	HEAT DET	0.0003	X	1	=	0.0003	0.0065	X	1	=	0.0065
E	HORN/STROBE 75CD	NONE	X	24	=	0	0.14	X	24	=	3.26
		TOTAL SYSTEM STANDBY CURRENT (AMPS)				0.41	TOTAL SYSTEM ALARM CURRENT (AMPS)				3.87

REQUIRED OPERATING TIME OF SECONDARY POWER SOURCE FROM NFPA 72 10.6.7.2.1.

STANDBY: 24 HOURS

ALARM: 0.083 HOURS

REQUIRED STANDBY TIME (HOURS)		TOTAL SYSTEM STANDBY CURRENT (AMPS)		REQUIRED STANDBY CAPACITY (AMP-HOURS)	REQUIRED ALARM TIME (HOURS)		TOTAL SYSTEM ALARM CURRENT (AMPS)		REQUIRED ALARM CAPACITY (AMP-HOURS)	TOTAL REQUIRED CAPACITY (AMP-HOURS)		FACTOR OF SAFETY (PER NFPA 10.6.7.2.1.1)	REQUIRED BATTERY CAPACITY (AMP-HOURS)
24.00	X	0.41	=	9.87	0.08	X	3.87	=	0.32	10.19	X	1.20	**12.23**

Figure 50. Battery Calculations

The calculated required battery capacity, as seen in Figure 50, is 12.23 Ah. Thus, the original secondary power supply is insufficient for the current layout of the fire alarm system. However, it is noted that renovations were performed on the fire alarm system in the Business Building since original construction, and it is assumed that with the upgraded fire alarm system came an upgraded secondary power supply to support the new system.

Inspection, Test, and Maintenance

System Documentation is required per NFPA 72 Chapter 7, and such documentation includes records of completion (system, power), specifications, wiring diagrams, and floor plans.

NFPA 72 Section 14.6.1.1 requires a set of reproducible as built installation drawings, operation and maintenance manuals, and a written sequence of operation. Please refer to Appendix B for the most recent system inspection performed by the Environmental Health and Safety Facility at Cal Poly.

System inspection for the Business Building refers to NFPA 72 Table 14.3.1 for procedures. Methods and frequency of inspection can be found in this table. Components to be inspected include but are not limited to:

- Visual Inspection of
    - Control Equipment
    - Supervising station alarm systems – transmitters + receivers
    - Batteries

- Remote annunciators
- Initiating devices
- Fire alarm control interface
- Notification appliances

System testing for the Business Building refers to NFPA 72 Table 14.4.3.2 for procedures. Methods and frequency of testing can be found in this table. Components to be tested include but are not limited to:

- Control equipment and transponder
- Fire alarm control unit trouble signals
- Supervising station alarm systems – transmission equipment
- Secondary power supply
- Battery tests
- Remote annunciators
- Conductors – metallic, non-metallic
- Initiating devices
- Interface equipment
- Alarm notification appliances
- Emergency control functions

Maintenance should be executed per NFPA 72 Section 14.5. Rather than giving detailed maintenance instructions, this section points to the manufacturer's published manual for maintenance instructions.

Conclusion

Overall, the system is violating full coverage requirements for both fire detection and fire notification per the 2013 edition of NFPA 72. Regarding smoke detection, corridor detector placement exceeds the allowable separation distance, and floors 2 and 3 lack detection altogether. The same is true for rooms if they were designed to have full area coverage. Fire notification requirements are met throughout all corridors of the building, but many rooms do not meet the visibility requirements set forth in NFPA 72 Chapter 18. Finally, the Business Building's secondary power supply for the fire alarm system is insufficient if it has not been replaced since original construction. If this building is considered to have full fire detection and alarm coverage, major flaws exist. A redesign of the system to meet current code standards should include notification appliances in every occupiable portion of the building, as well as appropriate smoke detection throughout. Locations of the appliances and devices shall be in accordance with NFPA 72.

Along with the smoke management system, the fire alarm system is integrated into the fire suppression system also. The fire suppression system of the building is discussed in the next section.

Fire Suppression System

Existing Condition

The Business Building is not equipped with a fire sprinkler system. Fire hoses located in cabinets throughout the building were designed as the primary fire suppression system implemented for this building. These fire hoses as seen in Figures 51 and 52, were previously defunct, but were recently put back in service, as attested to by the record seen in Figure 53. Appendix C contains the shop drawings for the original fire hose cabinet system.

Figure 51. Functional Fire Hose.

Figure 53. Fire Hose Cabinet.

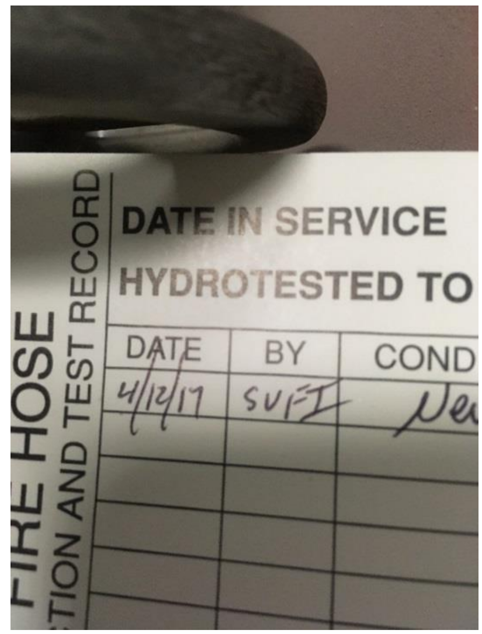

Figure 52. Recent Testing Record.

Fire extinguishers also exist throughout in the fire hose cabinets as well as in specific cabinets intended for fire extinguishers. Three dry standpipes currently exist in the building, one in each of the stairways, as seen in Figures 54, 55, and 56. Each of these standpipes have 2 ½ inch fire department connections (FDC's) so that firefighters can attach their hoses and attempt to extinguish the fire.


Figure 54. Dry Standpipe FDC 1/3.


Figure 56. Dry Standpipe FDC 2/3.


Figure 55. Dry Standpipe FDC 3/3.

2 ½ inch dry and wet standpipe FDC's were also located on the south side of the building exterior, as seen in Figure 57. The wet standpipe FDC's are intended to supplement the fire hose water demand if necessary.

Figure 57. Siamese Connections on Exterior South Side.

Although not required at the time of construction, the current edition of the CBC would require an automatic sprinkler system in this building, per CBC 903.2.1.3. Because of the lack of automatic fire suppression, a wet pipe quick response sprinkler system was designed and is presented to replace the fire hose cabinet fire suppression system.

Water Supply Characteristics

For a sprinkler system to be properly designed, water supply characteristics must be identified. Currently, no water supply information exists for the Business Building. The nearest building with water supply information available is Engineering IV, Building 192, with the relative location shown in Figure 58.

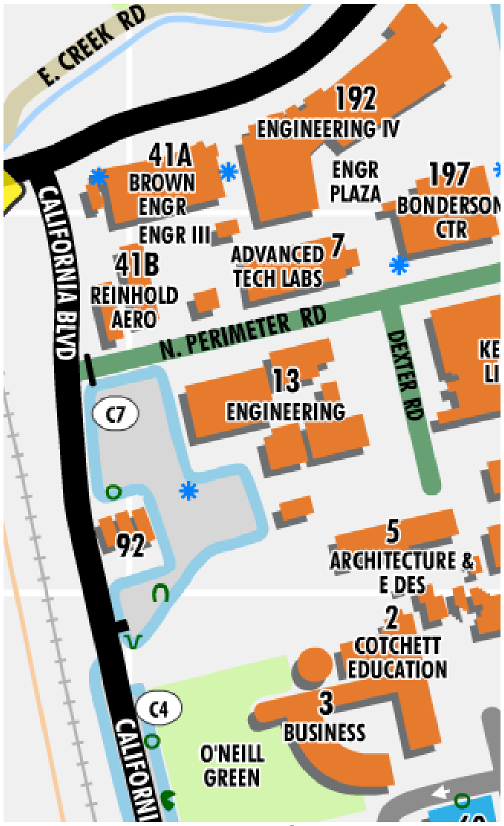

Figure 58. Location of Engineering IV.

The flow test for Engineering IV provided a static pressure of 80 psi, a residual pressure of 65 psi, and a water flowrate of 1244 GPM

Automatic Sprinkler System Design Criteria

The building is categorized as light hazard occupancy, per NFPA 13 Section A.5.2. Light hazard occupancies represent the least severe fire hazard since the fuel loads and heat release rates are expected to be small. Table 14 summarizes the design information.

Table 14. Sprinkler Design Information.

Fourth Floor Design Information		Code Reference
Density	0.1 gpm/SF	11.2.3.1.1
Sprinkler Operation Area	1500 SF	11.2.3.1.1, 11.2.3.2.3.1
Max Coverage per Head	225 SF	Table 8.6.2.2.1
Number of Sprinklers	11	
Sprinkler	TYCO TY3211	
Orifice Size	0.5" NPT	
K	5.6	
Hose Stream Allowance	100 gpm	Table 11.2.3.1.2
Water Supply Duration	30 min	Table 11.2.3.1.2

Sprinkler operation area can have a design reduction due to relatively low ceiling heights. Using 11.2.3.2.1 of NFPA 13 and using ceiling heights of 10 ft, a 40% reduction can be introduced, meaning a remote area needs to only be 900ft. However, to keep the estimate conservative, a remote area of 1200 ft will be used. The Design/Area Method discussed in Section 11.2.3.2 of NFPA 13 is employed to determine if the water supply can provide the necessary sprinkler demand. Appendix C contains sprinkler head catalog information.

Density/Area Method

The general requirements of this method are as follows:

1. The water supply requirements for sprinklers only shall be calculated from the density/area curves of Figure 59.

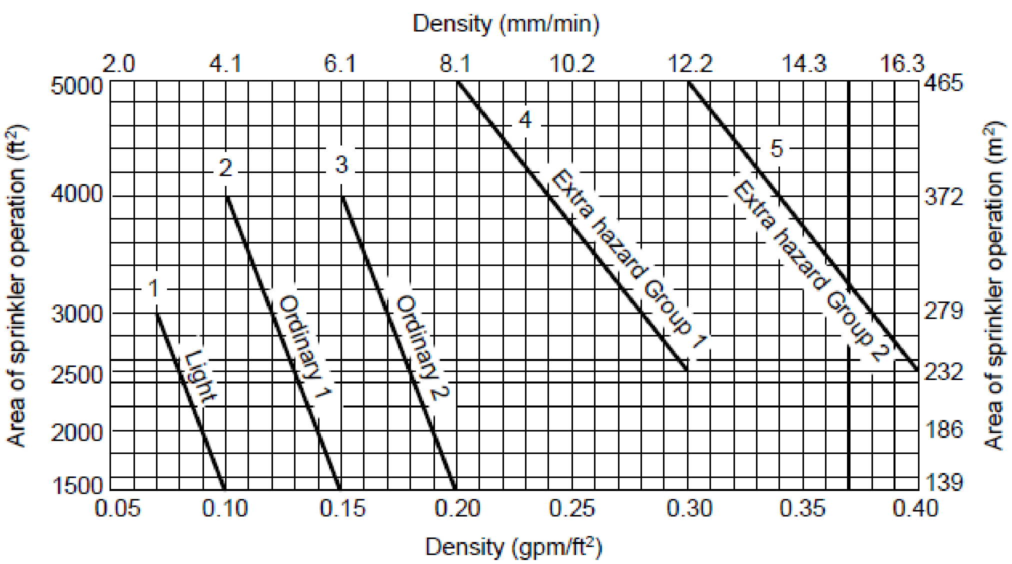

Figure 59. Density/Area Curve of NFPA 13 Figure 11.2.3.1.1.

2. Spray sprinklers must be used.
3. The number of sprinklers in the design area shall never be less than five.

More specific requirements for the Density/Area method are found in Section 11.2.3.2 of NFPA 13. The designed system presented is intended to meet all the listed requirements.

The most hydraulically demanding area is analyzed using the Density/Area method, which in this case is the most remote area away from the designed sprinkler riser. The sprinkler riser location and remote area location can be seen in Figure 60.

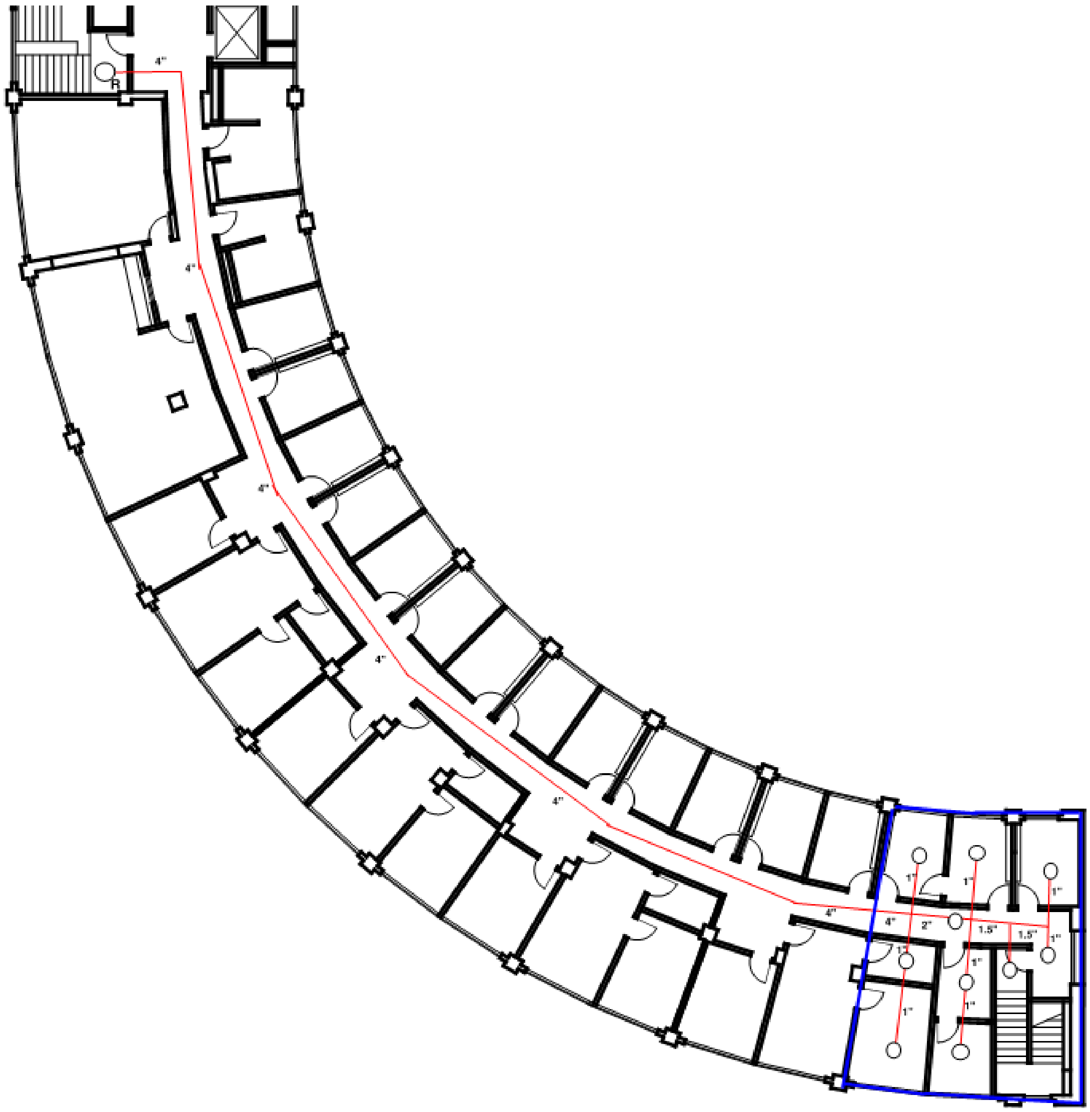

Figure 60. Design Remote Area and Design Riser Location.

All piping under 4" is Schedule 40 steel with a C factor of 120. All piping 4" and above is thin wall steel, apart from the source to underground connection, which is ductile iron. Thin wall steel

has a C factor of 120, while Ductile Iron has a C factor of 150. The following figure shows the pipe sizes used in the hydraulic calculations for the remote area.

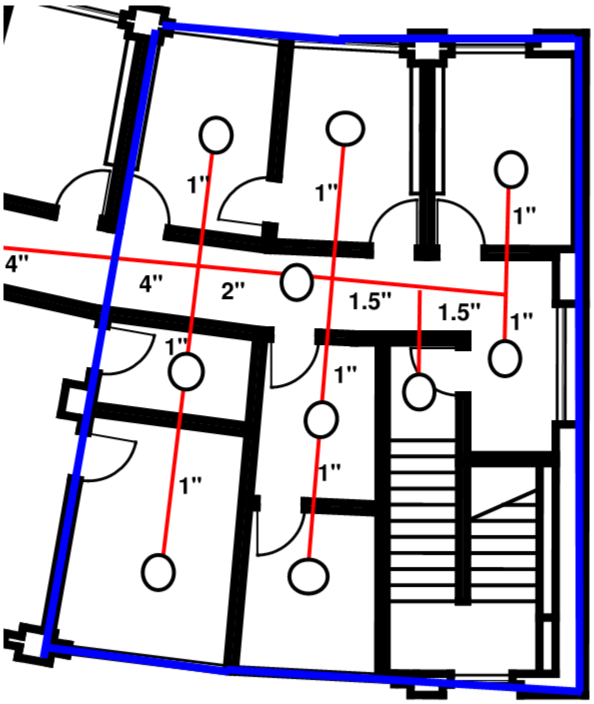

Figure 61. Pipe Sizes of Remote Area.

The remote area is approximately 1200 ft^2. The total hose stream allowance required for light hazard occupancies is 100 GPM for a 30-minute duration, per NFPA 13 Table 11.2.3.1.2. The riser location is specifically designed to be placed in the center stairway to provide the shortest remote distances.

Elevation change from base of riser to the top of the riser on the 4th floor is 53'. Per original construction documents, the fourth floor has an elevation of 349', while the ground floor has an elevation of 307.5'. With ceiling heights of 10', top of riser reaching 2.5' above the ceiling, and the supply piping dropping to 4' below the ground floor, the elevation change from underground to the top of the riser will be 63'. It was assumed that the source is 15' below the base of the riser, since the building was built on a slope and is at a higher elevation than Engineering IV, which is where the water supply information was extracted from.

2 check valves and 2 gate valves exist for back flow prevention from the base of the riser to the source.

Hydraulic Calculations

To ensure that the sprinkler system is provided with the necessary pressure and flow rate, the most hydraulically demanding area will be analyzed. The sprinkler that is farthest away from the

supply, i.e. the sprinkler that receives the least flow and pressure, needs to meet code requirements for minimum pressure and flow. Thus, the rest of system will be designed around the most hydraulically demanding area.

Using information from Table 14, minimum flow per sprinkler can be solved for.

$$225\ ft^2 / sprinkler * 0.1GPM / ft^2 = 22.5GPM / sprinkler$$

Each sprinkler requires a minimum flow of 22.5 gpm. Required pressure is solved for using the equation:

$P=(QK)^2$ Where Q is the flow rate of interest, and K is the discharge factor.

For the sprinkler of interest, Q=22.5 gpm, and K=5.6. Thus, minimum required pressure at the sprinkler is 16.1 psi.

Calculations were performed using Hydraulic Analyzer of Sprinkler Systems (HASS) to solve for the water flow demand and pressure demand at the base of the riser for the most remote area. HASS is a software used to analyze fire sprinkler systems. Please refer to Appendix C for these calculations.

Results / Conclusion

Calculations resulted in a required demand of 247 GPM at 66.8 psi. With the required hose stream allowance of 100 GPM, the total required demand is **347 GPM** at **66.8 psi**. The demand curve can be seen in Figure 62.

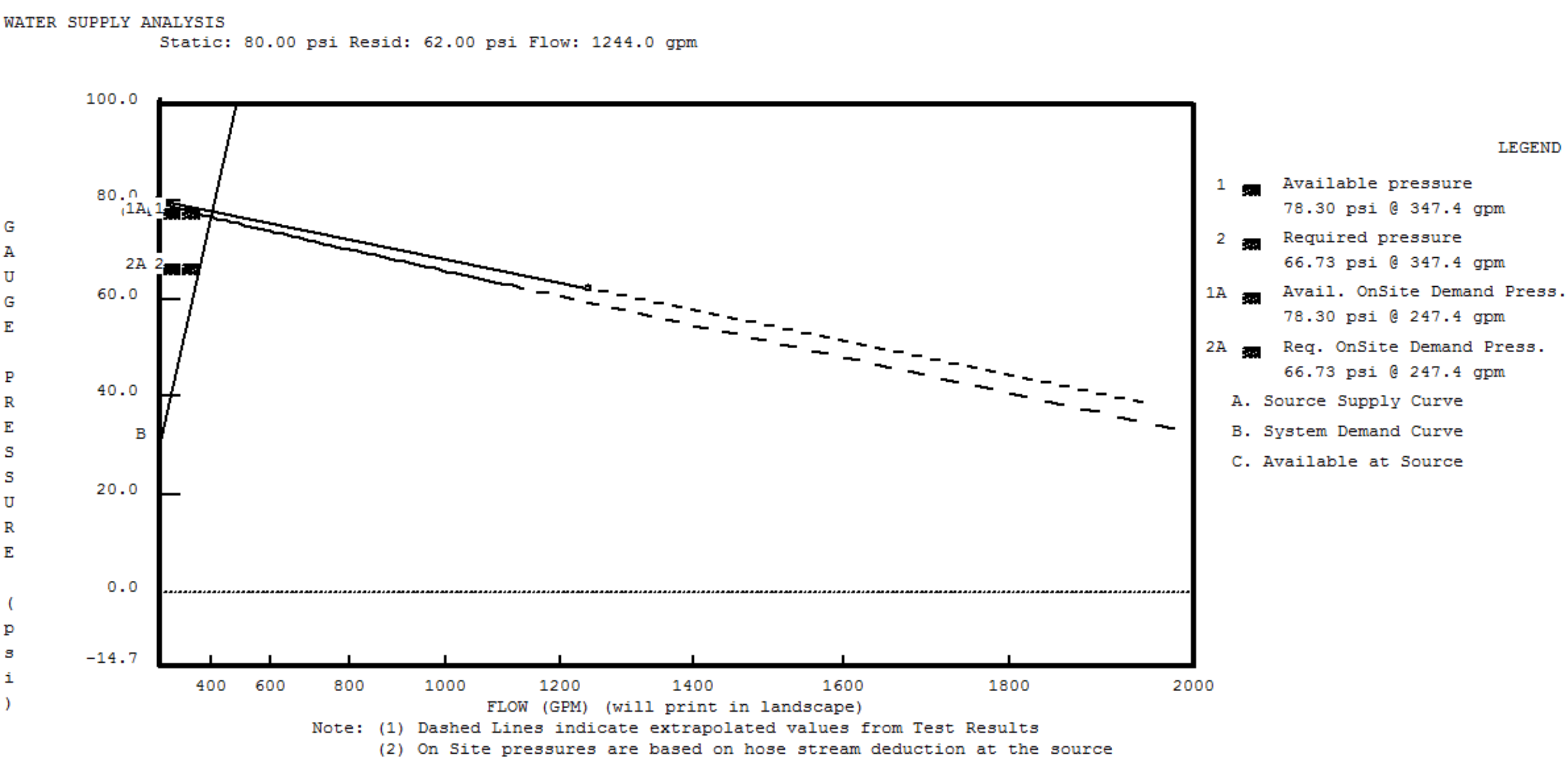

Figure 62. Water Demand Graph.

According to calculations performed by HASS, there is a sufficient supply of both flow and pressure from the source for the required demand on the fourth floor of the Business Building. Additionally, a 10% safety factor is met to ensure the reliability of this calculation.

Inspection, Testing, and Maintenance

To ensure reliability of the sprinkler system and the prevention of fire related tragedy, inspection, testing, and maintenance are required at regular intervals. The system shall be maintained in accordance with Table 5.1.1.2 of NFPA 13.

Per the Fire Protection Handbook, inspection procedures are to be implemented by the property owner. In addition, the property owner can utilize an insurance company, the fire department, a sprinkler contractor, or use central station supervision to inspect the system. The recommended inspection type is a sprinkler contractor, as the contractor provides periodic examination and reports to the property owner, which can be of high value. The property owner can then utilize the knowledge given by the sprinkler contractor and share it with whomever to allow for more frequent check-ups if need be. The inspection provided by the sprinkler contractor shall cover all components and systems needed to properly protect the property.

Quick-Response Sprinklers must be tested after twenty years, and every ten years following, where the test comprises of 1 percent of the total number of sprinklers installed in the facility. Any sprinkler that fails the test shall be replaced. Any sprinkler that shows contamination, corrosion, or paint, should be replaced.

An example of spring-time testing is as follows:

Testing procedures will include opening cold weather valves, testing water motor gongs, conducting waterflow tests, and testing a fire pump if it is present.

Maintenance of specific components will be provided by the sprinkler contractor. Such components include water supply equipment, control valves and meters, sprinklers and sprinkler piping, quick opening devices, pressure gauges, waterflow alarm devices, fire department connections, and any available sprinkler system supervisory system.

It is imperative that the building owner keeps all records of changes occurring to any part of the building. It is equally important that he or she keeps records of inspections to ensure compliance and future reliability of the system.

Conclusion

The Business Building is currently not equipped with any sort of automatic fire suppression system. The fire hoses and extinguishers located throughout the building require manual activation, and occupants in a rush to escape may ignore these fire extinguishing items. Therefore, it is in the best interest of the Building Owner to provide an automatic sprinkler system in the Business Building. If the water supply is equal to or greater than that of the Engineering IV building, the supply is adequate for the most hydraulically demanding area of the building. This area only requires 347 GPM at 67 psi, where the supply provides 347 GPM at roughly 78 psi. In the performance based analysis discussed in the subsequent section, a

functioning automatic sprinkler system installed in the building would cause many of the possible fire scenarios to pose a much smaller risk.

Performance Based Analysis

Prescriptive fire protection features of the building have been analyzed up to this point in the report. An Emergency Response Plan developed for occupant safety (with its own set of Appendices) can be found attached in Appendix D.

The performance based approach to analyze the fire and life safety of the building will be discussed throughout the remainder of this report. The intent of a performance based analysis is to evaluate whether a building meets certain measurable performance requirements without a specific prescribed method by which to attain those requirements. In the case of the Business Building, the performance criteria will be met if the available safe egress time (ASET) is greater than the required safe egress time (RSET).

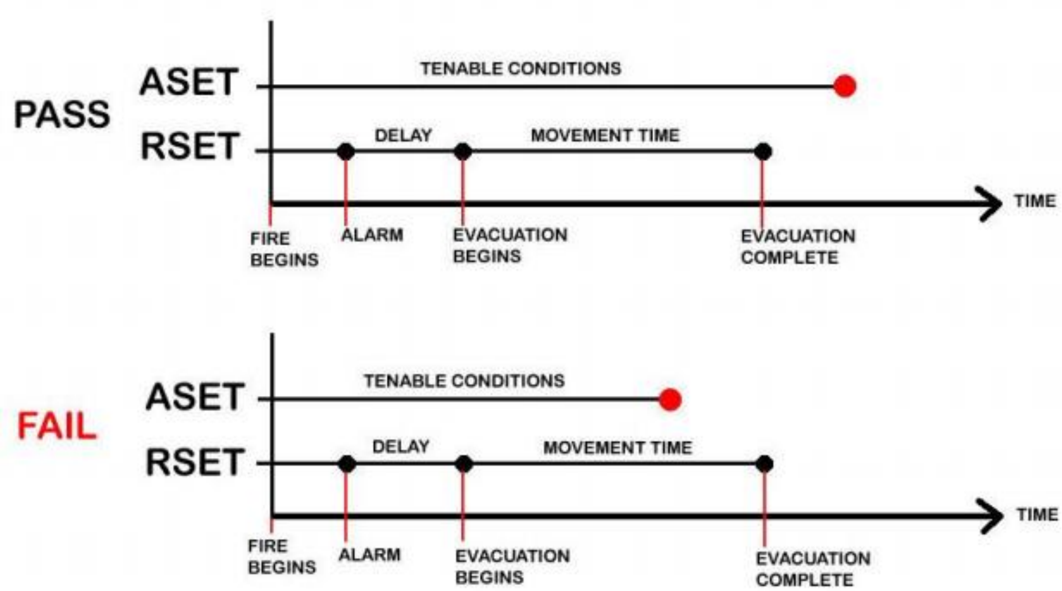

Figure 63. ASET vs RSET Pass and Fail Graph.

ASET is the amount of time that elapses between fire ignition and the development of untenable conditions. RSET is the amount of time, starting on fire ignition, that is required for occupants to evacuate a building or space and reach the building exterior or a protected exit enclosure [4]. Subsequent sections will discuss the ASET, based on an analyzed fire scenario using Fire Dynamics Simulator (FDS), and then will examine the RSET, based on calculated occupant egress times. Finally, the two times are compared, and recommendations are provided.

ASET

The ASET for the Business Building can change depending on the fire scenario evaluated. In general, the more hazardous the fire scenario, the less available safe egress time. Therefore, multiple possible hazardous fire scenarios were considered. It is important to note that all fire

scenarios explored are not developed just for the sake of this report. The possibility of these fire scenarios taking place exists and measures should be taken that the resulting consequences are minimized.

Two different types of design fire scenarios listed in Section 5.5.3 of the LSC should be considered in this building. One of these scenarios is Design Fire Scenario 1 (LSC 5.5.3.1), which is an occupancy-specific fire representative of a typical fire for the occupancy. It explicitly accounts for occupant activities, number and location of occupants, room size, contents and furnishings, fuel properties and ignition sources, ventilation conditions, and identification of the first item ignited and its location. Design Fire Scenario 8 is the design scenario considered in this report. Design Fire Scenario 8 (LSC 5.5.3.8) considers a fire originating in ordinary combustibles in a room or area with passive and active fire protection systems rendered ineffective. It addresses the concern regarding unreliability or unavailability of each fire protection system or feature.

Three possible fire scenarios are presented in the following sections. The first two are briefly discussed, and the final scenario is used in the ASET analysis as it is deemed to be the most hazardous and provide the least available safe egress time.

Fire Scenario 1

A teacher lounge exists on the fourth floor. This teacher lounge contains a large amount of combustibles throughout the room, seen in Figure 65. Ignition sources involved include electrical appliances such as the microwave, coffee maker, and refrigerator, as seen in Figure 64.

Figure 65. Teacher Lounge - Combustibles on Shelves.

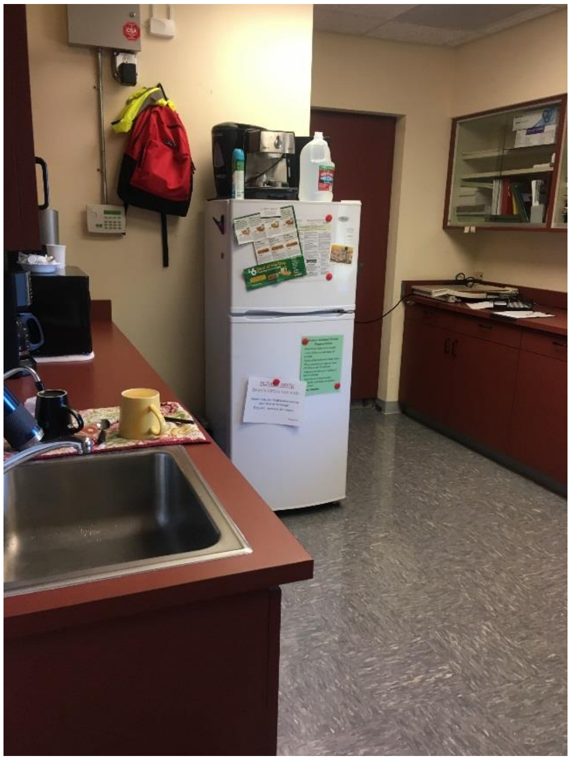

Figure 64. Teacher Lounge - Possible Ignition Sources.

The door leading into this room is connected to an unrated corridor, but this corridor leads into the rated corridor of the fourth floor. Both the door into the teacher lounge and the door leading into the rated corridor are open. Although the door leading into the teacher lounge is not required to be self-closing, the door leading into the rated corridor needs to be self-closing, and as seen in Figure 66 it is propped open with a wedge.

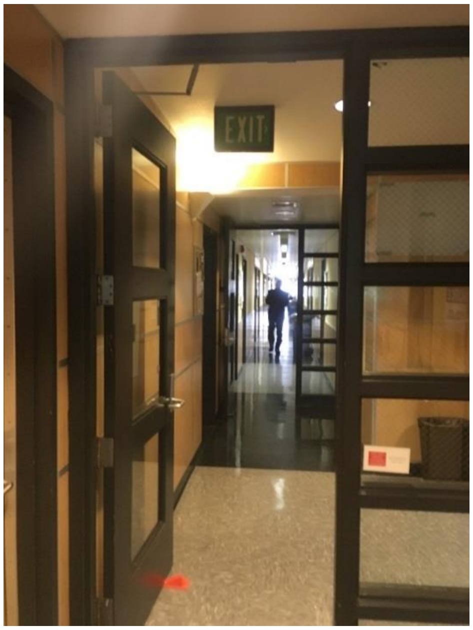

Figure 66. Propped Fire Door.

This scenario was considered because fire ignition and spread is possible in the teacher lounge and the propped open door can jeopardize the safety of the occupants from other parts of the building using the rated corridor as a means of egress.

Fire Scenario 2

An information and student support center also located on the fourth floor of the Business Building posed a possible fire hazard. This room had an access window with a shutter (it is undetermined if this shutter would automatically close in the case of a fire) and a propped open fire door, as seen in Figures 67 and 68.

Figure 68. Information and Support Services Center – Propped Fire Door.

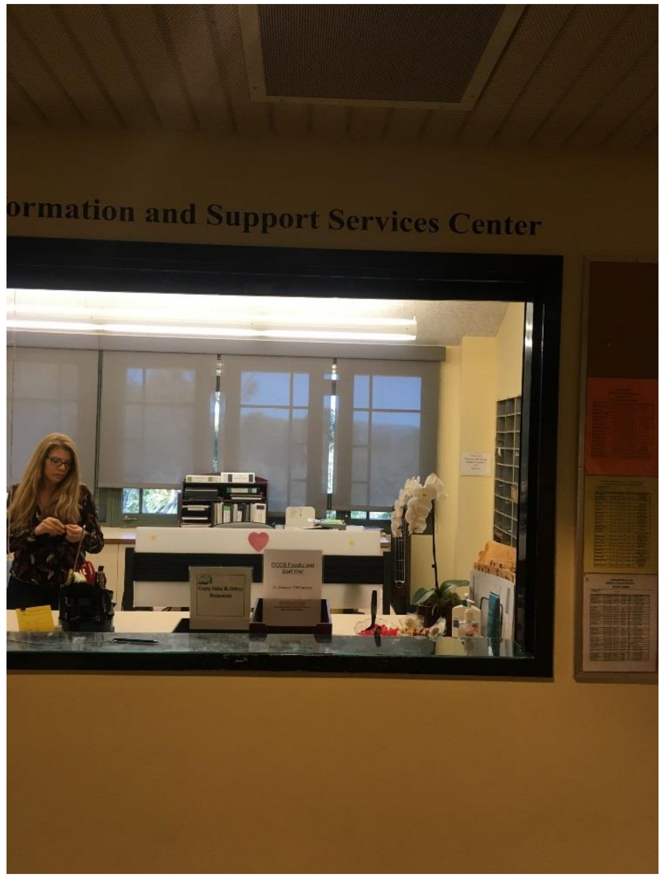

Figure 67. Information and Support Services Center – Open Access Window.

Inside the room is a significant amount of paper to the point where it is reminiscent of a mail room. This room is considered in the ASET analysis because the propped open fire door leads directly into the rated corridor, the primary means of egress of all occupants on the fourth floor to get to a protected exit enclosure. Thus, once again, a fire in this room could jeopardize the safety of all fourth-floor occupants using the protected corridor.

Fire Scenario 3 – Selected Fire Scenario

On the third floor exists a student lounge directly adjacent to the rated corridor. This student lounge has two self-closing doors propped open, one leading to an adjacent room, and the other leading to the rated corridor. Directly across from the propped-open door leading into the corridor is another propped open door leading into a computer lab. Figures 69, 70, and 71 show the lounge and location of the propped open doors.

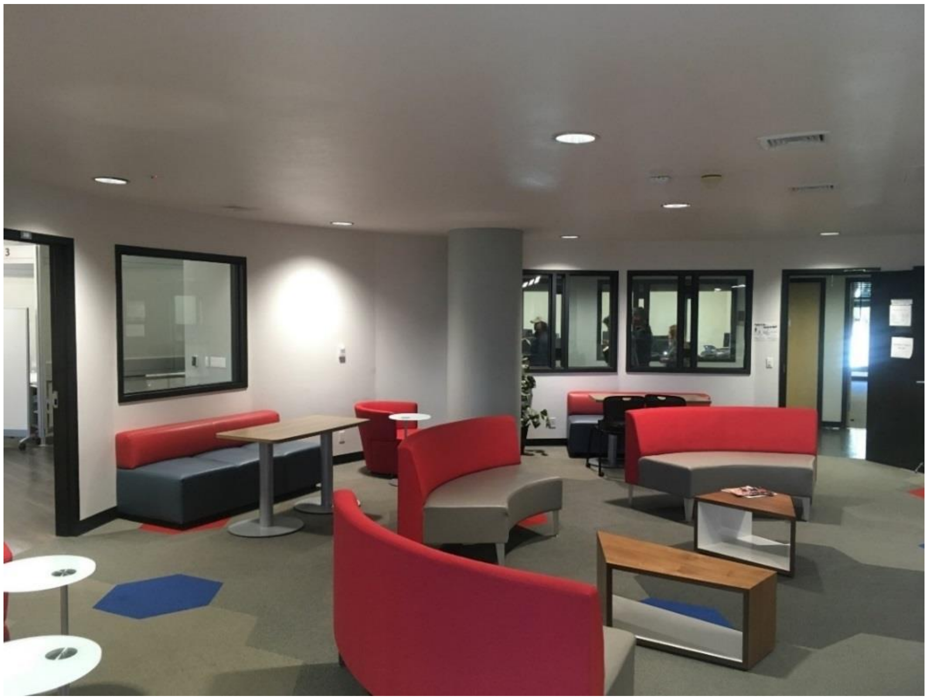

Figure 69. Student Lounge.

Figure 71. Student Lounge – Propped Fire Door.

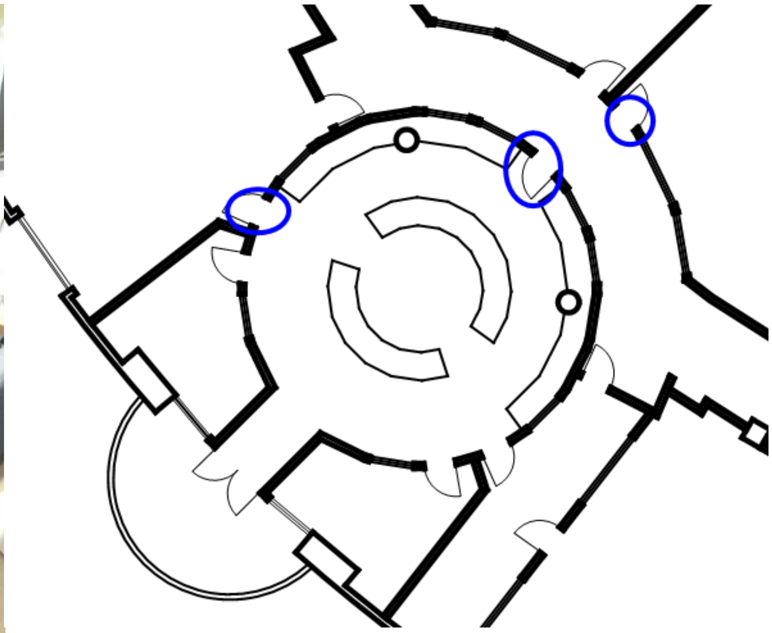

Figure 70. Student Lounge – Location of Propped Fire Doors.

Along with those propped-open doors, the fire door leading into the enclosed stairway is also propped open, effectively compromising the enclosure rating. The propped open stair door and location can be seen in Figures 72, 73, and 74.

Figure 73. Enclosed Stair – Propped Fire Door Leading into Corridor

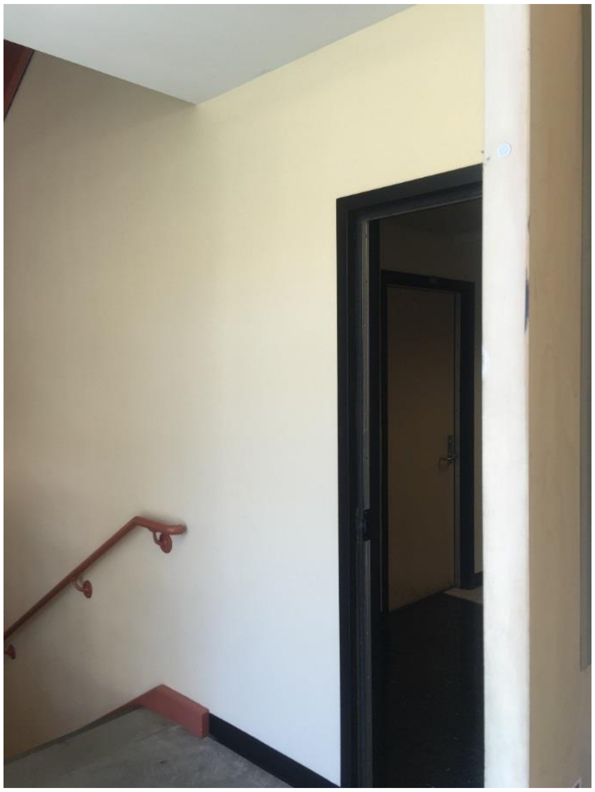

Figure 72. Enclosed Stair – Propped Fire Door.

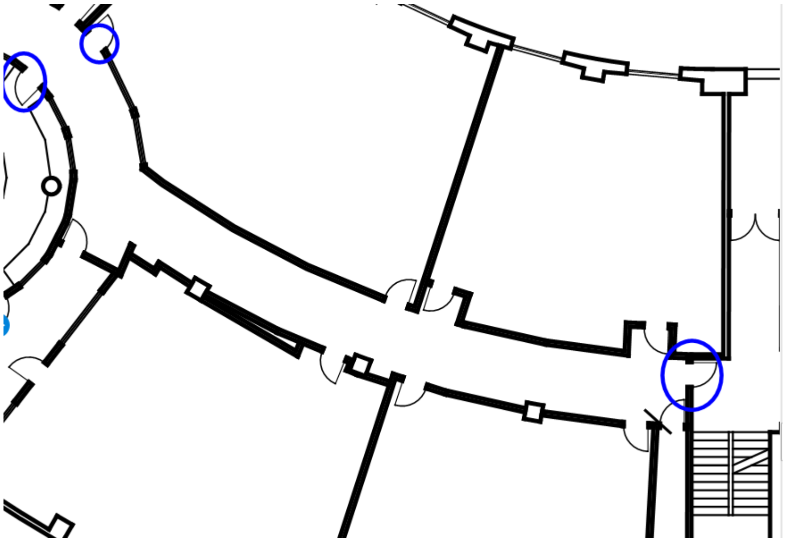

Figure 74. Enclosed Stair – Location of Propped Fire Door.

Because of the significant impact the propped open fire doors will have on the ASET, Fire Scenario 3 has been selected. It is believed that this scenario will produce the lowest ASET out of the proposed scenarios, which is why it is analyzed in this report.

A likely fire could start by the ignition of the shredder hooked up to an electrical outlet (assumed to be faulty, which causes the ignition), as seen in Figure 75. After the shredder ignites, the fire is assumed to spread to the carboard box, and subsequently to the adjacent wastebasket and recycling bin.

Figure 75. Fire Origin.

Fire Growth Parameters

The shredder is assumed to burn like a television set, since they have relatively similar sizes and similar compositions, both typically composed of primarily polycarbonate. The heat release rate (HRR) profile of a burning television set over time is demonstrated in Figure 76.

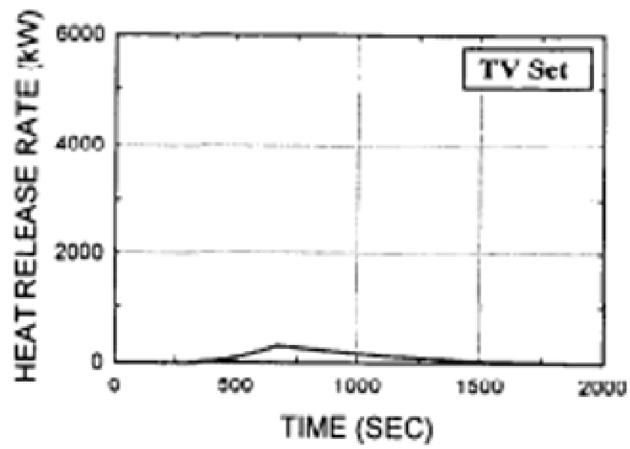

Figure 76. HRR Curve of TV Set.

The HRR peaks after 680 seconds at 300 kW and has a fire growth rate of α = 0.002163 kW/s^2. This data has been acquired by a study undergone by Kim and Lilley [5]. After the HRR of the initial fire reaches 17 kW, the cardboard box ignites [6]. Ignition of the cardboard occurs at 90 seconds after ignition, and it is assumed shortly after (10 seconds) that the fire spreads to the combustibles in the wastepaper basket and plastic bag in the recycling bin. It is then assumed that both the basket and bin attain sustained ignition.

Data for the HRR profile of a wastepaper basket filled with multiple milk cartons has been acquired also from Kim and Lilley, and the graph can be seen below.

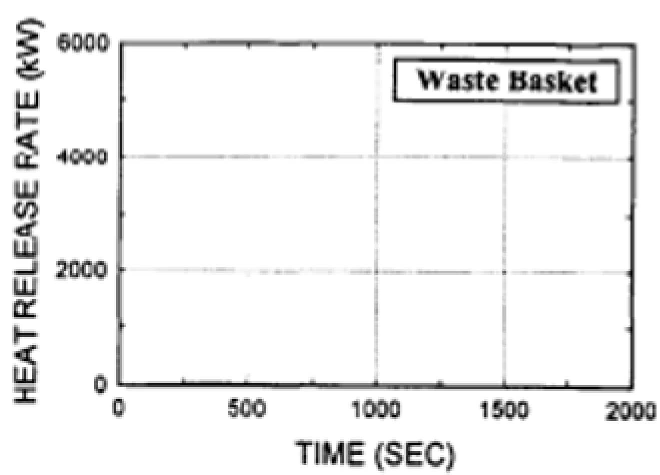

Figure 77. HRR Curve of Waste Basket.

The apparent lack of heat release in the graph above is due to the relatively small HRR of the tested wastepaper basket in comparison to the HRR scale. The test yielded a peak HRR of 15 kW, with a fire growth rate like that of the television set. Another test by Yamada [7] utilizing wastepaper baskets of different materials yielded a peak HRR ranging from 22 kW to 42 kW. The wastepaper basket composition most like the existing basket in the student lounge,

polypropylene, yielded a peak HRR of 41.8 kW. The same fire growth rate provided by Kim and Lilley is assumed.

Data for the large recycling bin is obtained from a study published by FEMA [8]. Assuming a polypropylene composition and thus a similar fire growth rate as the wastepaper basket, the max HRR for the large bin is 300 kW. It is important to note that the room contains multiple couches that meet California Bulletin 133, which requires the HRR of such products to be no more than 80 kW. Fire spread to couches in this room is not considered in this analysis, but the occurrence of such an event is possible and is discussed later in the recommendations section of this report.

The fire is assumed to follow the t-squared model:

$$Q = \alpha t^2$$

Where Q is the HRR, α is the fire growth rate parameter, and t is time.

Fuel Characteristics and Combustion Products

The fuel characteristics and combustion products for the burning items are summarized below. The following data was obtained from Appendix A of the SFPE Handbook [9].

Shredder –

- Polycarbonate – PC-$CH_{0.88}O_{0.13}$
- Soot yield – 0.112 g/g
- CO yield – 0.054 g/g
- ΔH – 31.6 kJ/g

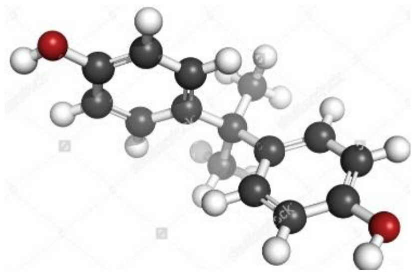

Figure 78. Molecular Structure of PC.

Wastepaper Basket, Recycling Bin –

- Polypropylene – PP-C_3H_6
- Soot yield – 0.059 g/g
- CO yield – 0.024 g/g
- ΔH – 43.4 kJ/g

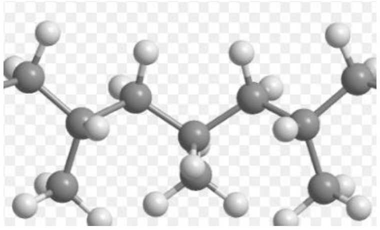

Figure 79. Molecular Structure of PP.

Fuel characteristics include soot and carbon monoxide yield, and these yields will have a direct impact on the tenability of spaces considered. Prior to discussion of the tenability criteria, it is imperative to assess the performance criterion used in this analysis.

Performance Criterion

The performance criterion of the LSC Section 5.2.2 is used in this analysis, stating: *any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions.* More specifically, Method 2 of the LSC (Section A.5.2.2) is employed, stating: *each area will be completely evacuated before the smoke and toxic gas layer reaches 6 ft above the*

floor. Essentially if untenable conditions, as prescribed in the following section, reaches 6 ft above the floor, the performance criterion is not met.

Tenability Criteria

Generally, the three tenability criteria employed in a RSET vs ASET performance based analysis are visibility, incapacitating gas dosage, and temperature.

Visibility

Visibility is typically the first criteria examined in a general fire modeling scenario, as it is typically the first criteria to fail. Purser and McAllister [10] suggest that occupants will not use an escape route if the visibility is less than 3 meters (m). They suggest that a visibility less than 5 m in small enclosures and 10 m in large enclosures could impair or prevent the escape of occupants. Jin [11] states that a 4m visibility limit should be adequate for occupants familiar with the building, while unfamiliar occupants would need 13 m of visibility. A 10 m visibility limit is conservative and is the selected visibility limit.

Carbon Monoxide Concentration

The inhalation of intoxicating gases plays a significant role in the incapacitation of occupants during a fire scenario. The two major asphyxiant gases in fires are carbon monoxide (CO) and hydrogen cyanide (HCN). In this analysis, only CO concentration will be considered. CO is always present to some degree in fires, and thus there is always some threat of asphyxia from CO exposure. Carbon monoxide combines with hemoglobin in the blood, resulting in toxic asphyxia because it reduces oxygen supplied to body tissue [10]. Purser and McAllister suggest that an occupant should be exposed to a CO concentration of no more than 1400 parts per million (ppm) over a 30-minute period, per Table 63.28 of the SFPE Handbook. However, Table 63.9 suggests that 30,000 ppm min should be the maximum exposure for any occupant. Therefore, over a 30-minute period, the occupant should not be exposed to more than 1000 ppm. The more conservative limit of 1000 ppm is selected in this analysis.

Temperature

Exposure to high temperatures can cause incapacitation through three ways: hyperthermia, skin pain/burns, and respiratory tract burns. Hadjisophocleous [12] summarizes lower and upper limits of deterministic criteria. Among these criteria is pre-flashover life safety temperature, where the lower limit is 65 °C. Purser and McAllister suggest that the allowable temperature should not exceed 60 °C throughout a 30-minute exposure. High temperatures are directly related to the erythema of the occupant, where above the stated tenability boundary, the pain will progress towards an unbearable limit. 60 °C has been selected as the tenability limit.

An overview of the tenability limits can be seen below.

Tenability Criteria	Limit at 6 ft. above Floor
Visibility	Minimum - 10 m
CO Concentration	Maximum – 1000 ppm
Temperature	Maximum - 60 °C

Tenability Analysis

To determine whether the selected fire scenario would cause a failure in the performance criteria, the event was modeled using Pyrosim and Fire Dynamics Simulator (FDS). FDS is defined as a *large-eddy simulation code for low-speed flows, with an emphasis on smoke and heat transport from fires* and *a computational fluid dynamics (CFD) model of fire-driven flow* [13]. Essentially, this NIST-developed program models fire and smoke evolution of inputted fire scenarios with a relatively high-degree of accuracy. Pyrosim is simply a graphical user interface for FDS.

The model in Figure 80 is intended to simulate the fire scenario within the area seen in the floor plan below to it. The areas modeled are environmentally connected to the fire origin location due to the propped open doors mentioned previously.

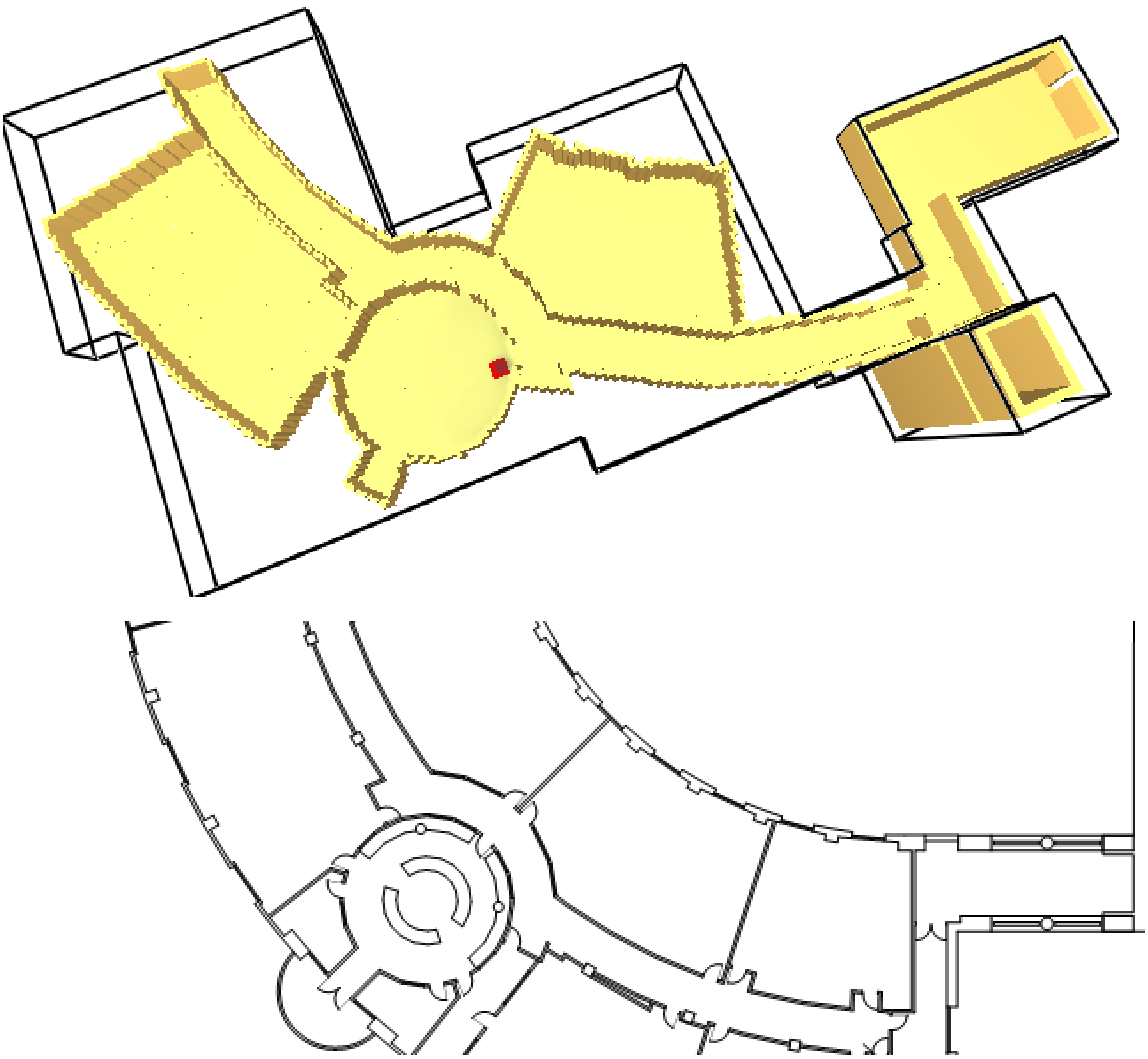

Figure 80. Comparison of Model to Floorplan.

Figure 81 below shows the wastepaper basket and recycling bin when they ignite, around 100 seconds.

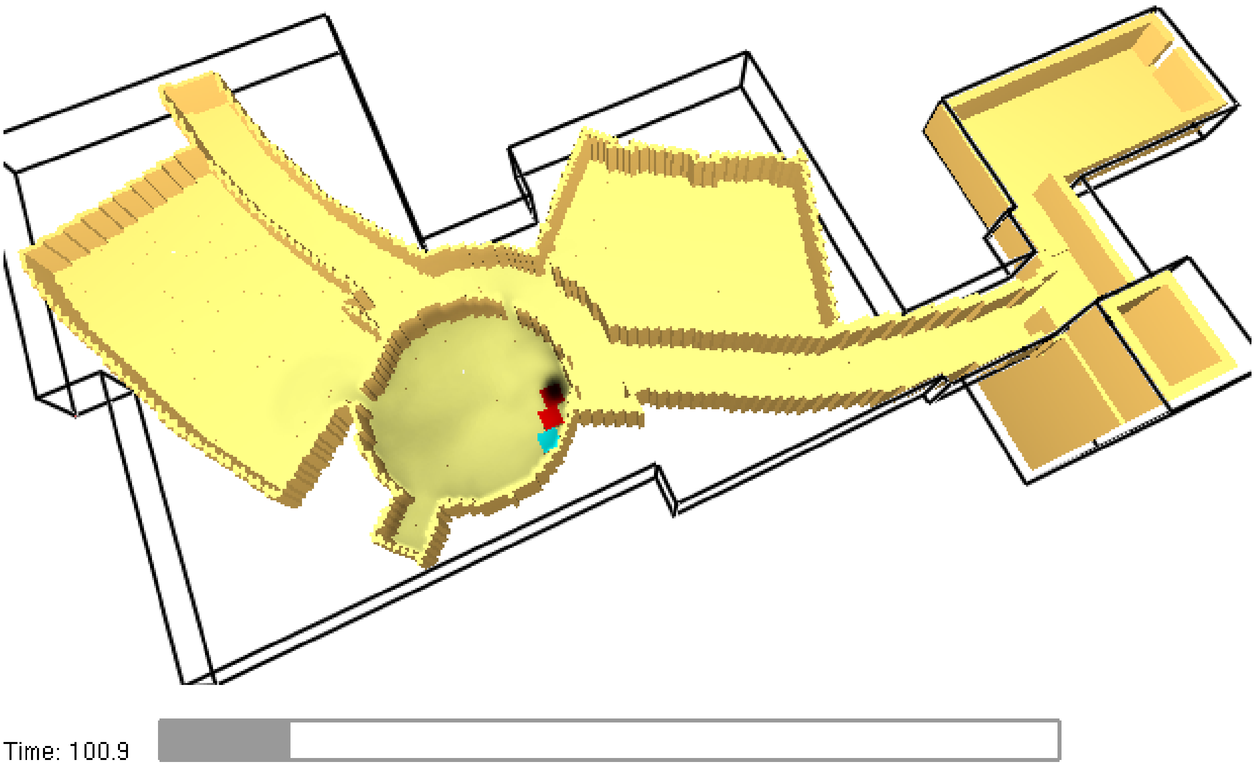

Figure 81. Simulation at Time of Wastepaper and Recycling Bin Ignition.

Following are the times at which each tenability limit is met. The tenability limits are analyzed in the corridor, the primary means of egress, which leads to the stairway. Although the door leading into the enclosed stairway is simulated as open in this scenario, all the tenability criteria passed in the stairway area for a 700-second duration.

Carbon Monoxide Concentration

The carbon monoxide concentration was monitored throughout a 700-second duration to evaluate when it exceeds the tenability limit, as seen in Figure 82.

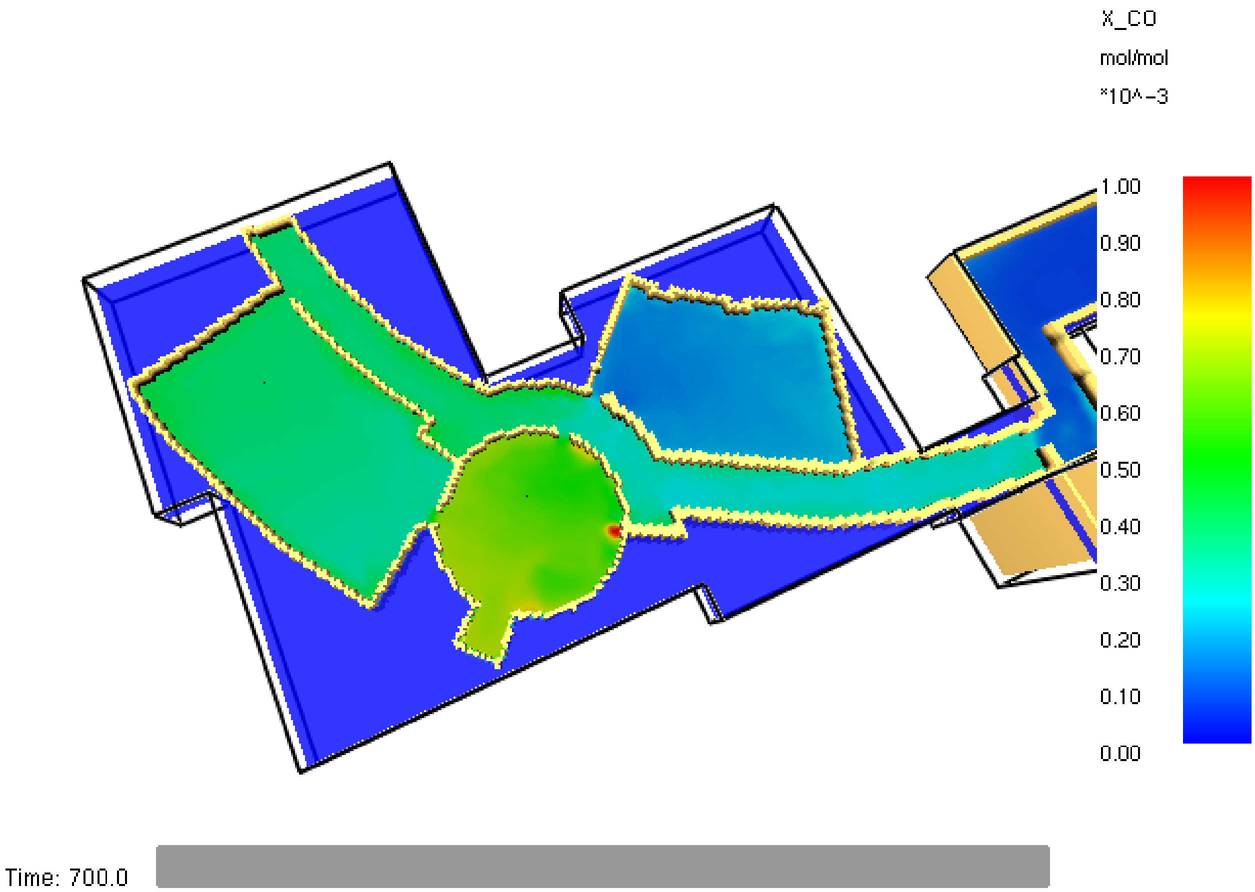

Figure 82. CO Concentration after 700 s.

The CO concentration does not exceed the 1000 ppm limit throughout the simulation.

Temperature

The model barely reaches the full duration of the simulation before it is assumed the temperature limit is reached, as seen in the Figure 83.

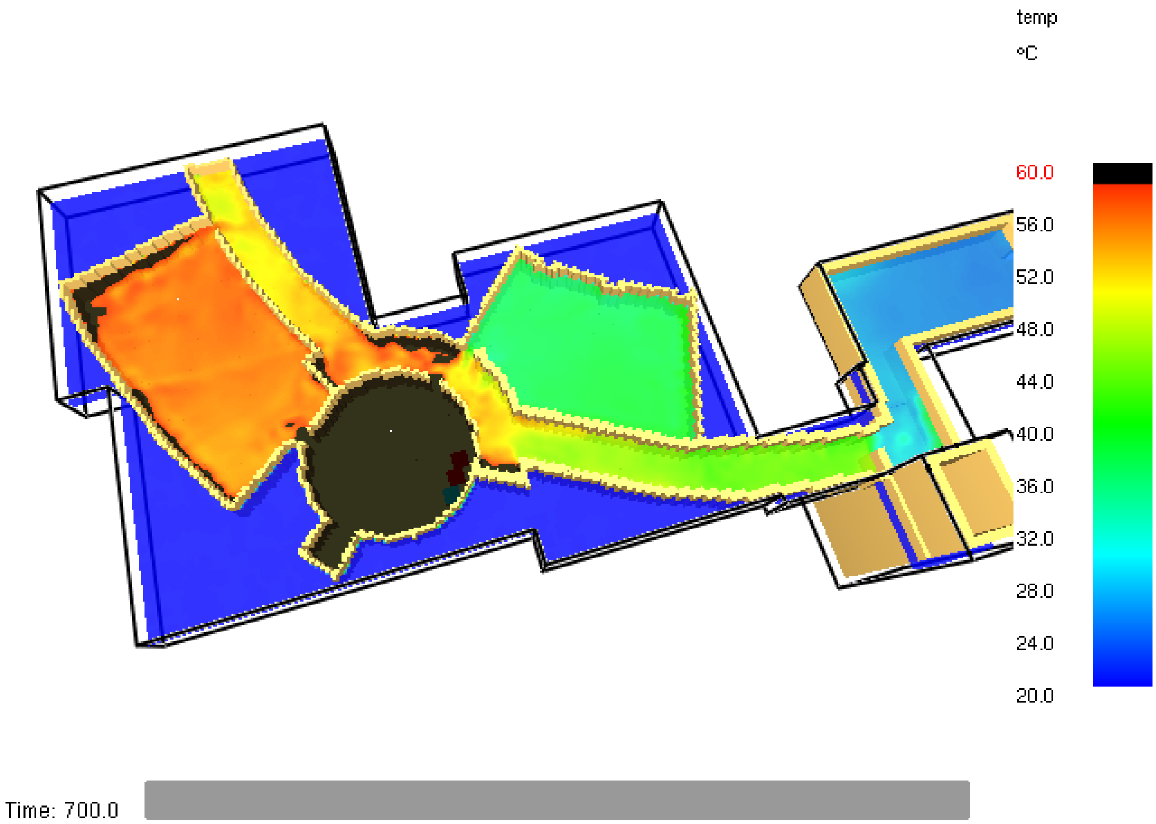

Figure 83. Temperature after 700 s.

Visibility

Visibility was analyzed under two different conditions. As mentioned previously in the prescriptive section of this report, multiple exit signs were found not illuminated. Whether exit signs are illuminated or not plays a direct role in the visibility of the occupants in which smoke obscuration exists.

Visibility (S) is a function of C, the characteristic constant, and K, the light extinction coefficient, where S = C/K. The characteristic constant is fully dependent on whether illuminated signs exist or not. Thus, C=3 for a light-reflecting sign (non-illuminated) and C=8 for a light-emitting sign. The light emitting signs result in better visibility.

If the exit signs remain in their current non-illuminated condition in the selected fire scenario, visibility drops below 10 m at 300 seconds, as seen in Figure 84.

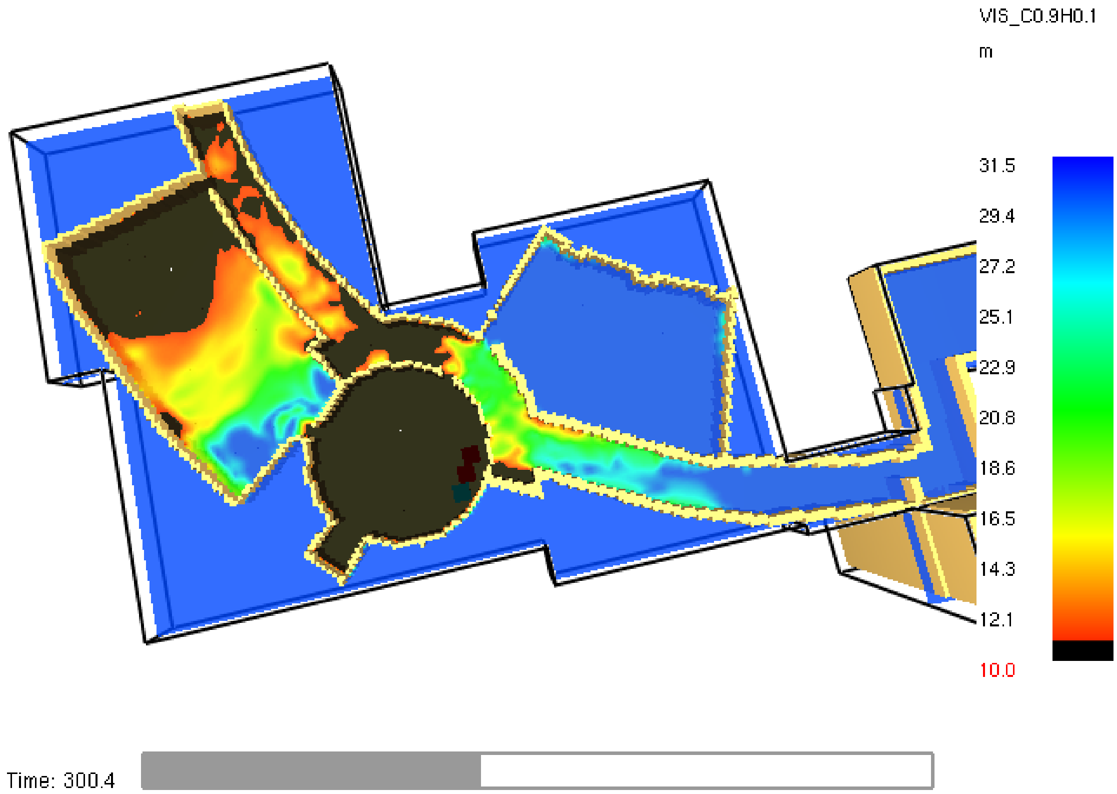

Figure 84. Time when Visibility Drops below 10 m, C=3.

If exit signs are illuminated, visibility drops below 10 m at 354 seconds, as seen in Figure 85.

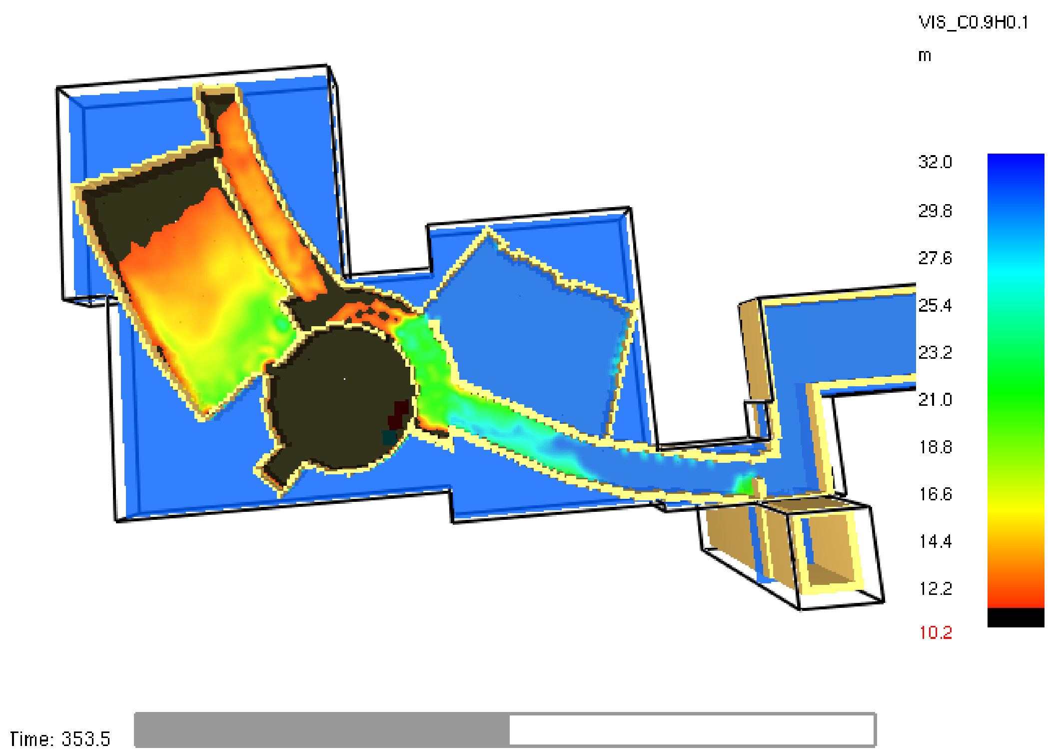

Figure 85. Time when Visibility Drops below 10 m, C=8.

When the exit signs are light-emitting, the occupants have an extra 53 seconds to evacuate before untenable conditions develop.

Result Summary

The tenability criteria for CO and temperature did not exceed the maximum allowable limit throughout a 700 second duration. Visibility drops below 10 m at **300 seconds** with non-illuminated signs, and **353 seconds** with illuminated signs.

RSET

The approach used in this analysis to determine RSET is an egress analysis based on the total time required for occupants to exit the building when the building is at full capacity.

RSET is calculated as the sum of individual times for different events in the fire scenario.

$RSET = t_d + t_n + t_{p-e} + t_e$

t_d: time from fire ignition to detection
t_n: time from detection to notification of occupants of a fire emergency
t_{p-e}: time from notification until evacuation commences
t_e: time from the start of evacuation until safety is reached

RSET can be evaluated in two period, the pre-evacuation period, and the movement period, as depicted in Figure 86.

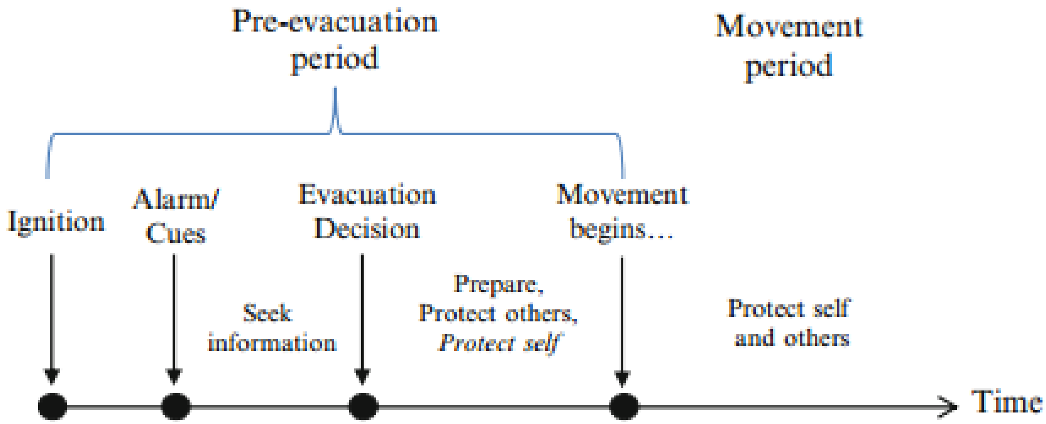

Figure 86. Categorization of RSET.

Pre-evacuation Period

First, occupants in the Business Building must be made aware of the fire. Thus, the first component is fire detection. Smoke detectors were inputted in the FDS models presented earlier. Detectors activated 49 seconds after fire ignition in the simulation.

The notification appliances will activate 30 seconds after detection, per Chapter 37 of the Fundamentals of Firefighter Skills [14], which will make occupants aware of the situation.

Pre-movement times vary depending on occupant characteristics. These characteristics are listed below.

Alertness and Limitation considers how much an occupant is paying attention to his or her surroundings, and whether they can physically and mentally react to a given stimuli that may indicate a fire.

Commitment deals with occupants that may under prioritize the necessity to exit a building after fire notification. Committed occupants may be focusing on an activity that may lead them to "brush off" warning sounds.

Staff refers to how those with fire protection training respond and instruct in life safety situations. Those with training can greatly reduce egress time during an unexpected situation.

Familiarity deals with whether occupants know their way around a building, and perhaps have participated in fire drills. If occupants are familiar with the building, the egress time will be reduced.

In this case, it is assumed the students are alert, familiar with the surroundings, and don't have a commitment to stay where they are.

Studies providing insight on pre-movement times in different scenarios is provided in Chapter 64 of the SFPE Handbook. One study was on a five-floor university in New Zealand, and the occupant characteristics and observational conditions were like the scenario being analyzed in the Business building. Table 64.9 of the SFPE Handbook (Table 15) demonstrates the summary of this study.

Table 15. Pre-Movement Times in Various Scenarios.

Source	Observational conditions (L: location, N: nature, SC: spatial configuration, P: participants, E: environment, V: variable)	Procedure			Sample		Results (sec)	
		Strategy	Staff	Technology	Collection method	Size	Mean [S.D., range]	Additional information
Olsson and Regan [77], [78]	L: NZ N:AE1–3 SC: university AE1: floor 1; AE2 floors 8; AE3: 5 floors P: AE1: 278, AE2: 716, AE3: 494 V: different events and alarms (AE1–3)	Full	–	AE1: AL AE2: PV AE3: LV	Video	–	38, 28[a] [–,–] 19,24[a] [–,–] 20, 27[a][–,–]	[a]Means for different location/areas in each event A siren was used

The results column of this study reveals the average pre-movement time. 38 seconds was used as it is the most conservative pre-movement time.

Thus, summing all the times in the pre-evacuation period:

$t_d + t_n + t_{p\text{-}e} = 49 + 30 + 38 =$ **117 seconds**

Movement Period

To solve for the initial movement to evacuation time, the occupant load must be considered for the areas under consideration. The total occupant load of Level 3 is 335. The third floor has 3 exits, spaced roughly equidistant apart. Therefore, it is assumed that 1/3 of the load (112 occupants) will use the southeast stair, including occupants intimate with the fire origin, as the means of egress. The worst-case room considered in this analysis is the room opposite to the fire origin, which is a computer lab that has two exits into the corridor. The fire door closest to the room of fire origin is propped open. The room of fire origin was not considered because it is likely that if a fire started in that room when it is occupied, the pre-evacuation period would be at a minimum. Please see Figure 87 for the room under consideration.

Smoke will initially enter this room through the propped open fire door. It is assumed all occupants in this room will use the door closer to the stair to escape. This door is circled in Figure 87.

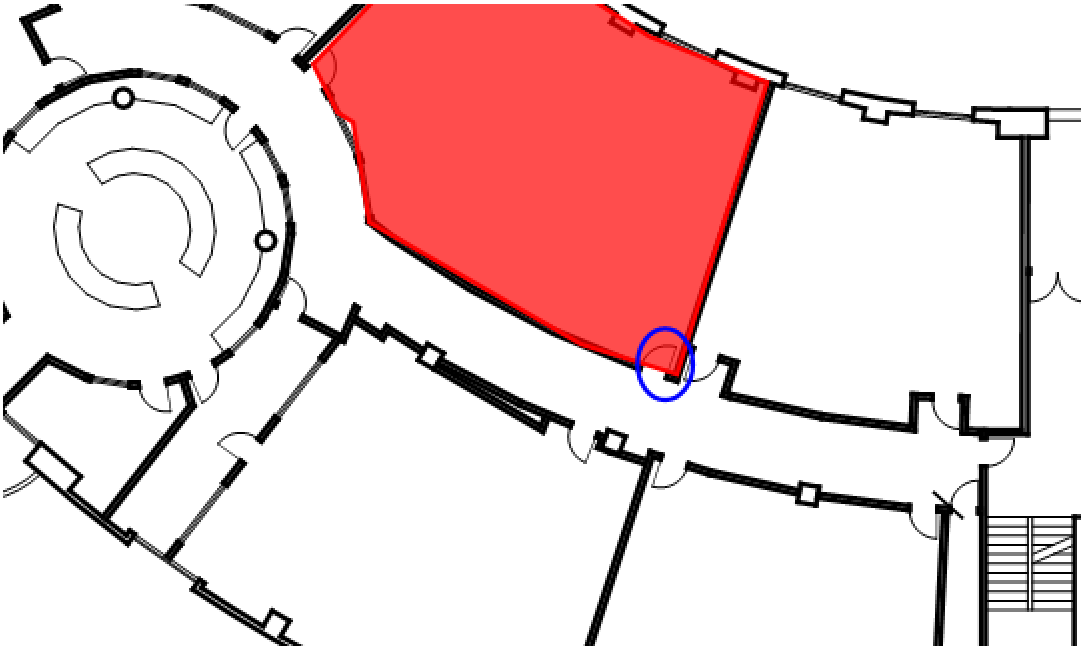

Figure 87. Computer Lab used for RSET Analysis.

Egress calculations follow:

Per Table 59.4 of the SFPE Handbook, the unimpeded speed of travel is approximately 235 feet per minute (ft/min). In this analysis, a travel speed of 200 ft/min is used.

- For the occupants in the computer lab, additional delay at the doorway is calculated as follows (using Chapter 59 of the SFPE Handbook):
  - Effective door width (with boundary layer reduction) for a 3-foot door = 24 inches (2 feet)

- Specific flow through doors: Fsm = 24 people / (min ft)
- Flow of doors: Fc = 24 people / (min ft) x 2 ft = 48 (people)/min
- The occupant load of the computer lab is 38 people at capacity.
- Time delay through door = (38 people) / (48 (people)/min) = **47.5 seconds**

- Horizontal travel time:
  - Travel distance to stair door from most remote area in computer lab: 100 feet
  - Egress travel speed = 200 ft/min
  - Travel time = (100 ft) / (200 ft/min) = **30 seconds**
- Delay passing through the stair door is calculated as follows:
  - Effective door width (with boundary layer reduction) for a 3-foot door = 24 inches (2 feet)
  - Specific flow through doors: Fsm = 24 people / (min ft)
  - Flow of doors: Fc = 24 people / (min ft) x 2 ft = 48 (people)/min
  - The maximum occupant load through the stair door is 112.
  - Time delay through door = (112 people) / (48 (people)/min) = **140 seconds**

Altogether, the movement period totals at **218 seconds**. A safety factor of 1.5 is used, thus bringing the movement period time to **327 seconds.**

Although the occupants are technically not safe in the stair, it was assumed that once they enter the stair they are safe. Because the corridor fails before the stair fails, actions must be taken to rectify the threat regardless.

Total RSET

Combining both pre-movement and movement periods, the total RSET is now solved for:

RSET = $t_d + t_n + t_{p-e} + 1.5(t_e)$ = 49 + 30 + 38 + 1.5(218) = **444 seconds**. In the next section, RSET will be compared to ASET and the performance criterion will be assessed.

ASET vs RSET

For the performance criterion to be considered successful, tenable conditions must exist in the path of egress until occupants have fully evacuated. The available safe egress time must exceed the required safe egress time, as seen in Figure 88.

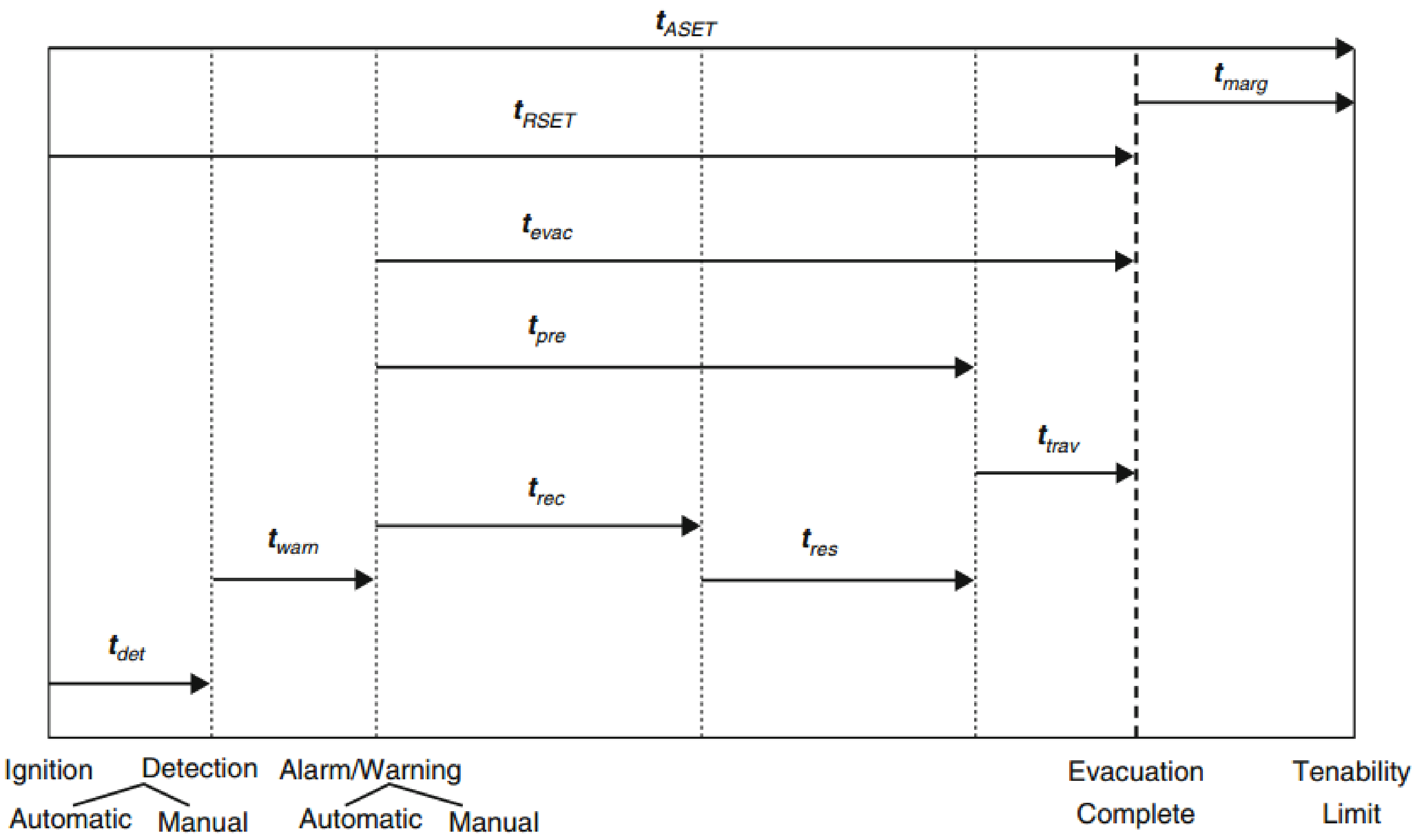

Figure 88. Ideal ASET Situation.

Because the visibility is the only tenability criteria that fails in a 700-second duration of the fire scenario simulation, it is the restricting tenability criteria. Visibility fails at 300 seconds in current building conditions. Thus, the ASET is 300 seconds. As reported in the previous section, the RSET is 444 seconds. Therefore, the RSET exceeds the ASET and Method 2 of the LSC is not met. The current condition of Floor 3 is unacceptable regarding occupant life safety and measures should be taken to improve conditions immediately.

Conclusions & Recommendations

Both prescriptive and performance based analyses are executed on the Orfalea College of Business in this report, using the California Building Code, the Life Safety Code, and relevant NFPA standards. The prescriptive requirements are generally met. These requirements include those regarding egress systems, structural fire protection, fire detection and alarm systems,

smoke management systems and fire suppression systems. In instances where the prescriptive codes are violated, the ramifications of such violations could be severe.

Such violations in the egress system include the placement of tables and chairs in the means of egress of the silo, effectively reducing the egress width below what is acceptable. These obstructions can impede egress movement, which is dangerous when there is over 200 people in one lecture hall with only two exits, and the egress movement towards one exit is impeded. To remedy this issue, the Owner must ensure that no obstructions are placed in any means of egress, by administrative means or even by providing a means by which all furniture is permanent (such as the rest of the fixed seating).

The fire alarm system does not meet current full-coverage requirements listed in NFPA 72. The second and third floor corridors, as well as many rooms lack smoke detection as well as visible notification. It is recommended that a full-coverage upgrade is implemented to provide occupants with the highest probability of escaping a fire scenario.

The fire suppression system is unreliable, due to its dependence on manual suppression. Fire hose cabinets exist throughout the building, but an automatic sprinkler system would greatly reduce the impact of most possible fire scenarios, not only for occupant safety but also to minimize property damage. An automatic sprinkler system is expensive, but because much of the piping is already existent for the manual suppression system, the cost-effectiveness may be higher.

Violations in requirements regarding structural fire protection relate to the issues identified in the smoke management system. Far too many fire doors meant to be self-closing were propped open, effectively compromising rated corridors and exit enclosures. The entire foundation of all three presented fire scenarios relied on propped-open fire doors to allow smoke spread into the corridor. These violations are undoubtedly the most concerning issue found in the Business Building.

In the performance, based analysis, the RSET, at 444 seconds, exceeded the ASET, at 300 seconds. Because the RSET exceeds the ASET, the performance criterion is not met, and the campus should re-evaluate their fire protection features in the Business Building as soon as possible. To mitigate much of the risk, maintain all rated doors in their appropriate position and rid the building of wedges. Periodic administrative door regulation is one way to ensure doors remain in their proper position. This recommendation may seem excessive, but because of the lack of active smoke control, the fire doors are the sole protection against smoke spread. Additionally, ensure exit signs are illuminated to extend the ASET. Finally, it is important to note that the scenario analyzed did not consider fire spread to the rest of the combustible couches located throughout the room of fire origin. Although expensive, sprinklers may indeed stop the fire from spreading and reducing the ASET to an even greater degree due to the amount of combustibles located in the student lounge.

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