June 2015

Course | FPE 596: Culminating Experience in Fire Protection Engineering

Professors | Christopher Pascual & Frederick W. Mowrer

Author | Christopher Torres

Photo #1: Construction Innovation Center at California Polytechnic State University, San Luis Obispo

[FIRE AND LIFE SAFETY ANALYSIS]

Statement of Disclaimer

Key Words

Cal Poly, Construction Innovation Center, Building 186, Fire & Life Safety Analysis, Prescriptive Analysis Approach, Fire Structure Protection, Means of Egress, Fire Alarm & Communication, Fire-Suppression System, and Performance–Based Analysis Approach

Acknowledgement

Christopher Torres would like to acknowledge and thank the following individuals for their assistance and guidance during the Fire Protection Engineering Master Program. The results of this endeavor would not have been possible without you.

Professor Frederick Mowrer

Professor Christopher Pascual

Dr. Chris Lautenberger

Dr. David Rich

Professor Lonnie Simonian

Associate Professor Thomas Korman

Professor Kevin Dong

Dr. Francisco Joglar

Mr. Morgan Hurley

Architect Rex Wolf

Ivy Rose Jose Ando

Table of Contents

Table of Contents – Continuation

Table of Contents – Continuation

Appendices

1. Scope of Work / Introduction

The Trustees of the California State University (client) has requested a comprehensive fire and life safety analysis of Building 186, Construction Innovation Center, at California Polytechnic State University, San Luis Obispo. The analysis includes an evaluation of the fire structure protection, means of egress, fire alarm & communication, and fire–suppression system.

1.2. Executive Summary

The report summarizes the analysis of the existing fire protection features and systems installed in the Construction Innovation Center at California Polytechnic State University, San Luis Obispo. The center is divided into three individual buildings (Buildings A, B and C) and are connected at each floor by an exterior balcony. The analysis includes two different approaches. A prescriptive analysis approach has been used to examine if the installed fire protection features and systems compliance with the latest edition of the codes and standards in California. This approach includes an evaluation of the fire structure protection, means of egress, fire alarm & communication, and fire-suppression system of the center. A performance–based analysis approach has also been used to assess whether the building occupants will egress the center before conditions become untenable. Fire Dynamics Simulator and Pathfinder, two computer software programs, have been used to determine the available and required safe egress time. A fire scenario has been selected for Buildings A and B to assess its tenability conditions. Building C was not selected as part of the tenability analysis due to time constraint and low existing ignition sources.

2. Codes & Standards

For the purpose of this report, all prescriptive requirements toward the Construction Innovations Center will be taken from the California Building Code (CBC) and California Fire Code (CFC), 2013 edition, unless stated otherwise. The center will be considered “new building” and thus the provisions from CBC Chapter 34 for existing building will not apply.

2.1. Partial List of Applicable Codes during Construction

2001 Building Standards Administrative Code, Part 1, Title 24 C.C.R.
2001 California Building Code (CBC) Part 2, Title 24 C.C.R. (Based on 1997 UBC)
2001 California Electrical Code (CEC) Part 3, Title 24 C.C.R. (Based on 1999 NEC)
2001 California Mechanical Code (CMC) Part 4, Title 24 C.C.R. (Based on 2000 UMC)
2001 California Plumbing Code (CPC) Part 5, Title 24 C.C.R. (Based on 2000 UPC)
2001 California Energy Code, Part 6, Title 24 C.C.R.
2001 California Elevator Safety Construction Code, Part 7, Title 24 C.C.R.
2001 California Historical Building Code, Part 8, Title 24 C.C.R.
2001 California Fire Code (CFC) Part 9, Title 24 C.C.R.

2.2. Partial List of Applicable Standards during Construction

NFPA 13, 1999 Edition – Automatic Sprinkler Systems
NFPA 20, 1999 Edition – Stationary Pumps
NFPA 24, 1995 Edition – Private Fire Service Mains
NFPA 72, 1999 Edition – National Fire Alarm Code (California Amended)

Note: See UL Standard 1971, 2002 Edition, for "Visual Devices"

3. Authority Having Jurisdiction

All major emergencies within campus must be coordinated with the following agencies and Authorities Having Jurisdiction (AHJ):

- SLO City and County first responder agencies
- State of California, Office of Emergency Services (State OES)
- County Office of Emergency Services (County OES)
- Federal Emergency Management Agency (FEMA)

4. Building General Description

The Construction Innovations Center is an approximately 30,000 square feet center dedicated to the Construction Management Department. The center was completed in 2008. It is located on the south–west of California Polytechnic State University, San Luis Obispo, as illustrated in *Appendix A*. It features seven laboratories, 12 classrooms and lecture halls, faculty offices, and headquarters for the California Center for Construction Education. The center is divided into three individual buildings, as illustrated in Photo #2.

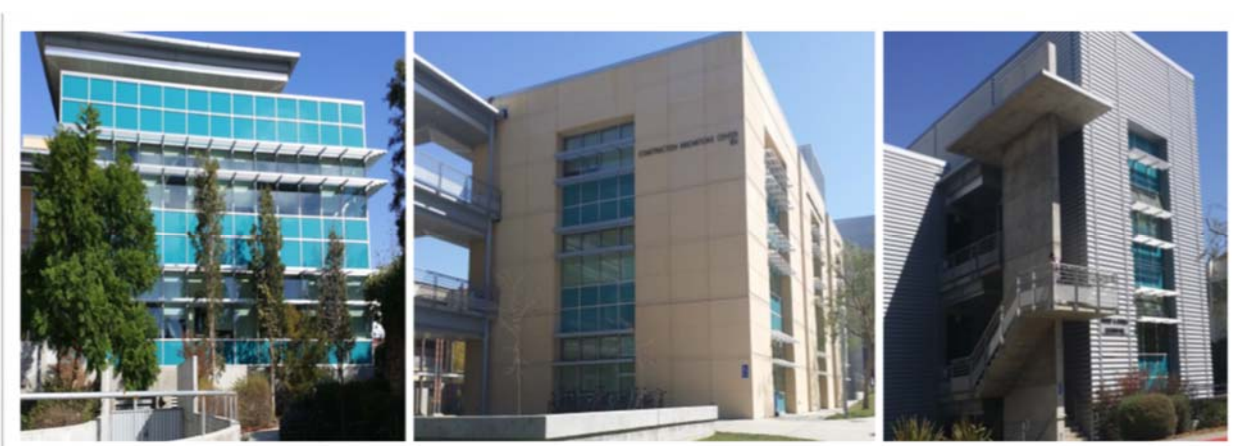


Photo #2: Building A (left), Building B (middle), & Building C (right)

5. Occupancy Classification

References – CBC Section 304.1

The Construction Innovations Center has been classified as Group B Occupancy. This classification is appropriate since the center contains classrooms and laboratories, of less than 50 occupants, for educating students above the 12th grade. *Appendix E* illustrates a color coding representation of varies spaces within the center.

5.1. Small Assembly Spaces

References – CBC Section 303.1.2

The Construction Innovations Center comprises of rooms and areas used for assembly purposes such as waiting areas. These spaces have been treated as an accessory to the primary occupancy since its occupant load is less than 50 persons or less than 750 square. Additionally, they have been classified the same as the primary occupancy classification, Group B Occupancy, as illustrated in *Appendix E*.

5.1.1. Accessory Occupancies

References – CBC Section 508.2

The purpose of these accessory occupancies is to be secondary to the building's primary function. The activities that occur in accessory use rooms or spaces are necessary for the primary occupancy to properly operate.

6. Building Existing Dimensional Characteristics

The existing dimensional characteristics of the Construction Innovation Center include features such as the areas, height, and amount of stories of the center.

6.1. Building Existing Areas

The area of each floor is the "footprint" of the building. The area is measured within the perimeter formed by the inside surface of the exterior walls. There are two types of floor areas, as described below:

- **Gross Area**: This includes all occupied and non–occupied spaces such as mechanical shaft, elevator shafts, toilet rooms, closets, and mechanical equipment rooms.
- **Net Area**: This only includes actual occupied spaces and excludes circulation spaces (corridors or stairways) and service & utility spaces (restrooms and mechanical & electrical equipment rooms).

The gross and net floor area is primarily used for the determination of occupant load. The existing gross areas for the Construction Innovations Center are described in the table below:

Floors	Building A	Building B	Building C	Total
Basement	1,770 SF	0 SF	0 SF	1,770 SF
First	5,384 SF	8,178 SF	3,004 SF	21,498 SF
Second	5,384 SF	8,184 SF	3,054 SF	17,488 SF
Third	2,525 SF	8,264 SF	3,054 SF	14,573 SF
Total	15,144 SF	24,626 SF	9,122 SF	48,882 SF

6.2. Building Existing Height & Story

Building height is measured to the highest roof surface. In the case of a building with multiple roof levels, the highest of the various roof levels must be used to determine the building height. If the highest of the various roof levels is a sloped roof, then the average height of that sloped roof must be used.

A story is the portion of a building that is in between the upper surface of a floor and the upper surface of the floor or roof next above.

The existing height and story for the Construction Innovations Center are described in the table below:

Buildings	Existing Stories [a]	Existing Height [b]
A	3	46 feet
B	3	46 feet
C	3	58 feet

a. The existing stories for each building only include levels above grade.
b. The existing height is measured between grade plane and top of parapet.

6.2.1. Basement

Defining the amount of stories above grade is important in determining the allowable height for the Construction Innovations Center. The code, by definition, establishes which stories of a building are those above grade plane. These include stories that have its finished floor surface entirely above grade plane or the finished surface of the floor next above is as follow:

- More than 6 feet above grade plane; or
- More than 12 feet above the finished ground level at any point.

Building levels not categories as a story above grade plane is, by definition, a basement. Building A from the Construction Innovation Center consists of a single basement, as illustrated in *Photo #3*. The finished surface of the floor next above is at grade plane and it is not more than 12 feet above the finished ground level at any point.

Photo #3: Entrance to basement at Building A from the Construction Innovation Center

6.2.2. Penthouse

References – CBC Section 1509.2.3

The Construction Innovations Center contains an enclosed, unoccupied rooftop structure, used for sheltering mechanical and electrical equipment. *Photo #4* illustrates this type of unoccupied rooftop structure known as a penthouse for each building of the center. A penthouse would not affect the measurement of building height and can be located above the maximum allowed roof height provided that it complies with the limitations of CBC Section 1509. Note that penthouses must only be used for the purposes of sheltering mechanical or electrical equipment, tanks, or vertical shaft openings in the roof assembly.

Photo #4 – Penthouses from the Construction Innovations Center

6.2.2.1. Penthouse Allowable Height

References – CBC Section 1509.2.1

Penthouses constructed on each building do not exceed18 feet in height for a Type II Construction measured between the roof deck and average height of the roof of the penthouse. Therefore, theses roof structures will not be counted as an additional story.

6.2.2.2. Penthouse Allowable Area

References – CBC Section 1509.2.1

The aggregate area of each penthouse does not exceed one third the area of the supporting roof deck. Therefore, theses roof structures will not be counted as an additional story.

6.2.3. Ship Ladder

References – CBC Section 1009.14

Building A from the Construction Innovation Center utilized a ship ladder to access the unoccupied roof from the third floor, as illustrated in *Photo #5* and *Appendix C*. Ship ladders are permitted to be used for access to unoccupied roofs when approved by the code official.

Photo #5 – Door Leading to the Ship Ladder in Building A on the Third Floor

6.2.4. High–Rise Classification

References – CBC Section 403

The height for high–rise classification is measured from the lowest level of fire department access to the highest occupied floor. If this measurement is greater than 75 feet, the building will be subjected to high–rise provisions. The highest occupied floor for the Construction

Innovations Center is approximately 30 feet. Therefore, the center is not subject to high–rise provisions.

7. Building Allowable Dimensional Characteristics

References – CBC Section 503.1

The provisions for governing the allowable dimensional characteristics for the Construction Innovations Center on the basis of occupancy classification and type of construction are established in CBC Chapter 5. This chapter also establishes CBC Table 503 as the primary tool for determining the minimum type of construction. The existing building height, story, and area for the center are permitted to increase if they do not exceed the limits specified in CBC Table 503.

7.1. Building Story & Height Modifications

References – CBC Section 504.2

The building height limitations of CBC Table 503 for the specified type of construction are permitted to be increased by one story and 20 feet when protected throughout with an approved automatic sprinkler system in accordance with NFPA 13.

7.2. Building Area Modifications

References – CBC Section 506.1

The building areas limitations of CBC Table 503 for the specified type of construction are permitted to increase due to frontage and automatic sprinkler system protection in accordance with CBC Equation 5–1.

$$A_a = \left[A_t + (A_t * I_s) + \left(A_t * I_f\right)\right]$$

Equation 5–1

A_a	=	Allowable building area per story (square feet).
A_t	=	Tabular building area per story in accordance with Table 503 (square feet).
I_s	=	Area increase factor due to sprinkler protection as calculated in accordance with Section 506.3.
I_f	=	Area increase factor due to frontage as calculated in accordance with Section 506.2.

7.2.1. Automatic Sprinkler System Increase

References – CBC Section 506.3

The allowable area for the Construction Innovation Center is permitted to be increased with an additional 200 percent ($I_s = 2$) for buildings, with more than one story above grade plane, equipped throughout with an approved automatic sprinkler system in accordance with NFPA 13.

7.2.2. Frontage Increase

References – CBC Section 506.2

The allowable area for the Construction Innovation Center is permitted to be increased when more than 25 percent of its perimeter is toward the public way or open space with a minimum width of 20 feet. The frontage increase must be determined in accordance with CBC Equation 5–2. The center is permitted to be increased with an additional 50 percent ($I_f = 0.5$).

$$I_f = [F/P - 0.25] * W/30$$

Equation 5–2

I_f	=	Area increase due to frontage.
F	=	Building perimeter that fronts on a public way or open space having 20 feet open minimum width (feet).
P	=	Perimeter of entire building (feet).
W	=	Width of public way or open space (feet) in accordance with CBC Section 506.2.1.

Note that the maximum percentage for frontage increase with the entire building perimeter toward a public way or open space is 75 percent.

7.2.2.1. Width Limits

References – CBC Section 506.2.1

The term $\{W\}$ in CBC Equation 5–2 represents the weighted average of the width of any portion of the perimeter that fronts on a public way or open space with a width of 20 feet or more. The weighted average must be determined in accordance with CBC Equation 5–3. The term $\{w_n\}$ is measured perpendicular from each applicable exterior wall of the building to the closest interior lot line.

$$W = [(L_1 * w_1) + (L_2 * w_2) + (L_3 * w_3) \dots]/F$$

Equation 5–3

L_n	=	Length of a portion of the exterior perimeter wall.
w_n	=	Width of open space associated with that portion of the exterior perimeter wall.
F	=	Building perimeter that fronts on a public way or open space having a width of 20 feet or more.

Values use for $\{w_n\}$ range between 20 feet and 30 feet. Open spaces and public way with a measured width greater than 30 feet must use an exact value of 30 feet when calculating the weighted average, regardless of the actual distance.

8. Fire Apparatus Access

References – CFC Section 503.1

A fire apparatus access must be provided with access roads such that vehicles may approach to within 150 feet of any point along the exterior wall of the first story measured by an approved route. The value of 150 feet is intended to be the maximum length of hose needed to reach any point along the exterior building from a fire department vehicle. Access roads will be designed and constructed in accordance with the requirements of local fire department vehicles. *Appendix B* and *Photo #6* illustrates the existing fire access lane for the Construction Innovation Center.

Photo #6 – Fire Access Lane for the Construction Innovation Center

Note that any modification must be approved by the AHJ if the design is not providing perimeter access around the building for access by fire apparatus. Additional external standpipes might be required for fire fighter to apply water to the exterior of the building.

8.1. Surface

References – CFC Section 503.2.3

The code does not specify a particular type of surface to be used for the fire apparatus access roads. Therefore, a performance–based approach must be applied. The surface must carry the load of the anticipated emergency response vehicle and withstand all–weather driving capabilities. The Construction Innovation Center uses a combination of cement and asphalt as the surface for its fire apparatus access road.

8.2. Turning Radius

References – CFC Section 503.2.4

The turning radius of an access road should be based on the turning radius of the anticipated responding emergency vehicles and must be approved by the fire code official.

8.3. Grade

References – CFC Section 503.2.7

The grade of the fire apparatus access road must be within the limits established by the fire code official based on the fire department's apparatus. Generally, any grade exceeding 10 percent is required to have the approval of the fire code official.

8.4. Dimensions

References – CFC Section 503.2.1

Fire apparatus access roads must have a minimum unobstructed horizontal and vertical clearance of 20 feet and 13 feet 6 inches, respectively. The intent of the minimum horizontal clearance is to provide enough space for fire apparatus to pass one another during fire-ground operations. The minimum vertical clearance is the standard clearance used for highways bridges and underpasses. The existing fire access lane used for the Construction Innovation Center underpasses a bridge that complies with the minimum vertical clearance of 13 feet 6 inches, as illustrated in Photo #7.

Photo #7 – Bridge Connecting Buildings 186 and 21

9. Construction Type Classification

References – CBC Section 601.1

The code requires every building to be classified as one of five possible types of construction. Each type of construction denotes the kinds of materials permitted to be use and the minimum fire resistance ratings associated with the structural elements of the building. The table below

demonstrates the tabulated values from CBC Table 503 and their corresponding modification for Group B Occupancy and all the possible type of constructions.

The Construction Innovations Center was categorized as a construction type of IIA. The existing dimensional characteristic of the center, even without the modifications, complies with this type of construction.

Group B	Type I		Type II		Type III		Type IV	Type V	
	A	B	A	B	A	B	HT	A	B
Tabulated Height	UL	160	65	55	65	55	65	50	40
Modified Height	UL	180	85	75	85	75	85	70	60
Tabulated Area	UL	UL	37,000	23,000	28,500	19,000	36,000	18,000	9,000
Modified Area	UL	UL	129,500	80,500	99,750	66,500	126,000	63,000	31500
Tabulated Story	UL	11	5	3	5	3	5	3	2
Modified Story	UL	12	6	4	6	4	6	4	3

10. Buildings on same Lot

References – CBC Sections 503.1.2 & 705.3

Buildings A, B, and C of the Construction Innovations Center can be evaluated as portions of one building. The height of each building and the aggregate floor area comply within the limitations of CBC Table 503 as modified by frontage and automatic sprinkler system protection increase.

The center has been constructed in the same lot with Building 76 (Powerhouse) and Building 187 (Simpson Strong–Tie Material Lab), as illustrated in Photo #8. An imaginary line between them must be drawn to for the purposes of determining the required wall and opening protection, projections, and roof-covering requirements. The location of the assumed imaginary line between the existing and new building must be such that the exterior wall and opening protection of the existing building meet the criteria as set forth in CBC Sections 705.5 and 705.8. *Appendix B* illustrates the location of these buildings.

Photo #8: Building 76 (left) & Building 187 (right)

11. Total Allowable Building Area

References – CBC Sections 506.4, 506.4.1, & 506.4 Exception 1

The total allowable building area of a single occupancy building with more than one story above grade plane must be determined in accordance with CBC Section 506.4. The existing aggregate bui1ding area for the Construction Innovation Center must not exceed the allowable aggregate building area. If the total allowable area is exceeded, a higher construction type must be used or the conditions of an area increase must be met unless it already has. The determination of the total allowable building area, for buildings with three or more stories above grade plane, is determined by multiplying three to the allowable building area per story. The center complies with the provision described in CBC Section 506.4, as determined from the table below.

Allowable Building Area per Story	Multiplying Factor	Total Allowable Building Area	Total Existing Building Area
129,500 SF	3	388,500 SF	48,882 SF

The single basement area from Building A of the center is not required to be included toward the total building area when evaluating total allowable area.

12. Fire Structure Protection

Building elements used for the construction of the Construction Innovations Center, generally, are required to maintain a minimum degree of fire resistance to delay vertical (i.e., gravity) load-carrying collapse of the building due to fire exposure for a theoretical amount of time.

12.1. Minimum Fire Resistance Rating

References – CBC Sections 602.2 & Table 601 Footnote d

Types II construction are those types of construction in which the building elements listed in CBC Table 601 are of noncombustible materials. The table below demonstrates the existing and minimum fire-resistance rating requirements for building elements of a construction type of IIA.

Building Elements	Minimum Fire Resistance Rating	Existing Fire Resistance Rating
Primary Structural Frame	1 hour	0 hour
Exterior Bearing walls	1 hour	1 hour
Interior Bearing walls	1 hour	0 hour
Exterior Nonbearing walls and partitions	CBC Table 602	1 hour [a]
Interior Nonbearing walls and partitions	0 hour	0 hour
Floor Construction and Associated Secondary Members	1 hour	0 hour
Roof Construction and Associated Secondary Members	1 hour	0 hour

a. See section on exterior nonbearing walls of this report

Buildings of type IIA construction are permitted to use an automatic sprinkler system in compliance with NFPA 13 as an alternative to one-hour fire-resistance-rated construction, provided such system is not used for allowable height and area increase. In addition, the 1-hour substitution for fire resistance of exterior walls is not permitted.

The Construction Innovations Center has adopted this provision to omit the one one-hour fire-resistance-rated construction requirement. The center still complies with the applicable provisions of CBC Table 503, even without any height or area modifications.

12.1.1. Fire Separation Distance

References – CBC Table 602 Footnotes a & e

The table below demonstrates the fire-resistance rating requirements of Group B Occupancy for exterior nonbearing walls and partitions based on fire separation distance. Fire separation distance is the distance from the exterior wall of the building to one of the three following property locations, measured perpendicular to the exterior wall face:

- The closest interior lot line;
- To the centerline of a street, an alley or public way, or
- To an imaginary line between two buildings on the property.

Exterior bearing walls must also comply with the higher fire-resistance ratings specified in CBC Tables 601 and 602. Note that the required minimum fire-resistance rating of each exterior wall in each story of a building must be determined separately.

Fire Separation Distance = X (feet)	Type of Construction	Group B Occupancy
X < 5	IIA	1 hour
5 ≤ X < 10	IIA	1 hour
10 ≤ X < 30	IIA	1 hour
X ≥ 30	IIA	0 hour

12.2. Primary Structural Frame

The Construction Innovations Center is not required to have a fire resistance rating for its primary structural frame due to CBC Table 601 Footnote {d}.The primary structural frame must include all of the following structural members:

- The columns;
- Structural members having direct connections to the columns, including girders, beams, trusses and spandrels;
- Members of the floor construction and roof construction having direct connections to the columns; and
- Bracing members that are essential to the vertical stability of the primary structural frame under gravity loading shall be considered part of the primary structural frame whether or not the bracing member carries gravity loads.

12.2.1. Secondary Members

Secondary members are not considered part of the structural frame. The following structural members are considered secondary members:

- Structural members not having direct connections to the columns;
- Members of the floor construction and roof construction not having direct connections to the columns; and
- Bracing members other than those that are part of the primary structural frame.

12.3. Exterior Walls

References – CBC Section 705.6, 602.2, 705.8.1, & 705.8.1 Exception 1.1

The fire-resistant-rated exterior walls must be constructed to remain intact for the duration of the required fire-resistance-rated construction. In addition, the supporting elements must also be fire-resistance rated for the same duration of time.

The required fire-resistance rating of exterior walls with a fire separation distance of greater than 10 feet must be rated for exposure to fire from the inside. However, the fire resistance rating of the exterior wall must be from both sides when the fire separation distance is 10 feet or less.

The maximum area of unprotected and protected openings permitted in an exterior wall for each story of a building must not exceed the percentages specified in the table below:

Fire Separation Distance (feet)	Degree of Opening Protection	Allowable Area
3 to less than 5	Unprotected, Non-Sprinkler (UP,NS) [a]	Not Permitted
	Unprotected, Sprinkler (UP,S) [b]	15%
	Protected (P) [c]	15%
5 to less than 10	Unprotected, Non-Sprinkler (UP,NS) [a]	10%
	Unprotected, Sprinkler (UP,S) [b]	25%
	Protected (P) [c]	25%
10 to less than 15	Unprotected, Non-Sprinkler (UP,NS) [a]	15%
	Unprotected, Sprinkler (UP,S) [b]	45%
	Protected (P) [c]	45%

a. The degree of protection of openings is unprotected in a non-sprinkler building
b. The degree of protection of openings is unprotected in a sprinkler building
c. The degree of protection of openings is protected

The separation distance between Building 76 and Building A is approximately 11 feet, as illustrated in *Appendix B.* Therefore, the fire resistance rating of the exterior wall must be rated for exposure to fire from the inside. In addition, the allowable area for protected openings is 45 percent.

The separation distance between Building 187 and Building B is approximately 7 feet, as illustrated in *Appendix B.* Therefore, the fire resistance rating of the exterior wall must be from both sides. In addition, the allowable area for protected openings is 25 percent.

The separation distance between Building 187 and Building C is approximately 3.5 feet, as illustrated in *Appendix B.* Therefore, the fire resistance rating of the exterior wall must be from both sides. In addition, the allowable area for protected openings is 15 percent.

Note that the exterior wall on the first story of the building that is facing the street is permitted to have unlimited unprotected openings since the fire separation distance is greater than 15 feet.

12.3.1. Exterior Bearing Walls

Exterior bearing walls are the outermost walls that enclose the building and support any structural load other than their own weight. The required fire resistance of these exterior bearing

walls is determined by the higher of two fire-resistance ratings. The first method of determining the fire-resistance rating is based on CBC Table 601 for the type of construction of the building. The second method of determining the fire-resistance rating is based on CBC Table 602 for the fire separation distance of the building. Whichever of the two tables requires the higher fire resistance rating will dictate the minimum required fire-resistance rating of the exterior bearing wall. The Construction Innovations Center will be requiring a one-hour fire-resistance rating for its exterior bearing walls in accordance to method one. The exterior bearing walls for the center are constructed of metal panel siding and steel studs with precast concrete panel system.

12.3.1.1. Concrete Walls

References – CBC Section 722.2.1.1 & Table 722.2.1.1

The minimum equivalent thicknesses of precast concrete walls for fire-resistance ratings of 1 hour to 4 hours are shown the table below:

Concrete Type	Minimum Slab Thickness (inches) for Fire-Resistance Rating `of				
	1 hour	1.5 hours	2 hours	3 hours	4 hours
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-Lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

The table can also be applied to reinforced concrete. The equivalent thickness is the same as the actual thickness of these walls since they are solid with flat vertical surfaces.

12.3.2. Exterior Nonbearing Walls & Partitions

Exterior nonbearing walls are the outermost walls that enclose the building and only support their own weight. The minimum required fire-resistance rating is based solely on CBC Table 602 for the fire separation distance of the building. The Construction Innovations Center consists of several glazed curtain walls with aluminum members. Attached to these curtain walls are aluminum sunshades.

12.4. Interior Bearing Walls

Interior bearing walls are the inner walls of an enclose building that support any structural load other than their own weight.

12.5. Interior Nonbearing Walls & Partitions

Interior nonbearing walls are the inner walls of an enclose building that only support their own weight. These walls for the Construction Innovations Center only need to comply with all of the material requirements associated with construction type of IIA and are not required to have a fire-resistance rating. Note that nonbearing interior walls may be required to be fire-resistance rated when serving other purposes. These include interior walls serving to separate mixed occupancies, incidental uses, as well as corridor walls.

12.6. Floor Construction & Associated Secondary Members

The Construction Innovations Center is not required to have a fire resistance rating for its floor construction and associated secondary members due to CBC Table 601 Footnote {d}. The structural slab is of three inches concrete on three inches composite steel deck. Floor construction and associated secondary members provides a natural fire compartment in a building by means of a horizontal barrier that minimizes the vertical passage of fire from floor to floor.

12.6.1. Penetrations of Nonfire-Resistance Rated Floor Assemblies

Since the Construction Innovation Center is not required to have fire-resistance rated floors, another method must be used to prevent the migration of smoke through the center.

12.6.1.1. Item Penetrations

References – CBC Section 714.4.2.1 & 714.4.2.2

Noncombustible penetrations items connecting not more than five stories or four floors are permitted when the annular space of the penetrating item is filled with an approved noncombustible material. This material must be tested to resist the free passage of flame and the products of combustion. It can also be filled with a material that is tested as a through-penetration firestop system.

Combustible and noncombustible penetrations items that connect not more than two stories or one floor are permitted when the annular space of the penetrating item is filled with an approved material to resist the free passage of flame and the products of combustion. The annular space is not required to be filled with noncombustible material.

12.7. Roof Construction & Associated Secondary Members

The Construction Innovations Center is not required to have a fire resistance rating for its roof construction and associated secondary members due to CBC Table 601 Footnote {d}. The

structural slab is of three inches concrete on three inches composite steel deck. Proper roof construction is necessary to prevent collapse from fire as well as potential impingement on adjacent buildings. Roof construction must comply with the same provisions for nonfire-resistance rated floor assemblies in accordance with CBC Section 714.4.2.

13. Shaft Enclosures

All openings in floor/ceiling or ceiling/roof assemblies are required to be protected to prevent fires or products of fire (smoke, heat, and hot gases) from spreading to other floors. The Construction Innovation Center consists of several shafts that extend through one or more stories of the center. These shafts are enclosed, vertical, openings that connect consecutive levels of the center. *Appendix G* illustrates the location of each shaft enclosure and their fire-resistance ratings.

13.1. Construction

References – CBC Section 713.2

Shafts are required to be enclosed in fire-resistance rated fire barriers or a combination of fire barriers and horizontal assemblies.

13.2. Material

References – CBC Section 713.3

Material used for shaft enclosures must comply with the material permitted by a Type IIA Construction.

13.3. Fire-Resistance Rating

References – CBC Section 713.4

Shaft enclosures are required to be fire-resistance rated even though the floors from the Construction Innovation Center are under the provision of CBC Table 601 Footnote {d}. The required fire-resistance rating for a shaft enclosure is related to the number of stories being connected. Shaft enclosures must have a minimum fire-resistance rating of 2 hours when connecting four stories or more, and a minimum of 1 hour when connecting less than four stories. Note that the number of stories connected by a shaft enclosure must include any basements. To keep the integrity of the floor construction, the fire-resistance rating of the shaft enclosure must not be less than the fire-resistance rating of the floors being penetrated, but need not exceed 2 hours. The center consists of one-hour fire-resistance rated shaft enclosures, as illustrated in *Appendix G*.

13.4. Openings

References – CBC Sections 713.7 & 713.7.1

The integrity of the shaft enclosures must be maintained with approved opening protective. Doors provided into shafts must be self-closing or automatic closing by smoke detection. Note that openings other than those necessary for the purpose of the shaft must not be permitted in shaft enclosures.

13.5. Penetrations

References – CBC Sections 713.8 & 713.8.1

Penetrations for items such as cables, cable trays, conduits, ducts, and piping in a shaft enclosure must be protected as required for fire barriers. Structural elements are permitted to penetrate a shaft enclosure if there are equally protected. Note that the penetrations other than those necessary for the purpose of the shaft must not be permitted in shaft enclosures.

14. Means of Egress

The goal of the means of egress strategy is to allow for the movement of building occupants to a location of relative safety prior to interior conditions becoming untenable. This allows for a progression of increasing safety extending from occupiable spaces to the public way. The mean of egress consists of three separate and distinct parts, as illustrated in Figure #1.

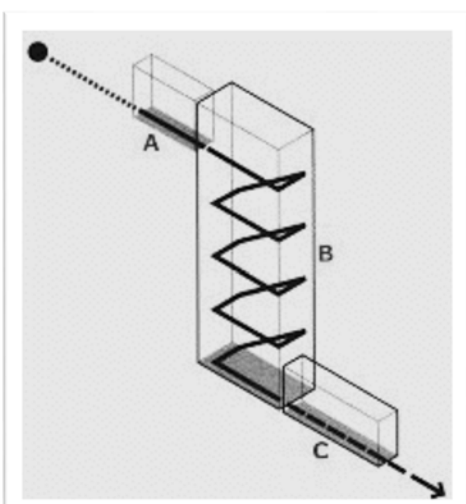


Figure #1: Means of Egress

A – An exit access is that portion of a means of egress system from any occupied portion of the building to the entrance of an exit.

B – An exit is that portion of a means of egress system from the termination of an exit access to the entrance of an exit discharge or public way.

C – An exit discharge is that portion of a means of egress system from the termination of an exit to a public way.

14.1. Ceiling Height

References – CBC Section 1003.2

The means of egress for the Construction Innovation Center have a minimum ceiling height of 7 feet 6 inches or 90 inches. The specified ceiling height is the minimum allowed in any part of the egress path, unless stated otherwise.

14.2. Protruding Objects

The limitation described by the code on protruding objects is of primary importance to those individuals with visual impairments. Protruding objects could slow down the egress flow through a corridor or passageway and injure someone hurriedly passing by. Persons with a visual impairment, who use a long cane for guidance, must have sufficient warning of these protruding objects.

14.2.1. Vertical Projections

References – CBC Sections 1003.2 Exception 3 & 1003.3.1

Protruding objects are permitted to extend below the required minimum ceiling height. The minimum headroom clearance over all walking surfaces is required to be maintained at 80 inches if not more than 50 percent of the ceiling area of a means of egress is reduced in height by protruding objects. When vertical clearance along a walking surface is less than 80 inches, such as underneath the stairway on the ground floor, some sort of barrier at or below 27 inches that is detectable by a person using a cane must be provided. A rail was used as a barrier underneath of Stair #1 on the ground floor, as illustrated in Photo #9.

Photo #9: Barrier Underneath of Stair #1 on the Ground Floor

14.2.2. Horizontal Projections

References – CBC Sections 1003.3.3 & 1003.3.3 Exception 1

Structural elements, fixtures or furnishings must not project horizontally from either side more than 4 inches over any walking surface between the heights of 27 inches and 80 inches above the walking surface. Persons with a visual impairment, who use a long cane for guidance, will most likely not encounter a protrusion object that is located higher than 27 inches above the walking surface before he/she collides with the object. Photo #10 illustrates a drinking fountain from the Construction Innovation Center that extends not more than 4 inches between 27 inches and 80 inches above the walking surface. Handrails are permitted to protrude 4.5 inches from the wall.

Photo #10: Drinking Fountain on the Second Floor at Building A

14.3. Occupant Load

References – CBC Sections 1004.1.2, 1004.4, & Table 1004.1.2

The amount of occupancy for each room and space within the Construction Innovation Center is determined in *Appendix F*. The calculated occupant loads, for rooms and areas without fix seating, were determined by dividing the floor area by the occupant load factor for a particular use. The occupant load factor establishes minimum occupant densities based on the function or actual use of the space, and not group classification. Note that occupant load in an area with fixed seats is readily determined. In spaces with a combination of fixed and loose seating, the occupant load is determined by a combination of the occupant load factor from CBC Table 1004.1.2 and a count of the fixed seats. The table below demonstrates the amount of occupant for each floor.

Floor	Building A	Building B	Building C	Total amount of Occupant
First	100 Persons	124 Persons	148 Persons	372 Persons
Second	96 Persons	125 Persons	141 Persons	362 Persons
Third	20 Persons	130 Persons	145 Persons	295 Persons
Total	216 Persons	397 Persons	434 Persons	1029 Persons

14.4. General Provisions for Means of Egress Doors

References – CBC Sections 1008.1

Egress doors must be easily recognized for immediate use and it must not be concealed by curtains, drapes, decorations or any similar materials.

14.4.1. Projections within Egress Door Openings

References – CBC Section 1008.1.1.1

Means of egress doors must meet certain criteria as to its width and height in order to be used safely and to provide accessibility to people with physical disabilities. There must not be projections above 34 inches from the floor within the clear width of the door. Projections of 4 inches are permitted between 34 inches and 80 inches above the floor.

14.4.2. Egress Doors in Series

References – CBC Section 1008.1.8

Space between two doors in a series must be 48 inches minimum plus the width of a door swinging into the space. Doors in a series must swing either in the same direction or away from the space between the doors.

14.4.3. Egress Door Swing

References – CBC Section 1008.1.2

Egress doors must be of the pivoted or side-hinged swinging type. In addition, it must swing in the direction of egress travel for rooms or area containing an occupant load of 50 or more occupants. Having an egress door swinging in a direction opposite from the egress flow can result in overcrowding during an emergency situation. Each room within the Construction Innovation Center contains less than 50 occupants. Therefore, egress doors are permitted to swing in any direction. Egress doors serving the exterior walls of each section of every floor do need to swing in the direction of egress flow since the cumulative of each room contains more than 50 occupants.

14.4.4. Door Opening Force

References – CBC Section 1008.1.3

The maximum force for pushing and pulling interior swinging egress doors without closer, other than fire doors, is 5-pound. For other swinging doors, the door latch must release when subjected to a 15-pound force. Once unlatched, a maximum force of 30 pounds is applied to start the door in motion by overcoming its stationary inertia. Once in motion, a maximum of 15 pounds of force is needed to keep the door in motion until it reaches its full open position and the required clear width is available.

14.4.5. Door Operations

References – CBC Section 1008.1.9

Egress doors must be readily openable from the egress side without the use of a key or special knowledge or effort. Note that the outside of an egress door can be locked as long as the inside in which the egress is flowing can unlock it without the use of tools, keys or special knowledge or effort.

14.5. Elevator

References – CBC Section 1003.7

The Construction Innovation Center is comprised of one elevator that connects through the first and third level, located in Building B, as illustrated in Photo #11. This elevator will not be used as part of the means of egress. Elevators may not provide a safe and reliable means of egress that is available for use at all times due to the possibility of power outages.

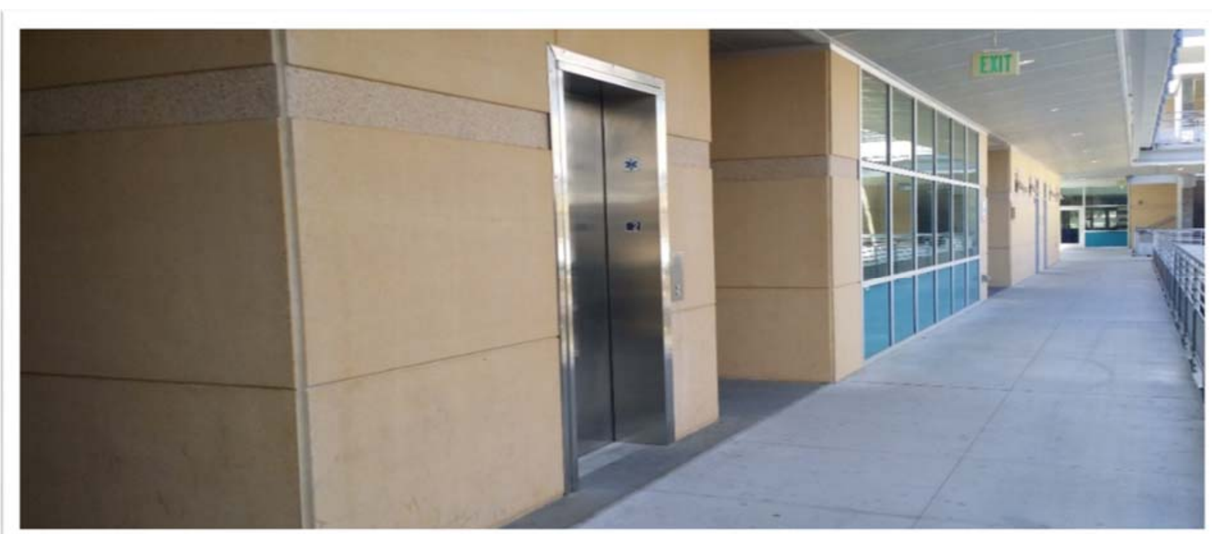


Photo #11: Elevator at the Third Floor from the Construction Innovation Center

14.6. Exit Access

The exit access begins at the furthest points within each room or space and ends at the entrance to the exit. Crawl spaces, concealed attic, and roof spaces are not considered to be part of the exit access.

14.6.1. Exit Access Doorways

References – CBC Section 1020.2.1

An exit access doorway is a door or access point along the exit access path. *Appendix G* illustrates each exit access doorway within the Construction Innovation Center. Exit Access doorways must comply with sections on *General Provisions for Mean of Egress Doors* and *Egress Capacity for Other Egress Components* from this report.

14.6.1.1. Number of Exit Access Doorways

References – CBC Section 1015

The number of exit access doorways required in each room or floor is associated with the amount occupant load within that room or floor. The table below represents an empirical judgment of the risks associated with the minimum number of exit access doorways. The Construction Innovation Center complies with the minimum amount of exit access doorways for Group B Occupancy.

Occupancy	One Egress Doorway	Two Egress Doorways	Three Egress Doorways	Four Egress Doorways
A,B,E,F,M,U	01 – 49	050 – 500	501 – 1000	1001 – ∞
H-1,H-2,H-3	01 – 03	004 – 500	501 – 1000	1001 – ∞
H-4,H-5,I-1, I-2,I-3,I-4, R	01 – 10	010 – 500	501 – 1000	1001 – ∞
S	01 – 29	029 – 500	501 – 1000	1001 – ∞

14.6.1.2. Exit Access Doors Arrangement

References – CBC Sections 1015.2.1 & 1015.2.1 Exception 2

Rooms or floors that require a minimum of two exit access doors must have a separation distance of not less than one-half of the length of the maximum overall diagonal dimension of that room or floor, measured in a straight line between exit access doors. A value of one-third is allowed to be use if the building is equipped throughout with an automatic sprinkler system in accordance with NFPA 13. The Construction Innovation Center complies with the one–third diagonal exit separation.

14.6.2. Common Path of Egress Travel

References – CBC Section 1014.3 & Table 1014.3

The common path of travel is the distance measured from the most remote point in a space to the point in the exit access path where the occupant has access to two required exits in separate directions. The Construction Innovation Center complies with the common path of egress travel distances of 100 feet for buildings with fire sprinkler system. Note that this distance must not exceed the amount as described in the table below.

Occupancy	Without Sprinkler System		With Sprinkler System
	Occupant Load ≤ 30	Occupant Load > 30	
B	100 feet	75 feet	100 feet [a]

a. Buildings equipped throughout with an automatic sprinkler system in accordance with NFPA 13

14.6.3 Exterior Exit Access Balcony

References – CBC Section 1019.1

The Construction Innovation Center consists of exterior egress balconies. Exterior egress balconies must conform to the same requirements as corridors for width, headroom, dead ends, and projections. Photo #12 illustrates the balcony connecting each floor of the center.

Photo #12: Balcony Connecting Each Floor of the Construction Innovation Center

14.6.3.1. Balconies Width

References – CBC Section 1018.2

The minimum width for balconies, specified in CBC Table 1018.2, is 44 inches. Please see section on *Egress Capacity for Other Egress Components* from this report for the actual width for balconies.

14.6.3.2. Headroom for Balconies

References – CBC Section 1026.5 Exception 2

The ceiling height of exterior egress balconies must be at least 7 feet above the walking surface. The Construction Innovation Center comprises of exterior egress balconies with slant ceiling height of 10 feet 6 inches and 12 feet 3 inches. The lowest value between the floor and ceiling height has been used in order to comply with the minimum 7 feet.

Additionally, the exterior exit stairways are not required to be fire rated since the ceiling height of each exterior egress balconies for the center is at least 7 feet above the walking surface layer.

14.6.3.3. Dead Ends

References – CBC Sections 1018.4 & 1018.4 Exception 2 & 3

Dead ends can seriously increase the time needed for an occupant to locate an exit, especially if the person is unfamiliar with his or her surroundings. The arrangement of dead ends must not exceed more than 20 feet in length. In occupancies such as Groups B, where the building is equipped throughout with an automatic sprinkler system in accordance with NFPA 13, the length of the dead end must not exceed 50 feet. Note that dead ends are permitted to be limited in length, where the length is less than 2.5 times its width.

The Construction Innovation Center consists of a single dead end on the third floor of Building A, as illustrated in Photo #13. The dead end has a length and width of 27 feet 6 inches and 20 feet, respectively. The center complies with the dead end measurement of 50 feet for building equipped with fire sprinkler system.

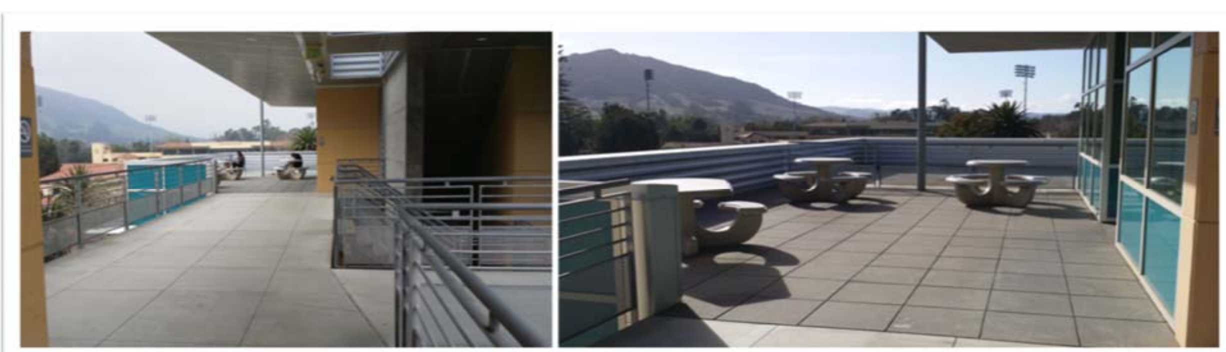


Photo #13: Dead End located on the Third Floor of Building A

14.6.3.4. Balcony Protection

References – CBC Section 1019.2 Exception 1

The balconies used for the Construction Innovation Center is not required to be separated from the interior spaces since there is at least two stairways provided and there are no dead-end conditions that require travel past an unprotected opening.

14.6.3.5. Openness

References – CBC Sections 1019.3 & 1026.5 Exception 2

The long side of each exterior egress balcony for the Construction Innovation Center has a minimum open exterior area of 50 percent. The open area above the guards is designed to minimize the accumulation of smoke or toxic gases. In addition, to have the exterior exit stairways from being fire rated, at least one-half of the total perimeters of the exterior balcony must be permanently open to the outside layer.

14.6.3.6. Balcony Location

References – CBC Section 1019.4

The location requirements for exterior exit access balconies are the same for exterior exit stairways. The exterior egress balconies from the Construction Innovations Center have a minimum fire separation distance of 10 feet measured from the exterior edge of the balcony to adjacent lot lines and from other buildings on the same lot. If the exterior egress balcony is closer than specified, then adjacent buildings' exterior walls and openings are to be protected in accordance with CBC Section 705.

14.6.3.7. Projections

References – CBC Sections 705.2, 705.2 Exception 1, & 705.2.1

The Construction Innovation Center comprises of exterior exit access balconies and aluminum sunshades that project horizontally from the center. Projections must not extend the minimum distance from the line used to determine the fire separation distance as shown in the table below. Each projection of the center has a fire separation distance greater than 5 feet and complies with the 40 inches minimum requirement.

Projections on the exterior walls of Building A, B, and C that face each other are not limited in length. Balconies of Types II construction are required to be constructed of noncombustible materials to prevent fire involvement and fire spread up or along the exterior of a noncombustible building.

Fire Separation Distance (FSD) [a]	Minimum Distance from Line used to Determined FSD [b]
0 feet to less than 2 feet	Projections not permitted
2 feet to less than 5 feet	24 inches
5 feet or greater	40 inches

a. Measured from the lot line or assumed lot line to the exterior wall – not to the edge of the overhang.
b. Distance from the line used to determine the FSD to the vertical edge of the overhang.

14.6.4 Exit Access Travel Distance

References – CBC Sections 1016.1, 1016.3, 1016.2, & Table 1016.2

The exit access travel distance is measured from the most remote point in a space to the point where it reaches an exit. It is important to consider the natural path of travel when measuring travel distance. For instance, occupants tend to migrate to more open spaces while egressing. Measurement of the natural path of travel typically excludes floor areas within 1 foot of walls, corners, columns and other permanent construction. Where the travel path includes passage through a doorway, the natural route is generally measured through the centerline of the door openings.

The Construction Innovation Center complies with the exit access travel distance of 300 feet, within each space, for buildings equipped with fire sprinkler system. Note that the exit access travel distance must not exceed 300 feet as described in the table below.

Occupancy	Without Sprinkler System	With Sprinkler System
B	200 feet	300 feet [a]

a. Buildings equipped throughout with an automatic sprinkler system in accordance with NFPA 13

14.6.4.1. Exterior Egress Balcony Increase

References – CBC Section 1016.2.1

An additional 100 feet of exit access travel distance is permitted when the last portion of an exit access occurs on an exterior egress balcony. Note that the length of the increase must not be more than the length of the exterior balcony.

14.7. Exit

References – CBC Section 1015.2

Exit components incorporated in the building include exterior exit doors at the level of exit discharge and exterior exit stairways. A color coded diagram of the incorporated exits are illustrated in *Appendix G*. Exits need to be noticeable and unobstructed at all times for the safety

of occupants, This would help them to evacuate the building easily, in case of an emergency situation.

14.7.1. Exit Components

Exit components used for the Construction Innovation Center includes exterior exit doorways, exterior exit stairways, and horizontal exit. *Appendix G* illustrates each exit components within the center.

14.7.2. Exterior Exit Doorways

References – CBC Sections 1020.2.1 & 1020.2.2

Exterior exit doors must comply with sections on *General Provisions for Mean of Egress Doors* and *Egress Capacity for Other Egress Components* from this report. The exterior exit door is to be the entry point of the exit discharge. It should also lead directly to the public way.

14.7.3. Exterior Exit Stairways

References – CBC Section 1026.2

The Construction Innovations Center is permitted to use exterior exit stairways since it is neither a high rise building nor exceeding six stories above grade plane. Stairs #1, #2, and #3 are constructed between the first floor and third floor. Stair #4 is constructed between first floor and glade plane.

14.7.3.1. Stairway Landings

References – CBC Section 1009.8

The top and bottom of each flight of stairs from the Construction Innovation Center comprises of a floor or landing. The minimum size, width and depth, of all landings in a stairway are determined by the actual width of the stairway. In addition, doors opening onto a landing must not reduce the landing to less than one-half the required width. When fully open, the door must not project more than 7 inches into a landing. Stair #4 is the only exterior exit stairway that comprises of a door opening onto its landing. *Appendix D* illustrates the existing width of each stairway as its compliance with the measurement of all its landings. Note that if a stairway is constructed wider than required, landings must be increased accordingly to avoid creating a bottleneck situation in the egress travel.

14.7.3.2. Vertical Rise

References – CBC Section 1009.10

Flight of stairs must not have a vertical rise greater than 12 feet between floor levels or landings. The limited height provides a reasonable interval for occupants with physical limitations to rest on a level surface and to minimize potential negative psychological effects of long and uninterrupted stairway flights. *Appendix C* illustrates the vertical rise of each stairway as its compliance with the maximum measurement of 12 feet between floor levels or landings.

14.7.3.3. Headroom for Stairways

References – CBC Sections 1003.2 Exception 4 & 1009.5

Stairways must have a minimum headroom clearance of 80 inches measured vertically between the edge of the nosings and the ceiling. The minimum clearance must be continuous between the upper landing and the lower landing, one tread depth beyond the bottom riser. In addition, the minimum clearance must be maintained to the full width of the stairway and landing.

14.7.3.4. Treads and Risers

References – CBC Section 1009.7.2

The riser height must be between 4 inches and 7 inches measured vertically between the nosings of adjacent treads. Rectangular tread depths must be 11 inches minimum measured horizontally between the nosings of adjacent treads.

14.7.3.5. Walking Surface for Outdoor Conditions

References – CBC Sections 1009.9.2 & 1009.9.1

The landings and treads of each stairway must be solid and in level with the firmly attached surface materials. However, exterior stairways must also be designed in a way that it would avoid accumulating water on the walking surface. Therefore, a maximum of two percent slope is permitted to elude the chance of water accumulation on the walking surface where someone might slip.

14.7.3.6. Enclosures under Exterior Stairways

References – CBC Section 1009.9.4

Underneath of each stairway from the Construction Innovation Center must be unenclosed, clear, and unused for any purpose. If the space under an exterior stairway is to be used, such as for storage, the area below the stairway must be separated from the stairway with walls and a ceiling with a fire-resistance rating of at least 1 hour. Refer to Photo #9 to visual an unenclosed, clear, and free space underneath of Stair #1. All other stairway simulates the same characteristic.

14.7.3.7. Stairway Handrails

References – CBC Sections 1009.15, 1012.6, & 1012.2

Handrails are required along each side of a flight of stairs. Note that handrails are not required along stairway landings. However, the code requires handrails to have an extension onto the landing for a smooth transition. Handrails must be extended 12 inches horizontally beyond the top riser and sloped a distance of one tread depth beyond the bottom riser. The height of handrails must be between 34 inches and 38 inches above the leading edge of stairway treads, landings or other walking surfaces.

14.7.3.8. Natural Ventilation

References – CBC Sections 1026.4 & 1026.3

An important factor in exterior exit stairways is natural ventilation. Sufficient natural ventilation is necessary to prevent smoke from being trapped above the stairway and, consequently, compromising safe egress. Each exterior exit stairway from the Construction Innovations Center has at least one of its sides open to a yard or public way. Note that the remaining sides are permitted to be enclosed by the exterior walls of the building. A minimum amount of exterior openness is required for exterior exit stairways. The open side must have a minimum of 35 square feet of aggregated open area between each floor level and intermediate landing. The required open area must be determined at a level higher than 42 inches above each floor level and intermediate landing.

14.7.3.9. Stairway Location

References – CBC Section 1026.5

The exterior exit stairways from the Construction Innovations Center have a minimum fire separation distance of 10 feet measured from the exterior edge of the stairway, including landing, to adjacent lot lines and from other buildings on the same lot. If the exterior exit stairway is closer than specified, then adjacent buildings' exterior walls and openings are to be protected in accordance with CBC Section 705. The 10 feet separation distance will protect the occupants of the exterior exit stairway from the effects of a fire in another building on the same lot or an adjacent lot. In addition, it reduces the exposure to heat and smoke.

14.7.3.10. Stairway Protection

References – CBC Sections 1026.5 & 1026.5 Exception 2

Exterior stairways from the Construction Innovations Center must be protected from interior fires that may project through windows or other openings and possibly endanger the occupants from using this portion of the means of egress. The protection of an exterior exit stairway is to be obtained by separating the exterior exit from the interior of the building. This can be done by using fire-resistance rating exterior walls of at least 1 hour with opening protective. However, separation is permitted to be omitted since the center is also comprised of exterior exit access

balcony serving more than two remote exits. This will allow occupants to have the option of using the balcony to gain access to either of the two available exits.

14.7.4. Horizontal Exit

References – CBC Section 1025.1

The Construction Innovation Center consists of a horizontal exit that extends vertically between the second and third floor with a 90 minute fire door. A horizontal exit is a fire-resistance-rated wall that subdivides a building into multiple compartments and provides an effective barrier to protect occupants from a fire condition within one of the compartments. The horizontal exit for the center has access to an exterior exit stairway in either direction.

14.7.4.1. Horizontal Exit Separation

References – CBC Section 1025.2

The separation used for a horizontal exit can be made of a fire wall, fire barrier, horizontal assemblies, or a combination. The minimum fire-resistance rating of the separation must be 2 hours. It must extend vertically through all levels of the building unless the floor assemblies have a fire-resistance rating of not less than 2 hours with no unprotected openings. Therefore, it its recommended that the Construction Innovation Center should have had its horizontal exit extended to each level since the floor assemblies are not fire rated.

14.7.4.2. Opening Protective

References – CBC Section 716.5 & Table 716.5

For the safety of occupants, it is important that doors used in horizontal exits be fire doors with an opening protective of not less than 90 minutes. A fire door is the primary component of a fire door assembly. Note that a fire door assembly is any combination of a fire door, frame, hardware, and other accessories that together provide a specific degree of fire protection to the opening. Fire door assemblies are required to be tested using the appropriate standard and must be installed in accordance with NFPA 80.

14.7.4.2.1. Door Closers & Stops

References – CBC Sections 716.5.9, 1025.3, Section 1003.2 Exception 5, & 1003.3.1 Exception 1

Fire doors must be self-closing or automatic closing by activation of a smoke detector. Door closers and stops are permitted to extend below the required minimum ceiling height. The minimum headroom clearance for door closers and stops is 78 inches. This projection into the doorway height is reasonable since these devices are normally mounted away from the center of the door opening; thus minimizing its probability of contact with occupants moving through the opening, as illustrated in Photo #14.

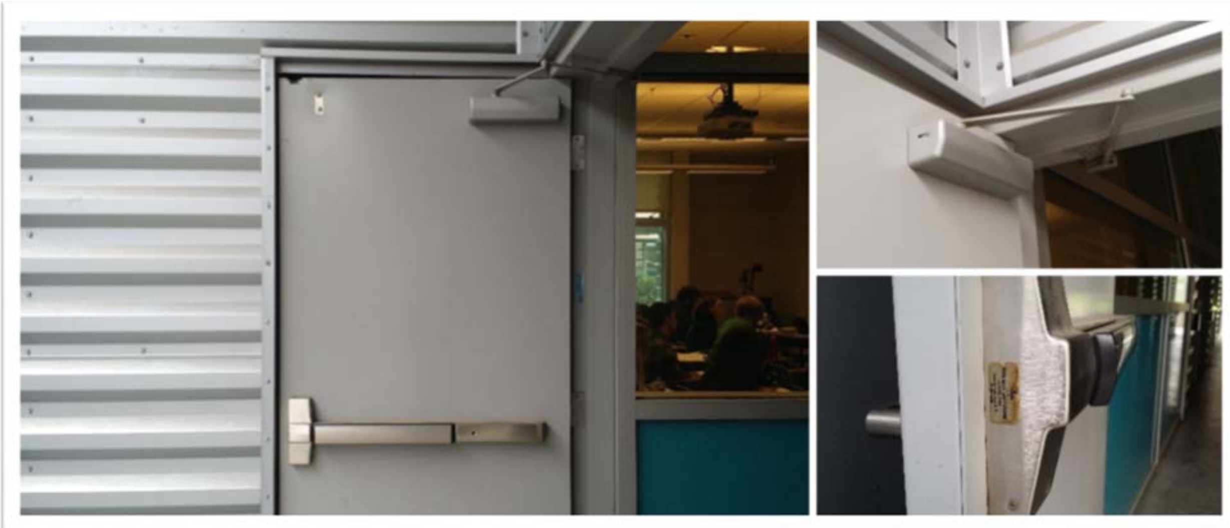


Photo #14: Fire Door within Horizontal Exit

14.7.4.2.2. Panic & Fire Exit Hardware

References – CBC Section 1008.1.10

A panic hardware is a door-latching assembly device that releases the latch upon the application of a force in the direction of egress travel. It is commonly used in educational and assembly type spaces where the number of occupants using the doorway is high. The hardware is intended so that the door can be easily opened during an emergency when pressure on the door is applied from the direction of egress travel.

Exit fire hardware is a panic hardware that is listed for use on fire door assemblies, as illustrated in Photo #14. The hardware must meet the objectives and requirement for panic hardware and function properly when exposed to the effects of a fire. Note that panic hardware and fire exit hardware can be similar in appearance.

14.7.4.2.2.1. Installation of Panic & Fire Exit Hardware

References – CBC Sections 1008.1.9.2, 1008.1.1.1, & 1008.1.10.1

Panic and fire exit hardware must be installed between 34 inches and 48 inches above the finished floor. The hardware is permitted to extend the full width of the door as long as it does not protrude more than 4 inches into the door clear width. Panic and fire exit hardware must comply with the following installation requirements:

- Panic hardware must be listed in accordance with UL 305
- Fire exit hardware must be listed in accordance with UL 10C and UL 305
- The actuating portion of the releasing device must extend at least 0.5 of door leaf width
- The maximum unlatching force shall not exceed 15 pounds

14.7.5. Number of Exits

The method for determining the number of exits is the same as determining the number of exit access doorways. The table below represents an empirical judgment of the risks associated with the minimum number of exits. The amount of exits provided by the Construction Innovation Center complies with the minimum requirements for a Group B Occupancy. Each floor is approximately 300 occupants; thus a minimum of two exits are required. The center is constructed with four exterior exits, as illustrated in *Appendix E*.

Occupancy	One Exit	Two Exits	Three Exits	Four Exits
A,B,E,F,M,U	01 – 49	050 – 500	501 – 1000	1001 – ∞
H-1,H-2,H-3	01 – 03	004 – 500	501 – 1000	1001 – ∞
H-4, H-5, I-1, I-2, I-3, I-4, R	01 – 10	010 – 500	501 – 1000	1001 – ∞
S	01 – 29	029 – 500	501 – 1000	1001 – ∞

14.7.6. Exits Arrangement

Exits are arranged in the same manner as exit access doors. The Construction Innovation Center complies with the exit arrangement in which uses a diagonal dimension of one-half.

14.7.7. Exit Signs

References – CBC Sections 1011.1 & 1011.1 Exception 1

Exits and exit access doors must be marked by an approved exit sign readily visible from any direction of egress travel, as illustrated in *Appendix G*. In cases where the signs are not visible to the occupants for some reason, additional illuminated signs must be provided indicating the direction of egress to an exit. Exit signs must be located within 100 feet or the listed viewing distance for the sign, whichever is less, from each other in an exit access corridor. Exit signs are not required in rooms or areas that require only one exit or exit access; the assumption is that the occupants are familiar enough with their surroundings to identify the exit.

14.7.7.1. Externally Illuminated Exit Signs

References – CBC Section 1011.6.2

Exit signs must be illuminated to be readily apparent in situations where the lights may be off or the building has lost power. The surface of each exit sign must be continuously illuminated to provide a light intensity of at least 5 foot-candles or 54 lux.

14.7.7.1.1. Power Source

References – CBC Section 1011.6.3

To ensure continued illumination at all times, exit signs must remain illuminated for a minimum duration of 90 minutes from an emergency power system in case of primary power is loss. Storage batteries, unit equipment, or an on-site generator may be use for an emergency power system.

14.8. Egress Capacity

References – CBC Sections 1005.3, 1004.1.1, & 1005.5

The code requires the utilization of two methods, a prescriptive and performance based approach, to determine the minimum width of egress components. The actual width for each egress component is determined by the larger of the two widths. The combined number of occupants must be utilized to determine means of egress capacity when occupants move to an exit between intervening rooms, areas, and spaces. Note that doorways that are not part of the means of egress are not limited in size.

Where multiple means of egress are required in the Construction Innovation Center, the loss of any one path cannot reduce its available capacity to less than 50 percent. An egress design with a large imbalance of egress component capacities relative to occupant load distribution may delay the egress time for occupants in a story, room, or area.

14.8.1. Egress Capacity for Stairway

References – CBC Sections 1005.3.1, 1005.3.1 Exception 1, 1009.4, & 1009.4 Exception 1

The width for egress stairways is calculated by multiplying the occupant load served by such stairway by a means of egress capacity factor of 0.30 inches per occupant. A means of egress capacity factor of 0.20 inches per occupant can be used for buildings equipped throughout with an automatic sprinkler system installed in accordance with NFPA 13 and an emergency voice/alarm communication system in accordance with NPFPA 72.

The minimum width for stairways must not be less than 44 inches. For instance, a stairway with a minimum of 44 inches width can accommodate 147 or 220 occupants when using a means of egress capacity factor of 0.30 or 0.20 inches per occupant, respectively. Note that a minimum width of 36 inches for a stairway is permitted when serving an occupant load of less than 50.

An egress capacity factor of 0.20 inches per occupant will be used for the Construction Innovation Center. The table below demonstrates compliance with the required width for egress stairways of the center. Stairs #3 and #4 was not used in the determination of egress capacity.

Floor	Total O.L.	Stairways	O.L	O.L. Factor	Calculated Width	Minimum Width	Provided Width
Second	362	Stair #1	181	0.2	37 in	44 in	66 in
		Stair #2	180	0.2	37 in	44 in	66 in
Third	295	Stair #1	85	0.2	17 in	44 in	66 in
		Stair #2	79	0.2	16 in	44 in	66 in

14.8.2. Egress Capacity for Other Egress Components

References – CBC Sections 1005.3.2, 1005.3.2 Exception 1, & 1008.1.1

The width for egress components, other than stairways, is calculated by multiplying the occupant load served by such component by a means of egress capacity factor of 0.20 inches per occupant. A means of egress capacity factor of 0.15 inches per occupant can be used for buildings equipped throughout with an automatic sprinkler system installed in accordance with NFPA 13 and an emergency voice/alarm communication system in accordance with NFPA 72.

The minimum width for means of egress components, other than stairways, must not be less than 32 inches. Therefore, a doorway with a minimum of 32 inches width can accommodate 160 or 213 occupants when using a means of egress capacity factor of 0.20 or 0.15 inches per occupant, respectively.

An egress capacity factor of 0.15 inches per occupant will be used for the Construction Innovation Center. The calculated width for each egress components, other than stairways, resulted in less than 32 inches. Therefore, the minimum required width must be 32 inches. This minimum required value complies with the typically provided width of 36 inches for the center.

14.9. Exit Discharge

References – CBC Section 1027.1

The exit discharge provides occupants with a path of travel away from the building. All components between the exterior of the building and the public way are considered to be the exit discharge, regardless of the distance. Exits must discharge directly to the exterior of the building. When it is not practical to discharge directly to the outside, there are four alternatives:

- Exit passageway [CBC Section 1023]
- Exit discharge lobby [CBC Section 1027.1 Exception 1]
- Exit discharge vestibule [CBC Section 1027.1 Exception 2]
- Horizontal exit [CBC Section 1025 Exception 3]

However, the above alternatives only apply to interior exit stairways. The exit discharge must be at grade or provide direct access to grade. Steps or stairs are occasionally required in exit

discharge leading to the public way when the terrain is sloped. Furthermore, exit discharge must not reenter a building.

14.9.1. Exit Discharge Capacity

References – CBC Section 1027.2

The capacity of the exit discharge must not be less than the required discharge capacity of the exits being served.

15. Fire Alarm System

References – CBC Sections 907.2 & 907.2.2.2

The Construction Innovation Center will be considered a new building. Therefore, provisions from CFC Chapter 11 for fire alarm systems on existing buildings will not apply. However, an approved fire alarm system is required for new buildings in accordance with NFPA 72. In addition, Group B buildings used for educational purposes must be provided with a manual or automatic fire alarm system. This provision applies to every community college and university.

The fire alarm system installed within the center is classified as a standalone system operating independently of other control systems. This system must, upon activation, provide occupant notification throughout the area protected by the system unless other alternative provisions are imbedded.

Fire alarm systems are installed in buildings to limit fire casualties and property losses by detecting the presence of a fire and notifying the occupants, the local fire department, or both of an emergency condition. Studies have shown that the use of early warning fire and smoke detection systems has resulted in a significant reduction overall in fire deaths. The sooner a fire is detected, the better the chances are for survival.

15.1. Power Supply

References – CBC Section 907.6.2

The operation of fire alarm systems is essential to life safety in buildings and must be reliable in the event the normal power supply fails. The fire alarm system used for the Construction innovation Center must have a primary and secondary power supply in accordance with NFPA 72.

15.1.1. Primary Power Supply

References – NFPA 72 Section 10.6.5.1

The branch circuit supplying the fire alarm equipment must supply no other loads and be supplied by one of the following:

- Commercial light and power
- An engine-driven generator or equivalent, where a person specifically trained in its operation and on duty at all times
- An engine-driven generator or equivalent arranged for cogeneration with commercial light and power, where a person specifically trained in its operation and on duty at all times

The Construction Innovation Center uses commercial light and power as its primary power supply. Keep in mind, an engine-driven generator is permitted as a primary power supply when commercial light and power service is sometimes not available at the location.

15.1.2. Secondary Power Supply

References – NFPA 72 Sections 10.6.7.3.1 & 10.6.7.2.1

NFPA 72 offers three alternatives for secondary supply:

- 24-hour storage battery
- An automatic-starting, engine-driven, generator and storage batteries with 4 hour capacity
- Multiple generators

The Construction Innovation Center uses 24–hour storage battery for a secondary power supply. The secondary power supply must have sufficient capacity to operate the system under standby mode for a minimum of 24 hours and, at the end of that period, must be capable of operating all alarm notification appliances under alarm mode for 5 minutes.

15.1.2.1. System Failure

References – NFPA 72 Sections 10.6.6.1 & 10.6.6.3

The secondary power supply must automatically provide power to the center system within 10 seconds whenever the primary power supply fails to provide the minimum voltage required for proper operation. Note that required signals must not be lost, interrupted, or delayed by more than 10 seconds as a result of the primary power failure.

15.1.2.2. Uninterruptible Power Supply

References – NFPA 72 Section A.10.6.6

The Construction Innovation Center consist of an uninterruptible power supply (UPS) equipment that allows a continuous and sufficient capacity to operate the fire alarm system until the secondary power supply is capable of operating the system, due to failure of the primary power supply. UPS equipment is used to prevent any signal loss or avoid signal delay of more than 10 seconds, are required by code. The location of the UPS equipment can be sited within the Electrical Room of Basement Level of Building A.

15.2. Fire Alarm Control Panel

The Construction Innovation Center comprises of NFS-640 intelligent fire alarm control unit, also known as fire alarm control panel, as illustrated in *Appendix H*. The panel acts as a point where all signals initiated within the protected building are received before the signal is transmitted to a constantly attended location. Furthermore, the fire alarm control panel contains controls to test and manually activate or silence systems. NFPA 72 does not prescribe requirements for the location of the fire alarm control panel. *Appendix I* illustrate the location of each fire alarm control panel used within the center.

15.2.1. Protection of Fire Alarm Control Panel

References – CBC Sections 907.4.1

A single smoke detector must be provided at the location of each fire alarm control panel. This smoke detector will activate the fire alarm control unit and allow it to either notify occupants or transmit a signal to a remote monitoring location before the fire impairs the fire alarm control panel. *Appendix I* illustrates the location of this smoke detector within the center. A single smoke detector may be seen in Photo #15 near one of the panels that is located in Building A.

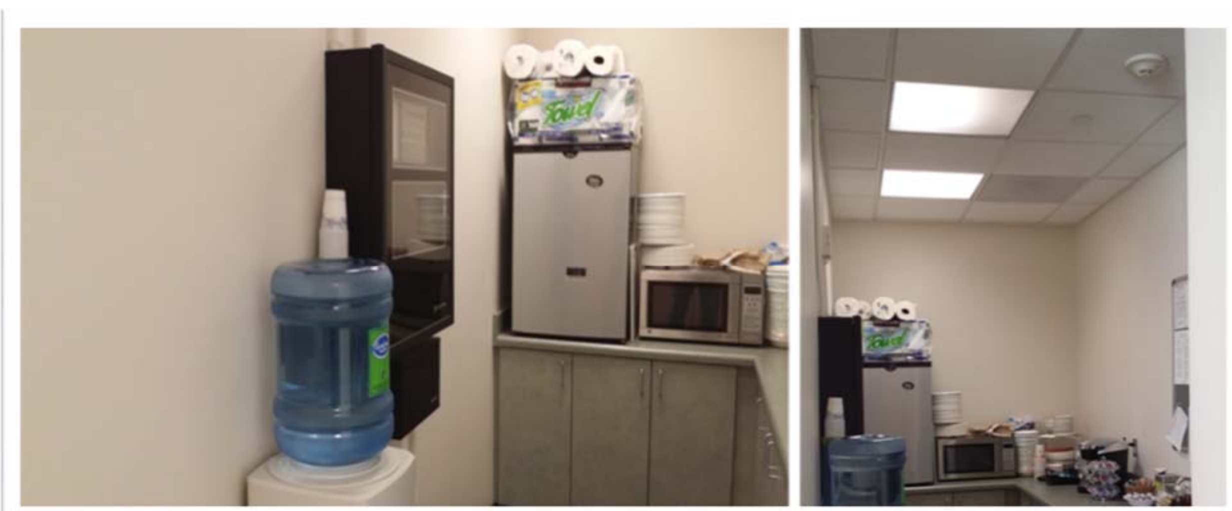


Photo #15: Fire Alarm Control Panel with Smoke Detector in Room CM06, Storage, from Building A

15.3. Fire Alarm Terminal Cabinet

The Construction Innovation Center comprises of several fire alarm terminal cabinets. These are steel enclosure in standard finish, hinged locking door, fire retardant plywood backboard. *Appendix I* illustrates the location of each fire alarm terminal cabinets within the center.

15.4. Fire Alarm System Signals

References – NFPA 72 Sections 10.10.1

Fire alarm system signals consist of alarm, supervisory, and trouble signals. Each of these signals must be distinctively annunciated. The typical means of accomplishing this is through the display at the fire alarm control panel or the use of an annunciator panel.

15.4.1. Alarm Signals

*References – NFPA 72 Section 3.3.257.1**

An alarm signal is an indication of an emergency requiring immediate action, such as a signal indicative of fire.

15.4.2. Trouble Signals

*References – NFPA 72 Sections 3.3.257.10**

A trouble signal is an indication that there has been an abnormal change in the normal status of a fire detection system or device. Note that the trouble signal is only associated with electronic portions of the fire protection system.

15.4.3. Supervisory Signals

References – NFPA 72 Section 3.3.257.9

A supervisory signal is an indication that there has been an abnormal change in the normal status of an initiating device. Note that the supervisory signal is only associated with physical conditions of the fire protection system, such as a closed valve.

15.4.4. Unwanted Alarm

References – NFPA 72 Sections 10.22, 3.3.307*, 3.3.307.2, 3.3.307.2*, 3.3.307.3, & 3.3.307.4*

The activation of alarm signal from a nonhazardous condition must be classified as unwanted alarm. These are sometimes called false alarms. Unwanted alarm is sub–classified as one of the following:

- **Malicious Alarm**: An unwanted activation of an alarm initiating device caused by a person acting with malice.
- **Nuisance Alarm**: An unwanted activation caused by mechanical failure, malfunction, improper installation or lack of proper maintenance, or an alarm activated by a cause that cannot be determined.
- **Unintentional Alarm**: An unwanted activation of an alarm initiating device caused by a person acting without malice.

- **Unknown Alarm**: An unwanted activation of an alarm initiating device or system output function where the cause has not been identified.

15.5. Monitoring of Fire Alarm System

References – CBC Section 907.6.5

The fire alarm system for the Construction Innovation Center must be monitored by an approved supervising station in accordance with NFPA 72. A supervising station is a facility that receives signals, related to the fire alarm system, and at which personnel are in attendance at all times to respond to these signals. The supervising station may be an approved:

- Central Station
- Remote Supervising Station
- Proprietary Supervising Station
- Other constantly attended location approved by the fire code official (Protected Premises)

The center is using a Protected Premises Fire Alarm System since the signals are sent within the campus to the University Police Department's Communication Center. The University Police is staffed 24 hours per week by professionally trained dispatchers. The campus has an emergency management plan which complies with the National Incident Management System (NIMS). The main plan establishes the emergency management structure under which the campus will operate in a disaster situation.

15.6. Initiating Devices

References – CBC Section 907.5 / NFPA 72 Section 17.1.2

A fire alarm system must first annunciate at the fire alarm control panel upon activation. Fire alarm systems must be activated by the following initiating devices:

- Automatic fire detectors.
- Automatic sprinkler system water–flow devices.
- Manual fire alarm boxes.
- Automatic fire-extinguishing systems.

Initiating devices are components from the fire alarm system that initiates transmission of a change-of-state condition. *Appendix I* and the table below demonstrate the initiating devices installed in the Contraction innovation Center. Most initiating devices used in the center are addressable in which allows the control panel to display the exact location of the activated device; this will allow fire personnel to quickly location the alarm.

Initiating Devices	Manufacture
Addressable Fire Alarm Box	Notifier
Addressable Multi–Sensor Detector	Notifier
Addressable Heat Detector	Notifier
Addressable Photoelectric Duct Detector	Notifier
Sprinkler Tamper Switch	Furnished By Others
Sprinkler Waterflow Switch	Furnished By Others

Note that NFPA 72 Chapter 17 for Initiating Devices is not intended to serve as the legal requirement or mandate to install initiating devices. This requirement or mandate belongs to legally adopted codes or ordinances, such as the California Building Code.

15.6.1. Types of Initiating Devices

There are two general types of initiating devices: manual and automatic. Sometimes the locally adopted code is not specific about the kind and extent of the automatic detection coverage required; therefore, the owner and the designer should consult with the local authority having jurisdiction. The California Building Code is silent as to the kind of detection (heat, smoke, flame, etc.) required for any specific type of occupancy. It is the designer duty to develop a detection strategy (type of detection and spacing) based on speed of response, environmental conditions, output functions to be initiated, and other project or loss control objectives.

15.6.2. Total Coverage

References – NFPA 72 Section 17.5.3.1

The Construction Innovation Center will have a total or complete coverage in which detectors are installed in all accessible compartments or spaces. Total coverage includes the followings:

- Rooms
- Halls
- Storage Areas
- Basements
- Lofts
- Spaces above Suspended Ceilings
- Closets
- Elevator Shafts
- Other Subdivisions and Accessible Spaces

15.6.2.1. Additional Coverage

*References – NFPA 72 Section 17.5.2**

Spaces that are separated by a partition that is more than 85 percent from the distance of the floor to ceiling must be considered as separate rooms. Partitions that are within 15 percent of the ceiling height are expected to interfere with the natural flow of the ceiling jet and delay detector response. Research on fire plumes and ceiling jets indicates that the thickness of ceiling jet under most conditions is approximately 10 percent of the floor–to–ceiling height in the fire compartment.

15.6.3. Manual Fire Alarm Box

References – CBC Sections 907.2.2

A manual fire alarm system must be installed in Group B occupancies where one of the following conditions exists:

- The combined Group B occupant load of all floors is 500 or more.
- The Group B occupant load is more than 100 persons above or below the lowest level of exit discharge.
- Group B occupancies containing educational facilities
- The fire area contains an ambulatory care facility.

The Construction Innovation Center complies with the first three existing conditions. Therefore, a manual fire alarm system is required. The center consists of manual fire alarm boxes, commonly known as pull stations, throughout all three buildings. The center uses a Notifier NBG–12LX, dual–action, pull station with an addressable interface.

15.6.3.1. Operation for Manual Fire Alarm Boxes

References – NFPA 72 Section 17.14.6 / CBC Section 907.4.2.7

Manual fire alarm boxes are manually operated device used to initiate an alarm signal. These pull stations are permitted to be single–action or double–action; a double–action requires two motions to activate the station. To operate the Notifier NBG–12LX pull station, the user must push in and pull down on the handle so the latch will be in the down/activated position. Once latched, the word "ACTIVATED" in bright yellow color will appear at the top of the handle. Note that manual fire alarm boxes must be operable with one hand. *Appendix J* illustrates the sequence of operation matrix for the activation of a manual fire alarm box.

15.6.3.1. Installation for Manual Fire Alarm Boxes

References – NFPA 72 Sections 17.14.3 & 17.14.4

Manually fire alarm boxes must be securely mounted on a background of contrasting color.

15.6.3.1. Locations for Manual Fire Alarm Boxes

*References – CBC Section 907.4.2.1 / NFPA 72 Sections 17.14.8.4 & 17.14.8.5**

Manual fire alarm boxes must be located within 5 feet of each exit on each floor of the Construction Innovation Center. These locations may include horizontal exits, entrance to stairs, and exit doors to the exterior. Additional manual fire alarm boxes must be located so that travel distance to the nearest box does not exceed 200 feet. This travel distance limitation is consistent with the exit access travel distance permitted for most non-sprinkler occupancies. The location of each manual fire alarm boxes provides occupants with adequate number of available devices in the path of egress. *Appendix I* illustrates the location of each manual fire alarm boxes.

15.6.3.2. Height for Manual Fire Alarm Boxes

References – CBC Section 907.4.2.2 / NFPA 72 Section 17.14.5

Manual fire alarm boxes must be mounted a minimum of 42 inches and a maximum of 48 inches, measured vertically, from the floor level to the activating handle or lever of the box. The height limitation for manual fire alarm boxes reduces the likelihood of damage or false alarms from accidental collision.

15.6.3.3. Color for Manual Fire Alarm Boxes

*References – CBC Section 907.4.2.3 / NFPA 72 Section 17.14.8.3**

Manual fire alarm boxes are to be painted or manufactured of the color red box. The distinctive and traditional red color will provide visual indication to occupants to identify the device.

15.6.3.4. Existing Conditions for Manual Fire Alarm Boxes

References – CBC Section 907.4.2.6 / NFPA 72 Section 17.14.8.2

Manual fire alarm boxes must be accessible, unobstructed, unobscured, and visible at all times. It is recommended that a minimum of 3 feet be kept clear, but more may be needed. There are times in which these manual fire alarm boxes are irrationally made inaccessible due to the nature of the room. Photo #16 illustrates a manual fire alarm box, within one of the laboratory rooms from Construction Innovation Center, being obstructed by an elongated wooden board.

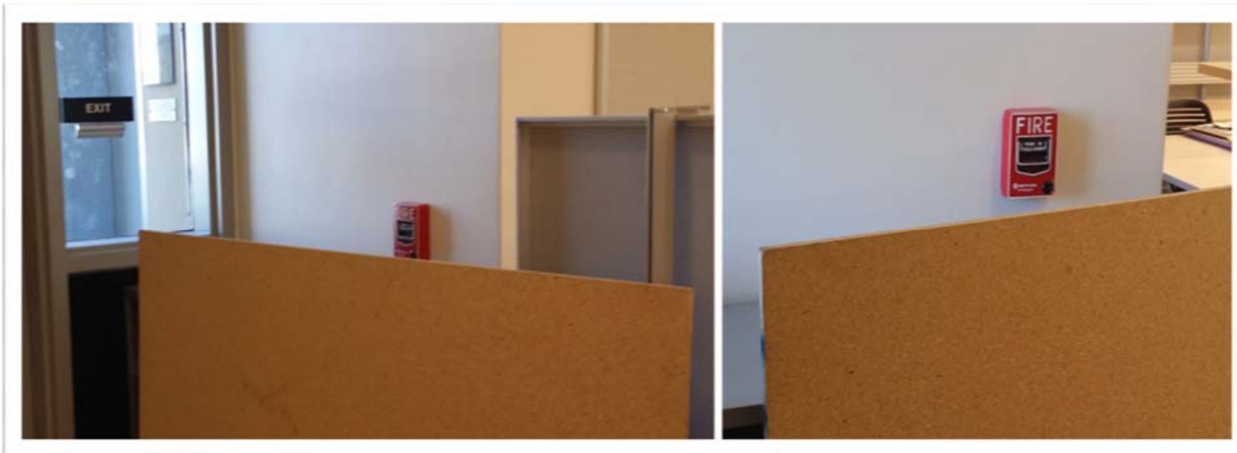


Photo #16: A Manual Fire Alarm Box being obstructed by an Elongated Wooden Board

15.6.4. Heat Detectors

The Construction Innovation Center is comprises of Notifier FST–851 addressable heat detectors. These thermal detectors use an innovative thermistor sensing circuit to produce 135°F or 57°C fixed-temperature. Although not explicitly stated in the code, heat detectors are generally used when the anticipated fire has achieved an energy output of at least 1.2 MW, which is the size fire used in determining the listed spacing for a heat detector.

15.6.4.1. Temperature Classification

References – NFPA 72 Section 17.6.2.1 & 17.6.2.3

Fixed–temperature heat detectors must be classified as to the temperature of operation in accordance with the table below. The table presents specific criteria for the nominal temperature classification versus the maximum ceiling temperature for the location of the detector. The heat detectors used for the Construction Innovation Center are classified as ordinary with an expected maximum ceiling temperature of 115 °F or 47 °C. Note that the temperature rating of the detector must have been least 20 °F or 11°C above the maximum expected temperature at the ceiling. The intent is to prevent unwarranted alarms due to variations in the ambient temperature.

Temperature Classification	Temperature Rating Range		Maximum Ceiling Temperature		Color Code
	°F	°C	°F	°C	
Low	100–134	39–57	80	28	Uncolored
Ordinary	135–174	58–79	115	47	Uncolored
Intermediate	175–249	80–121	155	69	White
High	250–324	122–162	230	111	Blue

Extra High	235–399	163–204	305	152	Red
Very Extra High	400–499	205–259	380	194	Green
Ultra high	500–575	260–302	480	249	Orange

15.6.4.2. Response Time Index Classification

References – NFPA 72 Section 17.6.2.2.2.3

The heat detectors used for the Construction Innovation Center must be marked with their response time index (RTI). RTI is a measure of the speed in which heat can flow into the detector and raise the temperature of the heat-sensing component. RTI can be thought of as the sensitivity of the heat-sensing element responding to the rise in temperature. Note that a low RTI indicates a more rapid response time if all affecting factors are held constant. The only method for determining RTI is the plunge test as outlined in FM Approval Standard 3210, *Heat Detectors for Automatic Fire Alarm Signaling*.

15.6.4.3. Number of Heat Detectors

The required number of heat detectors is a function of the spacing factor, {S}, of the chosen detector. {S} is established through a series of fire tests. The Notifier FST–851 addressable heat detectors are given 25 feet by 25 feet listed spacing. Keep in mind that the listed spacing for a heat detector is a combination of unrelated variables into a single parameter. These variables include fire size, fire growth rate, ambient temperature, ceiling height, and RTI. All these factors are lumped into a single parameter called the listed spacing.

15.6.4.4. Spacing of Heat Detectors

The occurrence of a fire is usually unknown; thus, detectors must be spaced accordingly to the geometry of the ceiling. The smaller the spacing, the more rapid the anticipated response of the system will be.

15.6.4.4.1. Spacing on Smooth and Regular Ceilings

References – NFPA 72 Section 17.6.3.1.1

The heat detectors used for the Construction Innovation Center on smooth and regular ceilings must follow the following:

- The distance between detectors must not exceed their listed spacing
- There must be detectors within a distance of one-half the listed spacing, measured at right angles from:
  - All walls
  - Partitions extending upward to within the top 15 percent of the ceiling height

- All points (i.e. corners) on the ceiling must have a detector within a distance equal to or less than 0.7 times the listed spacing (0.7S)

15.6.4.4.2. Spacing on Smooth and Irregular Ceilings

References – NFPA 72 Section 17.6.3.1.2

The heat detectors used for the Construction Innovation Center on smooth and irregular ceilings must follow the following:

- The distance between detectors are permitted to be greater than the listed spacing
- The maximum spacing from a detector to the farthest point of a sidewall or corner within its zone of protection is not greater than 0.7 times the listed spacing (0.7S)

15.6.4.5. Locations of Heat Detectors

*References – NFPA 72 Section 17.6.3.1.3.1**

The heat detectors used for the Construction Innovation Center must either be located on the ceiling not less than 4 inches from the sidewall or on the sidewalls between 4 inches and 12 inches from the ceiling.

15.6.5. Acclimate Plus Multi–Sensor Detectors

References – NFPA 72 Section 17.9.4.1

The Construction Innovation Center is comprised of Notifier FAPT-851 Acclimate Plus multi-sensor detectors. *Appendix I* illustrates the locations of each Acclimate Plus multi–sensor detectors within the center.

The term "multi–sensor" is used to describe a detector that senses two or more fire signatures to reach its alarm decision. It is capable of generating multiple alarm signals from the sensors either independently or in combination. The sensor output signal is mathematically evaluated to determine when an alarm signal is necessary. The evaluation can be performed either at the detector or at the control unit. This detector has multiple listing that establishes the primary function of the detector.

The table below demonstrates the differences between a combination, multi–criteria, and multi-sensor detectors.

Detector Type	Features
Combination	Multiple Sensors No Mathematical Evaluation Multiple Listings
Multi–Criteria	Multiple Sensors

	Mathematical Evaluation Single Alarm Signal Single Listing
Multi–Sensor	Multiple Sensors Mathematical Evaluation Multiple Alarm Signal Multiple Listing

The term "Acclimate Plus" signifies that the detector uses a combination of photoelectric and thermal sensing technologies that lower the probability of false alarms. There is no need for the installer to set the exact sensitivity levels at the control panel. Acclimate continuously samples the air in order to adjust its sensitivity and alarm thresholds. It does this automatically without user intervention. Acclimate continually looks for evidence of both smoke and heat in order to make a combined decision. For instances, acclimate will automatically become more sensitive in an area that is unoccupied, thus being able to give an earlier warning of an emergency.

15.6.5.1. Applicable to Smoke Detectors

References – NFPA 72 Section 17.7.1.4

The Notifier FAPT-851 Acclimate Plus multi–sensor detectors used within the Construction Innovation Center is listed under UL–268. This standard sets forth requirements for smoke detectors and mechanical guards to be employed in ordinary indoor locations in accordance with the NFPA 72. The term "ordinary indoor locations" is not defined in the code, however the authority having jurisdiction must decide whether a hazard area falls into this category. Ordinary indoor locations should be considered typical building spaces with relatively constant and not drastically changing environmental conditions, or conditions that would subject the smoke detectors to nuisance alarms. Note that the prescriptive requirements described in NFPA 72 for smoke detectors must only apply when installed in ordinary indoor locations. In some cases, which conditions falls outside the prescriptive requirements, a performance–based approach is needed or the use of a different type of fire detection than smoke detection.

15.6.5.2. Ambient Conditions Requirements

*References – NFPA 72 Section 17.7.1.8**

Smoke detectors must not be installed if any of the following ambient conditions exist:

- Temperature below 32°F or 0°C
- Temperature above 100°F or 38°C
- Relative humidity above 93 percent
- Air velocity greater than 300 ft/min or 1.5 m/sec

The temperature, humidity, and airflow criteria stated above reflect the criteria in the test standards used by the listing agency in the process of the listing evaluation. The Notifier FAPT-851 Acclimate Plus multi–sensor detectors complies with the required ambient conditions. The

table below demonstrates the specification of the Notifier FAPT-851 Acclimate Plus multi–sensor detector:

Specifications of the Notifier FAPT-851 Acclimate Plus Multi–Sensor Detector		
Operating Temperatures	=	0°C – 38°C or 32°F – 100°F
UL-Listed velocities	=	0 – 4000 ft/min or 0 – 1219.2 m/min
Relative humidity	=	10% – 93% noncondensing

15.6.5.3. Spacing for Smoke Detectors

The listing agencies do not provide a listed spacing for smoke detectors as they do for heat detectors. In the 2010 edition of NFPA 72, the technical committee adopted a prescriptive spacing for smoke detectors.

15.6.5.3.1. Spacing on Smooth and Regular Ceilings

*References – NFPA 72 Section 17.7.3.2.3.1**

The smoke detectors used for the Construction Innovation Center on smooth and regular ceilings must follow the following:

- The distance between detectors must not exceed a nominal spacing of 30 feet
- There must be detectors within a distance of one-half the nominal spacing, measured at right angles from:
  - All walls
  - Partitions extending upward to within the top 15 percent of the ceiling height
- All points (i.e. corners) on the ceiling must have a detector within a distance equal to or less than 0.7 times the nominal 30 feet spacing (0.7S)

15.6.5.3.2. Spacing on Smooth and Irregular Ceilings

References – NFPA 72 Section A.17.7.3.2.3.1 (2)

The smoke detectors used for the Construction Innovation Center on smooth and irregular ceilings must follow the following:

- The distance between detectors are permitted to be greater than the nominal spacing
- The maximum spacing from a detector to the farthest point of a sidewall or corner within its zone of protection is not greater than 0.7 times the nominal spacing (0.7S)

15.6.5.4. Locations for Smoke Detectors

*References – NFPA 72 Section 17.7.3.2.1**

The smoke detectors used for the Construction Innovation Center must either be located on the ceiling or on the sidewalls between ceiling and 12 inches from the ceiling.

15.6.6. Duct Smoke Detectors

The Construction Innovation Center has an HVAC system that supplies conditioned air to virtually every area of a center. Smoke entering into the air duct system is a big concern. Consequently, duct smoke detectors are installed to sense the presence of smoke in the duct. The center is comprises of an addressable FSD-751P air duct smoke detector.

15.6.6.1. Specifications for Duct Smoke Detectors

References – CBC Section 907.3.1 / NFPA 72 Section 17.7.5.5.1

Duct smoke detectors must be listed for the air velocity, temperature, and humidity present in the duct. The table below demonstrates the specification of the FSD-751P air duct smoke detector:

Specifications of FSD-751P Air Duct Smoke Detector

Duct Air Velocity	=	500 – 4,000 ft/min or 152.4 – 1219.2 m/min
Operating Temperature Range	=	32°F – 131°F or 0°C – 55°C
Humidity Range	=	10% – 93% noncondensing

15.6.6.2. Operations for Duct Smoke Detectors

References – CBC Sections 907.3.1 & 907.3.1 Exception 1 / NFPA 72 Section A.17.7.5.3

The Construction Innovation Center comprises of several addressable photoelectric duct smoke detectors. It is designed so sample air passing through the duct and allowing detection of a developing hazardous condition. Duct smoke detectors must be connected to the fire alarm control panel.

Upon activation of a duct smoke detector will initiate a visible and audible supervisory signal at a constantly attended location in which will alert building supervisory personnel that a detector has been activated. Note that the supervisory signal is not required where duct smoke detectors activate the building's alarm notification appliances.

The activation will also perform the intended fire safety function in accordance with the California Building Code and California Mechanical Code. All air handling equipment and fire-smoke dampers will automatically shut off. This will isolate toxic smoke and fire gases or

prevent their distribution throughout the areas served by the duct system. *Appendix J* illustrates the sequence of operation matrix for the activation of a duct smoke detector.

Note that smoke detectors can be applied for the following purposes:

- Prevention of the recirculation of dangerous quantities of smoke within a building
- Selective operation of equipment to exhaust smoke from a building
- Selective operation of equipment to pressurize smoke compartments
- Operation of doors and dampers to close the openings in smoke compartments

15.6.6.3. Limitations for Duct Smoke Detectors

Duct smoke detectors have specific limitations. These limitations include the followings:

- NOT a substitute for open area smoke detectors [*NFPA 72 Section 17.7.5.2.1*]
- NOT a substitute for early warning detection
- NOT a replacement for a building's regular fire detection system

15.6.6.4. Installation for Duct Smoke Detectors

*References – NFPA 72 Section 17.7.5.5.2**

Ducts tends to bends and change in cross-sectional area that may cause an uninform airflow within it. This flow can also become divided into layers depending on differing temperatures, resulting in smoke being concentrated in a portion of the duct cross-section. Therefore, air duct detectors must be properly installed to obtain a representative sample of the airstream. This installation must be permitted to be achieved by any of the following methods:

- Rigid mounting within the duct
- Rigid mounting to the wall of the duct with the sensing element protruding into the duct installation outside the duct with rigidly mounted sampling tubes protruding into the duct
- Installation through the duct with projected light beam

The duck smoke detectors used for the Construction Innovation Center have been installed outside the duct with rigidly mounted sampling tubes protruding into the airstream, as illustrated in Photo #17.

Photo #17: Duck Smoke Detector installed within the Construction Innovation Center

15.6.6.5. Locations of Duct Smoke Detectors

The fire–smoke dampers installed within the Construction Innovation Center are designed to be operated by the activation of duct smoke detectors. For that reason, duct smoke detectors must be located so that the detectors are between the last inlet or outlet upstream of the damper and the first inlet or outlet downstream of the damper. It is recommended that stratification and dead air space should be avoided in order to obtain a representative sample. Such conditions could be caused by return duct openings, sharp turns, connections, or long uninterrupted straight runs.

15.6.6.6. Accessibility for Duct Smoke Detectors

References – NFPA 72 Section 17.7.5.5.3

Duct smoke detectors must be accessible for cleaning by providing access doors or control units in accordance with NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*.

15.6.7. Supervisory Signal Initiating Device

References – NFPA 72 Section 3.3.132.5

The fire sprinkler system installed within the Construction Innovation Center uses both a suppression system and detection system. Supervisory signal initiating devices are part of the detection system that monitors a change of condition of a fire protection or life safety system.

15.6.7.1. Valve Tamper Switches

The Construction Innovation Center comprises of valve tamper switches in the fire sprinkler system. A valve tamper switch detects when a sprinkler valve has been partially or fully closed. These switches, when activated, annunciate the fire control panel and a 24 hour remote location. It also

15.6.7.2. Waterflow Switches

References – NFPA 72 Sections A.17.12.2 &17.12.2

The Construction Innovation Center consists of waterflow switches. A waterflow switch detects movement of water through the fire sprinkler system. The water in a wet pipe automatic sprinkler system riser is not static; it moves upward and downward in the riser due to the pressure deferential between the riser and the municipal water supply. Any air trapped in the sprinkler system piping will provide a compressible gas cushion that may enhance the tendency for water to flow due to variance of pressures in the water supply system. The alarm check valve in the sprinkler system tends to slow down, but not eliminate, this flow.

If activation occurs, the waterflow device must set an alarm no more than 90 seconds after a sustained flow of at least 10 gpm, or when flow occurs that is equal to or greater than that from a single sprinkler of the smallest orifice size installed in the system. Methods to minimize alarm response time include the following:

- Elimination of trapped air in the sprinkler system piping
- Use of an excess pressure pump
- Use of pressure drop alarm-initiating devices
- A combination thereof

15.7. General Location of Alarm Detectors

References – NFPA 72 Section 17.7.4.1

Detectors must not be located where their operation is being prevented by the airflow generated from air-handling systems. Furthermore, detectors should not be located in direct airflow or closer than 36 inches from an air supply diffuser or return air opening. The recommended 36 inches may be altered in some situations due to the high air velocity from the supply and return air, throw characteristics of the supply diffuser, or diffuser size.

15.8. Notification Appliances

References – CBC Section 907.5.2

An approved fire alarm notification appliances must be provided to the Construction Innovation Center. Notifying the occupants is usually accomplished by producing enough audible or visual

display to attract their attention and indicate that an emergency evacuation is necessary. Horns, bells, sirens, strobe lights, and speakers are the most common appliances used to provide this notification. The table below demonstrates the notification appliances installed in the center, as well as *Appendix I*. These notification appliances are as important as the initiating devices of the fire alarm system.

Notification Appliances	Manufacture
Sprinkler Waterflow Bell	Furnished By Others
Horn	Gentex
Horn with Waterproof Gasket/Enclosure	Gentex
Multi–Candela Strobe	Gentex
Multi–Candela Horn/Strobe	Gentex

15.8.1. Types of Notification Appliances

The code requires two general types of notification appliances: audible and visible. These two notification appliances are to be installed in conjunction with one another.

15.8.2. General Provisions for Audible Appliances

References – CBC Section 907.5.2.1

Audible alarm notification appliances must be provided to the Construction Innovation Center. The audible alarms must be distinctive, using a sound that is unique to the fire alarm system and used for no other purpose than alerting occupants to a fire emergency.

15.8.2.1. Sound Pressure for Audible Appliances

*References – CBC Section 907.5.2.1.1 / NFPA 72 Section 18.4.3.1**

Audible alarms must be capable of being heard above the ambient noise level to attract the attention of building occupants. It must provide a sound pressure level of 15 decibels above the average ambient sound level or 5 decibels above the maximum ambient sound level that lasts at least 60 seconds, whichever is greater.

15.8.2.1.1. Average Ambient Sound Pressure

References – NFPA 72 Section A.18.4.3 & Table A.18.4.3

In accordance with NFPA 72 Table A.18.4.3, the typical average ambient sound level for business occupancies is 55 decibels. This value is intended only for design guidance purposes and should not be used in lieu of actual sound level measurements. In that case, the audible notification appliances would need to deliver 70 decibels throughout the room. The table below

demonstrates the range of decibels for each Audible alarm notification appliances installed in the center.

Audible Notification Appliances	Range (Decibels)
Sprinkler Waterflow Bell	Not Available
Horn	62 – 82
Horn with Waterproof Gasket/Enclosure	62 – 82
Horn/Strobe	62 – 82

Audible notification appliances are typically rated by manufacturers and testing agencies at 10 feet from the appliance. Sound levels can be significantly reduced due to distance and losses through building elements. For instance, rule of thumb, the sound level decrease by about 6 decibels when distance from the source doubles.

15.8.2.1.2. Maximum Ambient Sound Level

*References – NFPA 72 Section 18.4.1.3**

Sound from normal or permanent sources, having a duration greater than 60 seconds, must be included when measuring the maximum ambient sound level. This measurement should be conducted during worst case conditions. This might require testing with doors and other barriers being opened and closed to determine the worst case. Sound from temporary or abnormal sources are not included when measuring maximum ambient sound level

15.8.2.2. Maximum Audible Appliance Sound Level

References – CBC Section 907.5.2.1.2

An audible alarm notification appliance must not exceed more than 110 decibels from its minimum hearing distance. Sound pressure above that level can cause pain or even permanent hearing loss.

15.8.2.3. Total Sound Pressure Level

*References – NFPA 72 Section 18.4.1.2**

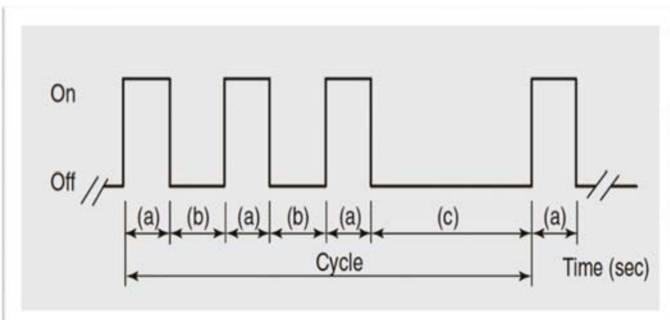
The total sound pressure level produced from the combination of the ambient sound pressure level and all audible notification appliances, operating within the minimum hearing distance, must not exceed 110 decibels.

15.8.2.4. Audible Alarm Signal

References – CBC Section 907.5.2.1.3 / NFPA 72 18.4.2.1, 18.4.2.4*, & 10.12.1*

The alarm audible signal pattern, used for the notification of occupants to evacuate from the building or relocate from one area to another, must be a standard alarm evacuation signal with a three pulse temporal pattern in accordance with NFPA 72. The use of the three pulse temporal pattern signal became effective on July 1, 1996, for new systems installed after that date. The pattern must be in accordance with Equation #2 and consist of the following order:

(1) "On" phase lasting 0.5 seconds ± 10 percent
(2) "Off" phase lasting 0.5 seconds ± 10 percent for three successive "on" periods
(3) "Off" phase lasting 1.5 seconds ± 10 percent



Phase **(a)** signal is on for 0.5 sec ± 10%

Phase **(b)** signal is off for 0.5 sec ± 10%

Phase **(c)** signal is off for 0.5 sec ± 10%

[**(c)** = **(a)** + 2**(b)**]

Total Cycle last for 4 seconds ± 10%

Equation 2: Temporal Pattern Parameters

The signal must be repeated for a duration appropriate for the purposes of evacuation of the Construction Innovation Center, but not less than 180 seconds. Note that the minimum repetition time is permitted to be manually interrupted. To preserve the temporal pattern, the standard alarm evacuation signal must be synchronized within a notification zone. Actuation of an alarm notification appliance must occur within 10 seconds after the activation of an initiating device.

15.8.2.5. Impractical use of Audible Appliances

In some circumstances, the ambient sound level may be too high for an audible appliance to be effective; thus, a visible appliance is required instead. Two different requirements are provided, as described below.

In accordance with the California Building Code, visible alarm notification appliances must be provided in lieu of audible alarm notification appliances when the average ambient noise is greater than 95 decibels. [*References – CBC Section 907.5.2.1.2*]

In accordance with NFPA 72, visible alarm notification appliances must be provided in lieu of audible alarm notification appliances when the average ambient noise is greater than 105 decibels. [*References – NFPA 72 Section 18.4.1.1**]

15.8.2.6. Location of Audible Notification Appliances

References – NFPA 72 Sections 18.4.8.1 & 18.4.8.2

Wall–mounted appliances must be mounted with their tops above the finished floors of not less than 90 inches and below the finished ceilings of not less than 6 inches. This mounting height limitation for audible appliances is to prevent common furnishings from blocking appliances after installation. Ceiling –mounted or recessed appliances are permitted. A number of notification appliances (horns, bells, etc.) must be strategically placed throughout the building to provide the amount of noise needed to get everyone's attention while they occupy their normal environment.

15.8.2.6. Coverage Areas

References – NFPA 72 Sections 18.4.1.4.2 & 3.3.178*

Audible appliances must be installed in occupiable areas required by the enabling code, law, or standard. Note that an occupiable area is an area of a building being occupied by people on a regular basis. For instance, a closet will not be considered an occupiable area.

15.8.3. General Provisions for Visible Appliances

References – CBC Section 907.5.2.3

Visible appliances must be provided to the Construction Innovation Center, except in exterior exit stairs and elevator cars. The intent is to avoid any confusion and disorientation from the high light intensity of these visible alarm notification appliances. The table below demonstrates the range of candelas for each visible appliance installed in the center.

Visible Appliances	Range (Candelas)
Multi – Candela Horn/Strobe	15, 30, 60, 75, 110
Multi – Candela Strobe	15, 30, 60, 75, 110

15.8.3.1. Public and Common Use Areas

*References – CBC Section 907.5.2.3.1 / NFPA 72 Section 18.5.1.2**

Visible appliances must be provided in public use areas and common use areas within the Construction Innovation Center, including but not limited to:

- Restrooms
- Corridors
- Multipurpose rooms
- Lobbies
- Meeting rooms

- Classrooms

Visible appliances must be installed in occupiable areas required by the enabling code, law, or standard. Note that an occupiable area is an area of a building being occupied by people on a regular basis. For instance, a closet will not be considered an occupiable area.

15.8.3.2. Visible Signaling

References – NFPA 72 Section A.18.5.1

Visible appliances must be clearly seen regardless of the viewer's position within the protected area. Note that the appliances are not required to be seen from each location in a space, but rather the operating effect must be seen.

15.8.3.3. Effective Intensity

*References – NFPA 72 Section 18.5.3.4**

Lights used for fire alarm signaling or complete evacuation signaling must be clear or nominal white and must not exceed an effective intensity of 1000 candelas. Effective intensity is the conventional method of equating the brightness of a flashing light to that of a steady-burning light source. As an individual move away from any light source, its illumination decreases. Figure #3 demonstrates the mathematical relationships between light source, intensity, and illumination.

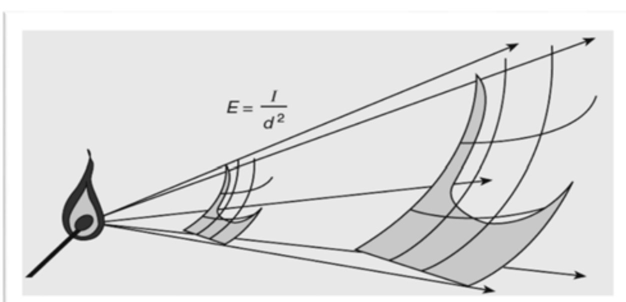


Figure #3: Light Source

E = Illumination (1 lumen/m2 or 1 lux)

I = Intensity of Source (1 cd or 12.57 lumens)

d = Distance from source to object (ft or m)

15.8.3.4. Location of Visible Notification Appliances

References – NFPA 72 Sections 18.5.5.1 & 18.5.5.2*

Wall–mounted visible appliances must have their entire lens at heights not less than 80 inches and not greater than 96 inches above the finished floor, unless mounted at height specified using the performance-based alternative. The minimum mounting height is intended for appliances from being blocked by common furnishings or equipment and, more importantly, to ensure a light pattern large enough to cover the intended space. The maximum mounting height is intended to keep the illumination from drastically reducing. Conditions where ceiling heights are

less than 80 inches, wall mounted visible appliances must be mounted within 6 inches of the ceiling.

15.8.3.5. Spacing of Visible Notification Appliances

References – NFPA 72 Section 18.5.5.4.2

Visible notification appliances must be installed in accordance with wall–mounted or ceiling–mounted requirements using one of the following:

- A single visible notification appliance.
- Two groups of visible appliances, where visual appliances of each group are synchronized, in the same room or adjacent space within the field of view. This must include synchronization of strobes operated by separate systems.
- More than two visible appliances or groups of synchronized appliances in the same room or adjacent space within the field of view that flash in synchronization.

15.8.3.5.1. Wall–Mounted Visible Appliances

References – NFPA 72 Sections 18.5.5.4.1, A.18.5.5.4, 18.5.5.4.3, & 18.5.5.4.5 & 18.5.5.4.4

Wall-mounted visible appliances are required to provide a minimum intensity in correlation to the maximum room size, as described from the table below. It is acceptable to use a higher intensity strobe in lieu of the minimum required intensity.

Maximum Room Size (ft)	Minimum Required Light Output (cd)	
	One Light per Room	Four Light per Room [a]
20 x 20	15	Not Allowed
28 x 28	30	Not Allowed
30 x 30	34	Not Allowed
40 x 40	60	15
45 x 45	75	19
50 x 50	94	30
60 x 60	110	30
63 x 63	150	37
68 x 68	177	43
70 x 70	184	60
80 x 80	240	60
90 x 90	304	95
100 x 100	455	135
110 x 110	455	135

120 x 120	540	135
130 x 130	635	185

a. One light per wall

Spacing for wall-mounted appliances in square spaces must be based on locating the visible appliance at the halfway distance of the wall. If a space configuration is not square, proper placement of visible appliances can be facilitated by breaking down the space into multiple independent squares and dimensions that fit most appropriately.

In situation where spacing for wall-mounted appliances is not located halfway distance of the wall, the effective intensity (cd) must be determined by measuring the distance to the farthest wall or by doubling the distance to the farthest adjacent wall, whichever is greater, to obtain maximum room size.

15.8.3.5.2. Ceiling–Mounted Visible Appliances

*References – NFPA 72 Sections A.18.5.5.4, 18.5.5.4.7, & 18.5.5.4.6**

Ceiling–mounted visible appliances are required to provide a minimum amount of intensity in correlation to the maximum room size and lens height, as described from the table below. It is acceptable to use a higher intensity strobe in lieu of the minimum required intensity.

Maximum Room Size (ft)	Maximum Lens Height [a] (ft)	Minimum Required Light Output [b] (cd)
20 x 20	10	15
30 x 30	10	30
40 x 40	10	60
44 x 44	10	75
20 x 20	20	30
30 x 30	20	45
44 x 44	20	75
63 x 63	20	80
20 x 20	30	55
30 x 30	30	75
50 x 50	30	95
53 x 53	30	110
55 x 55	30	115
59 x 59	30	135
63 x 63	30	150
68 x 68	30	177
70 x 70	30	185

a. This does not preclude mounting lens at lower heights.
b. One light.

Ceiling–mounted visible appliances must be installed at the center of the room in accordance with the table above. If the ceiling-mounted visible appliance is not located at the center of the room, the effective intensity (cd) must be determined by doubling the distance from the appliance to the farthest wall to obtain the maximum room size.

In situations where ceiling heights exceed 30 feet, ceiling-mounted visible appliances must be suspended at or below 30 feet, or at the mounting height determined using the performance-based alternative, or wall–mounted visible appliances must be installed.

15.8.3.5.3. Spacing in Corridors

References – NFPA 72 Sections 18.5.5.5.1, 18.5.5.5.3, 18.5.5.5.4, 18.5.5.5.5, & 18.5.5.5.7*

The balconies, which act like corridors, for the Construction Innovation Center have a width less than 20 feet. The installation of visible appliances in corridors with 20 feet or less in width must be rated not less than 15 candelas. This lower intensity is due to the assumption that occupants are usually alert, moving, and focused by the narrowness of the space.

Visible appliances must be located not more than 15 feet from the end of the corridor with a separation not greater than 100 feet between appliances. *Appendix I* illustrates the location of each visible appliances in the corridor. These visible appliances, when grouped in two or more in any field of view, must flash in synchronization.

Note that it is acceptable to use requirements for Spacing in Rooms to determine the number and location of visible appliances in corridors. If that's the case, it is not necessary to have visible appliances within 15 feet of the end of the corridor. Keep in mind that corridors that are more than 20 feet wide are treated the same as rooms.

15.8.4. Sprinkler Waterflow Bell

References – NFPA 13 Sections 6.9.3.2 & 8.17.1.1

A local waterflow alarm must be provided on every sprinkler system having more than 20 sprinklers on the premise. The Construction Innovation Center is comprised of outdoor sprinkler waterflow bells, as illustrated in Photo #18. These devices must be weatherproofed and guarded.

Photo #18: Sprinkler Waterflow Bell

15.8.5. Horn, Strobes, & Horn/Strobe

References – NFPA 72 Section 18.4.8.3

The Construction Innovation Center is comprised of EH24–R horns, GEC3–24WR horns/strobes, and GES3–24WR strobes. These notification appliances are illustrated in *Appendix H.* horns and strobes must comply with their corresponding requirements for audible and visible appliances, respectively, as described on this report. The location of combination horn/strobe must comply with the requirements for the mounting of visible notification appliances.

15.8.5.1. Mechanical Protection

References – NFPA 72 Section A.18.3.4

Situations exist where supplemental enclosures are necessary to protect the physical integrity of a notification appliance. Several Gentex GEH24–R horns used for the Construction Innovation Center are equipped with waterproof gasket/enclosures, as illustrated in Photo #19. These protective enclosures should not interfere with the performance characteristics of the appliance.

Photo #19: Gentex GEH24–R Horns equipped with Waterproof Gasket/Enclosures

15.9. Remotely Power Supply

References – NFPA 72 Section 10.6.8

The Construction Innovation Center is comprised of Fire Lite FCPS-24FS6(C/E), a six-amp remote power supplier with battery charger, as illustrated in *Appendix H*. The FCPS-24FS6(C/E) may be connected to any 12 or 24 volt fire alarm control panel or may stand-alone. The FCPS contains a battery charger capable of charging up to 7.0 amp hour batteries. *Appendix I* illustrates the location of each FCPS within the center.

Remotely located power supply may be used for the following applications:

- Expand notification appliance power an additional 6.0 A. Use up to four Class B (Style Y) outputs or four Class A (Style Z) outputs (using ZNAC-4).
- Use the FCPS to expand auxiliary regulated 24 volt system power up to 4.0 Amp.
- Use addressable control modules to activate the FCPS instead of activating it through the FACP notification appliance circuits. This typically allows for mounting the FCPS at greater distances*away from the FACP

15.10. Fire Alarm Zoning

References – CBC Section 907.6.3

The fire alarm system for the Construction Innovation Center must be zoned to shorten the response time in locating the fire by the emergency personnel. The fire alarm system must be divided into zones in accordance with the following requirements:

- Where the fire-protective signaling system serves more than one building, each building must be considered as a separate zone.
- Each floor of a building must be considered as a separate zone.
- Each section of floor of a building that is separated by horizontal exits must be considered a separate zone.
- Each zone must not exceed 22,500 square feet.
- The length of any zone must not exceed 300 feet in any direction.
- Annunciation must be further divided into zones where deemed necessary by the enforcing agency.

The fire alarm system for the center is divided into separate zones as described below:

- An individual zone per floor for manual pull stations
- An individual zone per floor for area smoke detectors
- An individual zone per floor for area heat detectors
- An individual zone per floor for sprinkler water flow switches
- An individual zone for each duct detector
- An individual zone for each elevator lobby smoke detector
- An individual zone per floor for sprinkler tamper switches

- Entire building is one zone

15.11. Annunciator

References – NFPA 72 Section A.10.18.3

An annunciator is a panel that displays the status of the monitored fire protection systems and devices. The primary purpose of an annunciator is to assist responding personnel to quickly and accurately determine the status of equipment or emergency control functions that might affect the safety of occupants. Note that the annunciator is not the fire alarm control unit; however, the control panel may include an annunciator.

15.11.1. Type & Location of Annunciator

References – NFPA 72 Section 10.18.3.2

The authority having jurisdiction determines the type and location of any required annunciator. The Construction Innovation Center comprises of LCD–80 annunciators, as illustrated in *Appendix H*. These annunciators have an 80 characters backlit liquid crystal display. They can be remotely located up to 6,000 feet from the control panel. *Appendix I* illustrates the location of each annunciator within the center.

15.12. Fire Alarm System Circuit

References – NFPA 72 Sections 23.4.2 & 23.4.2.1

There are three typical fire alarm system circuits: initiating device circuits, signaling line circuits, and notification appliance circuits. The new edition of NFPA 72, 2013, designates circuits solely by class. These designations include Class A, Class B, Class C, Class D, Class E, and Class X circuits. The selection of class must depend on the physical wiring of the circuit physically wired and the operation on the fire alarm control panel during the specified fault conditions. The specified fault conditions must result in the annunciation of a trouble signal at the center within 200 seconds.

15.12.1. Initiating Device Circuit

References – NFPA 72 Sections 3.3.133 & 23.5

The circuit that connects the automatic or manual initiating devices and fire alarm control panel, where the signal received does not identify the individual device activation, is known as an initiating device circuit (IDC). The fire alarm control panel interprets the increase in current as an alarm signal from one of the initiating devices when activated. Only one signal can be obtained since any one of the initiating devices can cause the incremental current flow. There are no initiating devices that can subsequently be recognized because the power supply has been shorted by the first responding device. Sometimes initiating device circuits are called zones; thus, the device puts the entire zone into the alarm state. The table below demonstrated the initiating devices that utilized an initiating device circuit within the Contraction Innovation Center.

Initiating Devices	Circuit
Sprinkler Tamper Switch	IDC
Sprinkler Waterflow Switch	IDC

Note that initiating device circuits must be classified based on its performance capabilities under fault conditions in accordance with the requirements for Class A or Class B.

15.12.2. Signaling Line Circuit

References – NFPA 72 Sections 3.3.8, 3.3.259 & 23.6

Most initiating devices installed within the Construction Innovation Center are classified as addressable units. An addressable device has the capability to have its status individually identified. The circuit between the addressable devices and the fire alarm control panel is essentially a time–domain multiplex circuit, and is called a signaling line circuit. The table below demonstrated the initiating devices that utilized a signaling line circuit within the Contraction Innovation Center.

Initiating Devices	Circuit
Addressable Fire Alarm Box	SLC
Addressable Multi–Sensor Detector	SLC
Addressable Heat Detector	SLC
Addressable Photoelectric Duct Detector	SLC

Note that signaling line circuits must be classified based on its performance capabilities under fault conditions in accordance with the requirements for Class A, Class B, or Class X.

15.12.3. Notification Appliance Circuit

References – NFPA 72 Section 3.3.174 & 23.7

The circuit that directly connects the notification appliances within the Construction Innovation Center is known as notification appliance circuit. The table below demonstrated the initiating devices that utilized a notification appliance circuit within the Contraction Innovation Center.

Notification Appliances	Circuit
Sprinkler Waterflow Bell	NAC
Horn	NAC
Horn with Waterproof Gasket/Enclosure	NAC
Multi–Candela Strobe	NAC

Multi–Candela Horn/Strobe	NAC

Note that notification appliance circuits must be classified based on its performance capabilities under fault conditions in accordance with the requirements for Class A, Class B, or Class X.

15.13. Wiring for Fire Alarm System

References – CBC Sections 907.6 & 907.6.1

The wiring for fire alarm system must be securely installed so it will function reliably in an emergency. The wiring must comply with the requirements of California Electrical Code and NFPA 72.

15.14. Notification Appliance Circuit Voltage Drop Calculations

References – CBC Sections 10.4.1 & A.10.4.1*

Notification appliance circuits require special treatment to ensure that the voltage supplied to all the connected appliances will be within the limits specified for proper operation of each appliance. The reasoning is that all electrical conductors include a small amount of resistance. This resistance increases if the length of the conductor increases or the conductor size decreases. As electrical current flows through the conductor it will experience a decrease in voltage between the source and at various points along the conductor path. For instance, the voltage drop in a 1000 foot run of 18 AWG wire would be greater than that of a 1000 foot run of 12 AWG. This is simply because a 18 AWG conductor is smaller in diameter than a 12 AWG conductor. Voltage that is below the operating range of the appliance can cause the appliances to perform at levels inadequate from the original design of the system. Therefore, voltage drop calculations must be performed to ensure proper performance of the appliance.

The notification appliances within the Contraction Innovation Center are using a nominal wire gauge size and nominal voltage of 12 AWG and 24 VDC, respectively, for a 7 strands uncoated copper at 75 °C. Consequently, when the voltage drop is being calculated, both the listed and the nameplate operating voltage must range between 16 and 33 VDC for 24 VDC units. The 16 VDC should be considered the minimum voltage that must be delivered to any appliance, especially at the end of each circuit.

15.14.1. Methodology for Voltage Drop Calculations

There are several methods in calculating the voltage drop between the control unit and the last notification appliance on the NAC. Three possible methods are as followed:

- **Point–to–Point Method**: Calculates each appliance load of the circuit separately.
- **Center–Load Method**: Assumes the entire appliance loads are at the middle of the circuit.
- **Lump Sum Method**: Assumes the entire appliance loads are at the end of the circuit.

The basis for the voltage drop calculations will be based on the worst–case operating condition when the fire alarm control panel's primary power supply has failed and the battery capacity is at its lowest point. ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems*, indicates a minimum value of 20.4 VDC for end of useful battery life. This value will be the starting point for the voltage drop calculations.

Appendix K demonstrates the notification appliance circuit voltage drop calculations for the Contraction Innovation Center. The formulas used for the calculations are described in the table below.

$$\boldsymbol{VD = [2 * L * R * I]/100} \qquad \boldsymbol{\%VD = [VD\ /\ 24] * 100}$$

$\boldsymbol{VD}$	=	Voltage drop
$\boldsymbol{L}$	=	One way length of circuit (feet)
$\boldsymbol{R}$	=	Conduction Resistance (ohm/feet)
I	=	Load current (amps)

15.15. Battery Calculation

References – NFPA 72 Section 10.6.7.2.1

The required battery capacity for a secondary power supply is calculated by determining the standby and alarm loads for the system. The manufacturer provides the current drawn for a fire alarm system component in both the standby and alarm mode. The calculation should include the normal standby supervisory quiescent load of 24 hours and the load during the specified alarm period of 5 minutes. A 20 percent safety margin must be added to the calculated amp-hour rating. The battery calculation for the Construction Innovation Center is demonstrated in *Appendix L*.

15.16. Inspection, Testing, & Maintenance

References – CBC Section 907.6.4 / NFPA 72 Section 14.2.2.1

Access must be provided to the fire alarm components used for the Construction innovation Center for periodic inspection, maintenance, and testing. Chapter 3 of NFPA 72 incorporated three criteria to judge the acceptability of equipment, wiring, and locations of these components:

- **Accessible (as applied to equipment)**: Admitting close approach; not guarded by locked doors, elevation, or other effective means. [*NFPA 72 Section 3.3.1*]
- **Accessible (as applied to wiring methods)**: Capable of being removed or exposed without damaging the building structure or finish, or not permanently closed in by the structure or finish of the building. [*NFPA 72 Section 3.3.2*]

- **Accessible, Readily (as applied to general locations)**: Capable of being reached quickly for operation, renewal, or inspections without requiring any intense effort or additional tools than normally required. [*NFPA 72 Section 3.3.3*]

15.16.1. Inspection of Fire Alarm System

References – NFPA 72 Sections 14.2.1.3, 14.3.1*, 14.3.2, & 14.3.3*

The fire alarm system installed within the Construction innovation Center must be periodic inspected to assure that obvious damages or changes that might affect the system operability are visually identified. A visual inspection should be conducted prior to any testing. Any improper installation, damaged, or nonfunctional components should be identified during the visual examination and be corrected before tests begin. *Appendix M* specifies the minimum frequencies for visual inspection of various fire alarm systems' components within the center.
Keep in mind, devices or equipment that is inaccessible due to safety consideration is permitted to be rescheduled for inspection, during shutdowns operations, if approved by the authority having jurisdiction. Situations, which pose a significant safety hazard to personnel conducting the inspection, might include continuous process operations, electrical equipment, radiation, and excessive height. Extended intervals must not exceed 18 months.

15.16.2. Maintenance of Fire Alarm System

References – NFPA 72 Sections 14.5.1, 14.5.2, & 14.5.3

The fire alarm system installed within the Construction Innovation Center must be maintained in accordance with the manufacturer's published instructions. The frequency of maintenance and cleaning will depend on the type of equipment and the local ambient conditions.

15.16.3. Testing of Fire Alarm System

References – NFPA 72 Sections 14.4.3.2 & 14.4.4.1*

The fire alarm system installed within the Construction Innovation Center must be periodic tested to statistically assure operational reliability. Periodic testing does not necessarily ensure proper system operation or availability other than at time of the test. However, the purpose of periodic tests is to minimize the potential time a system, function, or device might be out of service before discovery of the problem. *Appendix M* specifies the minimum frequencies for testing of various fire alarm systems' components within the center.

Similar as before, devices or equipment that is inaccessible due to safety consideration is permitted to be rescheduled for inspection, during shutdowns operations, if approved by the authority having jurisdiction. Situations, which pose a significant safety hazard to personnel conducting the inspection, might include continuous process operations, electrical equipment, radiation, and excessive height. Extended intervals must not exceed 18 months.

15.16.3.1 Testing Records

References – NFPA 72 Sections 14.6.2.1 & 14.6.2.3

Records must be retained until the next test and for 1 year thereafter. These records are permitted to be in paper or electronic.

15.16.3.2 Notification of Personnel

References – NFPA 72 Sections 14.2.4.1 & 14.2.4.2

It is required that everyone potentially affected to be notified before commencing fire alarm or signaling system tests. This includes the building occupants and any other individual or organizations affected by the testing. At the conclusion of the test, those previously notified and others, as necessary, must be notified that testing has been finished.

15.16.3.3 Testing of Fire Smoke Dampers

References – NFPA 72 Sections 14.2.4.3

System testing must be properly coordinated, by the owner or the owner's designated representative and service personnel, to prevent interruption of any critical building systems or component. The requirements described in NFPA 72 Chapter 14 for *Inspection, Testing, and Maintenance* only cover testing for fire alarm or signaling system up to the point of interface with other systems. The fire smoke damper, which is controlled by the smoke detector and connected to the fire alarm system within the center, is not required to have an operational test. Each system or component interfaced with the fire alarm system is tested in accordance with the applicable code or standard for that system or component. Therefore, the fire smoke damper would be inspected and tested in accordance with the requirements of NFPA 80 for *Standard for Fire Doors and Other Opening Protectives.*

15.16.4. Impairments & Deficiencies

References – NFPA 72 Section 14.2.2.2.3

The system owner or the owner's designated representative must be informed of any impairment, in writing, within 24 hours if a deficiency is not corrected at the end of system inspection, maintenance, or testing. Even though corrected, the problems should still be reported to the building owner or owner's designated representative to prevent it from reoccurring. It is important that any notifications to the building owner or owner's designated representative must be made in writing.

15.16.5. Inspection, Testing, & Service Personnel

References – NFPA 72 Section 10.5.3

The inspection, testing, and maintenance of systems installed within the Construction Innovation Center must be performed by a qualified and experienced personnel in accordance with NFPA 72. This personnel may either be an individually or affiliated with an organization that is registered, licensed, or certified by a state or local authority.

15.16.5.1. Inspection Personnel

References – NFPA 72 Section 10.5.3.1 & A.10.5.3.1*

Inspection personnel must have developed competence through training and experience acceptable to the authority having jurisdiction or meet the requirement stated for service personnel. They should have knowledge about equipment selection, placement, and installation requirements in accordance with NFPA 72 and the manufacturer's published documentation.

15.16.5.2. Testing Personnel

References – NFPA 72 Section 10.5.3.2 & A.10.5.3.2*

Testing personnel must have knowledge and experience of the testing requirements for fire alarm and signaling equipment, in accordance with NFPA 72, acceptable to the authority having jurisdiction or meet the requirement stated for service personnel. They should have knowledge about equipment selection, placement, and installation requirements in accordance with NFPA 72 and the manufacturer's published documentation.

15.16.5.3. Service Personnel

Service personnel, previously known as maintenance personnel, must be qualified and experienced in the maintenance and servicing of systems addressed within NFPA 72.

15.16.5.3.1. Service Personnel Qualifications

References – NFPA 72 Section 10.5.3.3

Service personnel must include, but not be limited to, one or more of the following:

- Personnel who are factory trained and certified for the specific type and brand of system being serviced
- Personnel who are certified by a nationally recognized certification organization acceptable to the authority having jurisdiction

- Personnel, either individually or through their affiliation with an organization that is registered, licensed, or certified by a state or local authority to perform service on systems addressed within the scope of NFPA 72
- Personnel who are employed and qualified by an organization listed by a nationally recognized testing laboratory for the servicing of systems within the scope of NFPA 72

15.16.5.3.2. Service Personnel Experience

References – NFPA 72 Sections 14.2.3.6 & A.14.2.3.6*

Service personnel should be able to do the following:

- Understand the requirements contained in NFPA 72 , *National Fire Alarm and Signaling Code*, and the fire alarm requirements contained in NFPA 70 , *National Electrical Code*
- Understand basic job site safety laws and requirements
- Apply troubleshooting techniques, and determine the cause of re alarm system trouble conditions
- Understand equipment specific requirements, such as programming, application, and compatibility
- Read and interpret re alarm system design documentation and manufacturer's inspection, testing, and maintenance guidelines
- Properly use tools and test equipment required for testing and maintenance of fire alarm systems and their components
- Properly apply the test methods required by NFPA 72 , *National Fire Alarm and Signaling Code*

16. Fire–Smoke Damper

References – CBC Section 717

The Construction Innovation Center comprises of several fire–smoke dampers in accordance with Ruskin model FSD60. These are listed devices installed in ducts designed to close automatically upon the detection of an initiating device. Fire–smoke dampers are designed to resist the passage of flame and smoke. The location of each fire–smoke damper within the center is illustrated in *Appendix I*.

The damper frame is constructed using the UniFrame Design Concept (UDC) with a roll-formed structural hat channel, reinforced at the corners, formed from a single piece of minimum 16 gage galvanized steel. The damper blades are airfoil shaped with 13 gage equivalent thickness formed from a single piece of galvanized steel. The bearings are of stainless steel turning in an extruded hole in the frame. The blade edge seals are of silicone rubber and galvanized steel mechanically locked in to the blade edge.

16.1. Activation of Dampers

References – CBC Section 717.3.3.3

The activation of fire–smoke dampers must comply with the requirements for both fire and smoke dampers.

The fire damper actuation device must have an operating temperature of approximately 50 °F above the normal temperature, but not less than 160 °F, within the duct system.

Smoke dampers that are installed within a duct must comply with certain requirements. A smoke must be installed in the duct within 5 feet of the damper with no air outlets or inlets between them. The detector must be listed for the air velocity, temperature, and humidity anticipated at the point where it is installed. In addition, dampers must close upon fan shutdown where local smoke detectors require a minimum velocity to operate.

The fire–smoke dampers used for the Construction Innovation Center are installed within the air duct system. These dampers are designed to close automatically upon the activation of a duct smoke detector or balcony smoke detector, as demonstrated in *Appendix J* for sequence of operation. The closing of the fire–smoke dampers has been included into the air handling equipment shutdown sequence when activated by the appropriate initiating device. Photo #20 illustrates the separation distance between a fire–smoke damper and duct smoke detector.

Photo #20: Duct Smoke Detector and Fire–Smoke Damper

16.2. Installation of Dampers

References – CBC Section 717.2

Fire smoke–dampers must be installed in accordance with the requirements of CBC Section 717, the manufacturer's installation instructions, and the damper’s listing.

16.3. Access & Identification of Dampers

References – CBC Section 717.4

Fire–smoke dampers installed within the Construction Innovation Center must be provided with an approved means of access that permits inspection and maintenance of the damper and its operating parts. An access door has been used at each damper with door size large enough to permit replacement o fusible links and resetting of dampers, as illustrated in Photo #18. Access doors in ducts must be tight fitting and suitable for the required duct construction. The table below demonstrates the minimum access doors size, used for the center, in correlation with the duct size.

Duct Size	Access Door Size	Required Number
12 inches and smaller	8 inches x 8 inches	1
14 inches – 20 inches	12 inches x 12 inches	1
22 inches – 48 inches	18 inches x 12 inches	1
48 inches – 96 inches	18 inches x 18 inches	2

Access door must be permanently identified on the exterior by a label having letters not less than 0.5 inches in height that reads: FIRE/SMOKE DAMPER.

16.4. Ratings of Dampers

References – CBC Section 717.3.2.3

The ratings of fire–smoke dampers installed within the Construction Innovation Center must comply with the requirements for both fire and smoke dampers on fire protection rating and leakage rating, respectively.

Fire dampers must have a minimum fire protection rating specified in the table below for the type of penetration. The table summarizes the required hourly ratings for fire dampers based on the fire-resistance-rated assembly that is being penetrated by the air distribution system. The dampers used for the center has a fire rating of 1.5 hours in accordance with UL555.

Type of Penetration	Minimum Damper Rating
Less than 3-hour fire-resistance-rated assemblies	1.5 hours
3-hour or greater fire-resistance-rated assemblies	3 hours

Smoke damper leakage ratings must be Class I or II. Elevated temperature ratings must not be less than 250 °F or 121 °C. The damper used for the center is classified as Leakage Class I Smoke Dampers in accordance with UL555S.

16.5. Testing of Dampers

References – CBC Section 717.3.1

Fire–smoke dampers must comply with the requirements of both UL 555 and UL 555S. Each damper must be manually tested for proper operation by removing fusible link or actuating EFL or PFL. Dampers that do not close completely must be repair or replace.

17. Automatic Fire Sprinkler System

References – NFPA 13 Section 3.4.11

The Construction Innovation Center comprise of an automatic wet pipe sprinkler system, in accordance with NFPA 13, throughout the entire center. This type of fire suppression system is used in warm climates in which it scarcely reaches below freezing point. The operating system of a wet-pipe sprinkler system begins with the activation of a sprinkler head due to an increase of heat. All branch lines are filled with static water until activation occurs that will discharge the water in a spray pattern over the fire area.

The system used for the center is a combination of underground and overhead piping designed in conformity with engineering standards. The most distinguishable system component of a wet pipe sprinkler system is the alarm valve. *Appendix N* illustrates the basic components of the systems.

17.1. Installation of Automatic Fire Sprinkler Systems

References – CBC Sections 903.3.1.1& 903.3.4

The Construction Innovation Center is required to be installed throughout with an automatic sprinkler system in accordance with NFPA 13. Note that if the standard allows for the omission of sprinklers in any location, then the center is still considered as sprinklered throughout.

17.2. Occupancy Hazard Classifications

References – NFPA 13 Sections 5.1.1, 5.2, 5.3.1.1, 5.3.2.1, 5.4.1, 5.4.2,

The occupancy hazard classifications form the basis of the design, installation, and water supply criteria of NFPA 13. This classification provides a convenient means of categorizing the fuel loads and fire severity associated with certain building operations. It is the primary decision in designing the fire sprinkler system in which will have a huge impact on the effectiveness of the system during a fire. The occupancy hazard classifications are presented as qualitative descriptions, rather than quantifiable measurements, as described below:

- **Light Hazard**: The quantity and/or combustibility of contents are low and fires with relatively low rates of heat release are expected.

- **Ordinary Hazard Group 1**: The quantity of combustibles is moderate, combustibility is low, stockpiles of combustibles do not exceed 8 feet, and fires with moderate rates of heat release are expected.
- **Ordinary Hazard Group 2**: The quantity and combustibility of contents are moderate to high, stockpiles of contents with moderate rates of heat release do not exceed 12 feet, and stockpiles of contents with high rates of heat release do not exceed 8 feet.
- **Extra Hazard Group 1**: The quantity and combustibility of contents are very high and dust, lint, or other materials are present, introducing the probability of rapidly developing fires with high rates of heat release but with little or no combustible or flammable liquids.
- **Extra Hazard Group 2**: Moderate to substantial amounts of flammable or combustible liquids or occupancies where shielding of combustibles is extensive.

The table below demonstrates the occupancy hazard classifications for the Construction Innovation Center.

Function	Occupancy	Density	Total Combined Inside & Outside Hose
Mechanical Rooms Service Rooms	Ordinary Hazard Group 1	0.15 GPM/ ft^2	250 GPM
Storage Rooms	Ordinary Hazard Group 1	0.15 GPM/ ft^2	250 GPM
Office Rooms General Building Areas	Light Hazard	0.10 GPM/ ft^2	100 GPM
Laboratory Rooms	Ordinary Hazard Group 1	0.15 GPM/ ft^2	250 GPM

The final determination on the acceptability of the occupancy classification is the responsibility of the authority having jurisdiction.

17.3. Sprinkler Heads

References – CBC Section 903.3.2

Glass bulb sprinklers contain a glycerin–based liquid that will expands when heated. The expansion is controlled by the size of the air bubble that is trapped in the glass tube of the device. As the liquid is heated, it will expand until the air has disappeared and there is no more room to expand. At that point, the liquid will exert a large enough force to shatter the glass of the bulb and operate the sprinkler. The size of this bubble and the expansion rate of the liquid establish the operating temperature of the sprinkler. There are several types of sprinkler heads used in buildings, as listed below:

- Standard Response Sprinklers
- Fast Response Sprinklers
  - Residential Sprinklers
  - Quick Response Sprinklers
  - Early Suppression Fast Response Sprinklers

- Quick Response Extended Coverage Sprinklers

The Construction Innovation Center comprises of TYCO Series TY-FRB Quick–Response Sprinklers throughout the center, as illustrated in Figure #4. Quick–response sprinklers are required in light hazard occupancies. A quick–response sprinkler uses a lighter material for the operating mechanism, compared to traditional sprinklers, that reduces the heat lag in the element. This will have a quicker heat absorption that results in an earlier activation of water discharge. Studies have shown that quick–response sprinklers operate up to 25 percent faster than traditional sprinklers and significantly increase the tenability of the environment.

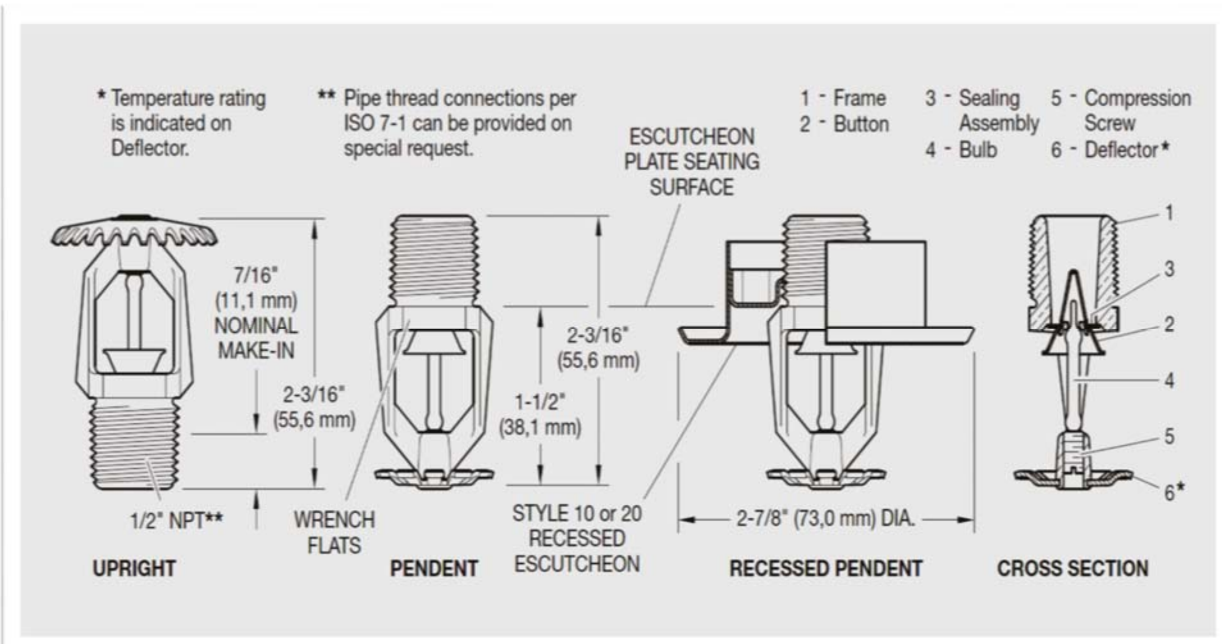


Figure #4: Quick Response Series TY-FRB Upright (TY3131) & Pendent (TY3231) Sprinklers 5.6 K-Factor

17.3.1. Temperature Rating

References – NFPA 13 Sections 6.2.5 & 6.2.5.1

The liquid within a bulb–glass sprinkler are uniquely color coded to represent the activation temperature of the device. The selection criterion for the temperature activation of a given sprinkler is a function of the highest ambient ceiling temperature of the expected vicinity. A thermometer may be used to determine the highest temperature encountered; it should be hung for several days at the location. The table below demonstrates the required temperature ratings, classifications, and color code for sprinklers:

Maximum Ceiling Temperature	Temperature Rating	Temperature Classification	Color Code	Glass Bulb Colors
100 °F	135 °F– 170 °F	Ordinary	Uncolored or Black	Orange or Red
150 °F	175 °F – 225 °F	Intermediate	White	Yellow or Green
225 °F	250 °F – 300 °F	High	Blue	Blue
300 °F	325 °F – 375 °F	Extra High	Red	Purple
375 °F	400 °F – 475 °F	Very Extra High	Green	Black
475 °F	500 °F – 575 °F	Ultra High	Orange	Black
625 °F	650 °F	Ultra High	Orange	Black

The sprinklers used for the Construction Innovation Center comprises of an activation temperature of 155°F throughout the center, except at basement in which the activation temperature occurs at 200°F. The basement is given a higher activation temperature due to the electrical equipment that produces a higher maximum ceiling temperature.

17.3.1.1. Skipping through Temperature Ratings

References – NFPA 13 Section 8.3.2

All sprinklers within the Construction Innovation Center must be installed with the same temperature range throughout a compartment. Sprinklers with different temperature ratings that are randomly installed throughout a compartment will operate at various times during a fire condition. This phenomenon is referred to as skipping, which can be detrimental to the system performance. The center complies with this provision since the sprinklers uses for each compartment have the same temperature ratings.

17.3.2. Thermal Sensitivity

References – NFPA 13 Section 3.6.1

Thermal sensitivity is a measurable expression of the sensitivity or responsiveness of a sprinkler's operating element when exposed to fire conditions. One measure of thermal sensitivity is the response time index (RTI), as measured under standardized test conditions. For sprinklers with the same temperature rating, those with a lower RTI value will operate sooner in a rapidly growing fire than sprinklers with a higher RTI value. Sprinklers are categories with the following thermal elements:

- **Fast Response Sprinklers**: Thermal element with an RTI of 50 (m–sec)$^{1/2}$ or less.
- **Standard Response Sprinklers**: Thermal element with an RTI of 80 (m–sec)$^{1/2}$ or more.
- **Special Response Sprinklers**: Thermal element with an RTI between 50 and 80 (m–sec)$^{1/2}$

17.3.3. Sprinkler Discharge Characteristics

References – NFPA 13 Section 6.2.3.1

The sprinklers used for the Construction Innovation Center have a nominal k–factor of 5.6 gpm/(psi)$^{1/2}$. K–factors are known as the coefficient of discharge. The larger the K factor in number, the more water it can discharge at a given pressure. The nominal k–factor is used to determine the sprinkler's flow rate at a particular pressure when calculating hydraulically designed systems. The table below describes the sprinkler discharge characteristics used for the center.

Nominal K-Factor [gpm/(psi)$^{1/2}$]	**K-Factor Range** [gpm/(psi)$^{1/2}$]	**Percent of Nominal K-5.6 Discharge**	**Thread Type** (inches NPT)	**Nominal Orifice Size** (inches)
5.6	5.3 – 5.8	100	½	½

17.3.4. Water Distribution Characteristics

The water distribution characteristics for a sprinkler consist of its shape and throw. Pendent and upright spray sprinklers have a discharge pattern of a parabolic shape. The discharge pattern for these sprinklers is fully developed at about 4 feet distance below the sprinkler. Most of the pattern development occurs within a zone beginning at the sprinkler deflector and extending 18 inches to 36 inches below the sprinkler. The obstructions to sprinkler discharge pattern development are a concern within this zone.

17.3.5. Installation Orientation

References – NFPA 13 Section 3.6.2

Sprinkler heads may be installed in buildings in several orientations, as described below:

- **Pendent Sprinklers**: Sprinklers mounted to the bottom of a branch line or pipe drop.
  - **Recessed Sprinklers**: A sprinkler with all or part of the body, other than the shank thread, is mounted within a recessed housing.
  - **Concealed Sprinklers**: A recessed sprinkler with cover plate.
  - **Flush Sprinklers**: A sprinkler with all or part of the body, including the shank thread, is mounted above the lower plane of the ceiling.
- **Sidewall Sprinklers**: A sprinkler installed along a wall or lintel, and discharge water away from the wall into the space.
- **Upright Sprinklers**: A sprinkler mounted to the top of branch lines or sprigs.

The Construction Innovation Center comprises of concealed and upright sprinklers, as illustrated in Photo #21.

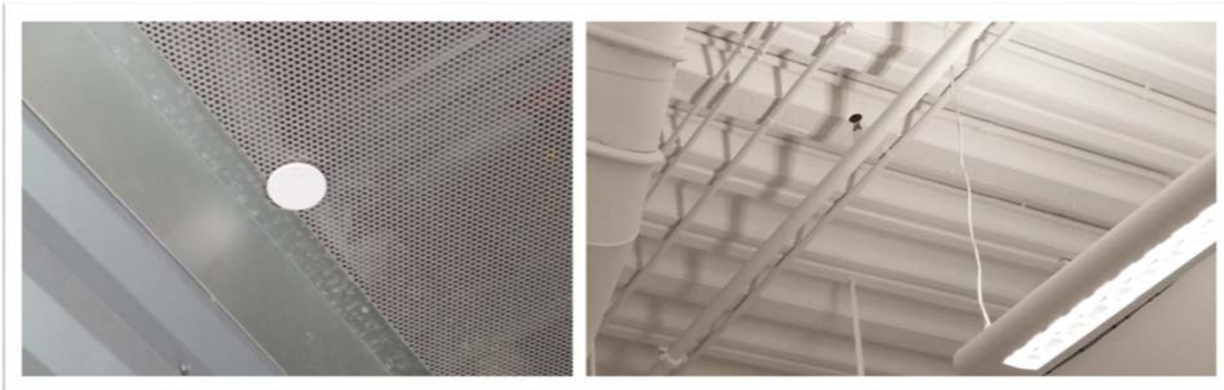


Photo #21: Concealed & Upright Sprinklers used for the Construction Innovation Center

17.3.6. Coverage

References – NFPA 13 Sections 3.6.4.3 & 3.6.4.10.1

The Construction Innovation Center comprises of only standards coverage, pendent and upright, sprinklers. Below describes the different type of coverage used for sprinklers:

- **Standard Coverage Sprinkler:** A type of spray sprinkler with maximum coverage areas as specified in NFPA 13 Sections 8.6 and 8.7 of this standard.
- **Extended Coverage Sprinkler:** A type of spray sprinkler with maximum coverage areas as specified in NFPA 13 Sections 8.6 and 8.7 of this standard.

The standards and extended coverage sprinklers are available in pendent, upright, and sidewall configurations. The advantage of extended coverage sprinklers is that their areas of coverage are greater than those established for standard sprinklers.

17.3.6.1. Protection Areas per Standard Sprinkler

References – NFPA 13 Sections 8.5.2, 8.5.2.1, 8.5.2.1.1, 8.5.2.1.2, & 8.5.2.2.2

The protection area of coverage per sprinkler $\{A_s\}$ is established, by multiplying the dimensions $\{S\}$ and $\{L\}$, as determined below:

- Along branch lines as follows:
  - Determine distance between sprinklers or obstruction (wall) in case of last sprinkler on branch line
  - Choose the larger of either the distance to the next sprinkler or twice the distance to the wall
  - Define dimension as $\{S\}$

- Between branch lines as follows:
  - Determine perpendicular distance between adjacent branch lines or obstruction (wall) in the case of last branch line

- Choose the larger of either the distance to the next branch or twice the distance to the wall
- Define dimension as {L}

17.3.6.2. Maximum Protection Area of Coverage

References – NFPA 13 Sections 8.6.2.2, 8.6.2.2.1, & 8.6.2.2.2

The maximum allowable protection area of coverage for a sprinkler {A_s} must be in accordance with the value indicated in the table below for light hazard and ordinary hazard:

Ceiling Construction Type	System Types	Maximum Protection Area	Type Hazard
Noncombustible unobstructed	Hydraulically Calculated Pipe Schedule	225 ft^2 200 ft^2	Light Light
Noncombustible obstructed	Hydraulically Calculated Pipe Schedule	225 ft^2 200 ft^2	Light Light
Combustible unobstructed with no exposed members	Hydraulically Calculated Pipe Schedule	225 ft^2 200 ft^2	Light Light
Combustible unobstructed with exposed members 3 ft or more on center	Hydraulically Calculated Pipe Schedule	225 ft^2 200 ft^2	Light Light
Combustible unobstructed with members less than 3 ft on center	All	130 ft^2	Light Light
Combustible obstructed with exposed members 3 ft or more on center	All	168 ft^2	Light Light
Combustible obstructed with members less than 3 ft on center	All	130 ft^2	Light Light
Combustible concealed spaces	All	120 ft^2	Light Light
All	All	130 ft^2	Ordinary

The maximum area of coverage of a sprinkler, in any case, must not exceed 225 ft^2.

17.3.7. Sprinkler Identification

References – NFPA 13 Section 6.2.2

All sprinklers must be permanently marked in the following order:

- One or two English uppercase alphabetic characters to identify the manufacturer
- Three or four numbers to identify the K-factor (orifice size) or orifice shape, deflector characteristic, pressure rating, and thermal sensitivity.

These four to six character sprinkler identification number, with no intervening spaces, is intended to identify the sprinkler operating characteristics. The sprinkler identification number may be used to identify the manufacturer through the listing at www.sprinklerworld.org. This may help field inspections to ensure that the model numbers on the plans are those actually installed.

The sprinklered used for the Construction Innovation Center consists of the following sprinkler identification number (SIN):

- **TY3131**: Upright 5.6K, 1/2″ NPT
- **TY3531**: Concealed 5.6K, 1/2″ NPT

17.4. General Provisions of Sprinklers

An automatic sprinkler system has been the most widely used method of automatically controlling a fire. Although automatic sprinkler systems have a remarkable record of success, it is possible for the system to fail.

17.4.1. Only New Sprinklers

References – NFPA 13 Sections 6.2.1& 6.2.1.1

Only new sprinklers must be installed within the Construction Innovation Center. This will permit a successful performance of the sprinkler actuation during the early stages of a fire.

Any sprinkler that has been removed for any reason must not be reinstalled; instead, a new sprinkler must be installed. The removal process of a sprinkler may damage the water seal and operating element, specifically a glass bulb type element, which could impact sprinkler performance without any visual indication.

17.4.2. Painting of Sprinklers

References – NFPA 13 Sections 6.2.6.2, 6.2.6.2.1, 6.2.6.2.2, & 6.2.6.2.3

Painting of installed sprinklers is the primary, but not the only, example of a problem known as loading. Loading is the buildup of foreign material on the sprinkler that may delay or prevent proper sprinkler activation. Painting of sprinklers can increase the possibility of a malfunction, by the following causes:

- Retard the thermal response of the heat-responsive element
- Interfere with the free movement of parts
- Render the sprinkler inoperative
- Invite the application of subsequent coatings

Sprinklers must only be painted by the sprinkler manufacturer. In situations where sprinklers have been painted by other than the sprinkler manufacturer, these sprinklers must be replaced with new listed sprinklers of the same characteristics. This also applies to cover plates on concealed sprinklers that have been painted by other than the sprinkler manufacturer; the cover plates must be replaced.

17.4.3. Stock of Spare Sprinklers

References – NFPA 13 Sections 6.2.9.1 & 6.2.9.2

The Construction Innovation Center must have at least six spare sprinklers within the premises so that any sprinklers that have operated or been damaged can be promptly replaced. The stock of spare sprinklers must include all types and ratings installed at the center. The actual number of spare sprinklers for protected facilities must follow the table below:

Total Amount of Installed Sprinklers	Amount of Spare Sprinklers
000 < 300	No fewer than 6 sprinklers
300 – 1000	No fewer than 12 sprinklers
1000 < ∞	No fewer than 24 sprinklers

The center promises of less than 300 installed sprinklers for Buildings A, B, and C. Therefore, no fewer than 6 spare sprinklers must be provided for each three buildings. The spare sprinklers for the entire campus of Cal Poly could be located in one location if acceptable to the authority having jurisdiction. However, regardless of which building had fire sprinkler activation, an immediate access to the supply of spare sprinklers is required. This could be accomplished by securing the sprinklers in a facility that has its access keys stored in a fire department lock box.

17.4.3.1. Cabinets used for Spare Sprinklers

References – NFPA 13 Sections 6.2.9.3, 6.2.9.6, 6.2.9.7, 6.2.9.7.1

The spare sprinklers used for the Construction Innovation Center must be kept in a cabinet where the temperature does not exceed 100°F at any time. The cabinet must have one sprinkler wrench, as specified by the sprinkler manufacturer, for each type of sprinkler installed to be used for the removal and installation of sprinklers in the system. A list of the sprinklers installed in the center must be posted in the sprinkler cabinet. The list must include the following:

- Sprinkler Identification Number (SIN) if equipped; or the manufacturer, model, orifice, deflector type, thermal sensitivity, and pressure rating
- General description
- Quantity of each type to be contained in the cabinet
- Issue or revision date of the list

17.5. Valves used for Automatic Fire Sprinkler System

References –NFPA 13 Sections 6.7, 8.16.1.5.1 & 6.7.1.3

Multistory buildings exceeding two stories in height, such as the Construction Innovation Center, are required to have the following devices on each floor level:

- Main Drain Valve
- Floor Control Valve
- Check Valve

All valves controlling connections to the water supply and the flow of water to sprinklers must be listed. Additionally, it must incorporate a method of readily determining that the valve is open. A closed valve is the primary reason why sprinkler systems do not perform adequately.

17.5.1. Main Drain Valve

References – NFPA 13 Sections 6.1.1.5, 6.7.3, 8.16.2.1, 8.16.2.4.1, 8.16.2.4.2, 8.16.2.4.6, & 8.17.4.1

The Construction Innovation Center comprises of 1.25 inches AGF #1000 Test–An–Drain valve with 0.5 inches orifice, as illustrated in *Appendix N*. This valve provides both the test function and the express drain function for a wet fire sprinkler system in accordance with NFPA 13.

Drain valves and test valves are two components that are not required to be listed but are required to be approved. These components do not affect system performance and, therefore, are not required to be listed.

All piping should be arranged so that the system can be drained to the main drain valve. Drain connections for systems supply risers complies with the required sized as shown on the table below:

Buildings	Existing Riser Size	Existing Drain Connection Size	Riser Size Requirements	Drain Connection Size Requirements
A	3 inches	1.25 inches	Up to 2 inches	0.75 inches or larger
B	3 inches	1.25 inches	2.5 , 3, 3.5 inches	1.25 inches or larger
C	3 inches	1.25 inches	4 inches and larger	2 inches only

The test connections are permitted to be used as main drain connections. The main drain test, as it is commonly called, is used to drain the system and help evaluate the water supply.

17.5.2. Floor Control Valves

References – NFPA 13 Sections 8.16.1.5

The Construction Innovation Center comprises of 3 inches GD–4765–8N grooved butterfly floor control valves, as illustrated in *Appendix N*. These floor control valves are used to isolate individual floors in multistory buildings. This will separate the sprinkler system for the purpose of conducting required main drain tests as required by NFPA 25.

17.5.3. Check Valves

References – NFPA 13 Sections 3.8.1.15.1, 8.16.1.1.3.1, 8.16.1.1.3.2, & 8.17.2.5.1

The Construction Innovation Center comprises of 3 inches Tyco Model CV–1F grooved check valves, as illustrated in *Appendix N*. These system riser check valve permits flow in one direction only and minimize water hammer caused by flow reversal.

A check valve is required for each source of water supply to isolate the supplies from each other. A listed check valve is also required in each fire department connection and must be located in an accessible location.

17.6. Pressure Gauges

References – NFPA 13 Sections 7.1.1.1, 6.1.1.5, 7.1.1.2, & 7.1.1.2.1

An approved pressure gauge must be installed in each system riser. Pressure gauges are not required to be listed but are required to be approved. These components do not affect system performance and, therefore, are not required to be listed. Two pressure gauges are required when an alarm check valve or system riser check valve is used at the connection to the water supply, located above and below each check valve. However, a pressure gauge is not required below individual floor control valve assemblies even when they contain a check valve and a water–flow switch. A single gauge pressure is used for each system riser at the Construction Innovation Center, as illustrated in *Appendix N*.

17.7. Positions of Automatic Fire Sprinkler Systems

References – NFPA 13 Sections 8.5.4.1.1 & 8.5.4.2

Sprinklers need to be properly positioned to perform adequately. Sprinkler deflector must be aligned parallel to ceilings, roofs, or the incline of stairs. Maintaining the deflector parallel will minimize obstructions to discharge, it will prevent the discharge from hitting a sloped ceiling, and result in a more effective discharge pattern. The distances between sprinkler deflector and ceiling above must be selected based on the type of sprinkler and the type of construction.

17.8. Spacing of Automatic Fire Sprinkler Systems

References – NFPA 13 Sections 8.5.3, 8.6.3.1, 8.6.3.2, 8.6.3.2.1, 8.6.3.2.2, & 8.6.3.3

Sprinklers are normally installed directly on branch lines. Therefore, spacing for sprinkler is measured from the distance between sprinklers on the same branch line and the distance between sprinklers on adjacent branch lines. The distance measured, in all cases, is the distance between the centerlines of adjacent sprinklers. The maximum allowable spacing for standard sprinklers must be in accordance with the value indicated in the table below for light hazard and ordinary hazard:

Ceiling Construction Type	System Types	Maximum Spacing	Type Hazard
Noncombustible unobstructed	Hydraulically Calculated Pipe Schedule	15 ft 15 ft	Light Light
Noncombustible obstructed	Hydraulically Calculated Pipe Schedule	15 ft 15 ft	Light Light
Combustible unobstructed with no exposed members	Hydraulically Calculated Pipe Schedule	15 ft 15 ft	Light Light
Combustible unobstructed with exposed members 3 ft or more on center	Hydraulically Calculated Pipe Schedule	15 ft 15 ft	Light Light
Combustible unobstructed with members less than 3 ft on center	All	15 ft	Light Light
Combustible obstructed with exposed members 3 ft or more on center	All	15 ft	Light Light
Combustible obstructed with members less than 3 ft on center	All	15 ft	Light Light
Combustible concealed spaces	All	----	Light Light
All	All	15 ft	Ordinary

The distance from sprinklers to walls, measured perpendicular to the wall, must not exceed 0.5 of the allowable distance between sprinklers as indicated in the table above. Additionally, sprinklers must be located a minimum of 4 inches.

17.9. Locations of Automatic Fire Sprinkler Systems

In general, sprinklers are located near the ceiling since heat rises to the top. When sprinklers are located further down from the ceiling, the response time generally increases, unless the sprinkler is located within the fire plume. Operation of sprinklers located very close to the ceiling can also be delayed if they are located in the dead–air space that develops under some ceilings. In some cases, obstructed construction requires that sprinklers be located further below the ceiling to

allow the sprinkler discharge pattern to develop. However, this arrangement results in a slower sprinkler response time. *Appendix O* illustrates the location of the automatic fire sprinkler system installed for the Construction Innovation Center.

17.9.1. Closets & Small Compartments

References – NFPA 13 Section 8.5.5.4

A single sprinkler is required in all closets, including those closets housing mechanical equipment, and compartments that are not larger than 400 feet^3 in size. This single sprinkler must be located at the highest ceiling space without regarding any obstructions or minimum distance to the wall.

17.9.2. Omitted Locations of Automatic Fire Sprinkler Systems

References – CBC Section 903.3.1.1.1

Even though the Construction Innovation Center is classified as sprinklered throughout, the omission of sprinkler protection in certain locations is allowed if an approved automatic fire detection system is installed. Note that sprinklers must not be omitted from any room merely because it is damp, fire–resistance rated construction, or contains electrical equipment. Below describes the various omitted locations not required to have sprinkler protection:

- Any room where the application of water constitutes a serious life or fire hazard.
- Any room or space where sprinklers are considered undesirable because of the nature of the contents, when approved by the fire code official.
- Fire service access elevator machine rooms and machinery spaces.
- Machine rooms and machinery spaces associated with occupant evacuation elevators.

17.9.3. Obstructions

References – NFPA 13 Sections 8.5.5.3.1, 8.5.5.3.2

Sprinklers must be installed under fixed obstructions that are over 4 feet wide. Sprinklers are not required under obstructions that are not fixed in place, such as the conference table in Room A101. Conference tables are often moved and are unlikely to have any significant combustibles located beneath them. Consequently, additional sprinklers do not need to be placed below the obstruction.

17.9.3.1. Obstructions to the Sprinkler Discharge

References – CBC Section 903.3.3 / NFPA 13 Sections 8.5.5.1, 8.5.5.2, 8.5.5.2.1, 8.5.5.3

Automatic fire sprinklers must be located to avoid any obstructions that will delay the activation or obstruct the water distribution pattern. NFPA 13 addresses three general areas of concern with regard to obstructions that might affect the sprinkler discharge.

The first concern, an overall circumstance, deals with the certainty that sufficient amount of water from the sprinkler reaches the hazard. Sprinklers must be located to minimize the obstructions of water discharges, or additional sprinklers must be provided to ensure adequate coverage of the hazard.

The second concern, deals with the obstruction to sprinkler discharge pattern development. These obstructions typically consist of continuous and non–continuous obstructions located within the first 18 inches of the sprinkler deflector. These types of obstructions can include piping, light fixtures, truss webs, or building columns. Obstructions located within this zone prevent the proper sprinkler discharge pattern from developing. As a result, sprinklers must be positioned so that they are located at a specified distance from the obstruction.

The third concern, deals with obstructions that prevent the sprinkler discharge from reaching the hazard. These obstructions typically consist of continuous and non–continuous obstructions that interrupt the water spray pattern once it is below the 18 inches discharge pattern development zone. These types of obstructions can include overhead doors, ducts, or decks. When these obstructions exceed a certain dimension, sprinklers must be located beneath them.

17.10. Riser Room Size

References – CBC Section 901.8

The code does not mandate the construction of a room to accommodate fire protection system risers. Buildings that do provide these rooms must have adequate spacing to facilitate their maintenance, inspection, service, repair, and replacement. There are no prescribed arbitrary dimensions; instead, the room size is based on clearances specified by the equipment manufacturers to ensure adequate space is available for its installation or removal. The door serving a riser room must be unobstructed and large enough to accommodate the removal of the largest piece of equipment.

The Construction Innovation Center comprises of a room used for housing fire protection system risers, as illustrated in Photo #22.

Photo #22: Riser Room at Building B

17.11. Water Supply

References – CBC Section 903.3.5

The criteria for an acceptable water supply for the Construction Innovation Center are contained in NFPA 13. An acceptable water supply must consist one of the following or any combination:

- Public or Private Waterworks System
- A connection including a Fire Pump
- Water Storage Tank at grade or below grade
- Pressure Tank
- Gravity Tank
- Penstock, Flume, River, Lake, Pond, or Reservoir
- A source of recycled or reclaimed water where the building owner (or their agent) has analyzed the source of the water and the treatment process (if any) that the water undergoes before being made available to the sprinkler system and determined that any materials, chemicals, or contaminants in the water will not be detrimental to the components of the sprinkler system it comes in contact with

The fire suppression system used for the center is connected to the campus domestic water supply system. Most public water supply systems serving a substantial number of customers are designed for a dual purpose, such as for normal domestic demands (drinking and sanitary) and emergency purposes. The center consists of two separate sprinkler system, Building A is provided with its own system while Building B & C share the same system, each system is connected to its own water supply.

17.11.1. Capacity

References – NFPA 13 Section 24.1.2

The water supply must be capable of meeting the hydraulically demanding area of the system, the most the remote design area, with sufficient flow and pressure for the required duration. The sprinkler system demand must ready at all time.

17.11.2. Water–Flow Tests

References – NFPA 13 Sections 24.2.2, 24.2.2.2

The volume and pressure of a public water supply must be determined from water–flow test data. Additionally, water–flow tests should be conducted on a routine basis to monitor the condition of the water supply. Over time, water supply systems are prone to degraded by pipe corrosion, scale buildup, and inadvertently closed valves. It is recommended that testing of public water supplies should be done at times of normal demand on the system.

The proper method of conducting this test is to use two hydrants within the vicinity of the Construction Innovation Center. The method of conducting the flow tests is as follows:

- Attach the gauge at hydrant {A} and obtain the static pressure.
- Either attach a second gauge to the hydrant {B} or use the pitot tube at the outlet.
- Have hydrant {B} opened wide.
- Read pressure at hydrant {A}, the hydrant where water is not flowing, to obtain the residual pressure.
- Read and use the pressure at hydrant {B} to compute the gallons flowing.

17.12. Hydraulic Analysis

References – NFPA 13 Section 3.3.15

A hydraulic analysis approach was used to design the fire sprinkler system installed within the Construction Innovation Center. This approach determines the pipe size of the fire sprinkler system, distributed with a reasonable degree of uniformity over a specified area, on a pressure loss basis to provide the following prescribed parameters:

- Water Density
- Minimum Discharge Pressure per Sprinkler
- Minimum Discharge Flow per Sprinkler

The hydraulic analysis approach is more preferable than those systems designed using a pipe schedule approach. Hydraulic designs provides for a more accurate analysis of the piping system, allow for the selection of the most suitable pipe sizes, and data that demonstrate the water supply is adequate for the sprinkler system demand.

The results of hydraulic analysis are often presented in graphical form. Graphical representation of the hydraulic analysis provides easier review and evaluation. The graph usually contains two curves — one that represents the system demand and another that represents the available water supply.

17.13. Monitoring of Automatic Fire Sprinkler System

References – CBC Section 901.6

The automatic fire sprinkler system installed within the Construction Innovation Center must be monitored by an approved supervising station in accordance with NFPA 72. The University Police Department’s Communication Center is being used as the supervising station for the center. All water supply control valves and water–flow switches are required to be electrically supervised.

17.14. Inspection, Testing, & Maintenance for Fire Sprinkler System

References – NFPA 25 Section 5.1.1.2

The wet–pipe sprinkler system installed for the Construction Innovation Center must demonstrate the minimum requirements for inspection, testing, and maintenance. *Appendix P* illustrates these services for several components of the wet–pipe sprinkler system in accordance with NFPA 25.

18. Fire Department Connections

References – CBC Section 912.1

Fire department connections are required for the Construction Innovation Center as an auxiliary water supply, as illustrated in Photo # 23. These connections give the fire department the capability of supplying the necessary water to the automatic sprinkler or standpipe system at a sufficient pressure. The fire department connections also serve as an alternative source of water should a valve in the primary water supply be closed.

Photo #23: Total of 3 Fire Department Connections at Construction Innovation Center

18.1. Locations of Fire Department Connections

References – CBC Sections 912.2 & 912.2.1

The location of fire department connections used for the Construction Innovation Center must be strategically planned with respect to hydrants, driveways, adjacent buildings, and landscaping. The fire code official must approve the location of any fire department connections. Additional consideration for the location of fire department connections are stated below:

- The fire apparatus and hose, while connected to a fire department connection, must not obstruct access to the building for other fire apparatus.
- Located on the street side of the building.

- Fully visible and recognizable from the street or nearest point of fire department vehicle access.

Appendix G illustrates the location of each fire department connection used for the center.

18.2. Access of Fire Department Connections

References – CBC Sections 901.4 & 912.3

Fire department connections must be readily accessible and maintained at all times. There must be no obstruction surrounding the fire department connection by fences, bushes, trees, walls, or any other fixed or moveable object. Access to fire department connections must be approved by the fire chief.

Note that threads provided for fire department connection must be compatible with the connections used by the local fire department.

18.2.1. Clear Space around Fire Department Connections

References – CBC Section 912.3.2

Wall–mounted and free–standing fire department connections must have a working space of not less than 36 inches in width, 36 inches in depth, and 78 inches in height. It must be maintained in front and sides of wall–mounted fire department connections or around the circumference of free–standing fire department connections, except as otherwise required or approved by the fire chief.

18.3. Signs for Fire Department Connections

References – CBC Section 912.4

A metal sign with raised letters at least 1 inch in size must be mounted on all fire department connections when serving automatic sprinklers or standpipes, as illustrated in Photo #24. Raised letters are required so that any repainting or fading of the colors on the sign will not affect its ability to be read. These signs must have one of the following written on its metal plates:

- AUTOMATIC SPRINKLERS
- STANDPIPES
- TEST CONNECTION
- Combination thereof as applicable

Additionally, signs must provide indication of the portions of the building being served if the fire department connection does not serve the entire building.

Photo #24: Sign used for the Fire Department Connection

19. Performance–Based Analysis

References – NFPA 101 Section 5.2

The basic concept of a performance–based approach is to provide an alternate method, from the traditional or prescriptive approach, for satisfying the fire protection and life safety intent of codes and standards applicable to a particular project.

A propose performance–based alternative must be agreed upon between the designer and authority having jurisdiction about the interpretation of the code in terms of goals, objectives, desired levels of safety, appropriate fire scenarios, assumptions, and safety factors.

A performance–based approach has been used for this report to determine whether the occupants will egress the Construction Innovation Center before conditions become untenable. It is important to demonstrate the potential hazard toward occupants when exposed to harmful products of combustion or smoke in buildings equipped with an automatic fire sprinkler system.

19.1. Computational Modeling

It is possible to get a reasonable good estimation when conducting a performance–based approach when using hand calculations. However, performing this approach can result too difficult when modeling highly populated enclosures and complex geometries. For this reason, alternative methods of calculation have been considered.

The use of computational models like Fire Dynamics Simulator and Pathfinder have been applied to simulate the fire behavior and people's movement, respectively, for the Construction

Innovation Center. Additionally, the primary tool used in modeling the complexity geometry of the center was designed in PyroSim.

19.1.1. Fire Dynamic Simulator

References – Fire Dynamics Simulator User Manual Version 5

Fire Dynamic Simulator (FDS) is a computational fluid dynamics model that was developed by the National Institute of Standard and Technology (NIST). The model numerically solves a form of the Navier–Stokes equations appropriate for low-speed, thermally driven flow, with an emphasis on smoke and heat transport from fires. FDS computes the temperature, density, pressure, velocity, and chemical composition within each numerical grid cell at each discrete time step. There are typically several million-grid cells and hundreds of thousands of time steps. FDS also computes the temperature, heat flux, mass loss rate, and various other quantities at solid surfaces. The effective use of this tool and the information it provides requires understanding of its capabilities and limitations.

19.1.1.1. Hot Gas Layer Temperature

The hot gas layer temperature is particularly important in fire scenarios because it can provide an indication of target damage away from the ignition source. FDS predicts the increase in environmental temperature attributable to the energy released by a fire. The room is divided into numerous control volumes. FDS can provide outputs for the average temperature of the control volumes in the upper layer of the computational domain.

19.1.1.2. Hot Gas Layer Height

The height of the hot gas layer is important in fire scenarios because it indicates whether a given target is immersed in and affected by hot gas layer temperatures. The concept of hot gas layer height is most relevant in two-zone models in which this attribute defines the interface between the upper and lower control volumes. FDS also provides the hot gas layer height output, which is calculated from the temperature profile within the height of the room.

19.1.1.3. Ceiling Jet Temperature

The ceiling jet is the shallow layer of hot gases that spreads radially below the ceiling as the fire plume flow impinges on it. This layer of hot gases has a distinct temperature that is higher than the temperature associated with the hot gas layer. The ceiling jet temperature can be obtained from the FDS model by inspecting the temperature profile in the pre-defined grid.

19.1.1.4. Plume Temperature

The fire plume is the buoyant flow rising above the ignition source. It carries the hot gases that ultimately accumulate in the upper part of a room to form the hot gas layer. The plume is characterized by a distinct temperature profile, which is expected to be higher than the ceiling jet and hot gas layer. This attribute is particularly important because of the numerous postulated scenarios that involve targets directly above a potential fire source. The plume temperature can be obtained from the FDS model by inspecting the temperature profile in the pre-defined grid.

19.1.1.5. Flame Height

The height of the flame is important in fire scenarios where targets are located close to the ignition source. Some targets are subject to flame temperatures because the distance between the target and the ignition source is less than the predicted flame height. The FDS combustion model has the capability to calculate flame height.

19.1.1.6. Radiated Heat Flux to Targets

Radiation is an important mode of heat transfer in fire events. FDS have sophisticated heat transfer models that account for radiation exchanges between room surfaces and the upper/lower gas layers. The thermal radiation to which a given target is exposed is a result of the heat balance at the surface of the target, which includes all of the exchanges, as well as the thermal radiation received from the flames.

19.1.1.7. Total Heat Flux to Targets

In contrast to thermal radiation or radiated heat flux, the total heat flux also includes convective heat transfer. Convective heat transfer is a significant contributor to target heat-up in scenarios that involve targets in the hot gas layer, ceiling jet, or fire plume. The FDS field model account for convection.

19.1.1.8. Target Temperature

The calculation of target temperature is perhaps the most common objective of fire modeling analyses. The calculation of target temperature involves an analysis of localized heat transfer at the surface of the target after determining the fire induced conditions in the room. FDS calculate the surface temperature of the target as a function of time, and consider the heat conducted into the target material.

19.1.1.9. Total Heat Flux to Walls, Floors, & Ceilings

The total heat flux to walls, floors, and ceilings are primarily contributed by radiation and convection. Because the heat conducted through the walls, floors, and ceilings does not contribute to room heat-up, it can be an important factor in the heat balance in control volume(s) in contact with the surfaces. The FDS field model calculates the total heat flux to walls, floors, and ceilings.

19.1.1.10. Temperature of Walls, Floors, & Ceilings

FDS provides the temperatures walls, floors, and ceilings as outputs. These outputs are part of the calculations required to determine the heat losses through boundaries.

19.1.1.11. Smoke Concentration

The smoke concentration can be an important attribute in fire scenarios that involve rooms where personnel may need to perform actions during a fire. This attribute specifically refers to soot concentration, which affects how far a person can see through the smoke (visibility). FDS calculate smoke concentration as a function of time. It determines smoke concentration as the fire plume carries combustion products into the hot gas layer.

19.1.1.12. Oxygen Concentration

Oxygen concentration is an important attribute potentially influencing the outcome of fires. in Oxygen concentration has a direct influence on the burning behavior of a fire, especially if the concentration is relatively low. FDS calculates the oxygen concentration in each control volume defined in the computational domain.

19.1.1.13. Room Pressure

Room pressure may be important when it contributes to smoke migration to adjacent compartments. FDS calculate room pressure as they solve energy and mass balance equations in the control volume.

19.1.2. Pathfinder

References – Pathfinder User Manual Version 2013

Pathfinder is an egress and human movement simulator developed by Thunderhead Engineering. It provides a graphical user interface to primarily create and run simulation models. Pathfinder also includes 2D and 3D visualization tools for results analysis. Occupants are represented as

circles moving inside a 3D triangulated mesh designed to match the real dimensions of a building model. This triangulated mesh can be entered manually or automatically based on imported data. Keep in mind, Pathfinder does not presently integrate results from a fire model or provide support for complex behaviors.

19.1.3. PyroSim

References – PyroSim User Manual Version 2014

PyroSim is a model construction tool for the Fire Dynamics Simulator developed by Thunderhead Engineering. The PyroSim interface ensures the correct format for the FDS input file. The user can work in either metric or English units and can switch between the two at any time. In addition, PyroSim offers high level 2D and 3D geometry creation features.

19.2. Tenability Analysis

*References – NFPA 101 Section 5.2.2**

NFPA 101, *Life Safety Code*, describes four methods that can be used to avoid exposing occupants to untenable conditions. These methods are as follow:

- **Method 1**: The design team can set detailed performance criteria that ensure that occupants are not incapacitated by fire effects.
- **Method 2**: For each design fire scenario…, the design team can demonstrate that each room or area will be fully evacuated before the smoke and toxic gas layer in that room descends to a level lower than 6 feet above the floor.
- **Method 3**: For each design fire scenario…, the design team can demonstrate that the smoke and toxic gas layer will not descend to a level lower than 6 feet above the floor in any occupied room.
- **Method 4**: For each design fire scenario…, the design team can demonstrate that no fire effects will reach any occupied room.

Method 2 has been used for this analysis. This method requires detailed modeling of both the available and required safe egress time. The available safe egress time (ASET) is the time from ignition until building become untenable. This was determined by evaluating the tenability criteria obtained from Fire Dynamics Simulator. The required safe egress time (RSET) is the time needed for occupants to evacuate from the building. This was determined by accumulating the individual times associated with fire detection, alarm activation, pre–movement, and travel time obtained from Pathfinder.

To ensure occupant safety from untenable conditions, the RSET must be less than ASET.

19.3. Tenability Criteria

The tenability criteria obtained from Fire Dynamics Simulator must be evaluated for each specific design fire scenarios in whether each room will be fully evacuated before the smoke or toxic gas layer descends within 6 feet above the floor. Tenability limits are often specified in terms of four criteria:

- Visibility
- Temperature
- Radiant Exposure
- Combustion Gas Toxicity

19.3.1. Visibility

References – SFPE Fire Protection Engineering 3rd Edition, Section 2, Chapter 6, Table 2-6.10

Reduced visibility can cause occupants to become disoriented and become trapped within the Construction Innovation Center because they are unable to find their way to an exit. In accordance to the SFPE Handbook, Babrauskas has listed a visible tenability limit for large enclosures and travel distances of 10 meters or 33 feet. Additionally, a visibility tenability limit for small enclosures and travel distances of 5 meters or 17 feet has been suggested. This value agrees with suggested values obtained from various documents such as the publication by George Hadjisophocleous and Yoon J. Ko, *Using a CFD Simulation in Designing a Smoke Management System in a Building*.

For this analysis, the visibility tenability limit was set at 17 feet. FDS was used to determine if the occupants would be exposed to conditions where the visibility within the fire floor will be less than 17 feet for the duration of egress time of the building. Keep in mind that the visibility criterion will failed if any portion of the floor level, with more than 20 feet away from the fire plume, has a visibility less than 17 feet at the horizontal plane six feet above the finished floor.

19.3.2. Temperature

References – SFPE Fire Protection Engineering 3rd Edition, Section 2, Chapter 6

There is a danger of incapacitation due to hyperthermia. Occupants may experience hyperthermia when their body absorbs more heat than it dissipates. Occupants can become incapacitated due to high temperatures from a fire in three methods:

- Heat Stroke
- Skin Pain and Burns
- Respiratory Tract Burns

Heat stroke can occur when occupants are exposed to hot environment, especially where there is high humidity and the subject is active.

Temperatures of 120 degrees Celsius have been observed to cause skin pain and burns in humans. Occupant's clothing affects the time and temperature of the onset of skin pain and burns to subjects in a fire.

Thermal burns to the respiratory tract may occur upon the inhalation of air above 60 degrees Celsius that is saturated with water vapor. An environment where air is saturated with water vapor can be present where water-based fire suppression is present.

For this analysis, the temperature tenability limit was set at 60 degrees Celsius, based on the temperature of water saturated air that can cause respiratory tract burns. Keep in mind that the temperature criterion will fail when the temperature, six feet above the walking surface, exceeds 60 degrees Celsius.

19.3.3. Combustion Gas Toxicity

References – SFPE Fire Protection Engineering 3rd Edition, Section 2, Chapter 6, Page 2–103

The toxicity levels released by products of combustion are of concern in the tenability analysis of fire within an enclosed space. The main toxins present during a fire are carbon monoxide (CO) and hydrogen cyanide (HCN). The existent of HCN is probable to appear when nitrogen-containing materials are involved in the fire. Nitrogen-containing materials include acrylics, polyurethane foams, melamine, nylon and wool. However, this analysis assumes that the fire will involve cellulistic material such as books and paper. Therefore, this analysis has only emphasized on the toxic level of CO.

Carbon monoxide levels are of concern during a fire in enclosed spaces because it combines with hemoglobin in the blood stream to form carboxyhemoglobin (COHb). COHb reduces the amount of oxygen in the blood and causes toxic narcosis that leads to unconsciousness and eventually death. Prediction of death caused by COHb concentrations in the blood is between 50 and 70 percent. Loss of consciousness has been predicted to occur between 30 and 40 percent concentrations.

This analysis predicts the concentration of CO (parts per million), at 6 feet above the finished floor within the enclosed space, to achieve 40 percent COHb in the bloodstream. Note that incapacitation by CO depends upon a dose accumulated over a period of time until the necessary COHb concentration is reached. For this analysis, 14 minute exposure duration was used to determine the limiting CO concentration to cause incapacitation.

The concentration of CO that causes incapacitation can be determined in accordance with SFPE Handbook Equation 6. The rearrangement of the equation for ppm CO result in 2,590 ppm at 40 %COHb and 25 RMV, typical for a 70 Kg human that is walking, for a 14 minute exposure. Keep in mind that the toxicity criterion will fail when the CO concentration, six feet above the walking surface, exceeds 2,590 ppm.

$$\%COHb = (3.317 * 10^{-5})(ppmCO)^{1.036}(RMV)(t) \qquad \textit{Equation 6}$$

$\%COHb$	=	COHb percent concentrations
$ppmCO$	=	CO concentration (ppm)
RMV	=	Volume of air breathed (feet)
t	=	Exposure time (minute)

19.4. Occupant Evacuation

References – SFPE Fire Protection Engineering 3rd Edition, Section 3, Chapter 13, Page 3–347

The risks to life safety in the business occupancy classification are relatively low. Exposure to the potential effects of fire is limited because business type facilities most often have low fuel loads, are normally occupied only during the daytime and, with some exceptions, are usually occupied for a set number of hours. The occupants are typically alert, ambulatory, conscious, aware of their surroundings, and generally familiar with the building's features, particularly the means of egress. Historically, this occupancy has one of the better fire safety records for the protection of life and property.

Total evacuation time comprises of several time sequence, as illustrated in Figure #5. The delay time, in particular, is the time for occupants to initiate their evacuation movement once they have perceived a notification or some cues of the fire. This time is comprised of perception, interpretation, and action.

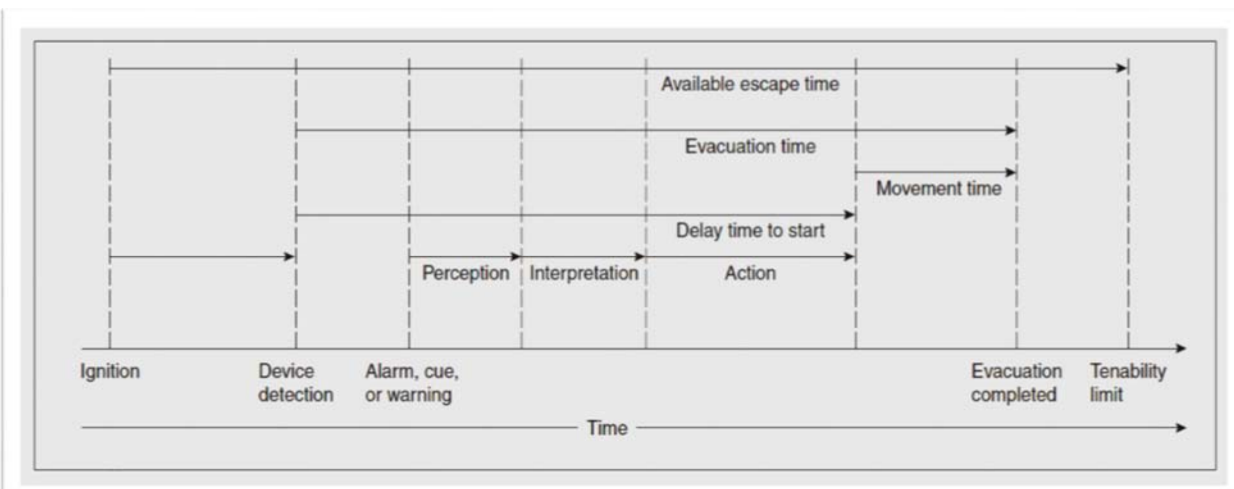


Figure #5: Sequence of Occupant Response to Fire

There have been many studies on the delay time that demonstrate different response time according to the type of warning obtained. The fire alarm signal is probably the least reliable indication of a fire due to large amount of false alarms, test alarms, or prank alarms that have reduced the credibility of notifying a real fire. A better indication of the problem is to obtain a

warning by others. Messages delivered through a voice communication system or directly told by staff that there is a fire seems to be taken most seriously by occupants to begin evacuating.

Most researchers in the field of *human behavior in fire* are hesitant at suggesting a corresponding number to delay time because of the limited research findings in this area. The table below suggests some delay time to start evacuation for similar occupancies in accordance to the warning systems available in the building. The center is suggested to have a delay time greater than 4 minutes for its warning system using fire alarm signal and staff with no relevant training.

Occupancy Type	W1 [a]	W2 [b]	W3 [c]
Offices	< 1 min.	3 min.	> 4 min.
Commercial & Industrial Buildings	< 1 min.	3 min.	> 4 min.
Schools	< 1 min.	3 min.	> 4 min.
Colleges & Universities	< 1 min.	3 min.	> 4 min.

a. Live directives using a voice communication system … with well-trained, uniformed staff that can be seen and heard by all occupants in the space.

b. Nondirective voice messages (prerecorded) and/or informative warning visual display with trained staff.

c. Warning system using fire alarm signal and staff with no relevant training

19.4.1. Detection Time

References – SFPE Fire Protection Engineering 3rd Edition, Section 2, Chapter 6, Page 4–10

Detection time is the time from ignition until the fire is detected. It may take a few seconds or hours, depending on the type of fire and the detection devices being used in the building. The publication on *Methods to Calculate the Response Time of Heat and Smoke Detectors Installed below Large Unobstructed Ceilings,* by Evans and Stroup, have established a computer program known as DETACT-QS. This program uses Alpert's equations on ceiling jet flow to predict the actuation time of fixed temperature & rate of rise heat detectors and sprinkler heads, in accordance to the user specified fire grow rate. DETACT-QS have been used to determine the activation of the automatic fire suppression system for the fire scenario.

19.4.1. Notification Time

References – NFPA 72 Section 10.12.1

Notification time is the time from detection until the sounding of the alarm. Notification time depends on the specification of the detection and alarm system. An additional 10 seconds have been included toward the activation time. The reason, the actuation of an alarm notification appliance must occur within 10 seconds after the activation of an initiating device.

19.4.2. Reaction Time (Perception & Interpretation)

Reaction time is the time when an occupant perceives an alarm or fire cue until the occupant decides to take action. Reaction time includes the time it takes to:

- Perceive an alarm or fire cue
- Interpret the alarm or fire cue
- Decide on a course of action

An alarm or fire cue may often be ambiguous, particularly in large buildings, which can extend the reaction time. The average reaction time is highly influenced by the performance of the detection and alarm system. The occupants, within a classroom setting, are typically conscious and aware of their surroundings. Their reaction time toward an alarm will generally be about 5 seconds.

19.4.3. Pre–Evacuation Time (Action)

Pre–evacuation time is the time when occupants are engages an activity before evacuating. The following are pre-movement activities that might occur within the Construction Innovation Center during a class session:

- Waiting for instruction from the professor
- Packing or putting away personal items
- Waiting for friends/colleagues

Packing and putting away personal property would be the most common pre-movement activity, in an emergency, where there is not an immediate danger to the person. Most students will have a pencil and sheets of paper or a folder in front on their desks while listening to the instructor. The time from initial decision to egress and complete packing time is about 15 seconds.

19.4.4. Movement Time

The movement time, the final component of an egress analysis, is the time required for occupants to reach a location of safety before beginning to evacuate. This travel time is primarily based on the location of the occupants and the speed at which they can navigate through the building. Pathfinder has been used to determine the travel time for each scenarios. Depending upon the building, factors that might contribute to the travel time are:

- Crowding Phenomena
- Unfamiliarity with the Building
- Occupants egress via the most familiar path, unless block

19.5. Building Characteristics & Occupant Characteristics

References – SFPE Fire Protection Engineering 3rd Edition, Section 3, Chapter 11, Page 3–349

In accordance with the case studies reported in the SFPE Fire Protection Engineering handbook, the characteristics of the building and of the occupants marked difference in delay time for occupants to start evacuating.

19.5.1. Building Characteristics

References – SFPE Fire Protection Engineering 3rd Edition, Section 3, Chapter 11, Page 3–350

The layout in which each floor and the entire Construction Innovation Center are organized has an impact on the possibility for the occupant to have developed a mental map of their surroundings. The way the center is designed provides occupants with visual access to the behavior of others; this is an important source of information for people to start evacuating rapidly. Visual access could also improve the perception of fire cues or strobe lights as well as the location of the closest exit.

19.5.2. Occupant Characteristics

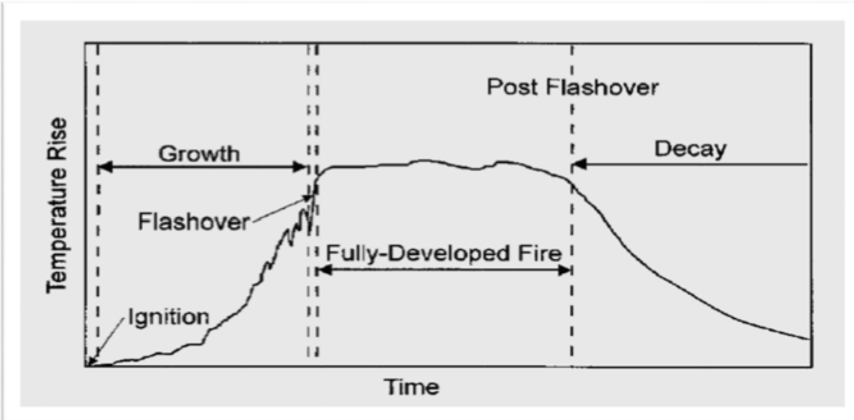
*References – NFPA 101 Section 5.4.5.2**

The selection of occupant characteristics to be used in the design calculations must provide an accurate reflection of the expected population within the Construction Innovation Center and approved by the authority having jurisdiction. Occupant characteristics must represent the normal occupant profile and be consistent across each fire scenario. Basic performance occupant characteristics are described in the appropriate appendix for each fire scenario.

19.6. Design Fire Scenarios

*References – NFPA 101 Section 5.5**

A fire scenario represents an outline of events and conditions that are critical to the outcome of real world fire situations. An appropriate fire scenario begins by understanding the existing conditions and type of occupancy of the building. There are several stages of development that a fire might go through in a particular fire scenario, as illustrated in Figure #6. Fire development varies depending on the combustion and physical characteristics of the primary fuel, the involvement of secondary fuel(s), the availability of air, and the influences due to the compartment.



(**1**) Ignition

(**2**) Growth

(**3**) Flashover

(**4**) Fully Developed Fire

(**5**) Post Flashover

(**6**) Decay

Figure #6: The stages of fire development

Flashover, in particular, occurs when fire spread beyond the ignition source to adjacent objects. The smoke layer temperature at which flashover occurs is generally in the range of 930 °F to 1300 °F. Flashover may also occur when the radiant heat flux is at 1.8 Btu/ft^2 or 20 kW/m^2 on the floor of the fire room.

To fully understand the impact of fire scenarios, the frequency of the fire needs to be determined. The following are three types of scenarios that should be considered:

- High–Frequency Fires & Low–Consequence Scenario
- Low–Frequency Fires & High–Consequence Scenario
- Special Problems Scenario

The first type of scenario is used to demonstrate whether the fire safety system can manage high frequent and relatively small fires, such as a wastebasket fire. The second type of scenario uses a less frequently and relatively large fire; it causes a greater challenge to the fire safety system, such as a fire in an egress path. These two scenario types assume that the fire safety system will function as designed. However, the third type of scenario account for those situations in which some aspect of the fire safety system might be compromised such as an improper closed valve on a sprinkler system.

The tenability for particular rooms or areas in Building A and B has been evaluated based on fire scenarios intended to represent a reasonably fire event. Building C was not selected as part of the tenability analysis due to the room configuration and lack of ignition sources. Each room from every floor of Building C are set identical; it comprises of rows of chairs use for lecturing, as illustrated in Photo #25.

Photo #25: Room C301, Classroom, from Building C

Fires are sometimes defined by their growth rate or the time it takes to reach a given heat release rate. Research has shown that most fires grow exponentially and can be expressed by the *power law fire growth model*. Therefore, for this analysis, t–squared fire growth rate was used to model each fire scenario. There are three categories for fire growth, each determined by the time required for the fire to reach 1000 Btu/sec or 1055 kW, as described below:

- **Slow**: A fire taking 400 seconds or more to reach 1000 Btu/sec.
- **Medium**: A fire taking 150 seconds or more and less than 400 seconds to reach 1000 Btu/sec.
- **Fast**: A fire taking less than 150 seconds to reach 1000 Btu/sec.

19.6.1. Fire Scenario in Building A

References – Upholstered Furniture Heat Release Rate: Measurements and Estimation

A fire scenario was designated in space A101A, *Seating Area*, from Building A. The main purpose of this apace is for people to sit and wait until they are called upon from the receptionist, as illustrated in Photo #26. This space was selected due to the type of ignitions sources and the possibility of the main exit door being blocked from a potentially large fire.

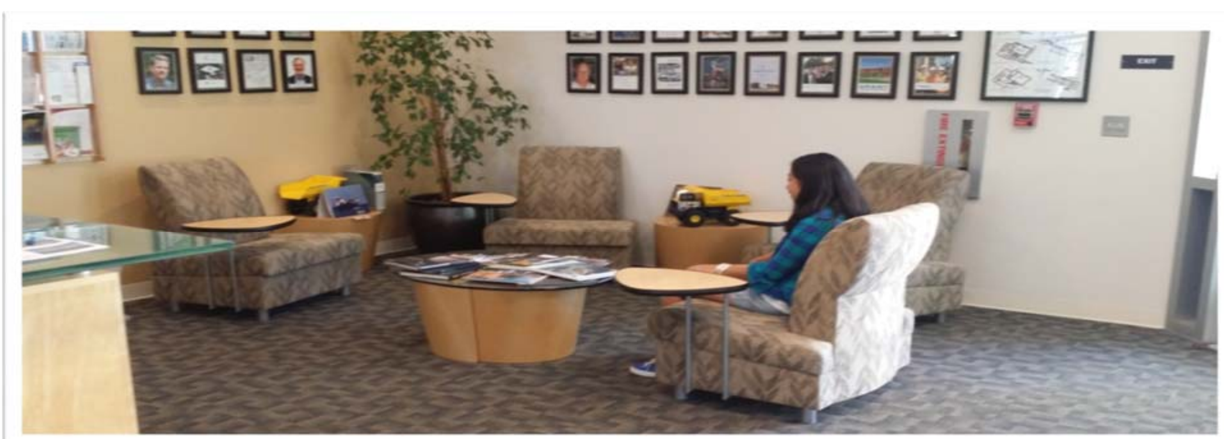


Photo #26 – Space A100A, Seating Area, from Building A

For this analysis, I have established a fire occurring on one of the couches closest to the door; this will persuade occupants to escape to an alternative exit. The couch is configured for one person without armrests. The couch is entirely upholstered and fitted with California foam. The frame, which is under the upholstery, is made out of kiln-dried maple wood that is free of knots, bark, or defects. The couch coverings are made of soft cotton fabric.

The publication by Vytenis Babrauskas, *Upholstered Furniture Heat Release Rate: Measurements and Estimation,* described the use of a furniture calorimeter to obtain information on the burning rate of 10 chairs. A quantitative assessment has been made on the effect of fabric types, padding types (cotton batting, ordinary polyurethane foam, and California-requirements foam), and frame types. The table below demonstrates theses 10 test specimens that were used in Vytenis Babrauskas' research.

Chair	Tests	Mass	Padding Material	Fabric	Frame
F21	T19, T45	28.3 kg	California Foam	Polyolefin	Wood
F22	T24	31.9 kg	FR Cotton Batting	Cotton	Wood
F23	T23	31.2 kg	FR Cotton Batting	Polyolefin	Wood
F24	T22	28.3 kg	California Foam	Cotton	Wood
F25	T29	27.8 kg	Non- California Foam	Polyolefin	Wood
F26	T25	19.2 kg	California Foam	Polyolefin	Wood
F27	T26	29.0 kg	Foam Cotton, Polyester	Cotton	Wood
F28	T28	29.2 kg	Foam Cotton, Polyester	Cotton	Wood
F29	T27	14.0 kg	Non- California Foam	Polyolefin	Polypropylene
F30	T30	25.2 kg	Non- California Foam	Polyolefin	Polypropylene

The table below summarizes the result of test data for each couch. There are two variables that are considered important when inputting the necessary values into the FDS model: the peak rate of heat release and the growth time. These two variables will assist FDS on describing the behavior of the fire.

Chair	Growth Time	Classification	Time to Peak	Maximum $\dot{Q}$	Total Q
F21	50 sec	Fast	280 sec	1970 kW	440 MJ
F22	2000 sec	Slow	910 sec	370 kW	425 MJ
F23	400 sec	Slow	450 sec	700 kW	461 MJ
F24	350 sec	Medium	650 sec	700 kW	369 MJ
F25	60 sec	Fast	260 sec	1990 kW	419 MJ
F26	200 sec	Medium	240 sec	810 kW	300 MJ
F27	200 sec	Medium	570 sec	920 kW	519 MJ
F28	425 sec	Slow	420 sec	730 kW	369 MJ
F29	100 sec	Fast	220 sec	1950 kW	446 MJ

For this analysis, the chairs marked as F21 have been selected to represent the chair being used in Space A100A due to their similarity. Therefore, it will have maximum heat release rate of 1970 kW with a growth time of 280 seconds, a medium growth fire, in accordance with Chair F21. A better representation of the heat release rate of Chair F21 is illustrated in Figure #7.

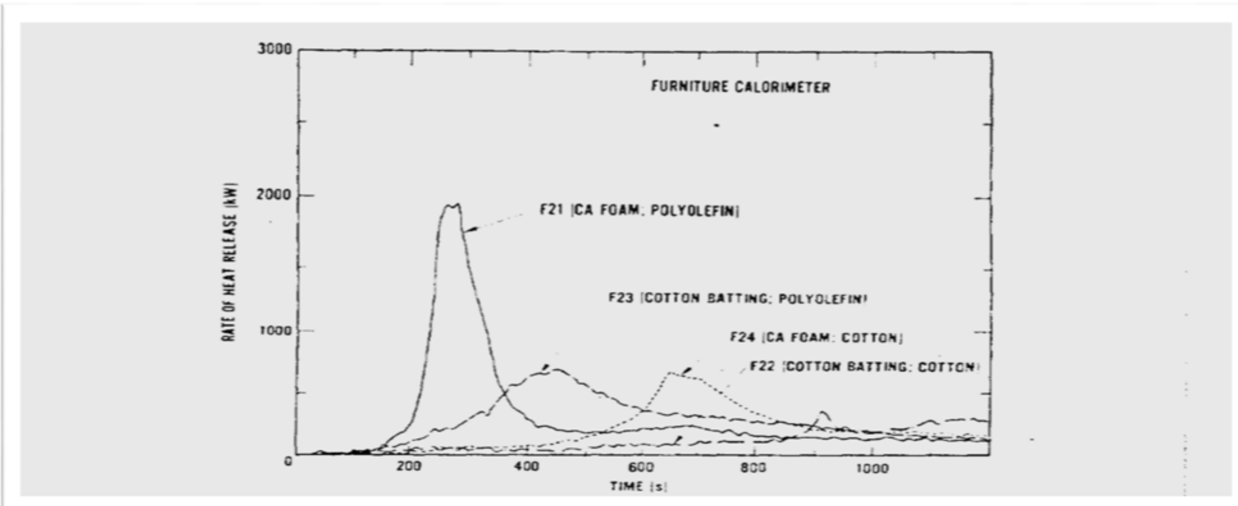


Figure #7: Effect of Specimen Padding and Fabric on Rate of Heat Release

Please see *Appendix Q* for the necessary information required to conduct this tenability analysis for Space A100A. *Appendix Q* includes the following:

- Location of Ignition
- Occupant Characteristics
- Room Characteristics
- Fire Characteristics
- Visibility Tenability from FDS
- Temperature Tenability from FDS
- Toxicity Tenability from FDS
- Activation Time from DETACT-QS
- Movement Time from Pathfinder

The table below demonstrates the results generated from the FDS model as a Pass or Fail experiment.

Tenability Criteria [a]	Tenability Limits	FDS Results
Visibility	17 feet	PASS
Temperature	60 °C	PASS
Toxicity	2,590 ppm	PASS

a. The tenability criteria are evaluated at 6 feet above the top of finished floor.

The table below demonstrates each time sequence of the occupant evacuation time from the fire room.

Occupant Evacuation Time	Explanation	Results
Activation Time	DETACT-QS (Sprinkler Activation)	150 sec
Notification Time	NFPA 72 Section 10.12.1	10 sec
Reaction Time	Medium Alert	3 sec
Pre–Evacuation Time	Packing of Office Supplies	10 sec
Movement Time	Pathfinder	49 sec
Total Evacuation Time		222 sec (3.7 min)

In accordance with the results generated from the FDS model and the calculated total evacuation time…the tenability limits were never reach when measured at 6 feet above the top of finished floor within the 222 seconds time frame. Therefore, space A101A from Building A may be considered tenable during a fire.

19.6.2. Fire Scenario in Building B

References – Prediction of HRR of Surface Materials in Large Scale Fire Test Based on Cone Calorimeter Results

A fire scenario was selected in Room B203, *Construction Management Lab–Lecture Format*, from Building B, as illustrated in Photo #27. The main purpose of this room is provided students the opportunity to work on varies school projects such as miniature wood modeling. This room was selected due to the type of ignitions sources that may result into a potentially large fire.

Photo #27: Room B203, Construction Management Lab–Lecture Format, from Building B

For this analysis, I have established a fire occurring on one of the wooden model. The fire will be located near at exit, resulting unavailable for occupants to use. The source of ignition may be caused from a faulty glue gun that has accidentally ignite nearby architectural model.

The publication by Ulf Wickstrom and Ulf Goransson, *Prediction of Heat Release Rate of Surface Materials in Large Scale Fire Test Based on Cone Calorimeter Results*, have analyzed varies type of woods and their ignition times in the cone calorimeter at 25 kW/m^2. The table

below demonstrates the rate of heat release of these varies wood products used by these two researchers.

Test Specimen	Thickness	Density	Ignition Time
Rigid Polyurethane Foam	30 mm	30 kg/m^3	1 sec
Insulating Fiberboard	13 mm	250 kg/m^3	28 sec
Expanded Polystyrene	50 mm	20 kg/m^3	100 sec
Medium Density Fiberboard	12 mm	600 kg/m^3	88 sec
Wood Panel, Spruce	11 mm	530 kg/m^3	94 sec
Particle Board	10 mm	750 kg/m^3	87 sec

For this analysis, the particle board has been selected to represent the type of material being used for architectural modeling in Room B203. Figure #8 illustrates the heat release rate for particle board when exposed at two irradiances of 25 kW/m^2 and 50 kW/m^2.

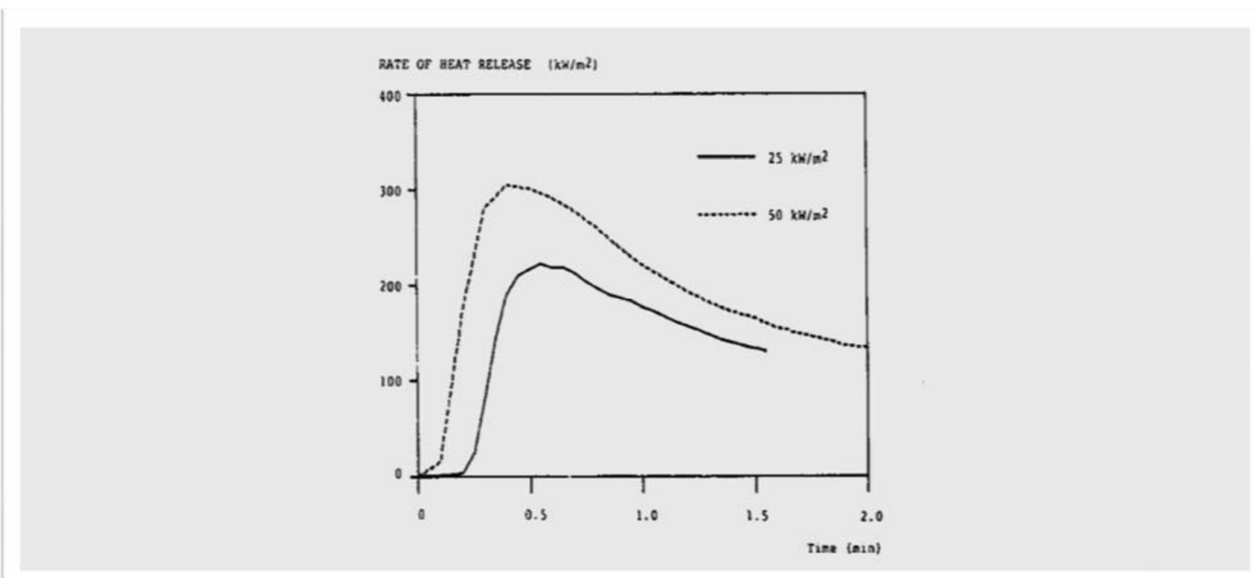


Figure #8: Heat Release Rate versus Time for Particle Board (25 kW/m^2 and 50 kW/m^2)

Please see *Appendix R* for the necessary information required to conduct this tenability analysis for room B203. *Appendix R* includes the following:

- Location of Ignition
- Occupant Characteristics
- Room Characteristics
- Fire Characteristics
- Visibility Tenability from FDS
- Temperature Tenability from FDS
- Toxicity Tenability from FDS
- Activation Time from DETACT-QS

- Movement Time from Pathfinder

The table below demonstrates the results generated from the FDS model as a Pass or Fail experiment.

Tenability Criteria [a]	Tenability Limits	FDS Results
Visibility	17 feet	PASS
Temperature	60 °C	PASS
Toxicity	2,590 ppm	PASS

a. The tenability criteria are evaluated at 6 feet above the top of finished floor.

The table below demonstrates each time sequence of the occupant evacuation time from the fire room.

Occupant Evacuation Time	Explanation	Results
Activation Time	DETACT-QS (Sprinkler Activation)	175 sec
Notification Time	NFPA 72 Section 10.12.1	10 sec
Reaction Time	Medium Alert	3 sec
Pre–Evacuation Time	Packing of School Supplies	10 sec
Movement Time	Pathfinder	28 sec
Total Evacuation Time		226 sec (3.8 min)

In accordance with the results generated from the FDS model and the calculated total evacuation time…the tenability limits were never reach when measured at 6 feet above the top of finished floor within the 226 seconds time frame. Therefore, space B203 from Building B may be considered tenable during a fire.

20. Conclusion & Recommendation

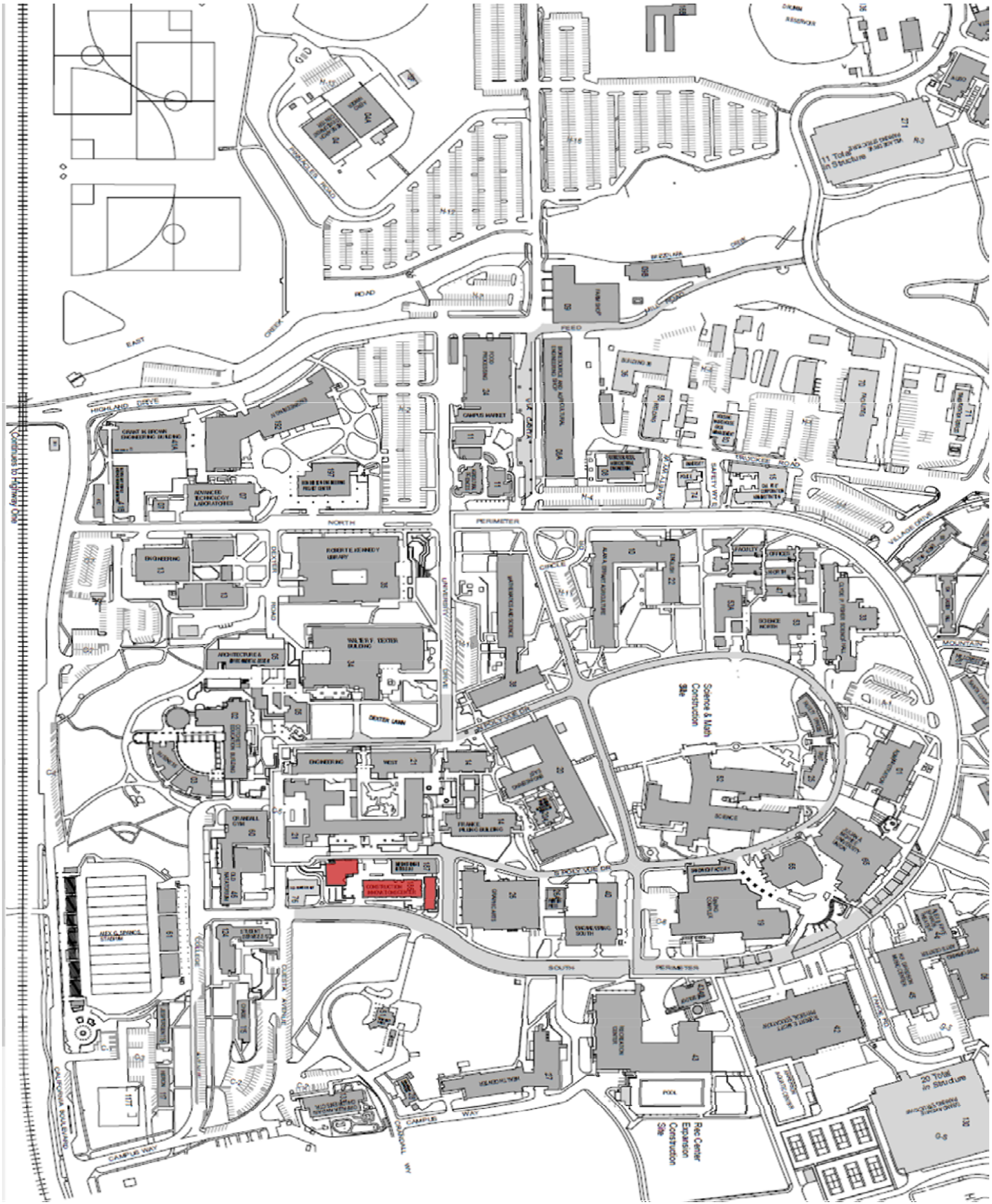
In accordance with my analysis, the Construction Innovation Center has complied with both the prescriptive analysis approach and performance-based analysis approach. The center has met each requirements within the latest codes and standards for the fire structure protection, means of egress, fire alarm & communication, and fire–suppression system. The center can be assumed tenable within each room and floor due to its high level of life safety; all three buildings are connected with each other by an exterior balcony at each floor. As a result, occupants have a quicker access to the outside in which minimizes their exposure time from a potential fire.

I recommend a more rigorous inspection throughout the center for any initiating devices or notification appliances that have been obstructed. Many initiating devices and notification appliances within the center are being blocked by inanimate objects that are limiting their access and lowering their performance.

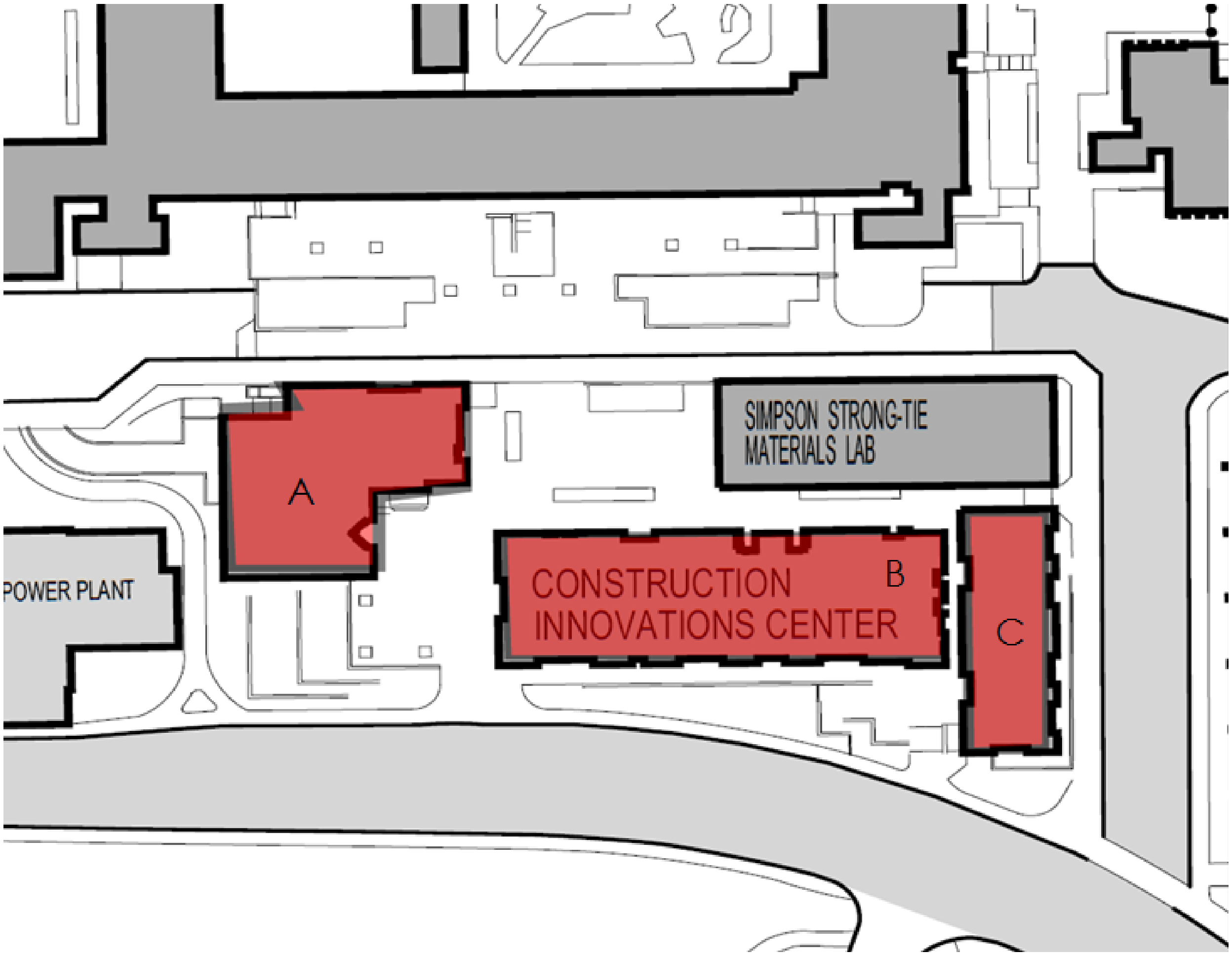
Appendix A

Campus Map

Appendix A. California Polytechnic State University



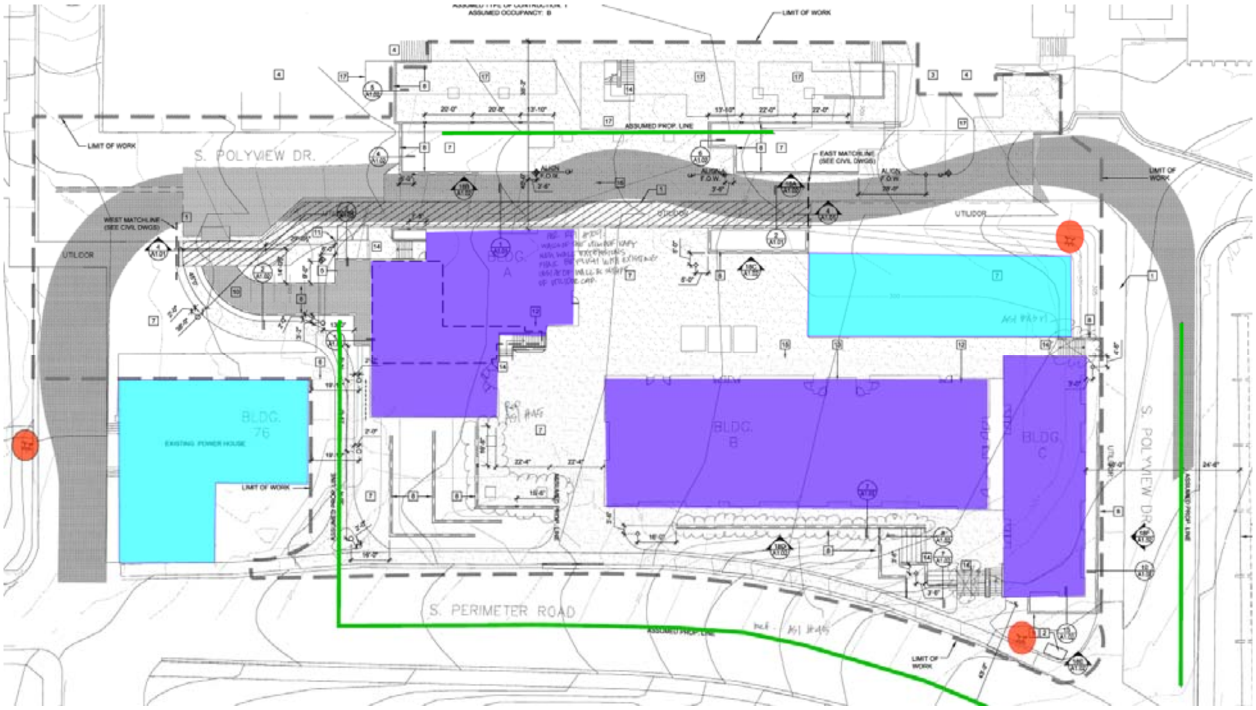
Appendix A. Construction Innovation Center



Appendix B

Site Plan

Appendix B. Site Plan



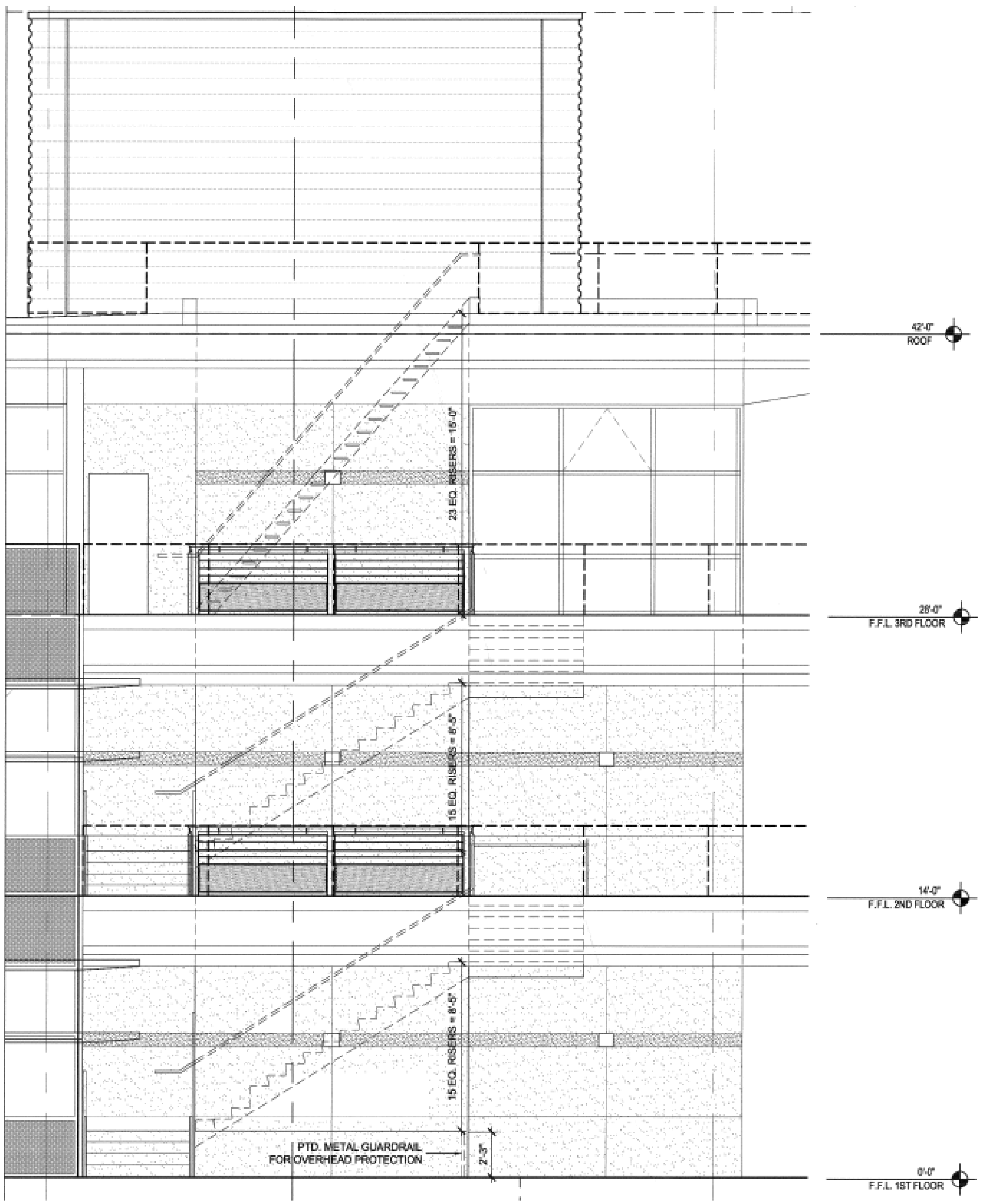
Legend

Construction Innovation Center	Property Lane
Existing Adjacent Buildings	Limit of Work
Fire Access Lane	Fire Hydrant

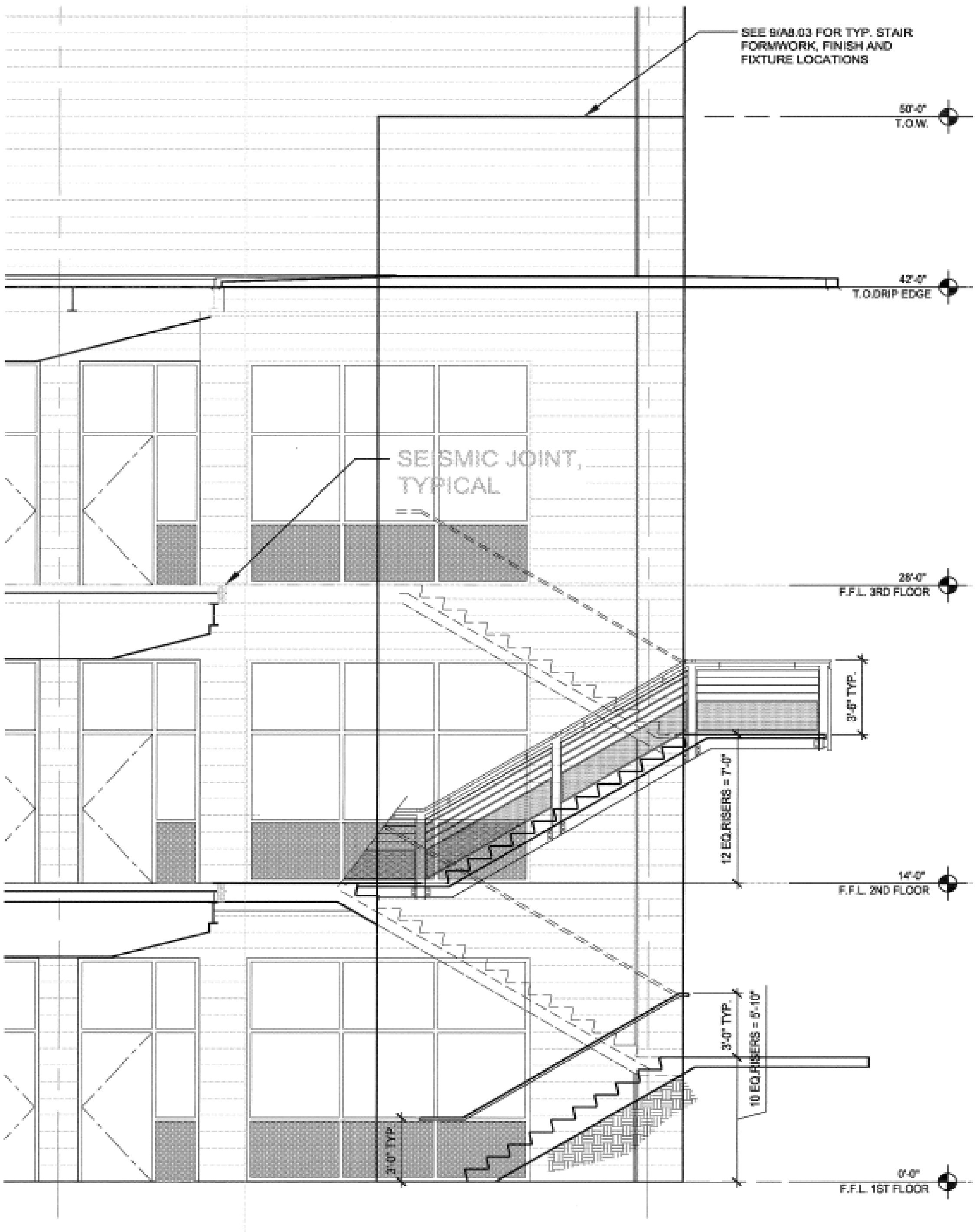
Appendix C

Stairways | Elevation Plans

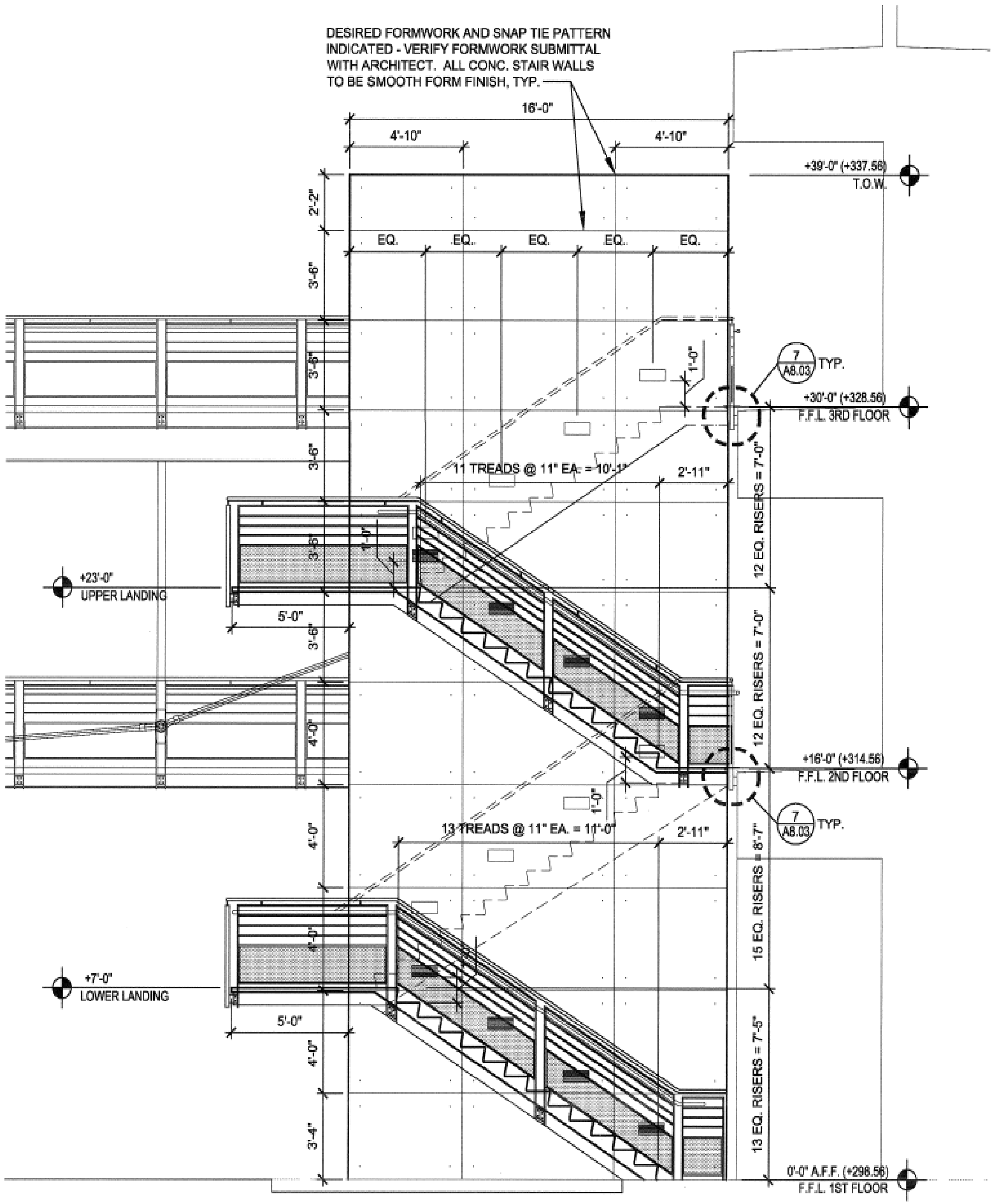
Appendix C. Stair #1



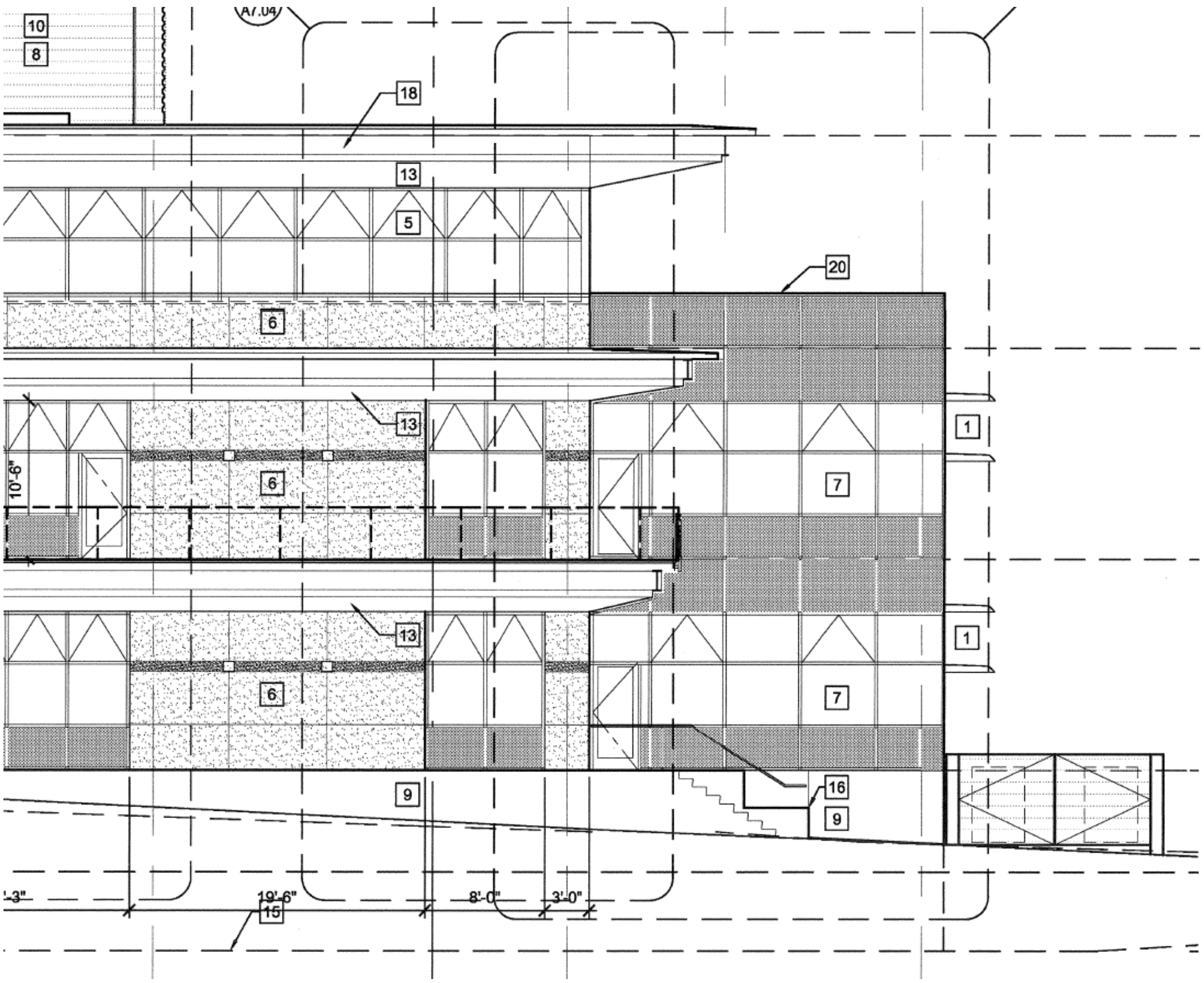
Appendix C. Stair #2



Appendix C. Stair #3



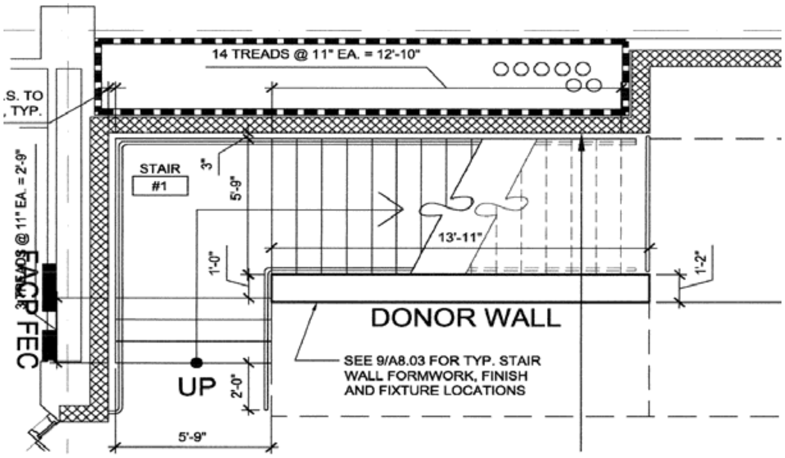
Appendix C. Stair #4



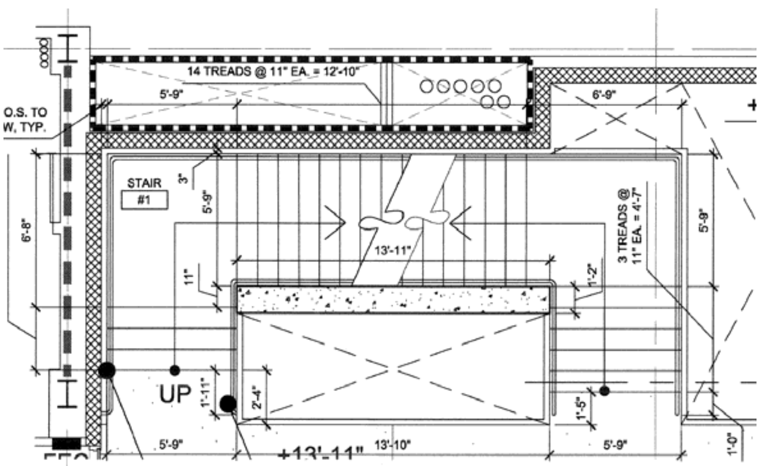
Appendix D

Stairways | Floor Plans

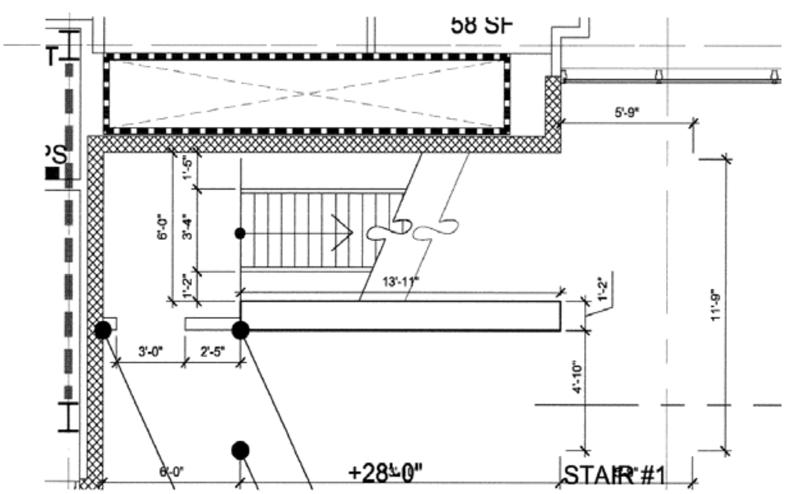
Appendix D. Stair #1



Floor 1

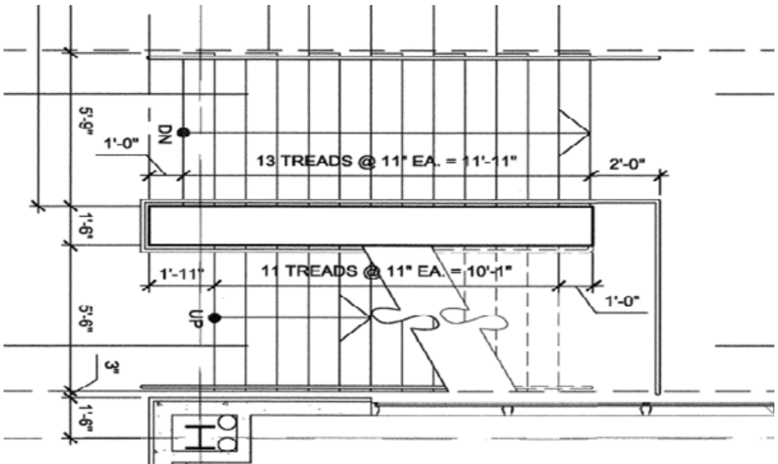


Floor 2

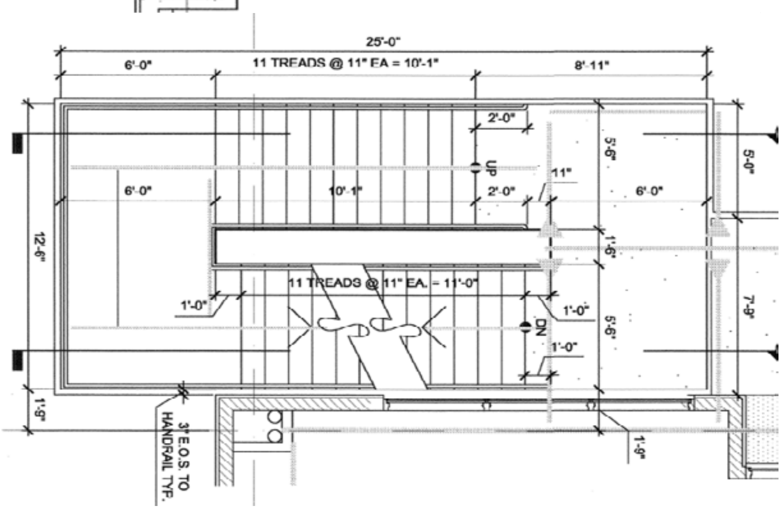


Floor 3

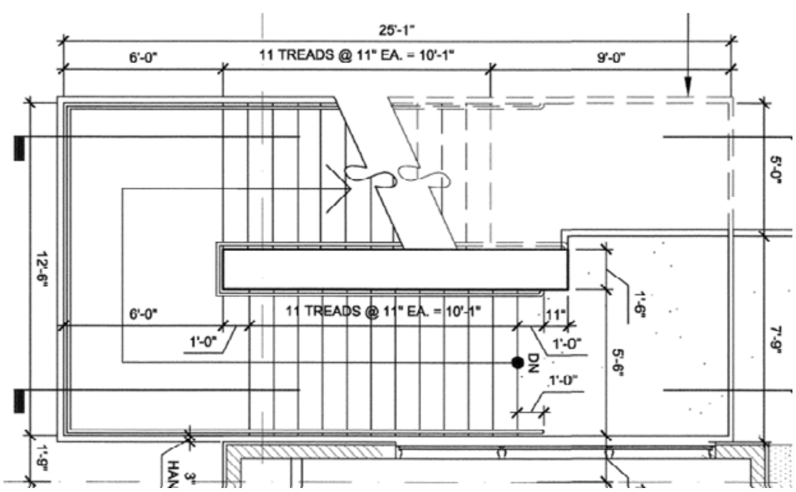
Appendix D. Stair #2



Floor 1

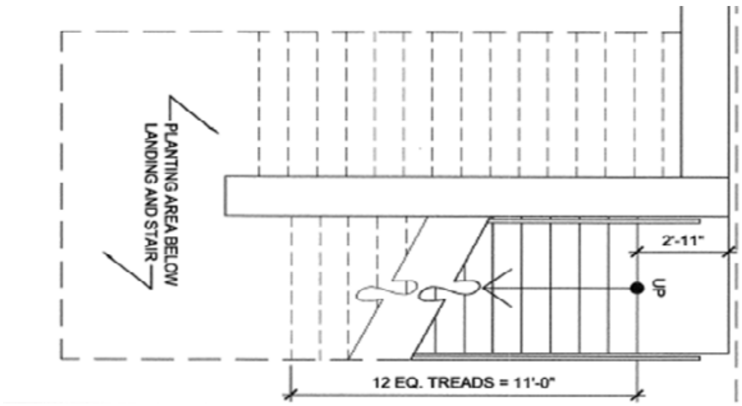


Floor 2

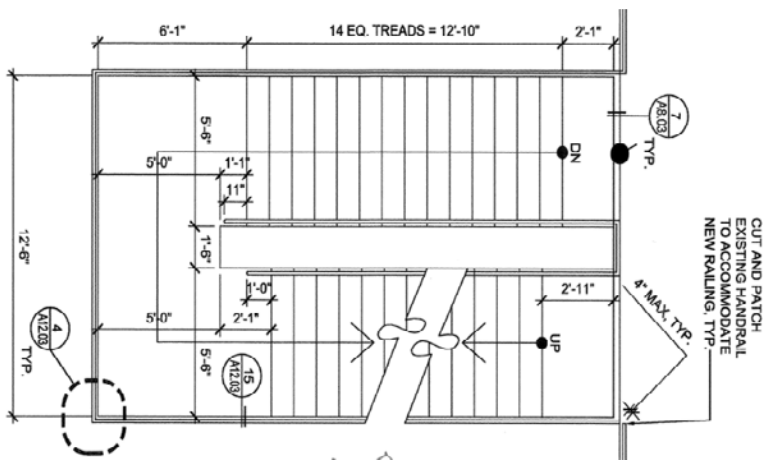


Floor 3

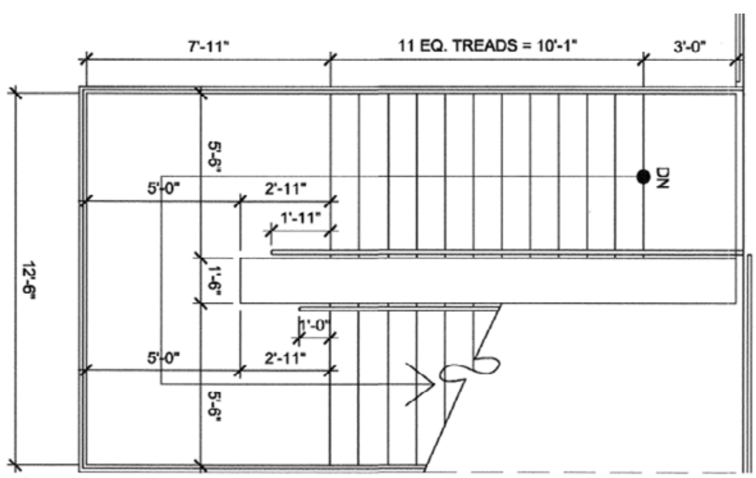
Appendix D. Stair #3



Floor 1

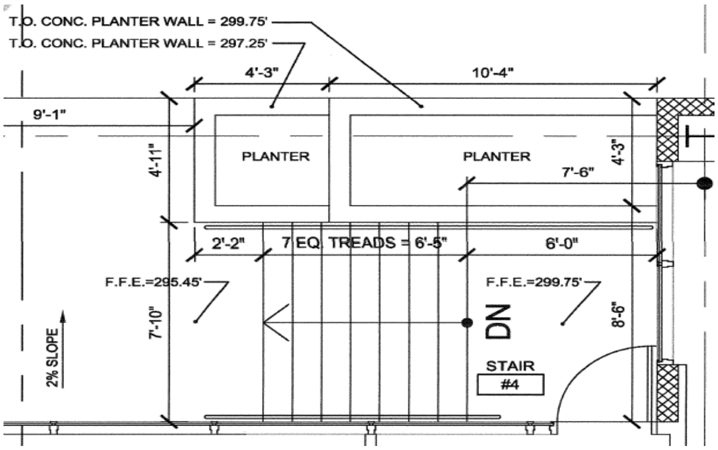


Floor 2



Floor 3

Appendix D. Stair #4

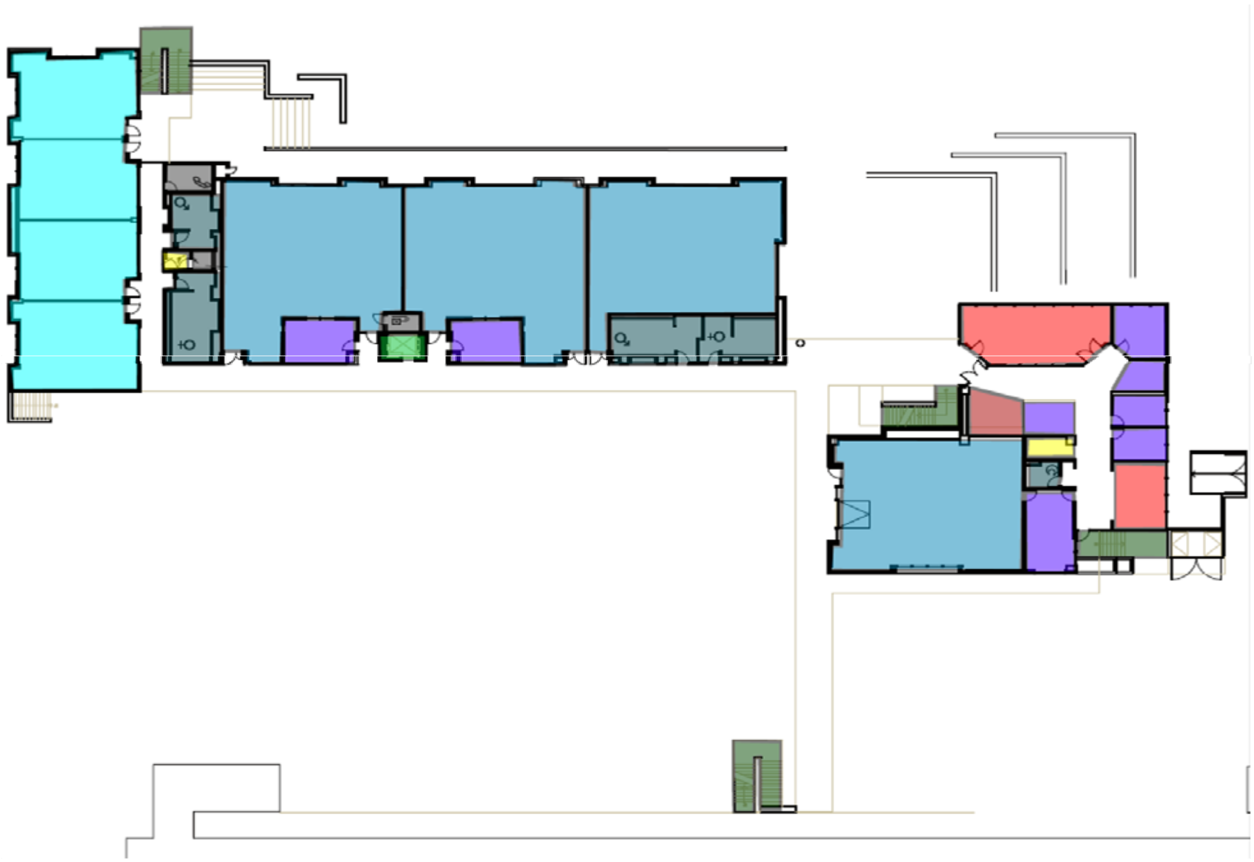


Floor 1

Appendix E

Color Coded Floor Plans

Appendix E. Floor Plan 1



Legend

	Office		Storage Room
	Conference Room		Stairs
	Waiting Area		Classrooms
	Utility Room		Educational Laboratory
	Elevator		Restroom

Appendix E. Floor Plan 2

Legend

	Office		Storage Room
	Conference Room		Stairs
	Waiting Area		Classrooms
	Utility Room		Educational Laboratory
	Elevator		Restroom

Appendix E. Floor Plan 3

Legend

Office	Storage Room
Conference Room	Stairs
Waiting Area	Classrooms
Utility Room	Educational Laboratory
Elevator	Restroom

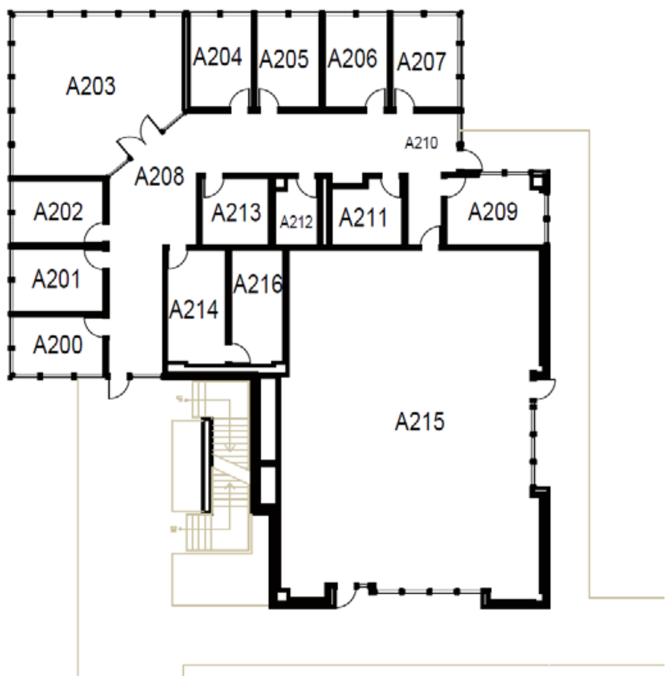
Appendix F

Occupant Load Calculation

Appendix F. Building A | First Floor

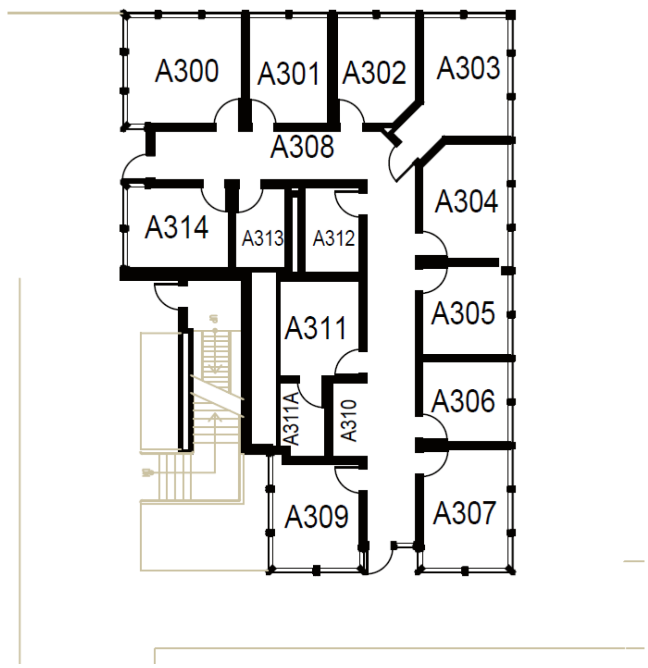
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
A100A	B	Waiting Area	165 SF	15 SF/Person	11
A100	B	Office	116 SF	100 SF/Person	2
A101	B	Conference	610 SF	15 SF/Person	41
A102	B	Office	200 SF	100 SF/Person	2
A103	B	Office	110 SF	100 SF/Person	2
A104	B	Office	110 SF	100 SF/Person	5
A105	B	Office	110 SF	100 SF/Person	2
A108	B	Office	300 SF	100 SF/Person	3
A112	B	Laboratory	1800 SF	50 SF/Person	36

Appendix F. Building A | Second Floor



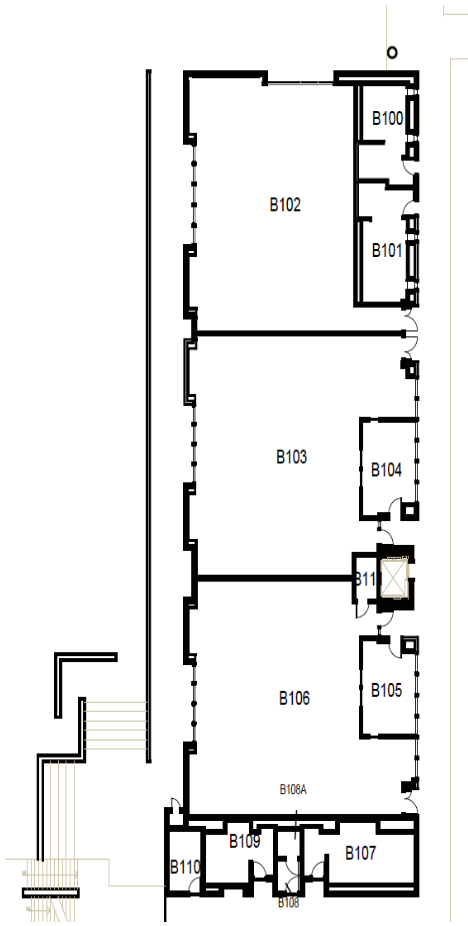
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
A200	B	Office	101 SF	100 SF/Person	2
A201	B	Office	110 SF	100 SF/Person	2
A202	B	Office	110 SF	100 SF/Person	2
A203	B	Conference	530 SF	15 SF/Person	36
A204	B	Office	115 SF	100 SF/Person	2
A205	B	Office	115 SF	100 SF/Person	5
A206	B	Office	115 SF	100 SF/Person	2
A207	B	Office	110 SF	100 SF/Person	2
A209	B	Office	300 SF	100 SF/Person	3
A211	B	Office	110 SF	100 SF/Person	2
A213	B	Office	154 SF	100 SF/Person	2

Appendix F. Building A | Third Floor



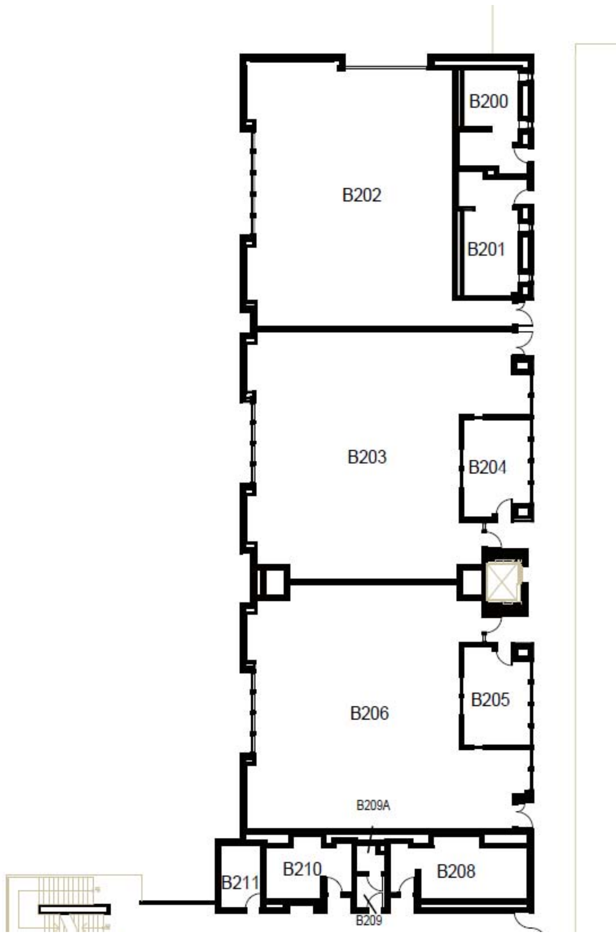
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
A300	B	Office	110 SF	100 SF/Person	2
A301	B	Office	110 SF	100 SF/Person	2
A302	B	Office	110 SF	100 SF/Person	2
A303	B	Office	110 SF	100 SF/Person	2
A304	B	Office	110 SF	100 SF/Person	2
A305	B	Office	110 SF	100 SF/Person	2
A306	B	Office	110 SF	100 SF/Person	2
A307	B	Office	110 SF	100 SF/Person	2
A309	B	Office	110 SF	100 SF/Person	2
A314	B	Office	122 SF	100 SF/Person	2

Appendix F. Building B | First Floor



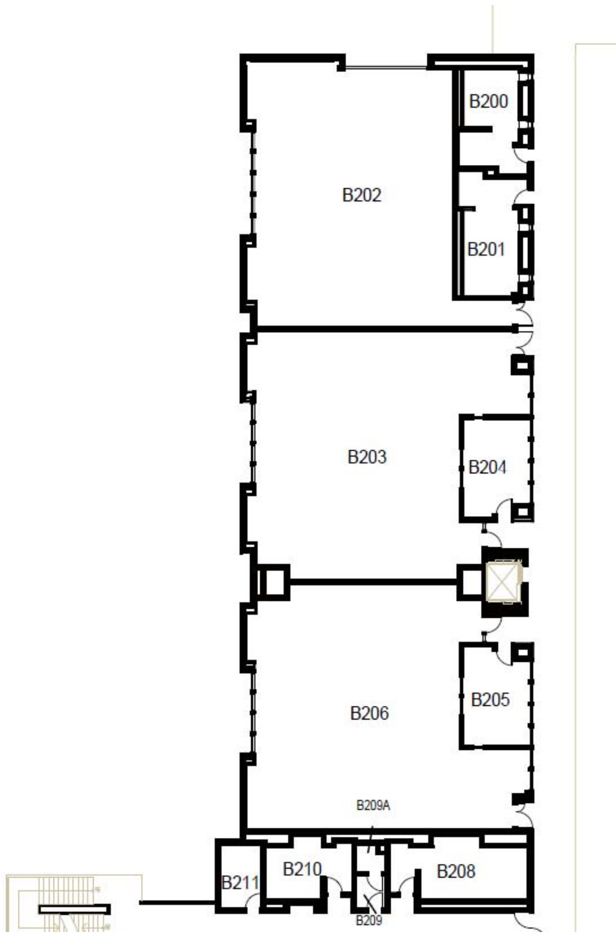
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
B102	B	Laboratory	1897 SF	50 SF/Person	38
B103	B	Laboratory	1994 SF	50 SF/Person	40
B104	B	Office	235 SF	100 SF/Person	3
B105	B	Office	235 SF	100 SF/Person	3
B106	B	Laboratory	1989 SF	50 SF/Person	40
B1110	B	IDF Room	102 SF	300 SF/Person	1

Appendix F. Building B | Second Floor



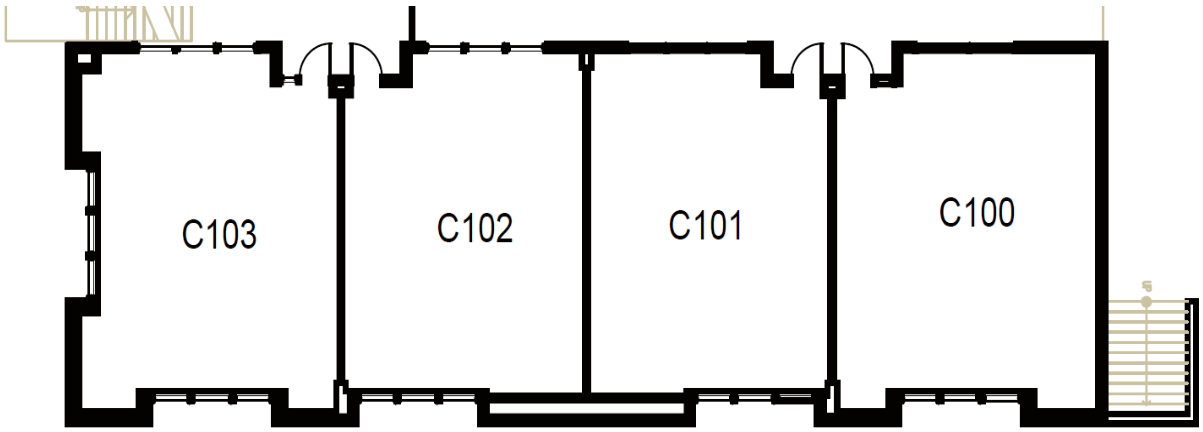
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
B202	B	Laboratory	1902 SF	50 SF/Person	39
B203	B	Laboratory	1986 SF	50 SF/Person	40
B204	B	Office	235 SF	100 SF/Person	3
B205	B	Office	235 SF	100 SF/Person	3
B206	B	Laboratory	1989 SF	50 SF/Person	40

Appendix F. Building B | Third Floor



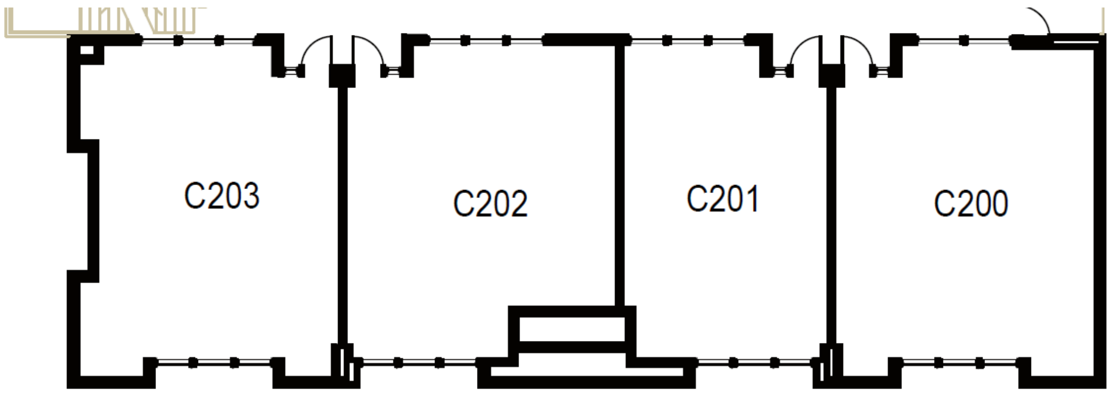
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
B302	B	Laboratory	1904 SF	50 SF/Person	39
B303	B	Laboratory	2450 SF	50 SF/Person	49
B304	B	Office	235 SF	100 SF/Person	3
B305	B	Office	235 SF	100 SF/Person	3
B306	B	Laboratory	2096 SF	50 SF/Person	42

Appendix F. Building C | First Floor



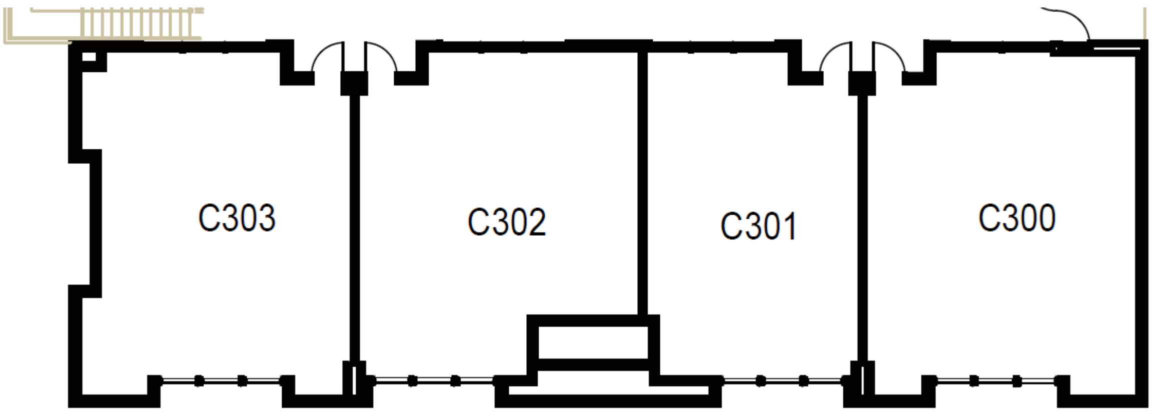
Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
C100	B	Lecture	728 SF	20 SF/Person	37
C101	B	Lecture	722 SF	20 SF/Person	37
C102	B	Lecture	721 SF	20 SF/Person	37
C103	B	Lecture	736 SF	20 SF/Person	37

Appendix F. Building C | Second Floor



Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
C200	B	Lecture	753 SF	20 SF/Person	38
C201	B	Lecture	566 SF	20 SF/Person	29
C202	B	Lecture	749 SF	20 SF/Person	38
C203	B	Lecture	759 SF	20 SF/Person	38

Appendix F. Building C | Third Floor

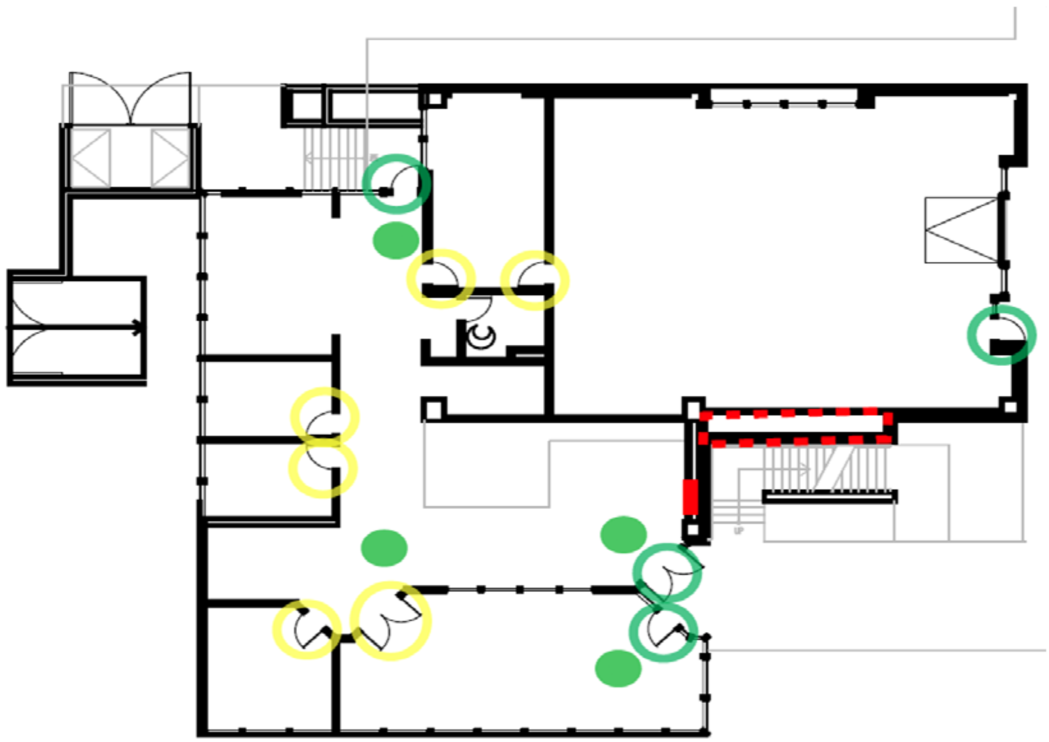


Rooms	Group	Function	Area	Occupancy Load Factor	Occupant Load
C300	B	Lecture	735 SF	20 SF/Person	37
C301	B	Lecture	564 SF	20 SF/Person	29
C302	B	Lecture	721 SF	20 SF/Person	41
C303	B	Lecture	759 SF	20 SF/Person	38

Appendix G

Means of Egress & Fire Structure Protection

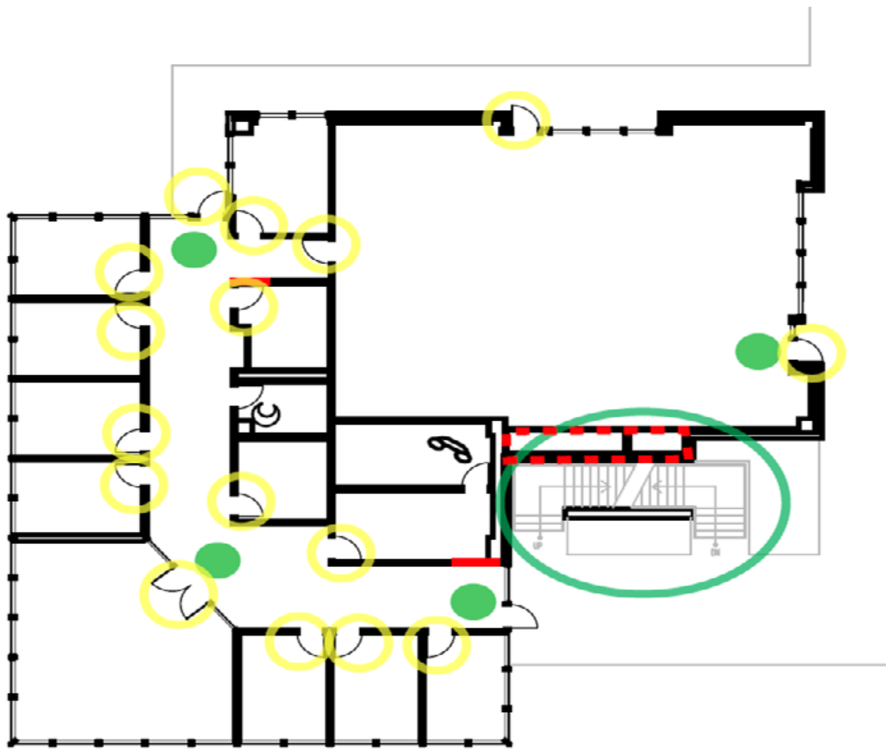
Appendix G. Building A | First Floor



Legend

	Exits Doors & Stairways		Exit Access Doors
	Exit Signs		Fire Extinguishers
	1 HR Fire Rated		2 HR Fire Rated

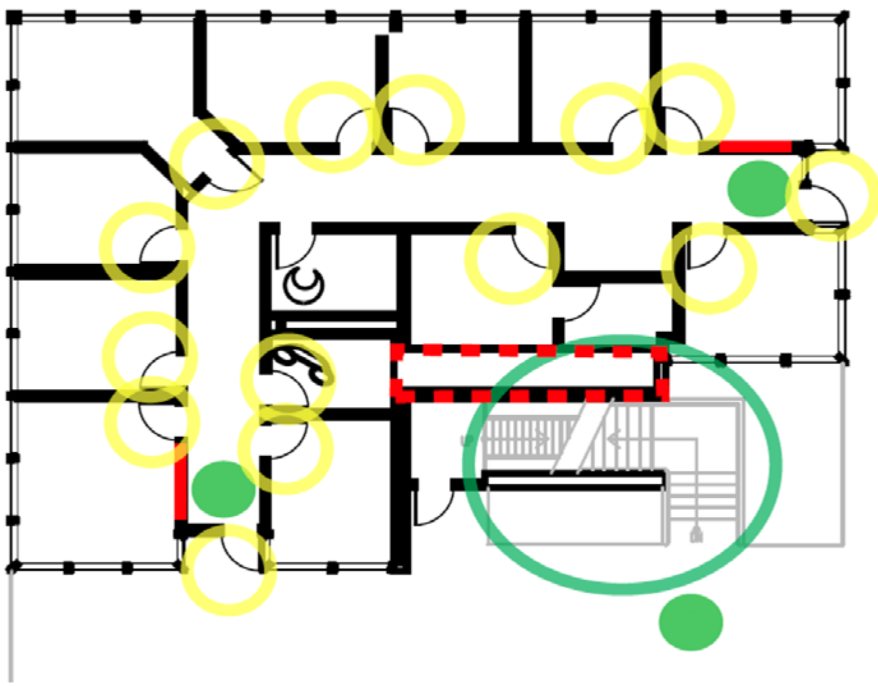
Appendix G. Building | A Second Floor



Legend

Exits Doors & Stairways	Exit Access Doors
Exit Signs	Fire Extinguishers
1 HR Fire Rated	2 HR Fire Rated

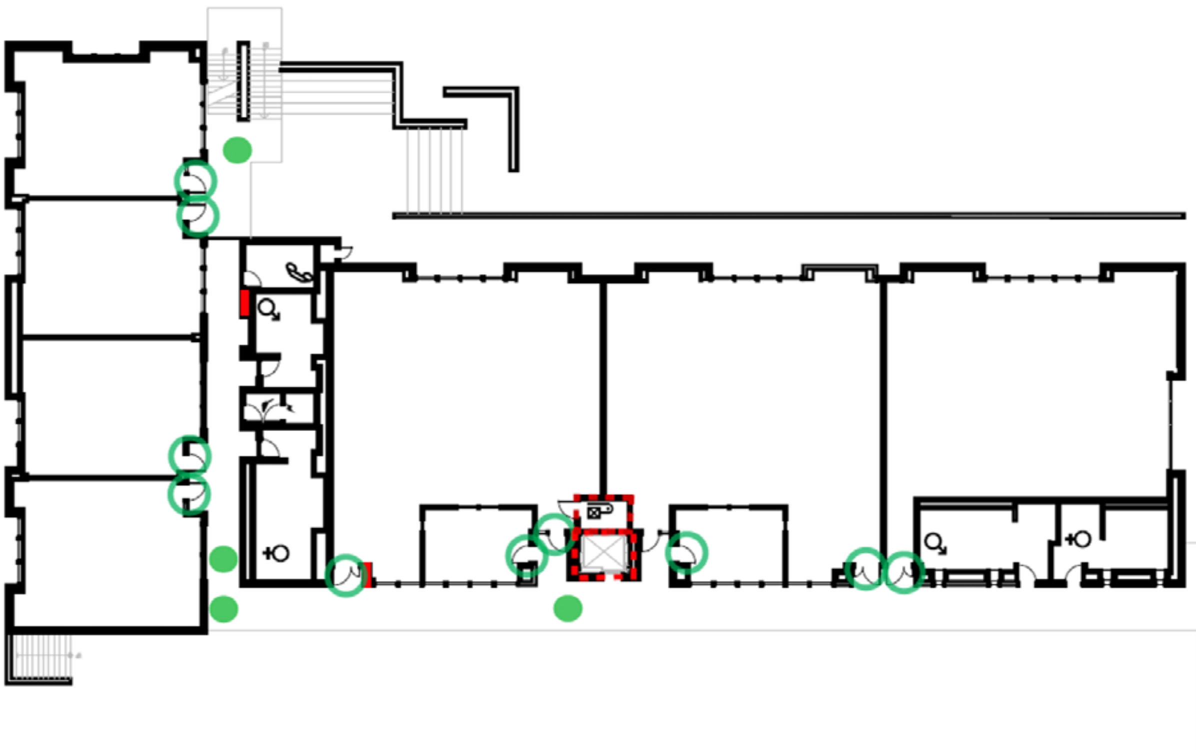
Appendix G. Building A | Third Floor



Legend

	Exits Doors & Stairways		Exit Access Doors
	Exit Signs		Fire Extinguishers
	1 HR Fire Rated		2 HR Fire Rated

Appendix G. Building B & C | First Floor



Legend

Exits Doors & Stairways

Exit Access Doors

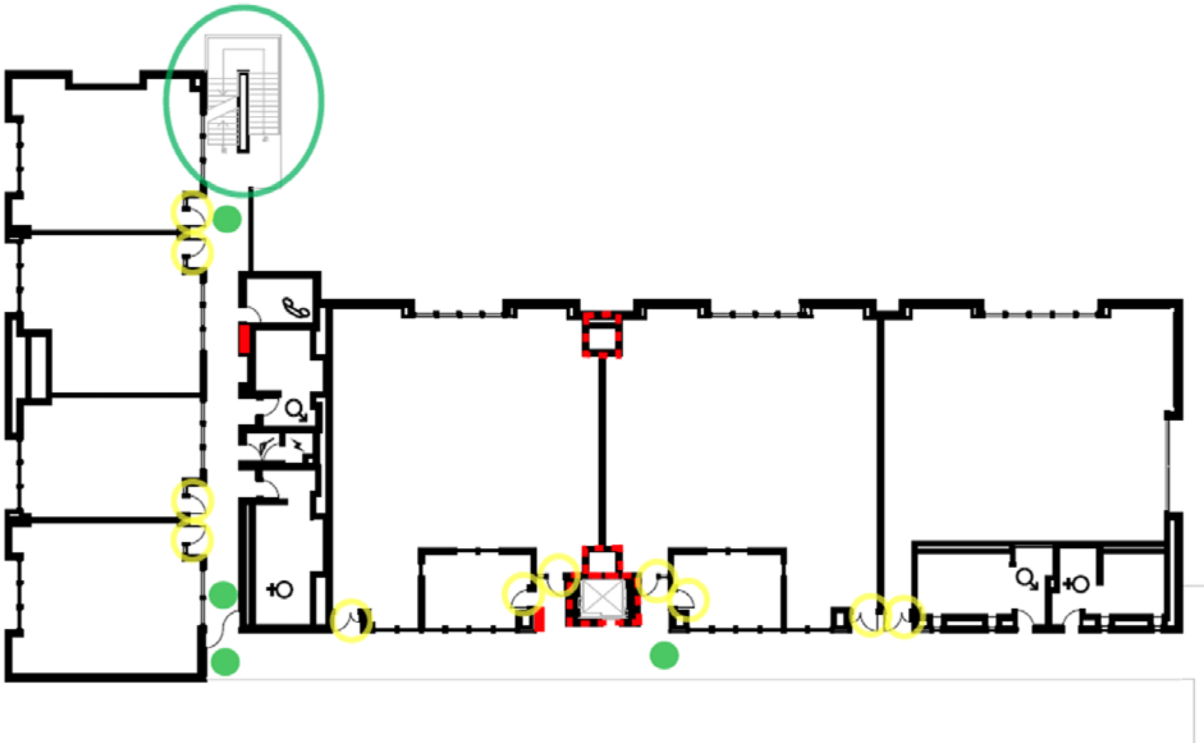
Exit Signs

Fire Extinguishers

1 HR Fire Rated

2 HR Fire Rated

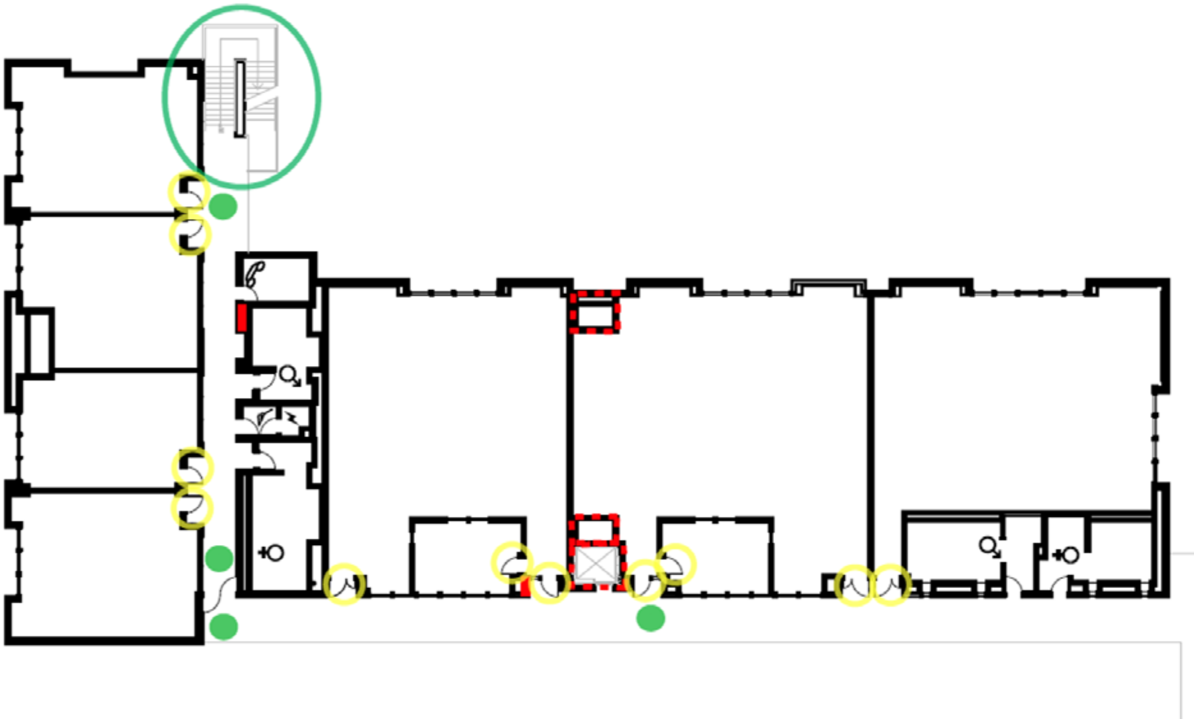
Appendix G. Building B & C | Second Floor



Legend

	Exits Doors & Stairways		Exit Access Doors
	Exit Signs		Fire Extinguishers
	1 HR Fire Rated		2 HR Fire Rated

Appendix G. Building B & C | Third Floor



Legend

	Exits Doors & Stairways		Exit Access Doors
	Exit Signs		Fire Extinguishers
	1 HR Fire Rated		2 HR Fire Rated

Appendix H

Fire Alarm Components

Appendix H. Addressable Fire Alarm Control Panel

Part Number	NFS–640
Manufacture	Notifier
CSFM Number	7165–0028:214
Mounting	Surface
Size (W*H*D)	24''*4.575''*5.21875''

Appendix H. Addressable Fire Alarm Box

Part Number	NBG–12LX
Manufacture	Notifier
CSFM Number	7150–0028:199
Mounting	Flush
Size (W*H*D)	4'' SQ. Deep

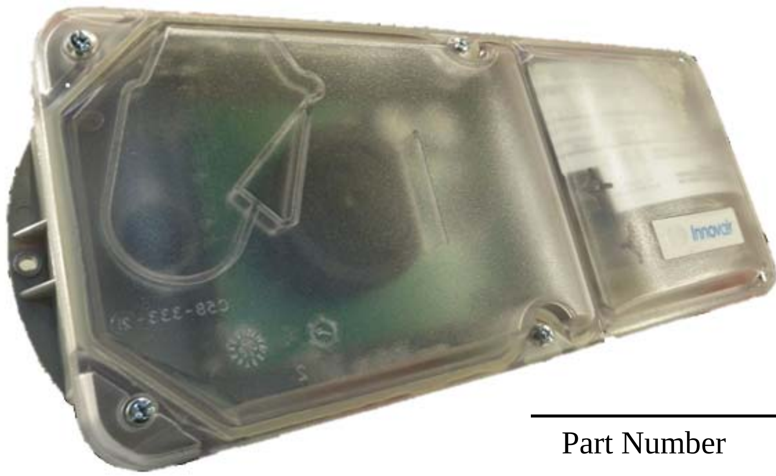
Appendix H. Multi–Sensor Detector

Part Number	FAPT–851
Manufacture	Notifier
CSFM Number	7272–0028:206
Mounting	Flush
Size (W*H*D)	4’’ SQ. Deep

Appendix H. Addressable Heat Detector

Part Number	FST–851
Manufacture	Notifier
CSFM Number	7272–0028:196
Mounting	Flush
Size (W*H*D)	4’’ SQ. Deep

Appendix H. Addressable Photoelectric Duct Detector



Part Number	FSD–751RP
Manufacture	Notifier
CSFM Number	3240–0028:205
Mounting	N/A
Size (W*H*D)	N/A

Appendix H. Horn

Part Number	GEH24–R
Manufacture	Gentex
CSFM Number	7135–0569:122
Mounting	Flush
Size (W*H*D)	4'' SQ. Deep

Appendix H. Multi – Candela Horn/Strobe

Part Number	GEC3–24WR
Manufacture	Gentex
CSFM Number	7135–0569:122
Mounting	Flush
Size (W*H*D)	4’’ SQ. Deep

Appendix H. Multi – Candela Strobe

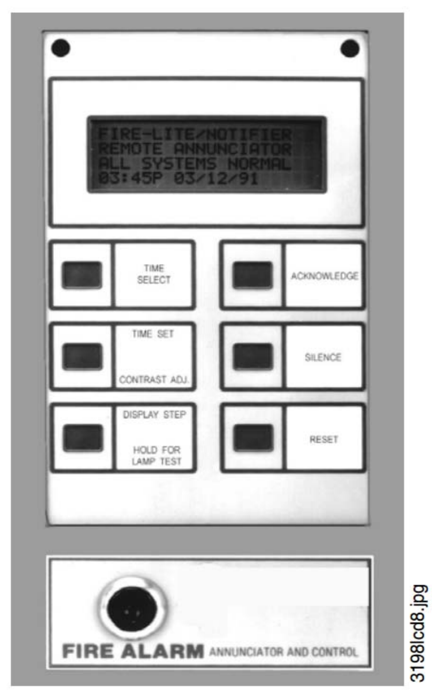
Part Number	GES3–24WR
Manufacture	Gentex
CSFM Number	7125–0569:123
Mounting	Flush
Size (W*H*D)	4’’ SQ. Deep

Appendix H. Remote Power Supply

Part Number	FCPS-24FS6
Manufacture	Notifier
CSFM Number	7315–0028:225
Mounting	Surface
Size (W*H*D)	14.5’’ x15’’ x 7.2’’

Appendix H. Annunciator

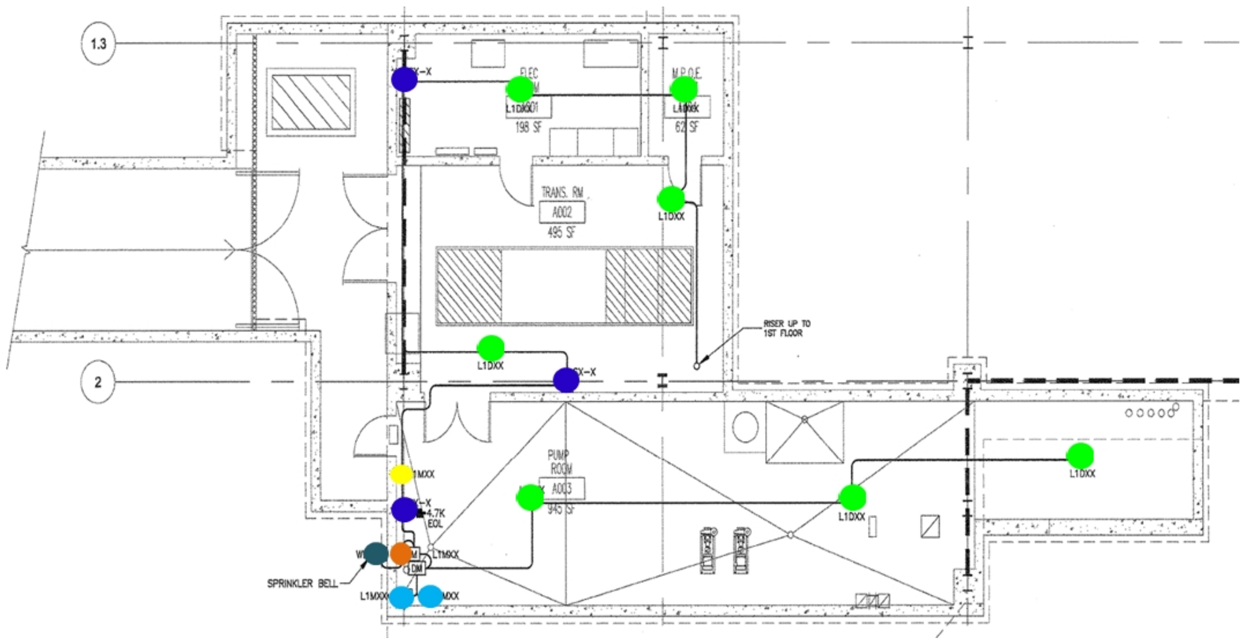
Part Number	LCD– 80
Manufacture	Notifier
CSFM Number	7120–0028:156
Mounting	Surface
Size (W*H*D)	4.5’’ x 8.5’’ x 2’’



Appendix I

Locations of Fire Alarm Components

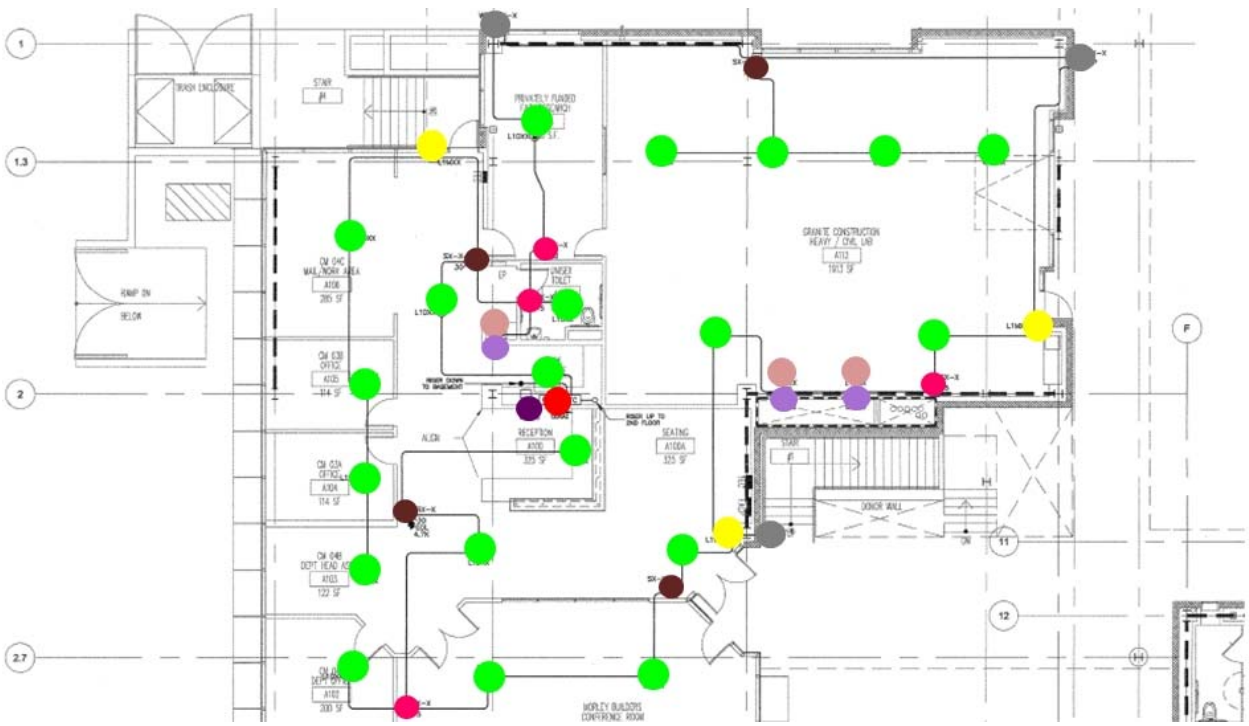
Appendix I. Building A | Fire Alarm Plans | Basement



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
H XX	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	B WP	Waterflow Bell

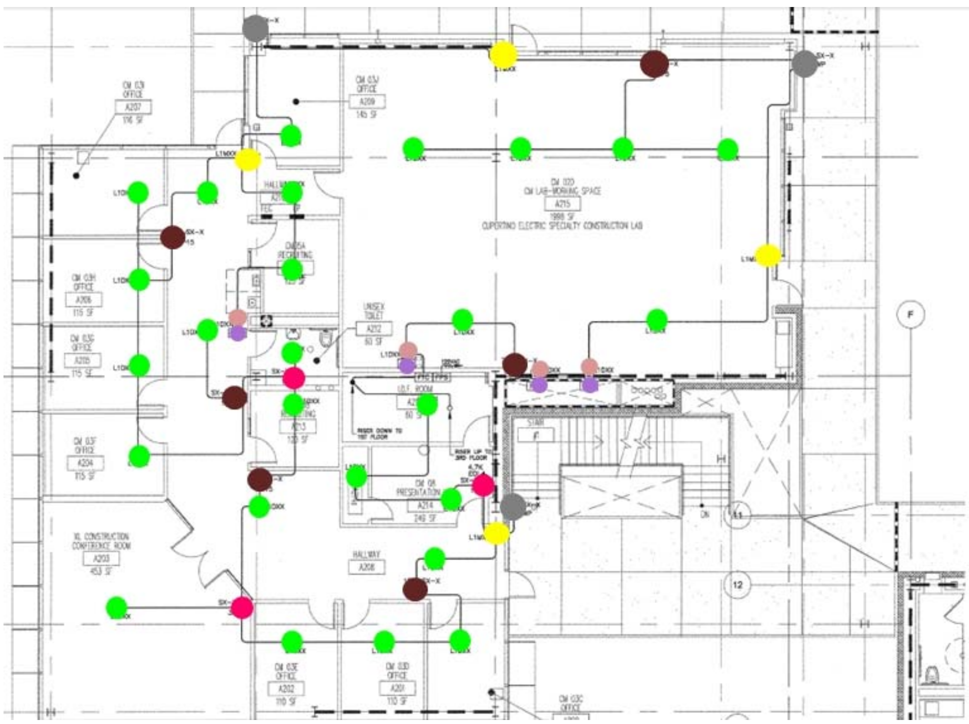
Appendix I. Building A | Fire Alarm Plans | First Floor



Legend

FACP	Fire Alarm Control Panel		ANN	Annunciator
H	Heat Detector		2	Multi–Sensor Detector
F	Pull Down Station		D	Duct Smoke Detector
FSD	Fire Smoke Damper		W	Waterflow Switch
H	Horn		H WP	Horn with Gasket
XX H	Horn/Strobe		XX	Strobe
T	Valve Tamper Switch		WP B	Waterflow Bell

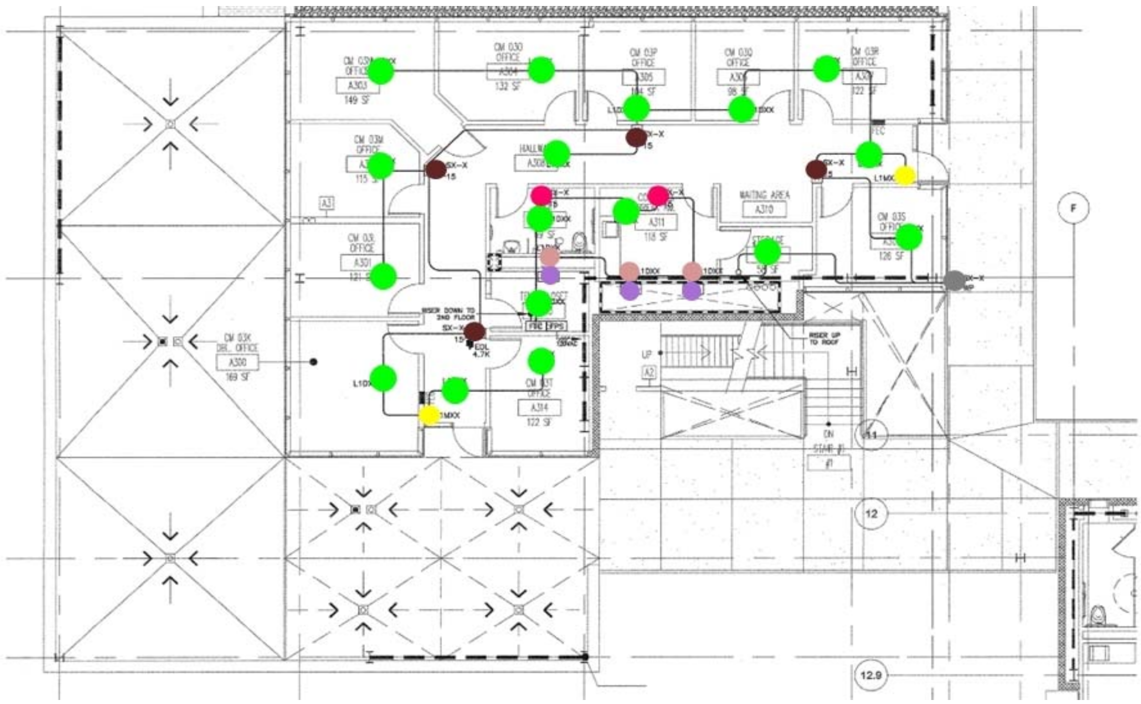
Appendix I. Building A | Fire Alarm Plans | Second Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
H XX	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	B WP	Waterflow Bell

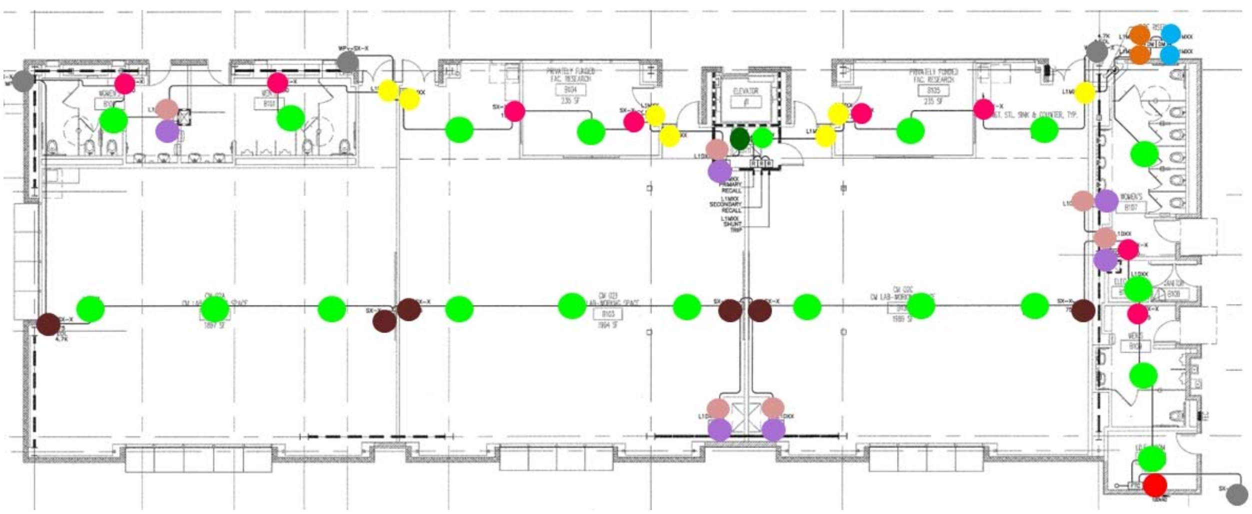
Appendix I. Building A | Fire Alarm Plans | Third Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
H XX	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	B WP	Waterflow Bell

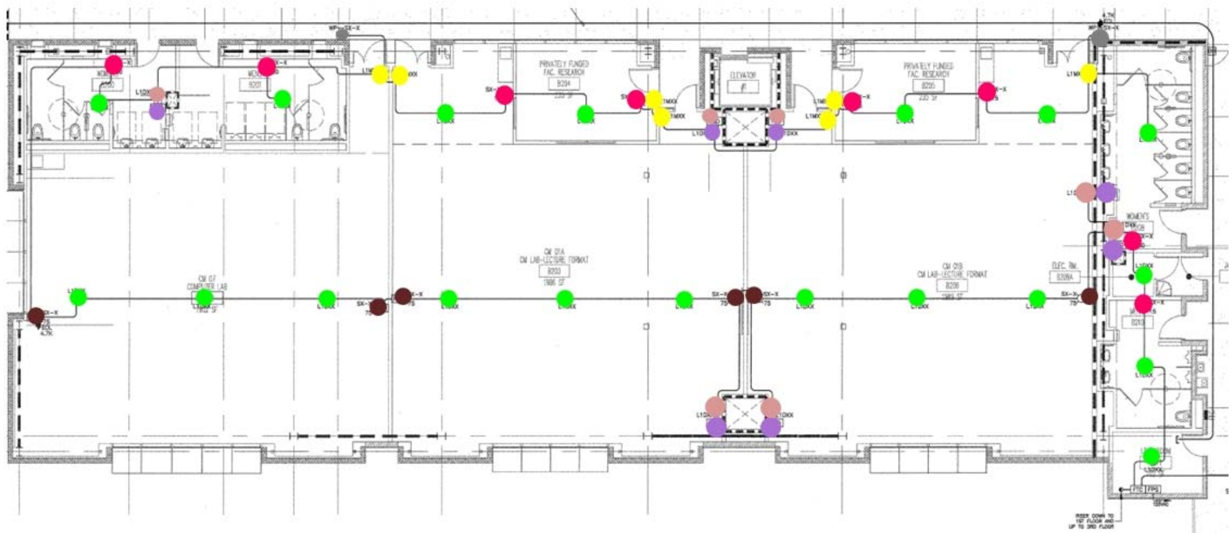
Appendix I. Building B | Fire Alarm Plans | First Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
H XX	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	B WP	Waterflow Bell

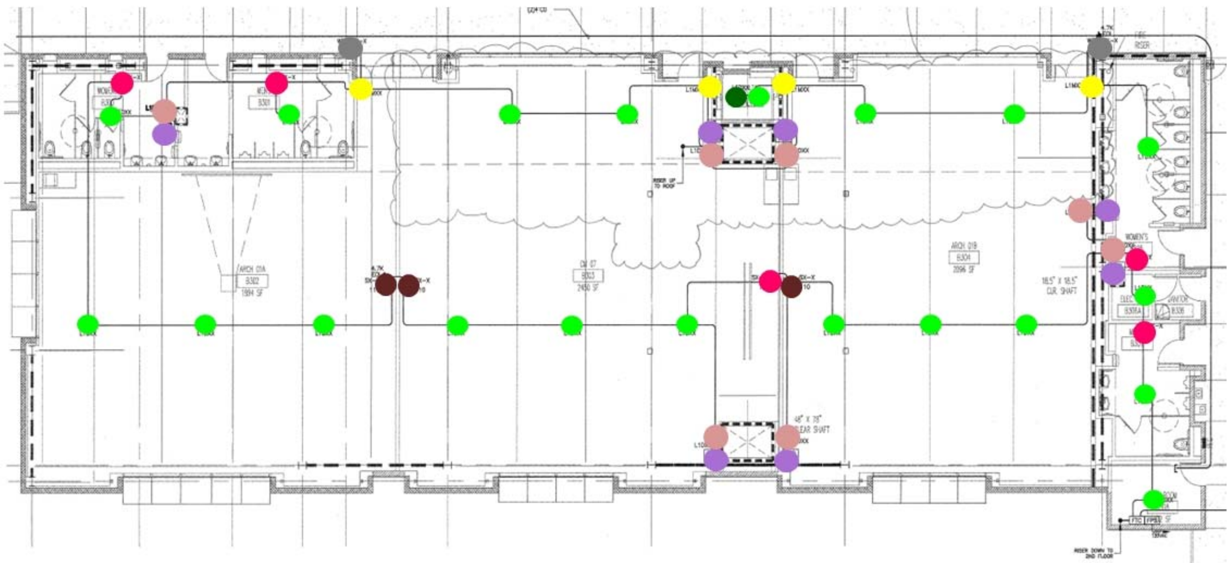
Appendix I. Building B | Fire Alarm Plans | Second Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
XX H	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	WP B	Waterflow Bell

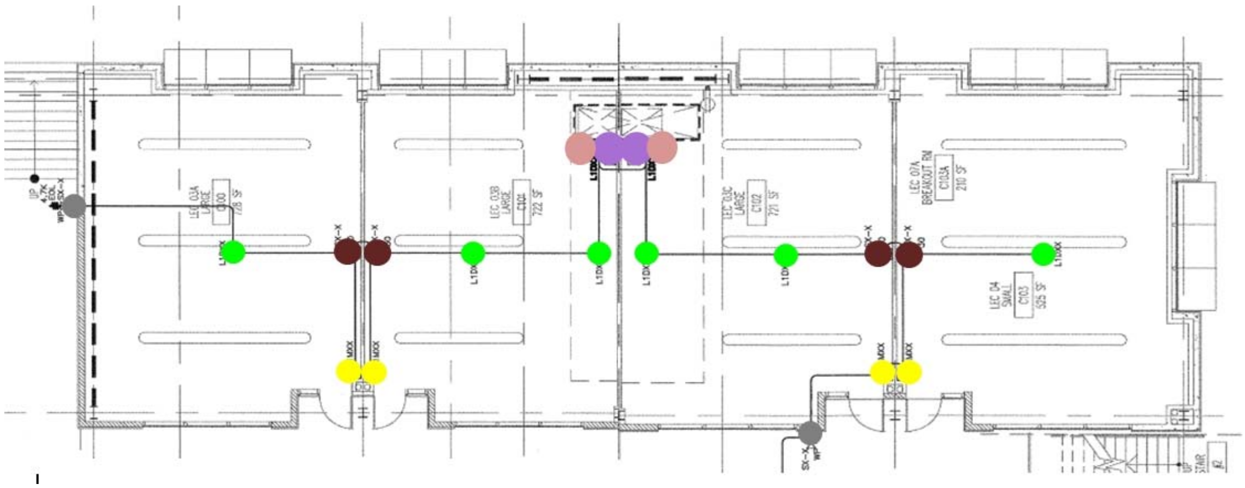
Appendix I. Building B | Fire Alarm Plans | Third Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
H XX	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	B WP	Waterflow Bell

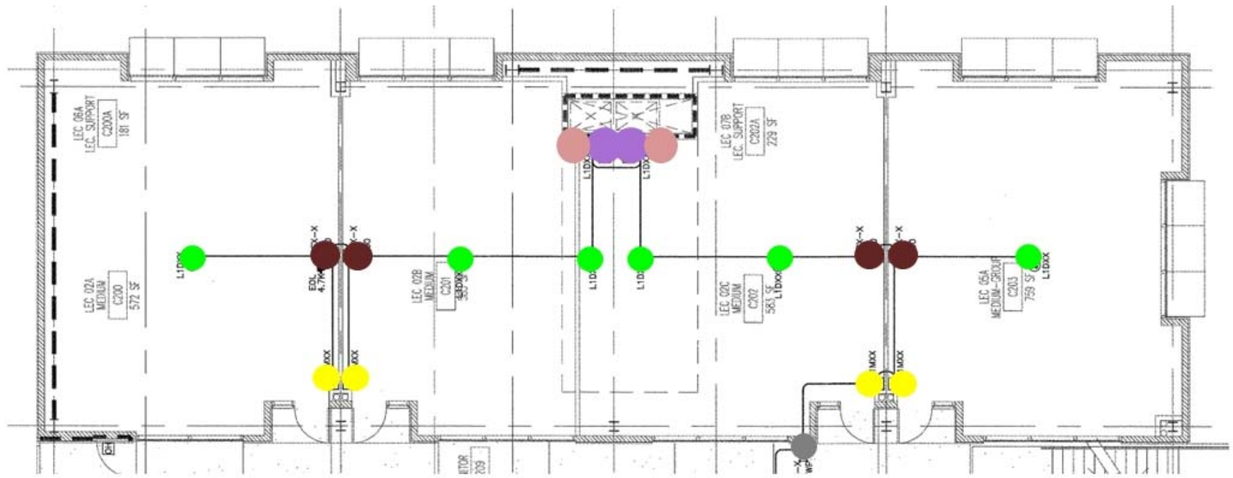
Appendix I. Building C | Fire Alarm Plans | First Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
H XX	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	B WP	Waterflow Bell

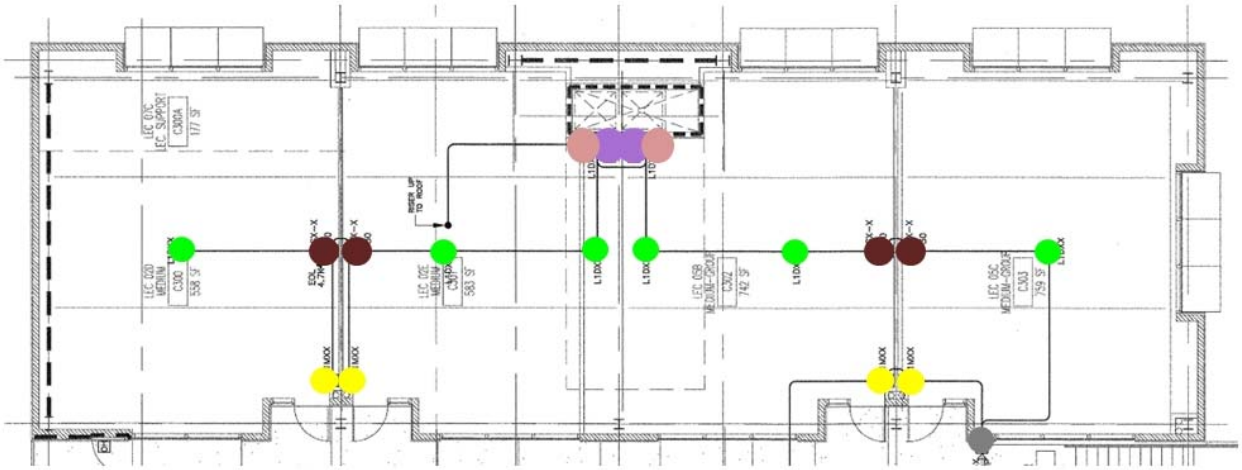
Appendix I. Building C | Fire Alarm Plans | Second Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector	2	Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
XX H	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	WP B	Waterflow Bell

Appendix I. Building C | Fire Alarm Plans | Third Floor



Legend

FACP	Fire Alarm Control Panel	ANN	Annunciator
H	Heat Detector		Multi–Sensor Detector
F	Pull Down Station	D	Duct Smoke Detector
FSD	Fire Smoke Damper	W	Waterflow Switch
H	Horn	H WP	Horn with Gasket
XX H	Horn/Strobe	XX	Strobe
T	Valve Tamper Switch	WP B	Waterflow Bell

Appendix J

Sequence of Operations

Appendix J. Sequence of Operations

	Annunciate At Fire Control Panel	Annunciate at 24 Hours Attended Remote Location	Activate Audible Alarm Signal Throughout Building	Shut Down All Air Handling Equipment / Close FSD	Elevator Shutdown	Recall Elevators Serving Fire Floor
Manual Pull Station	Yes	Yes	Yes	No	No	No
Heat Detector	Yes	Yes	Yes	No	No	No
Duct Smoke Detector	Yes	Yes	Yes	Yes	No	No
Elevator Lobby Detector	Yes	Yes	Yes	No	No	Yes
Elevator Shaft & Machine Room Smoke Detector	Yes	Yes	No	No	No	Yes
Sprinkler Water Flow Switch	Yes	Yes	Yes	No	No	No
Sprinkler Valve Tamper Switch	Yes	Yes	Yes	No	No	No
Special Extinguishing System	Yes	Yes	Yes	No	No	No
Generator Power Failure	Yes	Yes	No	No	No	No
Elevator Shaft & Machine Room Heat Detector	Yes	Yes	No	No	Yes	No
Corridor Smoke Detector	Yes	Yes	Yes	Yes	No	No

Appendix K

Notification Appliance Circuit Voltage Drop Calculations

Appendix K. Total Amount of Devises & Appliances

Circuit Number	**S1**	**S2**	**S1**	**S1**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**
Interior Horn **82 dBA @ 0.028 A**	0	3	0	0	0	0	0	0	0	0	0	0
Exterior Horn **82 dBA @ 0.028 A**	3	0	3	1	0	3	2	0	2	1	2	1
Horn / Strobe **82 dBA / 15cd @ 0.106 A**	1	0	4	4	0	0	0	0	0	0	0	0
Horn / Strobe **82 dBA / 30 cd @ 0.124 A**	2	0	0	0	0	0	4	0	0	4	0	4
Horn / Strobe **82 dBA / 75 cd @ 0.206 A**	2	0	2	0	6	0	0	6	0	0	0	0
Horn / Strobe **82 dBA / 110 cd @ 0.252 A**	0	0	0	0	0	0	0	0	0	0	3	0
Strobe **15 cd @ 0.078 A**	1	0	2	2	1	4	0	1	4	0	1	0
Strobe **30 cd @ 0.096 A**	1	0	1	0	1	2	0	1	2	0	3	0
Strobe **75 cd @ 0.180 A**	1	0	0	0	0	0	0	0	0	0	1	0
TOTAL DEVICE	11	3	12	7	8	9	6	8	8	5	10	5

Appendix K. Voltage Drop Calculations

Circuit Number	**S1**	**S2**	**S1**	**S1**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**
Building	A1	AB	A2	A3	B1	B1	C1	B2	B2	C2	B3	C3
Panel	FACP	FACP	FCPS	FCPS	FCPS	FCPS	FCPS	FCPS	FCPS	FCPS	FCPS	FCPS
Wire Size (AWG)	12	12	12	12	12	12	12	12	12	12	12	12
Resist. (ohm/ 1000 feet)	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
Length (feet)	340	109	353	175	195	445	139	197	440	109	442	142
Total Current (Amp)	1.208	0.084	1.176	0.608	1.422	0.588	0.552	1.422	0.560	0.524	1.358	0.524
Voltage Drop	1.63	0.04	1.64	0.42	1.10	1.04	0.30	1.11	0.98	0.23	2.38	0.29
Voltage Drop (%)	6.78	0.15	6.85	1.76	4.58	4.32	1.27	4.62	4.07	0.94	9.90	1.23

Appendix L

Battery Calculations

Appendix L. Building A | FACP @ First Floor

	Description	Standby Current (amps)		QTY		Total Standby Current (amps)	Alarm Current (amps)		QTY		Total Alarm current (amps)
1	CPU-640	0.2300	x	1	=	0.2300	0.2300	x	1	=	0.2300
2	KDM-2	0.0400	x	1	=	0.0400	0.0940	x	1	=	0.0940
3	NCM-W, NCM F	0.1100	x	1	=	0.1100	0.1100	x	1	=	0.1100
4	Pull SLC1	0.2000	x	1	=	0.2000	0.2000	x	1	=	0.2000
6	LCD-80	0.0500	x	1	=	0.0500	0.1000	x	1	=	0.1000
7	NBG-12LX	0.0003	x	10	=	0.0030	0.0003	x	10	=	0.0030
8	FAPT-851	0.0003	x	71	=	0.0213	0.0003	x	71	=	0.0213
10	FSD-751PL	0.0003	x	10	=	0.0030	-	x	10	=	-
13	FMM-1	0.0003	x	1	=	0.0003	0.0003	x	1	=	0.0003
14	FMM-1	0.0008	x	1	=	0.0008	0.0057	x	1	=	0.0057
A1	NOTIFI. CIR. S1	-	x	1	=	-	1.2080	x	1	=	1.2080
AB	NOTIFI. CIR. S2	-	x	1	=	-	0.0840	x	1	=	0.0840
				Total System Standby Current		0.6584			Total System Alarm Current		2.0563

Required Standby Time (Hours)		Total System Standby Current (Amps)		Required Standby Capacity (Amp-Hours)	Required Alarm Time [a] (Hours)		Total System Alarm Current (Amps)		Required Alarm Current (Amp-Hours)
24	x	0.6584	=	15.8004	0.0833	x	2.0563	=	0.1714

[a] 5 minutes x 1⁄60 = 0.0833 hours

Required Standby Capacity (Amps-Hours)		Required Alarm Capacity (Amps-Hours)		Total Required Capacity (Amps-Hours)		Factor of Safety		Required Battery Capacity (Amps-Hours)	Provided Battery Capacity (Amps-Hours)
15.8004	+	0.1714	=	15.9718	x	1.2	=	19.1662	55.00

Appendix L. Building A | FCPS @ Second Floor

	Description	Standby Current (amps)		QTY		Total Standby Current (amps)	Alarm Current (amps)		QTY		Total Alarm current (amps)
5	FCPS-24S	0.0650	x	1	=	0.0650	0.1450	x	1	=	0.1450
A2	NOTIF. CIR. S1	-	x	1	=	-	1.1760	x	1	=	1.1760
			Total System Standby Current			0.0650		Total System Alarm Current			1.3210

Required Standby Time (Hours)		Total System Standby Current (Amps)		Required Standby Capacity (Amp-Hours)	Required Alarm Time [a] (Hours)		Total System Alarm Current (Amps)		Required Alarm Current (Amp-Hours)
24	x	0.0650	=	1.5600	0.0833	x	1.3210	=	0.1101

[a] 5 minutes x 1⁄60 = 0.0833 hours

Required Standby Capacity (Amps-Hours)		Required Alarm Capacity (Amps-Hours)		Total Required Capacity (Amps-Hours)		Factor of Safety		Required Battery Capacity (Amps-Hours)	Provided Battery Capacity (Amps-Hours)
1.5600	+	0.1101	=	1.6701	x	1.2	=	2.004	7.20

Appendix L. Building A | FCPS @ Third Floor

	Description	Standby Current (amps)		QTY		Total Standby Current (amps)	Alarm Current (amps)		QTY		Total Alarm current (amps)
5	FCPS-24S	0.0650	x	1	=	0.0650	0.1450	x	1	=	0.1450
A3	NOTIF. CIR. S1	-	x	1	=	-	0.6080	x	1	=	0.6080
			Total System Standby Current			0.0650		Total System Alarm Current			0.7530

Required Standby Time (Hours)		Total System Standby Current (Amps)		Required Standby Capacity (Amp-Hours)	Required Alarm Time [a] (Hours)		Total System Alarm Current (Amps)		Required Alarm Current (Amp-Hours)
24	x	0.0650	=	1.5600	0.0833	x	0.7530	=	0.0628

[a] 5 minutes x 1⁄60 = 0.0833 hours

Required Standby Capacity (Amps-Hours)		Required Alarm Capacity (Amps-Hours)		Total Required Capacity (Amps-Hours)		Factor of Safety		Required Battery Capacity (Amps-Hours)	Provided Battery Capacity (Amps-Hours)
1.5600	+	0.0628	=	1.6228	x	1.2	=	1.947	7.20

Appendix L. Building B & C | FACP @ First Floor

	Description	Standby Current (amps)		QTY		Total Standby Current (amps)	Alarm Current (amps)		QTY		Total Alarm current (amps)
1	CPU-640	0.2300	x	1	=	0.2300	0.2300	x	1	=	0.2300
2	KDM-2	0.0400	x	1	=	0.0400	0.0940	x	1	=	0.0940
3	NCM-W, NCM F	0.1100	x	1	=	0.1100	0.1100	x	1	=	0.1100
4	SLC1 Device…	0.2000	x	1	=	0.2000	0.2000	x	1	=	0.2000
7	NBG-12LX	0.0003	x	30	=	0.0090	0.0003	x	30	=	0.0090
8	FAPT-851	0.0003	x	77	=	0.0231	0.0003	x	77	=	0.0231
9	FST-851	0.0003	x	2	=	0.0005	0.0003	x	2	=	0.0005
10	FSD-751PL	0.0003	x	25	=	0.0084	-	x	25	=	-
12	FRM-1	0.0002	x	5	=	0.0010	0.0002	x	5	=	0.0010
14	FDM-1	0.0008	x	2	=	0.0015	0.0057	x	2	=	0.0114
				Total System Standby Current		0.6235			Total System Alarm Current		0.6790

Required Standby Time (Hours)		Total System Standby Current (Amps)		Required Standby Capacity (Amp-Hours)	Required Alarm Time [a] (Hours)		Total System Alarm Current (Amps)		Required Alarm Current (Amp-Hours)
24	x	0.6235	=	14.9650	0.0833	x	0.6790	=	0.0566

[a] 5 minutes x 1⁄60 = 0.0833 hours

Required Standby Capacity (Amps-Hours)		Required Alarm Capacity (Amps-Hours)		Total Required Capacity (Amps-Hours)		Factor of Safety		Required Battery Capacity (Amps-Hours)	Provided Battery Capacity (Amps-Hours)
14.9650	+	0.0566	=	15.0215	x	1.2	=	18.0258	55.00

Appendix L. Building B & C | FCPS @ Second Floor

	Description	Standby Current (amps)		QTY		Total Standby Current (amps)	Alarm Current (amps)		QTY		Total Alarm current (amps)
5	FCPS-24S	0.0650	x	1	=	0.0650	0.1450	x	1	=	0.1450
B1	NOTIF. CIR. S1	-	x	1	=	-	1.4220	X	1	=	1.4220
B1	NOTIF. CIR. S2	-	x	1	=	-	0.5880	x	1	=	0.5880
C1	NOTIF. CIR. S3	-	x	1	=	-	0.5520	x	1	=	0.5520
		Total System Standby Current				0.0650	Total System Alarm Current				2.7070

Required Standby Time (Hours)		Total System Standby Current (Amps)		Required Standby Capacity (Amp-Hours)	Required Alarm Time [a] (Hours)		Total System Alarm Current (Amps)		Required Alarm Current (Amp-Hours)
24	x	0.0650	=	1.5600	0.0833	x	2.7070	=	0.2256

[a] 5 minutes x 1⁄60 = 0.0833 hours

Required Standby Capacity (Amps-Hours)		Required Alarm Capacity (Amps-Hours)		Total Required Capacity (Amps-Hours)		Factor of Safety		Required Battery Capacity (Amps-Hours)	Provided Battery Capacity (Amps-Hours)
1.5600	+	0.2256	=	1.7856	x	1.2	=	2.1427	7.20

Appendix L. Building B & C | FCPS @ Third Floor

	Description	Standby Current (amps)		QTY		Total Standby Current (amps)	Alarm Current (amps)		QTY		Total Alarm current (amps)
5	FCPS-24S	0.0650	x	1	=	0.0650	0.1450	x	1	=	0.1450
B2	NOTIF. CIR. S1	-	x	1	=	-	1.4220	X	1	=	1.4220
B2	NOTIF. CIR. S2	-	x	1	=	-	0.5600	x	1	=	0.5600
C2	NOTIF. CIR. S3	-	x	1	=	-	0.5240	x	1	=	0.5240
		Total System Standby Current				0.0650		Total System Alarm Current			2.6510

Required Standby Time (Hours)		Total System Standby Current (Amps)		Required Standby Capacity (Amp-Hours)	Required Alarm Time [a] (Hours)		Total System Alarm Current (Amps)		Required Alarm Current (Amp-Hours)
24	x	0.0650	=	1.5600	0.0833	x	2.6510	=	0.2209

[a] 5 minutes x 1⁄60 = 0.0833 hours

Required Standby Capacity (Amps-Hours)		Required Alarm Capacity (Amps-Hours)		Total Required Capacity (Amps-Hours)		Factor of Safety		Required Battery Capacity (Amps-Hours)	Provided Battery Capacity (Amps-Hours)
1.5600	+	0.2209	=	1.7809	x	1.2	=	2.1371	7.20

Appendix M

Inspection & Testing of Fire Alarm System

Appendix M. Inspection Scheduling

Component	Subcomponent	Initial Acceptance	Periodic Frequency
All Equipment	----	X	Annual
Fire Alarm Systems Monitored for Alarm, Supervisory, and Trouble Signals	Fuses	X	Annual
	Interfaced Equipment	X	Annual
	Lamps and LEDs	X	Annual
	Primary Power Supply	X	Annual
	Trouble Signals	X	Semiannual
Battery	Lead–Acid	X	Monthly
Remote Annunciators	----	X	Semiannual
Remote Power Supplies	----	X	Annual
Initiating Devices	Duct Detectors / Sampling Tubes	X	Semiannual
	Manual Fire Alarm Boxes	X	Semiannual
	Heat detectors	X	Semiannual
	Smoke Detectors	X	Semiannual
	Waterflow Devices	X	Quarterly
Fire Alarm Control Interface and Emergency Control Function Interface	Heat Detector: Elevator Shaft & Machine Room	X	Semiannual
Notification Appliances	Audible Appliances	X	Semiannual
	Visible Appliances	X	Semiannual

Appendix M. Test Scheduling

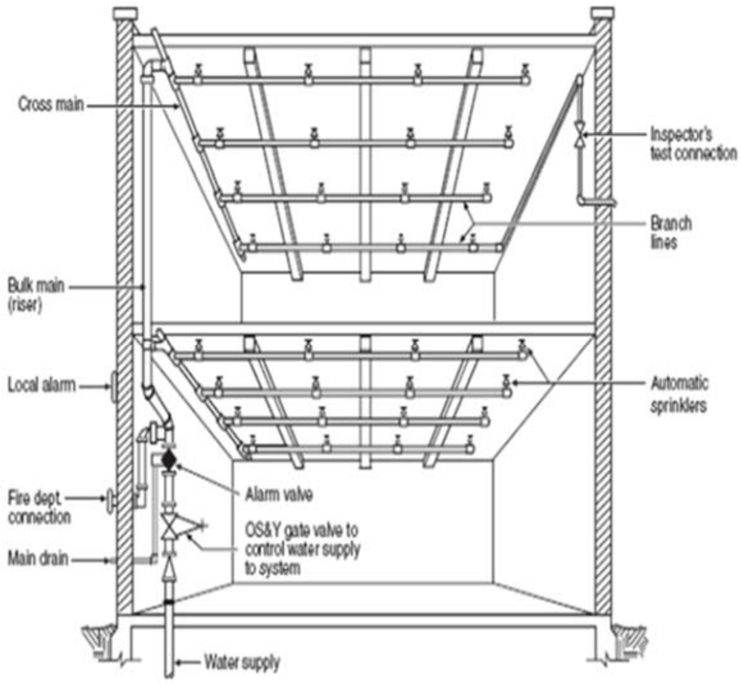
Component	Subcomponent	Initial Acceptance	Periodic Frequency
All Equipment	----	X	Annual
Fire Alarm Systems Control Equipment and Transponder	Fuses	X	Annual
	Functions	X	Annual
	Fuses	X	Annual
	Interface Equipment	X	Annual
	Lamps and LEDs	X	Annual
	Primary Power Supply	X	Annual
Secondary Power Supply	----	X	Annual
Remote Annunciators	----	X	Annual
Initiating Devices	Heat Detectors [a]	X	Annual
	Manual Fire Alarm Boxes	X	Annual
	Smoke Detectors	X	Annual
	Duct Type	X	Annual
	Multi-Sensor Fire Detector	X	Annual
Notification Appliances	Audible Appliances	X	N/A
	Visible Appliances	X	N/A

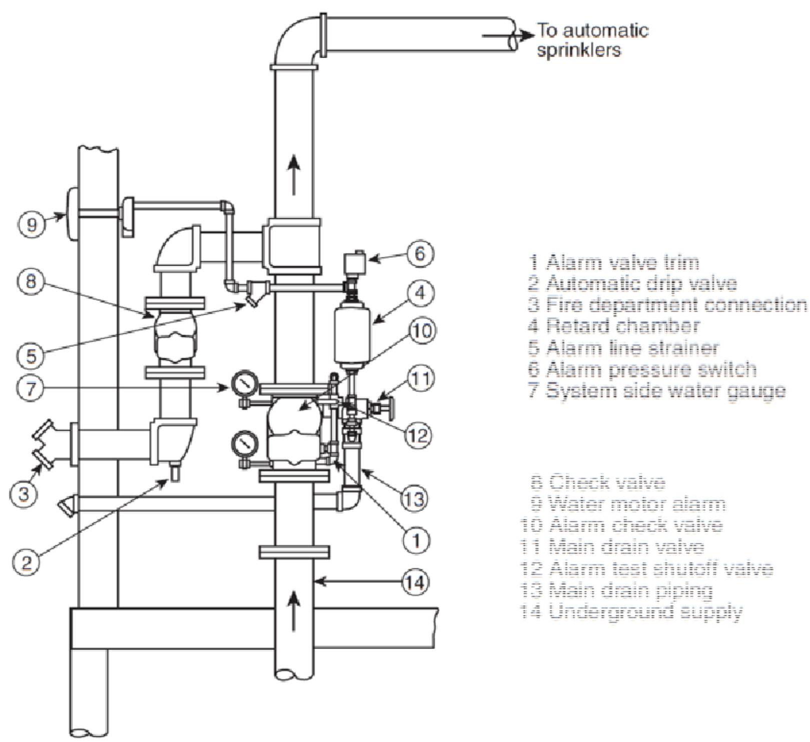
a Fixed-temperature, rate-of-rise, rate of compensation, restorable line, spot type (excluding pneumatic tube type)

Appendix N

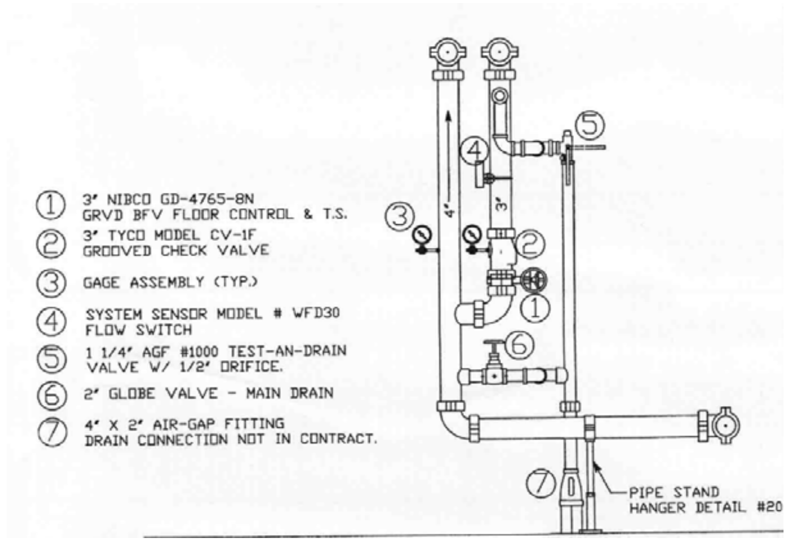
Automatic Fire Sprinkler System

Appendix N. Basic Parts of Wet Pipe Sprinkler System

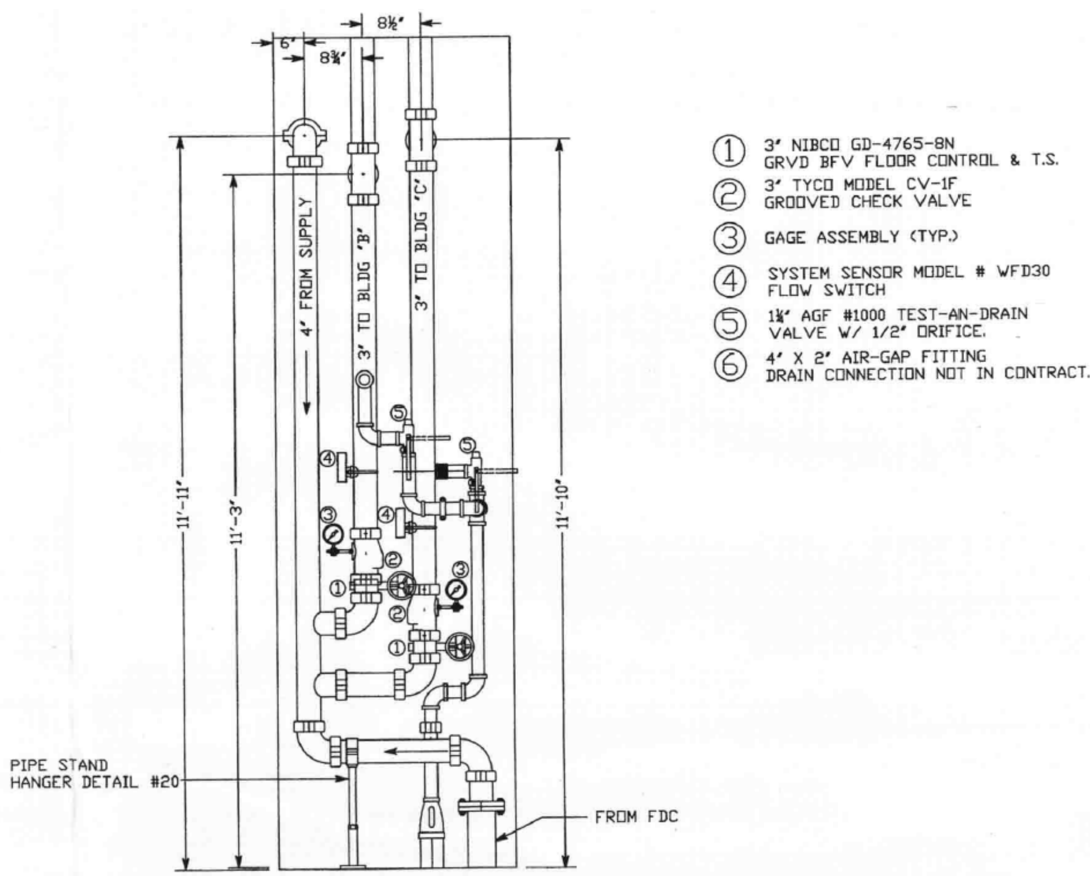




Appendix N. Building A | Control Riser



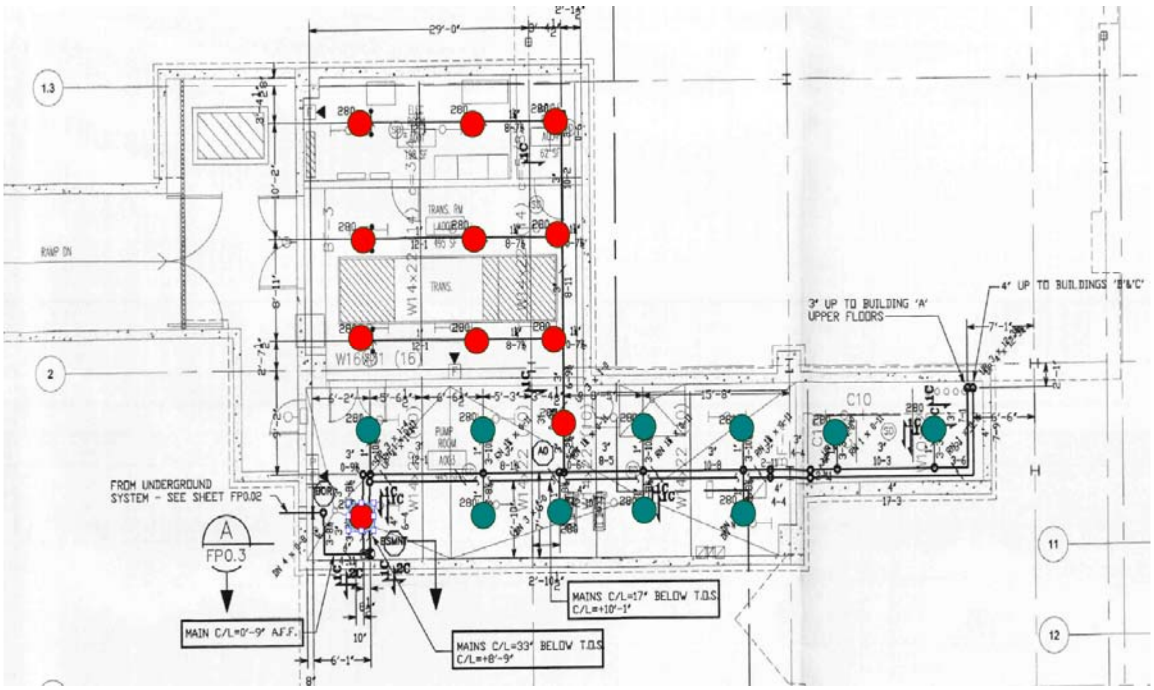
Appendix N. Building B & C | Riser Room



Appendix O

Location of Fire Sprinkler Components

Appendix O. Building A | Shop Drawings | Basement



Legend

TYCO Upright Quick Response Sprinkler

Fire Risers

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

Appendix O. Building A | Shop Drawings | First Floor

Legend

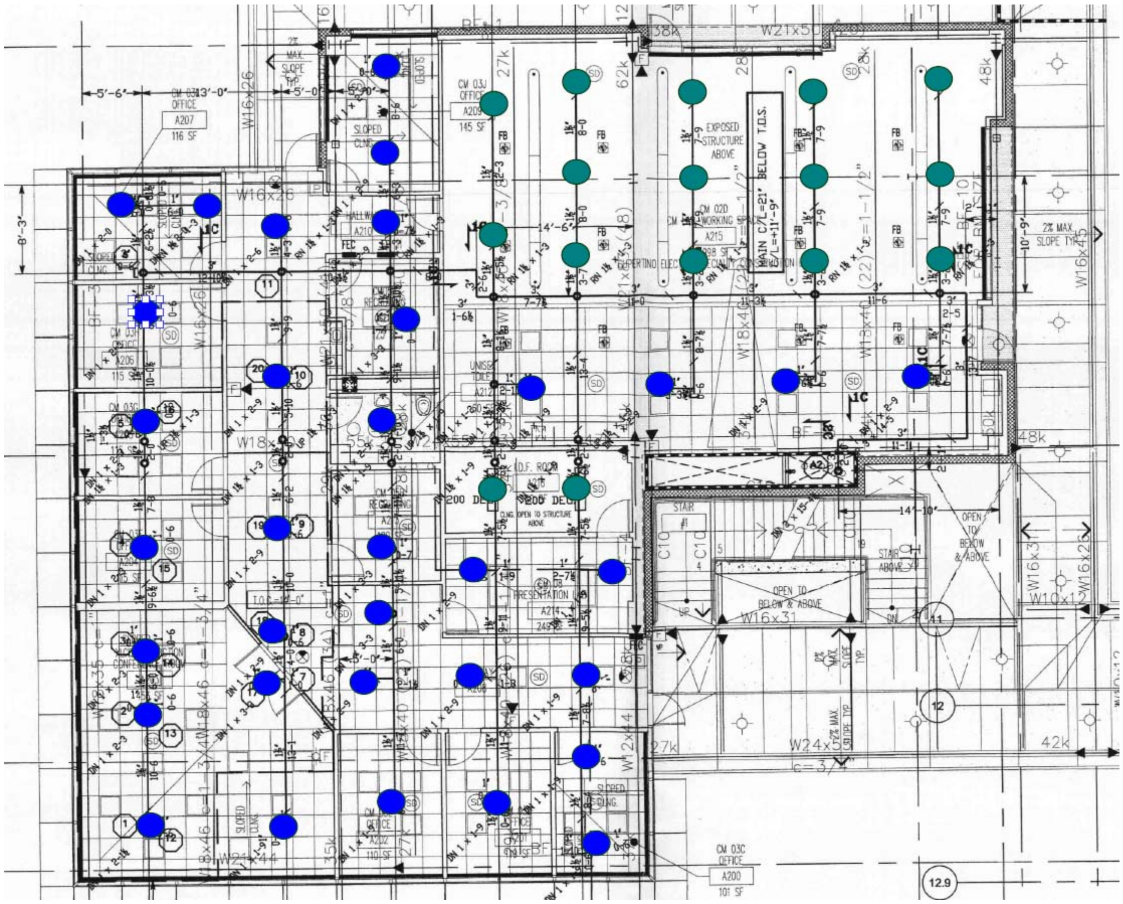
TYCO Upright Quick Response Sprinkler

Fire Risers

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

Appendix O. Building A | Shop Drawings | Second Floor



Legend

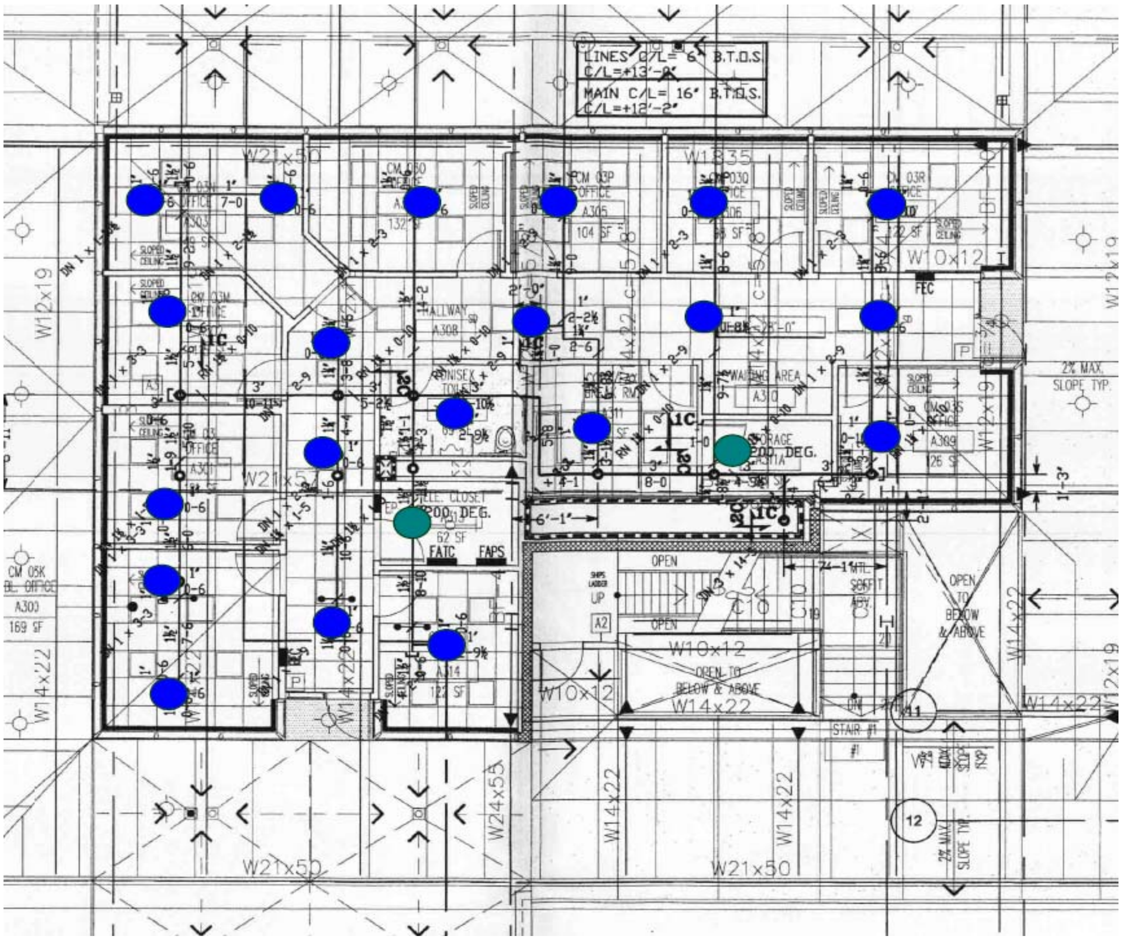
TYCO Upright Quick Response Sprinkler

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

Fire Risers

Appendix O. Building A | Shop Drawings | Third Floor



Legend

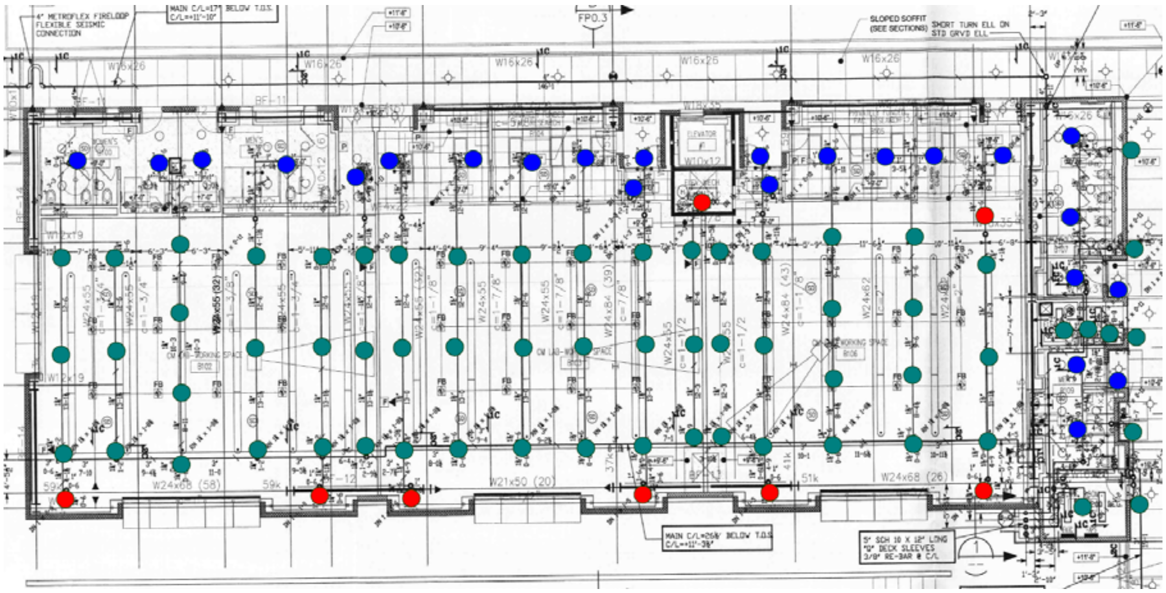
TYCO Upright Quick Response Sprinkler

Fire Risers

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

Appendix O. Building B | Shop Drawings | First Floor



Legend

TYCO Upright Quick Response Sprinkler

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

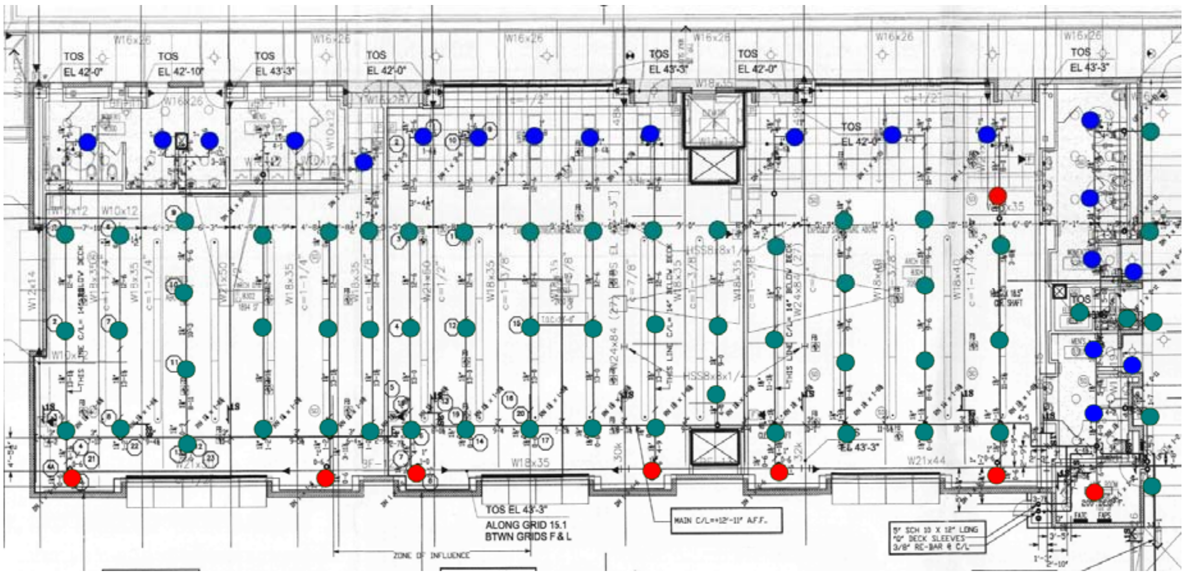
Fire Risers

Appendix O. Building B | Shop Drawings | Second Floor

Legend

TYCO Upright Quick Response Sprinkler	Fire Risers
TYCO Upright Quick Response Sprinkler (on spring)	
TYCO Concealed Quick Response Sprinkler	

Appendix O. Building B | Shop Drawings | Third Floor



Legend

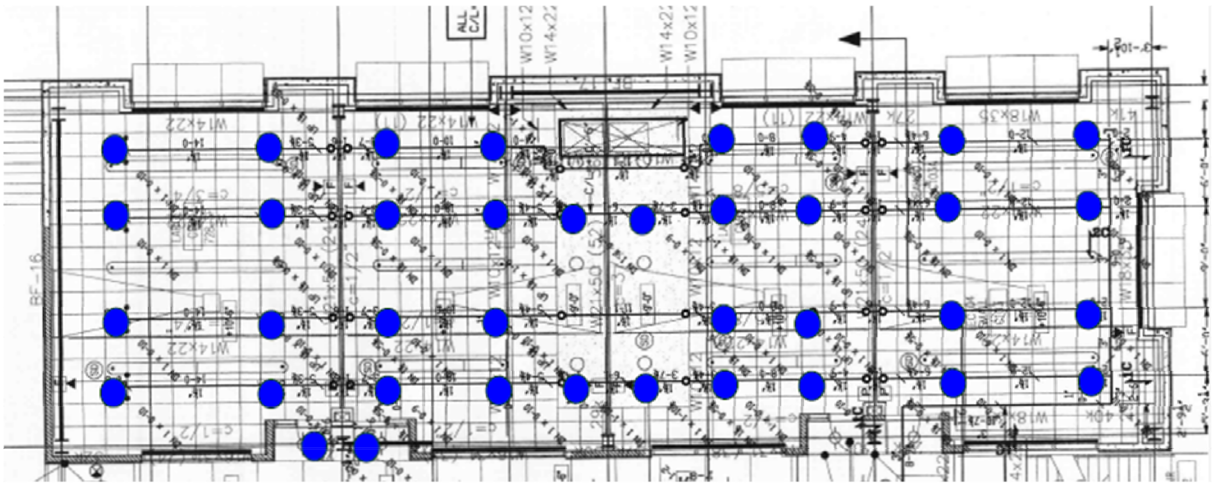
TYCO Upright Quick Response Sprinkler

Fire Risers

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

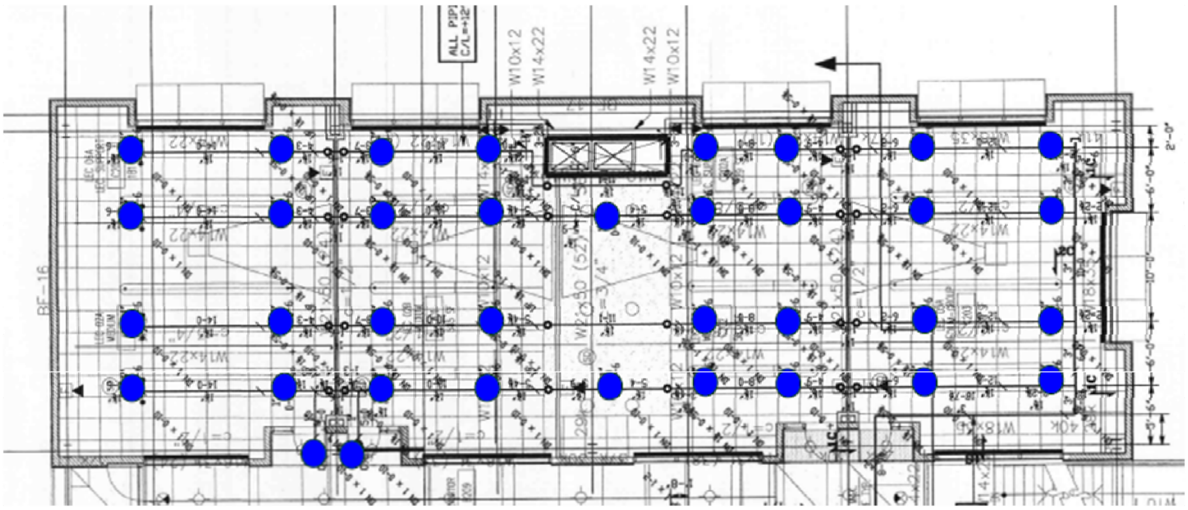
Appendix O. Building C | Shop Drawings | First Floor



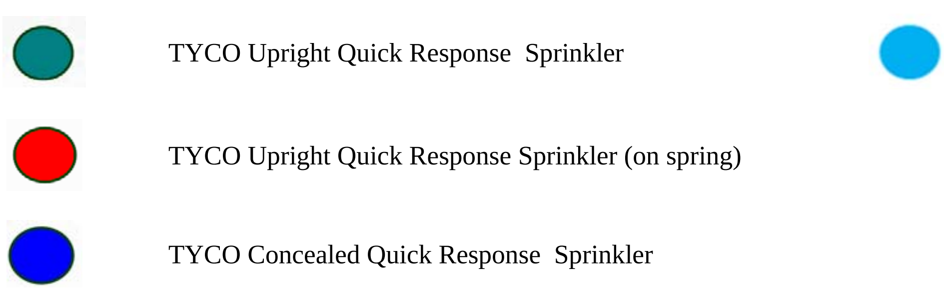
Legend

● (teal)	TYCO Upright Quick Response Sprinkler	● (light blue)	Fire Risers
● (red)	TYCO Upright Quick Response Sprinkler (on spring)		
● (blue)	TYCO Concealed Quick Response Sprinkler		

Appendix O. Building C | Shop Drawings | Second Floor



Legend



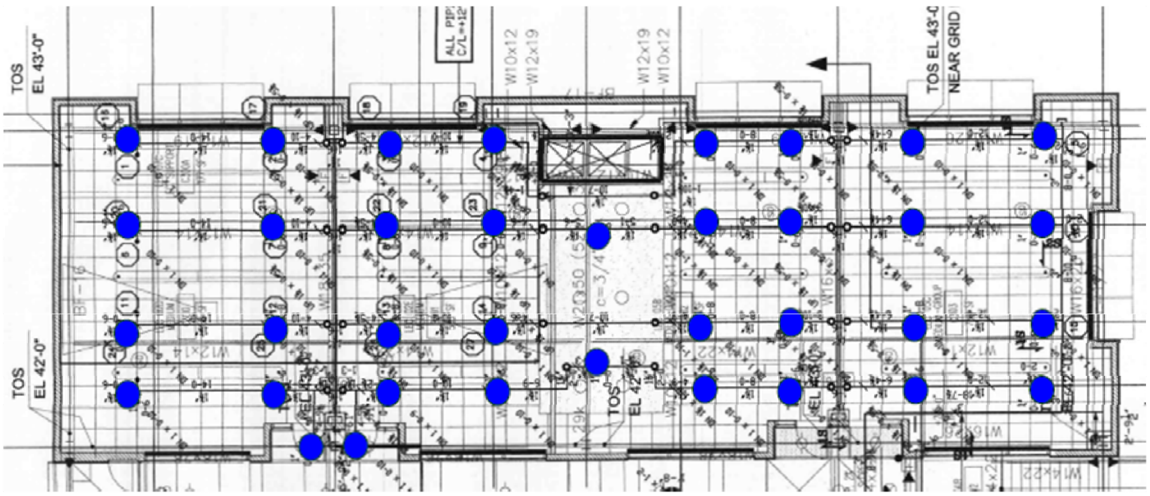
TYCO Upright Quick Response Sprinkler

Fire Risers

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

Appendix O. Building C | Shop Drawings | Third Floor



Legend

TYCO Upright Quick Response Sprinkler

Fire Risers

TYCO Upright Quick Response Sprinkler (on spring)

TYCO Concealed Quick Response Sprinkler

Appendix P

Inspection & Testing of Fire Sprinkler System

Appendix P. Inspection Scheduling

Component	Subcomponent	Periodic Frequency
Valve Supervisory Signal Devices	----	Quarterly
Supervisory Signal Devices	Except Valve Supervisory Switches	Quarterly
Gauge (Wet Pipe System)	----	Quarterly
Hydraulic Nameplate	----	Quarterly
Buildings	----	Annual
Hanger / Seismic Bracing	----	Quarterly
Pipe and Fittings	----	Quarterly
Sprinklers	----	Annually
Spare Sprinklers	----	Annually
Valve	All Type	Table 13.1.1.2
Obstruction	Internal Inspection of Piping	5 Years
Fire Department Connection	----	Quarterly

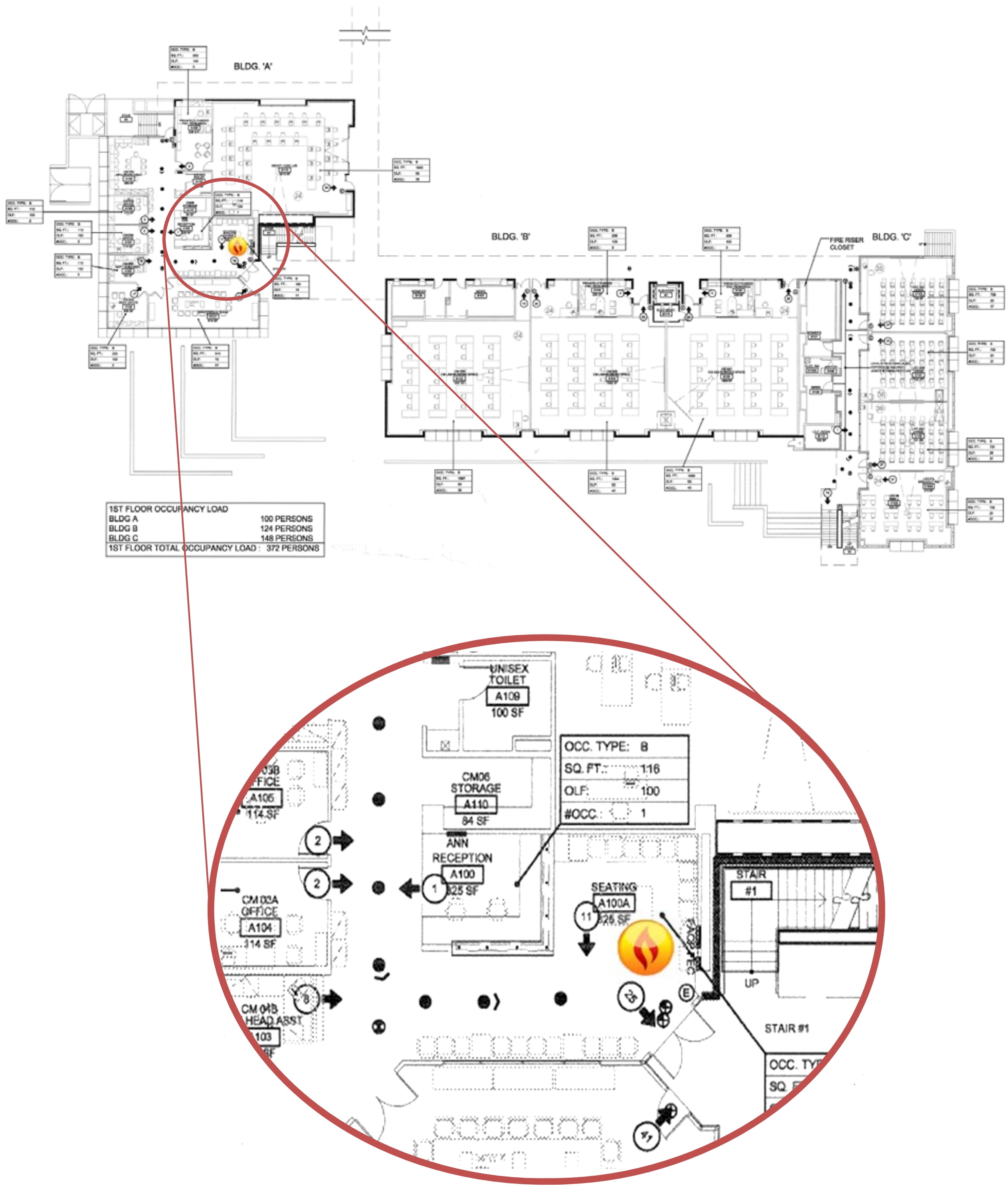
Appendix P. Test Scheduling

Component	Subcomponent	Periodic Frequency
Valve Supervisory Signal Devices	----	Table 13.1.1.2
Supervisory Signal Devices	Except Valve Supervisory Switches	Table 13.1.1.2
Main Drain	----	Table 13.1.1.2
Gauge	----	5 Years
Sprinklers	Fast Response	At 20 Years and 10 years thereafter
Sprinklers	----	At 50 Years and 10 years thereafter
Sprinklers	----	At 75 Years and 5 years thereafter
Sprinklers	Harsh Environment	5 Years
Valves	All Type	Table 13.1.1.2

Appendix Q

Fire Scenario in Building A

Appendix Q. Location of Ignition



Appendix Q. Occupant Characteristics

Occupant Characteristics	Description	Response
Alertness	Condition of being awake/asleep, can depend on time of day	Occupants are wide–awake
Responsiveness	Ability to sense cues and react	Not respondent to immediate surroundings
Commitment	Degree to which occupant is committed to an activity underway before the alarm	Occupants might be hesitant to indulge into unexpected activity
Focal Point	Point at which an occupant's attention is focused	Seated while waiting for an action to occur
Physical & Mental Capabilities	Influence on ability to sense, respond, and react to cues; might be related to age or disability	Healthy and educated adults between the ages of 18 and 40 years
Role	Influence on whether occupant will lead or follow others	A few will lead the way while most will follow
Familiarity	Influence of time spent in building or participation in emergency training	Occupant tend to be unfamiliar with their surrounding
Social Affiliation	Extent to which an occupant will act/react as an individual or as a member of a group	Occupants will tend to join a group
Condition over the Course of the Fire	Effects, both physiological and psychological, of the fire and its combustion products on each occupant	The mobility and reasoning of each occupants might lower after being expose to smoke

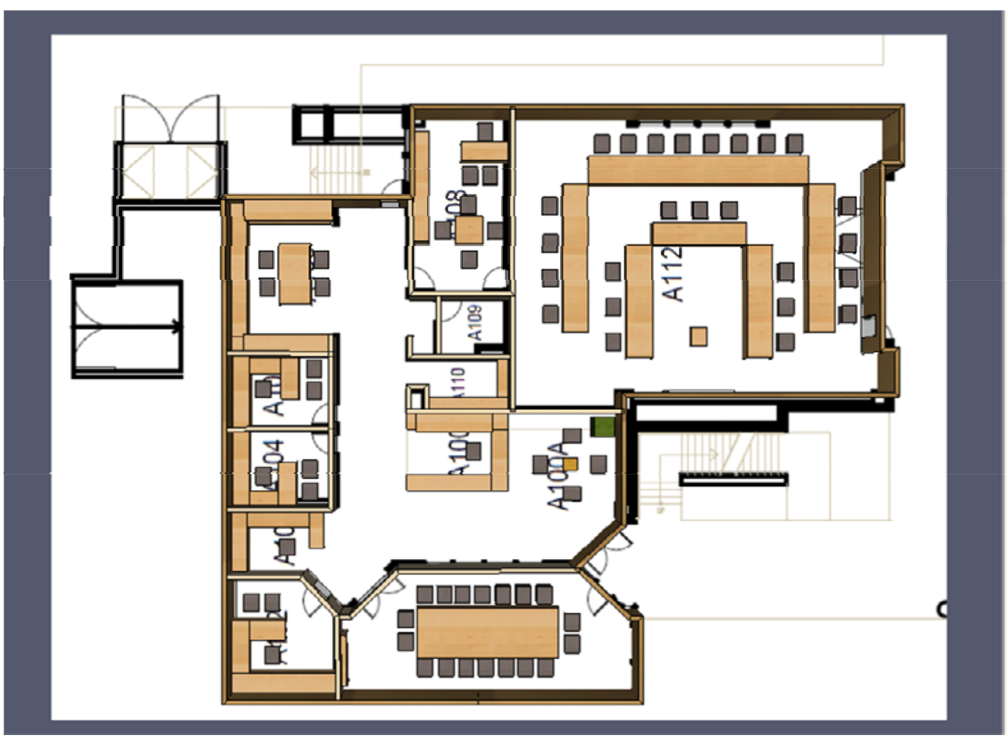
Appendix Q. Room & Fire Characteristics

Room Characteristics	Description	Results
Configuration	Area	325 SF
	Ceiling Height	10 feet 6 inches
	Ceiling Configuration (Smooth/Slope/Peak/Shed/Beam/Joints)	Smooth
	Windows & Doors	Open to Corridor
Environment	Ambient Temperature [a]	58.8 °F
	Humidity [b]	81.11%
	Background Noise	Office Work
Equipment	Heat-Producing Equipment	Computers
	HVAC	Yes
	Manufacturing Equipment	No
Functioning	Occupied	11 occupants
	Hours of the Day	Varies throughout the day
	Days of the Week	Monday to Friday
Potential Ignition Sources	Cause of Fire	Arson

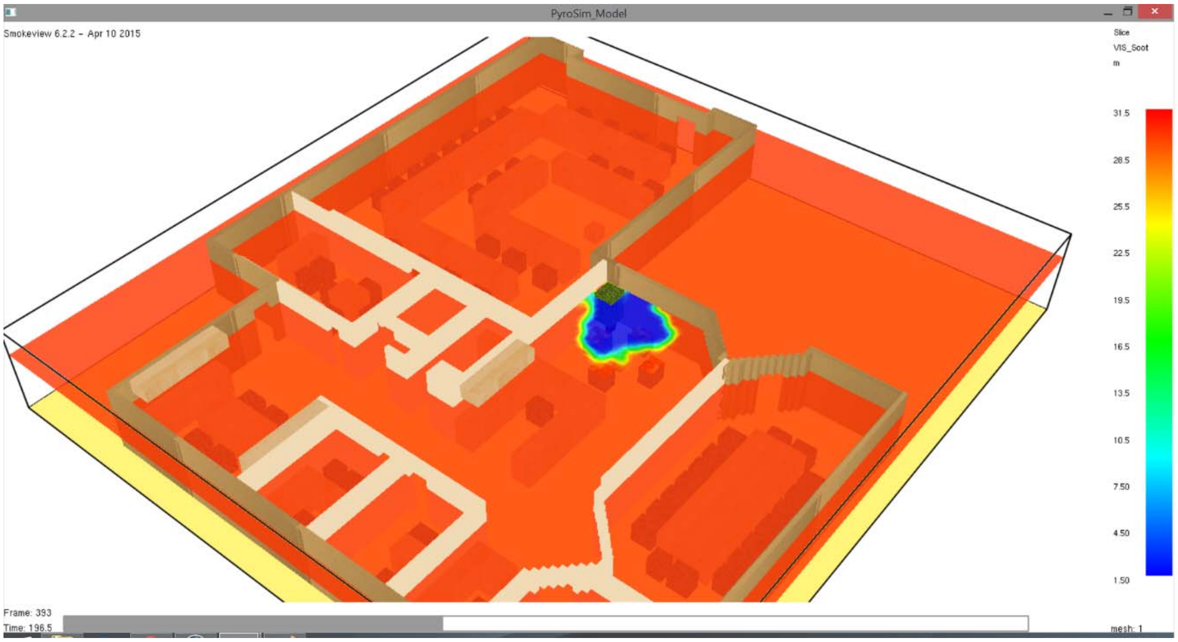
a. Annual average temperature for San Luis Obispo, California, from USA.com
b. Annual average humidity for San Luis Obispo, California, from USA.com

Fire Characteristics	Description	Response
Initial Fuel	State	Solid
	Fuel	Upholstered Chairs (4X)
	Fuel Configuration	5.31 ft^2
	Fuel Location	Space A100A
	Heat Release Rate	1970 kW
	Fire growth rate	Medium Developing Fire
Secondary Fuels	Proximity to initial fuels	Small Wooden Table Magazines Tree
	Amount	3, 6, 1
	Distribution	T-square
	Ease of ignitibility	Easy
	Extension Potential	Carpet

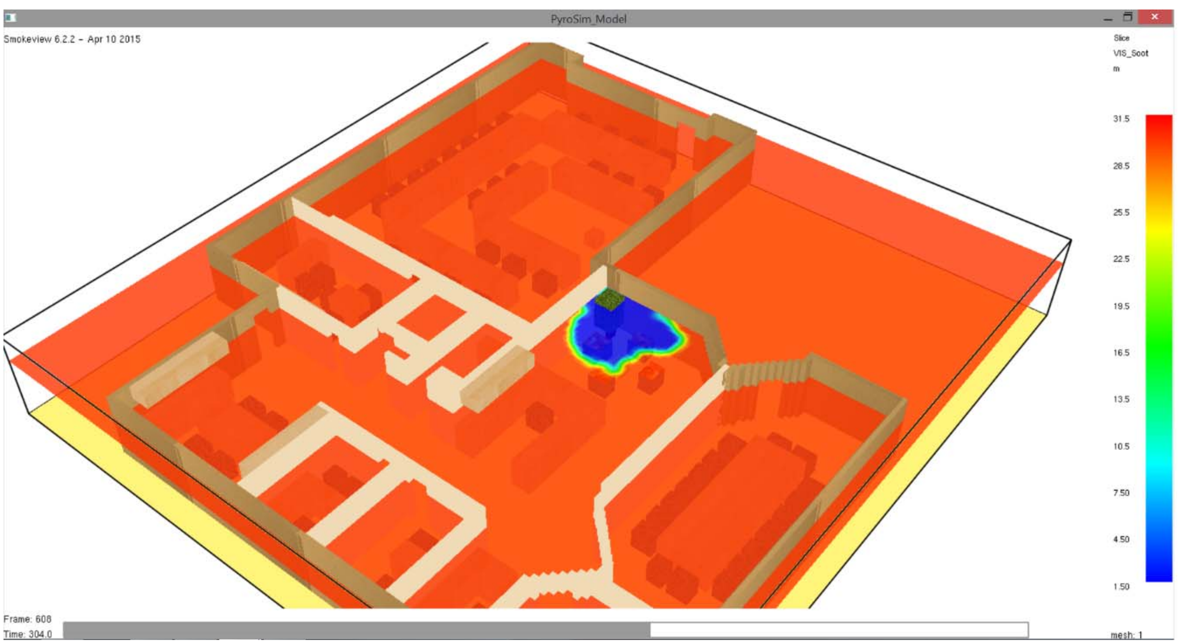
Appendix Q. PyroSim/FDS Model



Appendix Q. Visibility

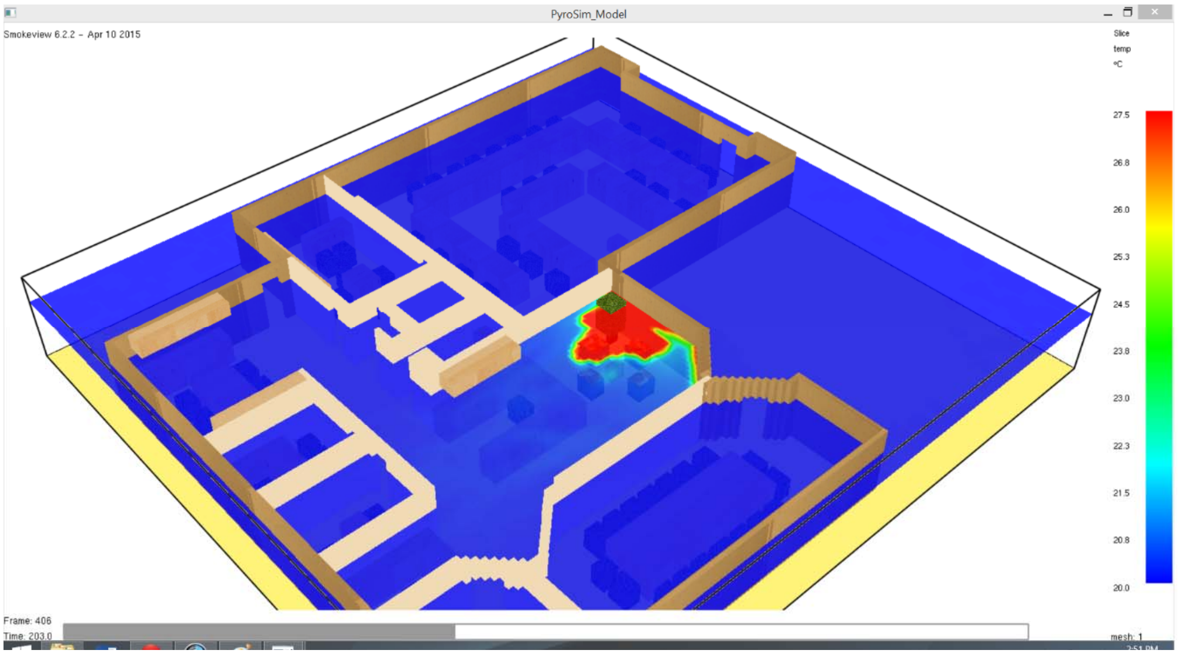


Time: 196.5 seconds

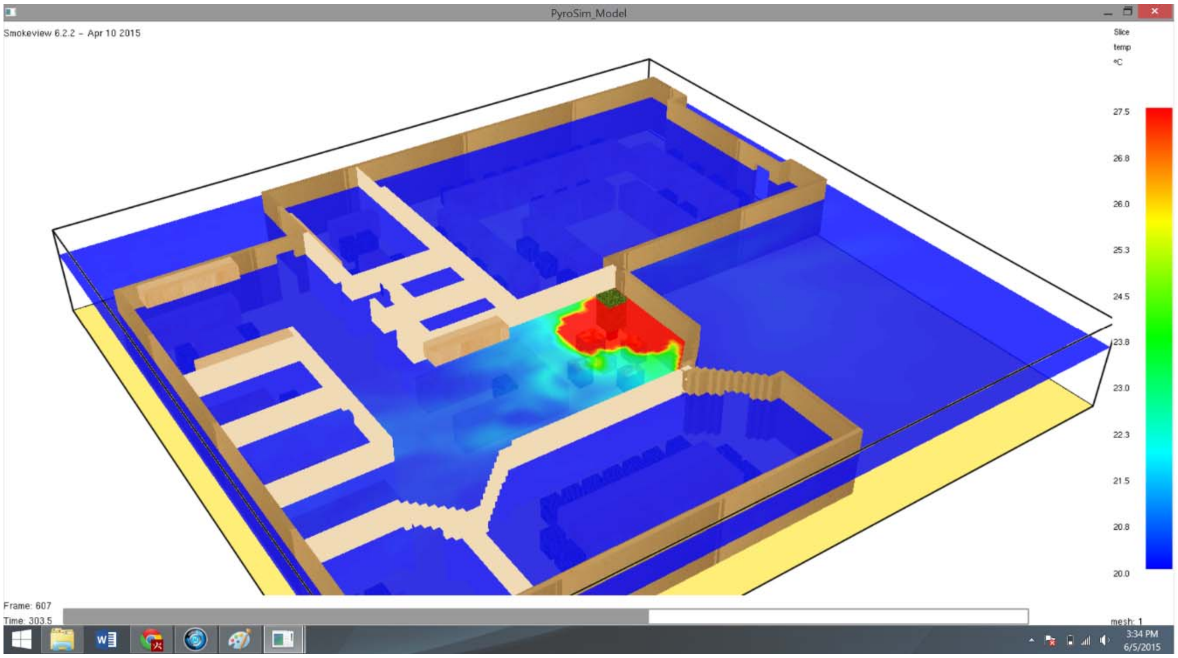


Time: 304 seconds

Appendix Q. Temperature

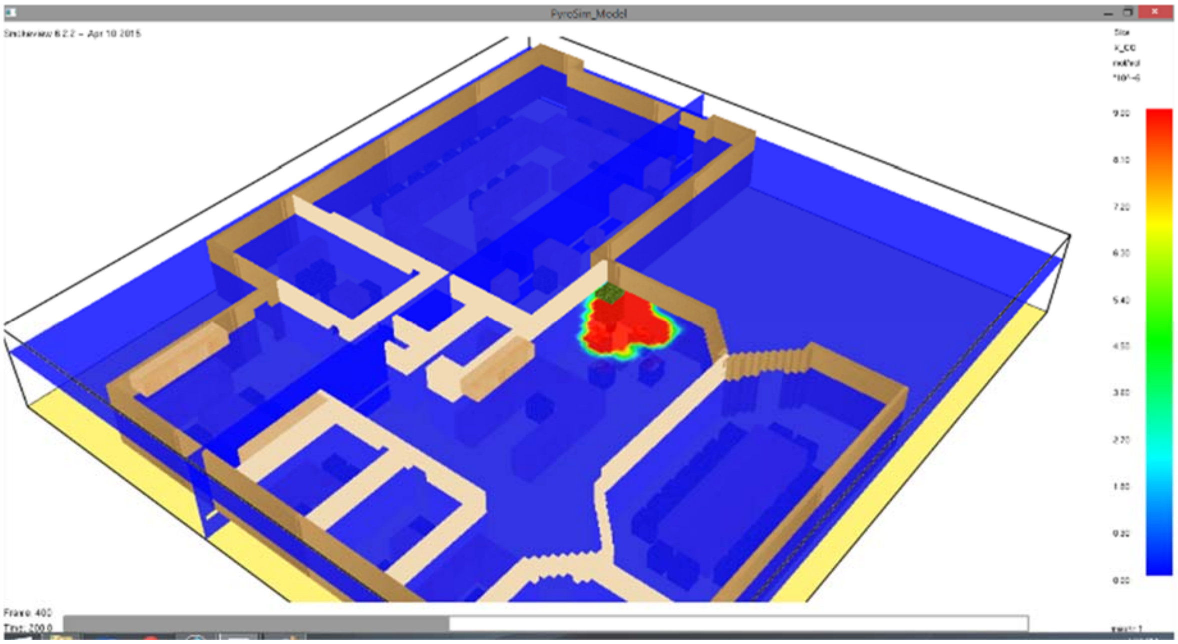


Time: 203 seconds

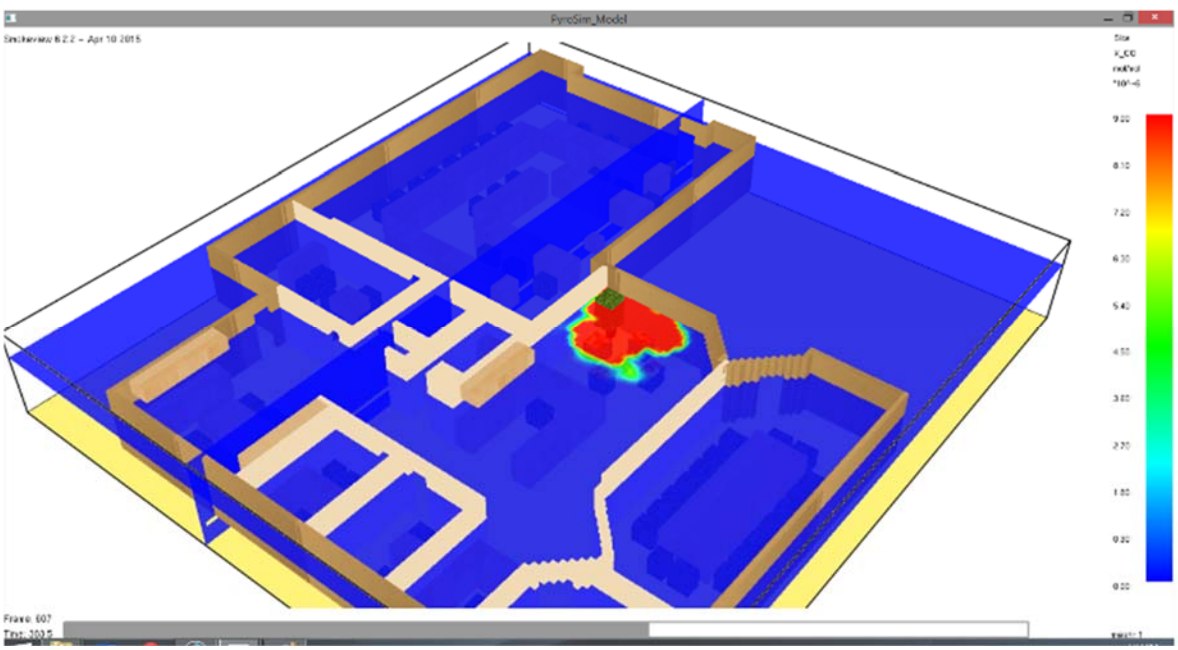


Time: 303.5 seconds

Appendix Q. Toxicity



Time: 200 seconds

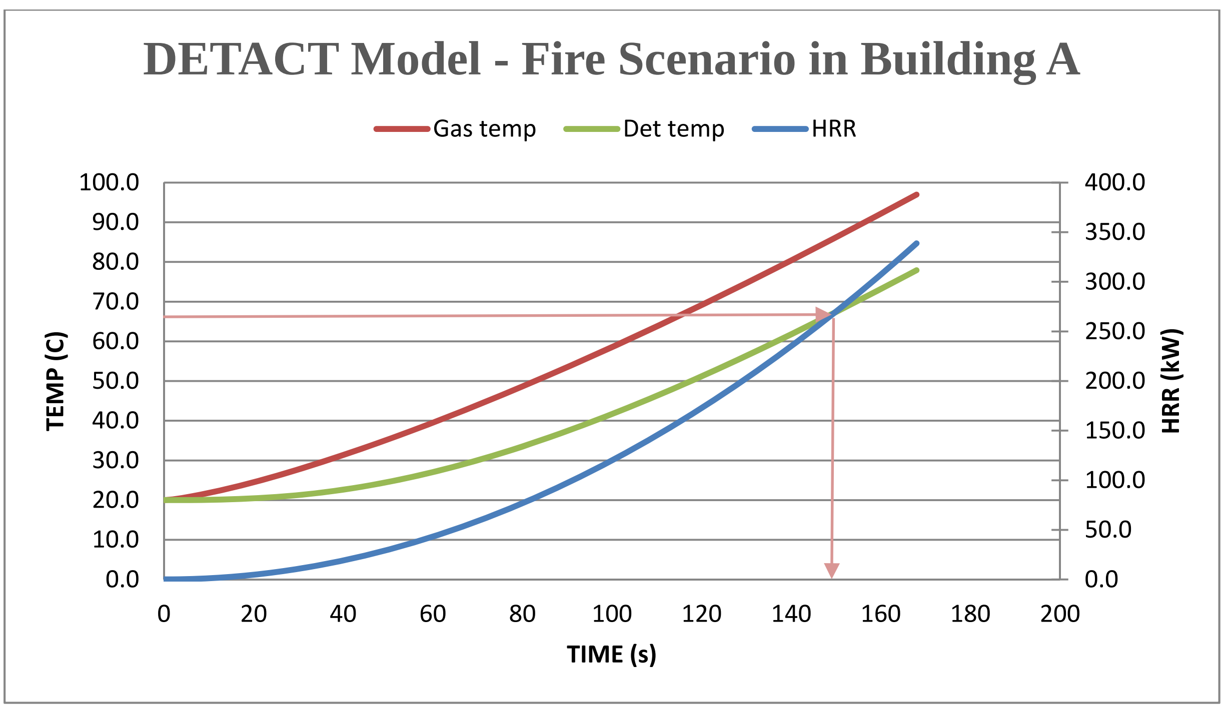


Time: 303.5 seconds

Appendix Q. Activation Time

Input Parameters	Values	Conversion	Calculated Parameters	Values
Ceiling height (H)	3.2 m	10.5 ft.	R / H	0.313
Radial distance (R)	1.0 m	3.3 ft.	dT(cj) / dT(pl)	0.651
Ambient temperature (To)	20 C	68 F	u(cj) / u(pl)	0.527
Actuation temperature (Td) [a]	20 +68.3 C	68+155 F		
Response time index (RTI) [b]	50 $(m * s)^{1/2}$	91 $(ft * s)^{1/2}$		
Fire growth power (n)	2	----		
Fire growth coefficient (k) [c]	0.012 kW/s^2	----		
Time Step (dt)	2 sec	----		

a. Activation Time [F]: Ordinary (135-170) / Intermediate (175-225) / High (250 – 300) / Extra High (325-375) / Very Extra High (400 – 475) / Ultra High (500–650)
b. RTI [$(ft * s)^{1/2}$]: Quick (< 91) / Standard (> 145)
c. Fire Growth Coefficient [$(kW/s)^2$]: Slow (0.003) / Medium (0.012) / Fast (0.047) / Ultrafast (0.400)



Appendix Q. Movement Time

Time: 0.0 / 49.0 seconds

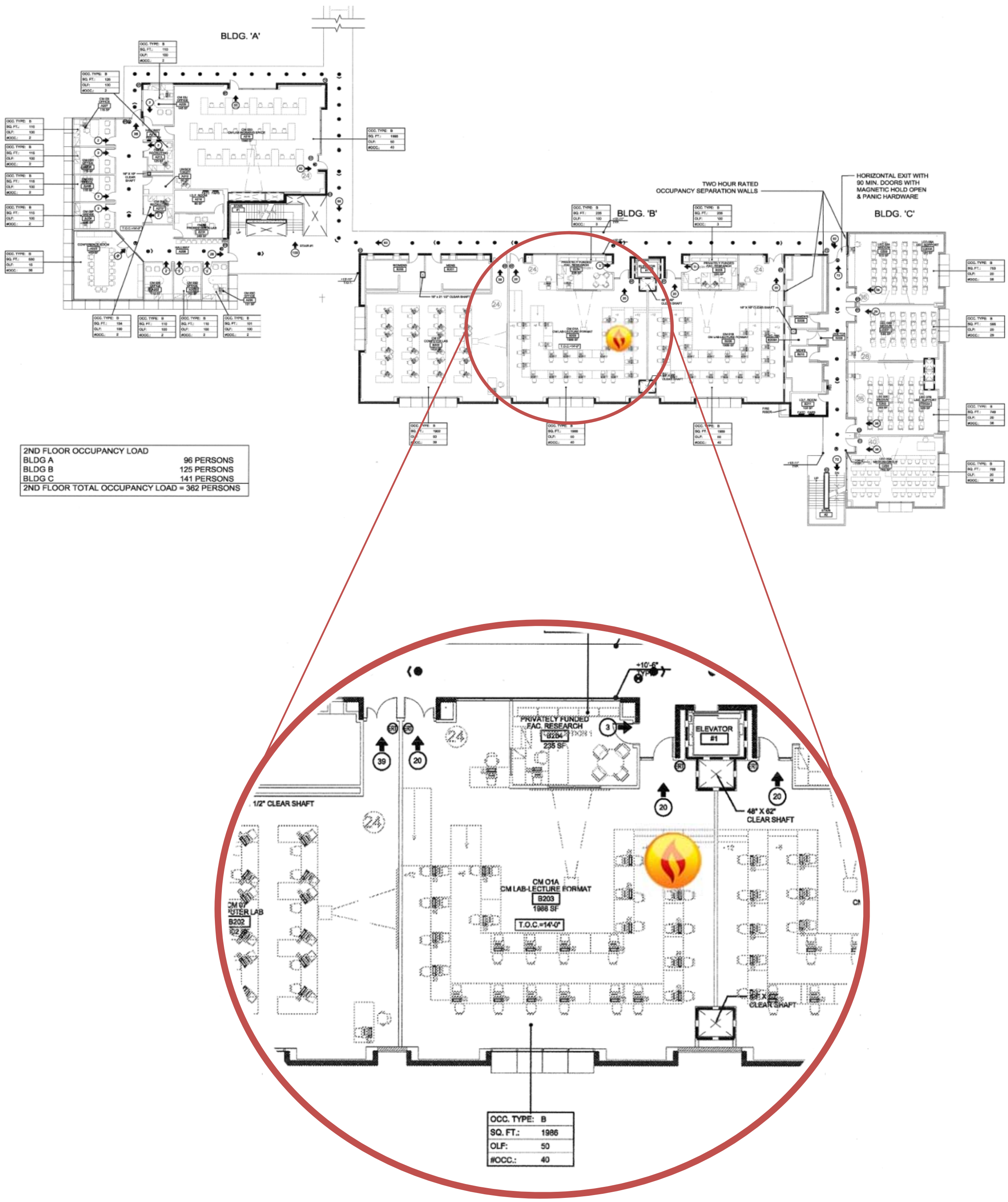
Time: 12.0 / 49.0 seconds

Time: 24.0 / 49.0 seconds

Appendix R

Fire Scenario in Building B

Appendix R. Location of Ignition



Appendix R. Occupant Characteristics

Occupant Characteristics	Description	Response
Alertness	Condition of being awake/asleep, can depend on time of day	Student tend to be wide-awake unless it's early in the morning
Responsiveness	Ability to sense cues and react	Not respondent to immediate surroundings
Commitment	Degree to which occupant is committed to an activity underway before the alarm	Students might be hesitant to indulge into unexpected activity
Focal Point	Point at which an occupant's attention is focused	Self-involved with work
Physical & Mental Capabilities	Influence on ability to sense, respond, and react to cues; might be related to age or disability	Healthy and educated young adults between the ages of 18 and 25 years
Role	Influence on whether occupant will lead or follow others	A few will lead the way while most will follow
Familiarity	Influence of time spent in building or participation in emergency training	Students tend to be very familiar with their surrounding after the second week of class
Social Affiliation	Extent to which an occupant will act/react as an individual or as a member of a group	Students will tend form a group then scatter
Condition over the Course of the Fire	Effects, both physiological and psychological, of the fire and its combustion products on each occupant	The mobility and reasoning of each students might lower after being expose to smoke

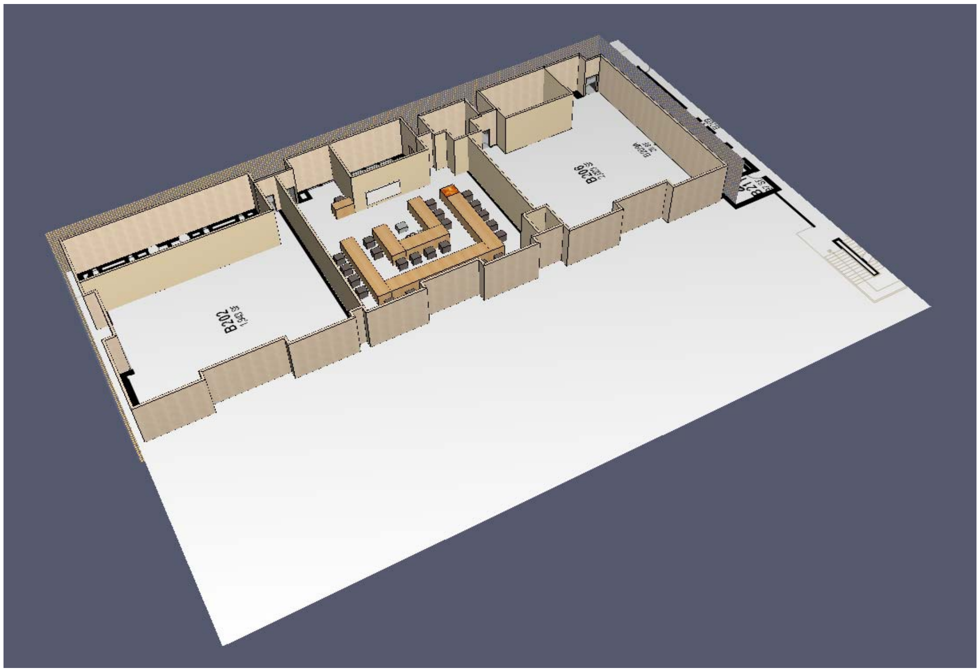
Appendix R. Room & Fire Characteristics

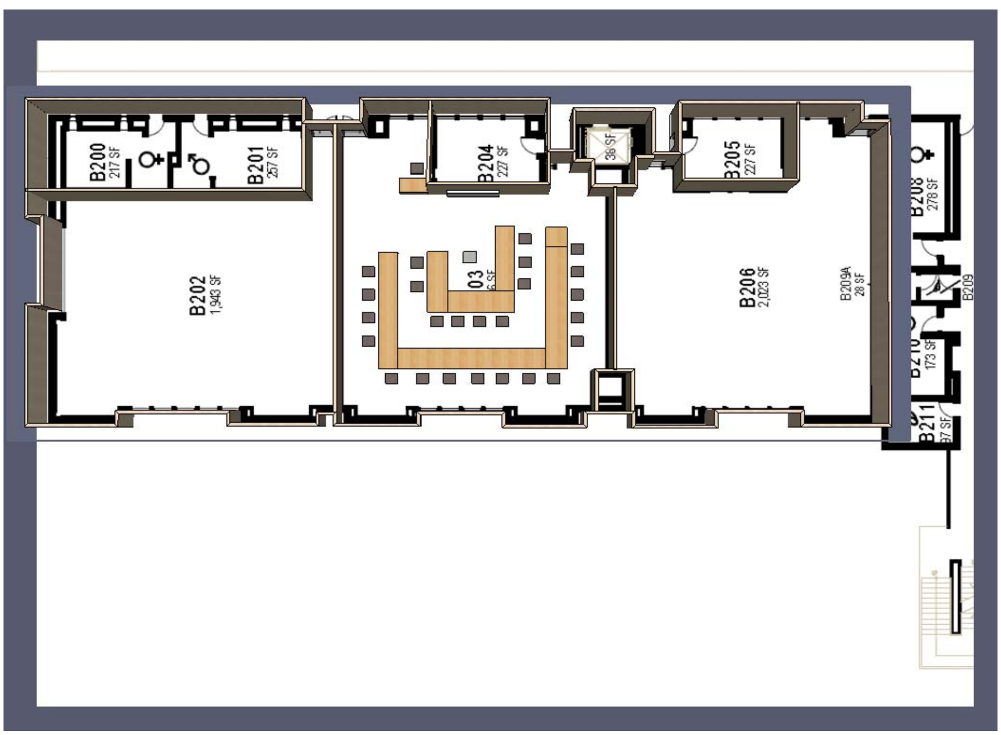
Room Characteristics	Description	Results
Configuration	Area	1986 SF
	Ceiling Height	14 feet
	Ceiling Configuration (Smooth/Slope/Peak/Shed/Beam/Joints)	Smooth
	Windows & Doors	1 windows & 2 doors
Environment	Ambient Temperature [a]	58.8 °F
	Humidity [b]	81.11%
	Background Noise	Electrical tools
Equipment	Heat-Producing Equipment	Computers
	HVAC	Yes
	Manufacturing Equipment	No
Functioning	Occupied	40 occupants
	Hours of the Day	Varies throughout the day
	Days of the Week	Monday to Friday
Potential Ignition Sources	Cause of Fire	Accidental fire from glue gun

a. Annual average temperature for San Luis Obispo, California, from USA.com
b. Annual average humidity for San Luis Obispo, California, from USA.com

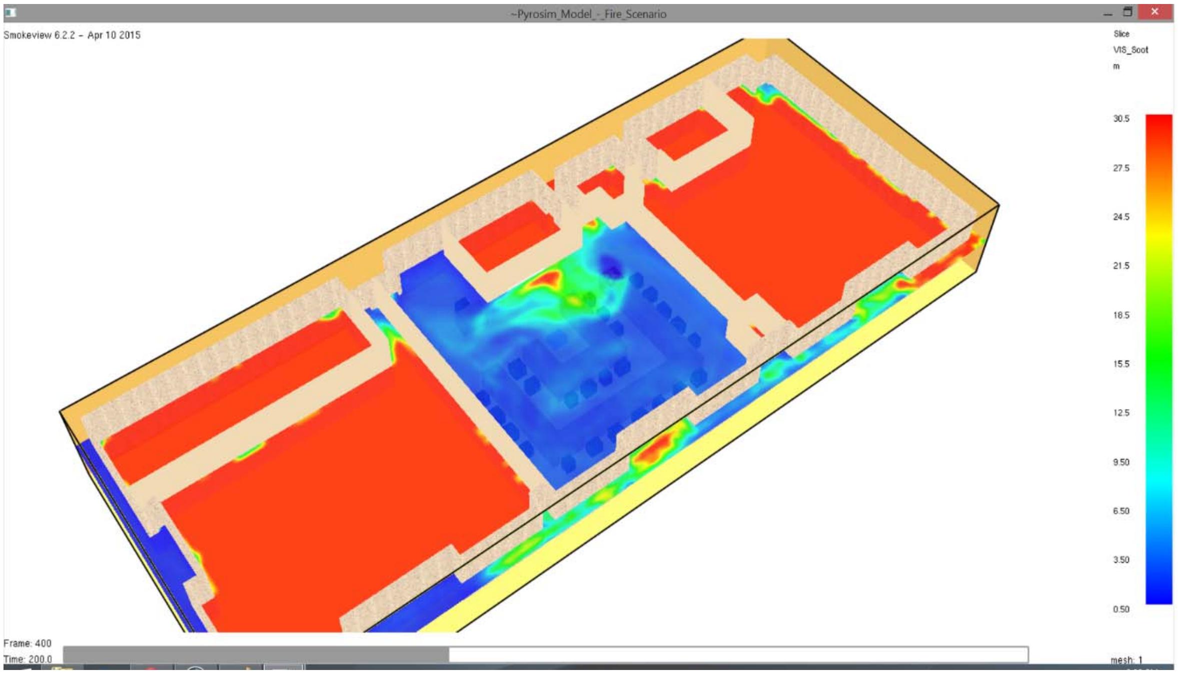
Fire Characteristics	Description	Response
Initial Fuel	State	Solid
	Fuel	Wooden Cardboard
	Fuel Configuration	16.55 ft^2
	Fuel Location	Room B203
	Heat Release Rate	300 kw/m^2
	Fire growth rate	Slow Developing Fire
Secondary Fuels	Proximity to initial fuels	Additional Wooden Cardboard Paper
	Amount	5, 10
	Distribution	T-square
	Ease of ignitibility	Easy
	Extension Potential	Wooden Desks

Appendix R. PyroSim/FDS Model

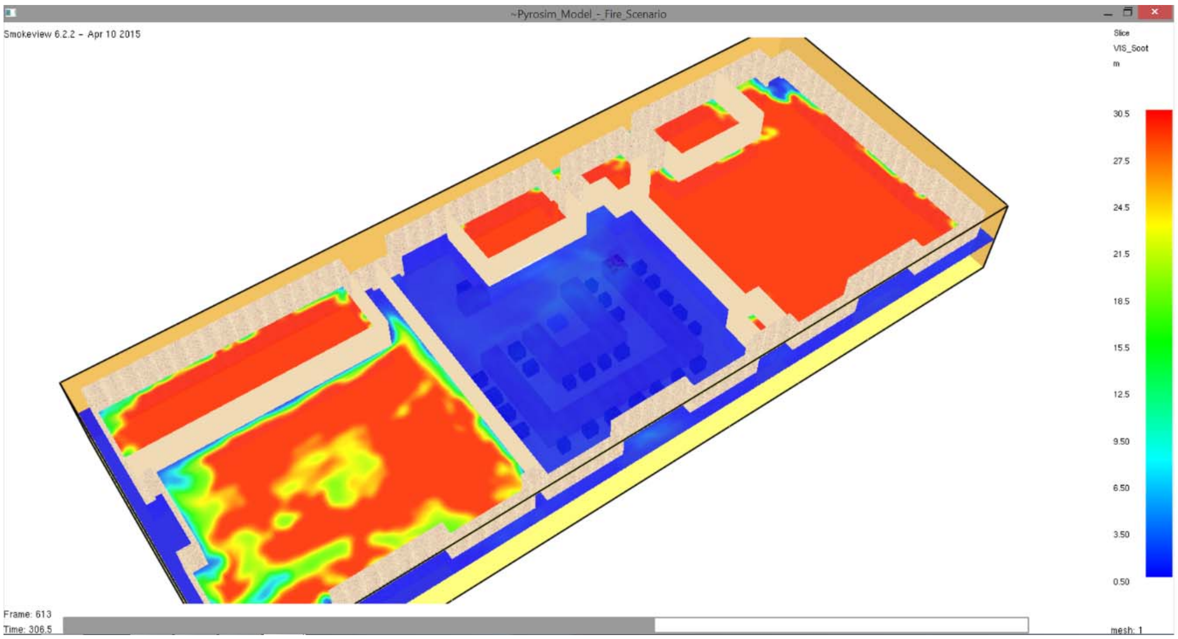




Appendix R. Visibility

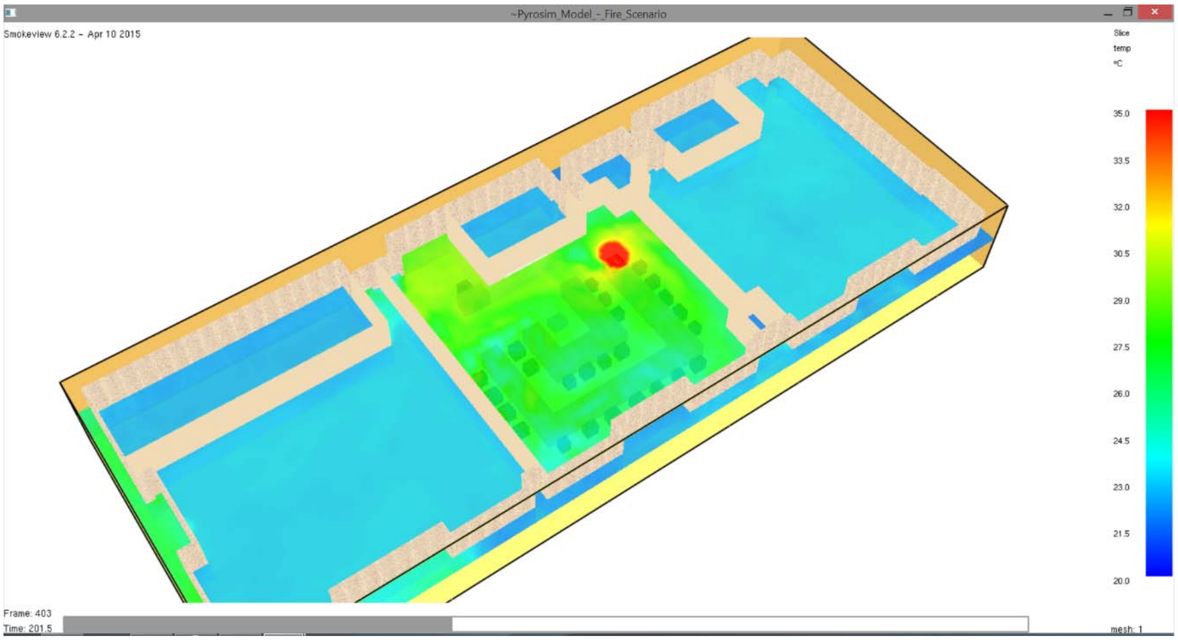


Time: 200 seconds

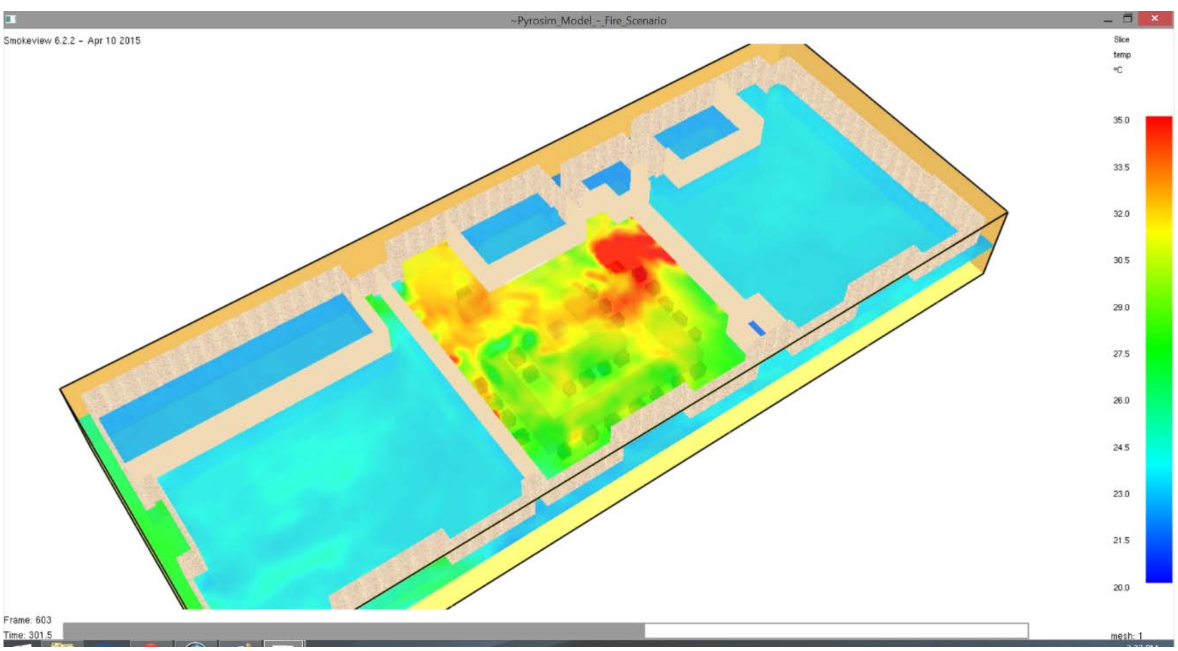


Time: 306.5 seconds

Appendix R. Temperature

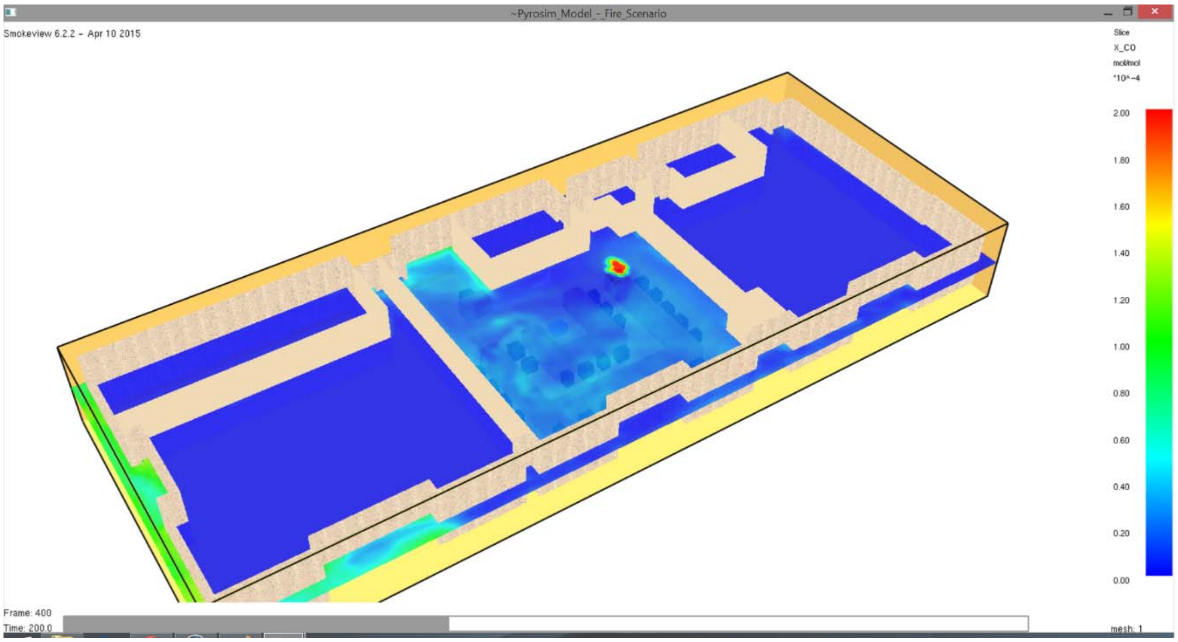


Time: 201.5 seconds

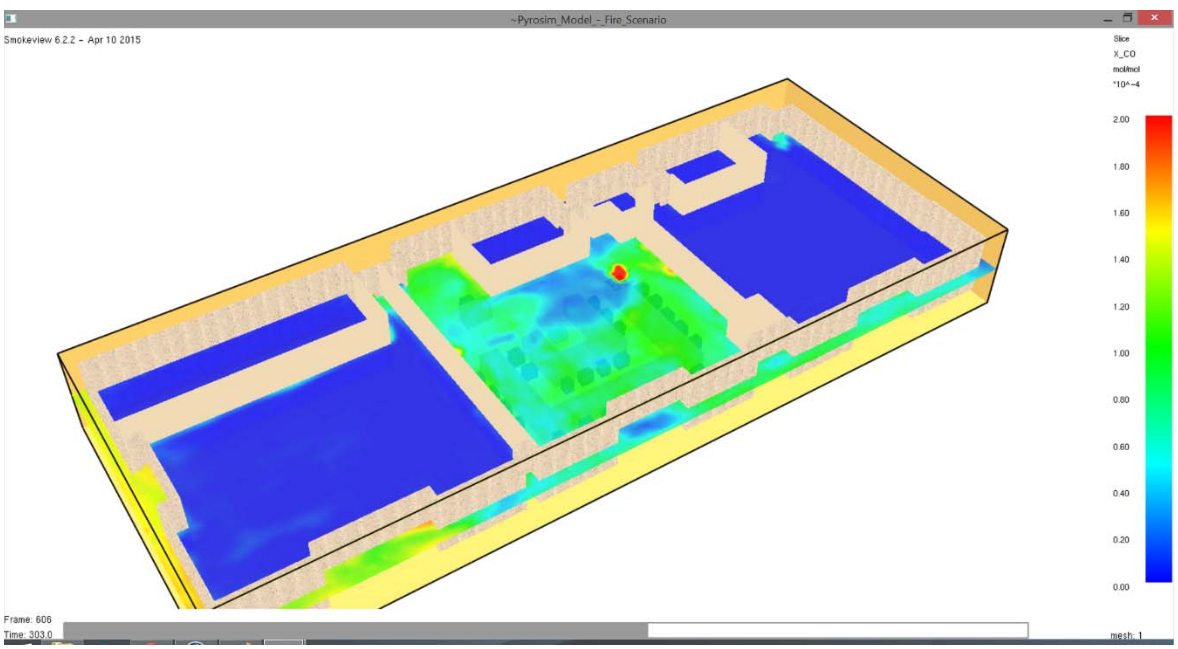


Time: 301.5 seconds

Appendix R. Toxicity



Time: 200 seconds

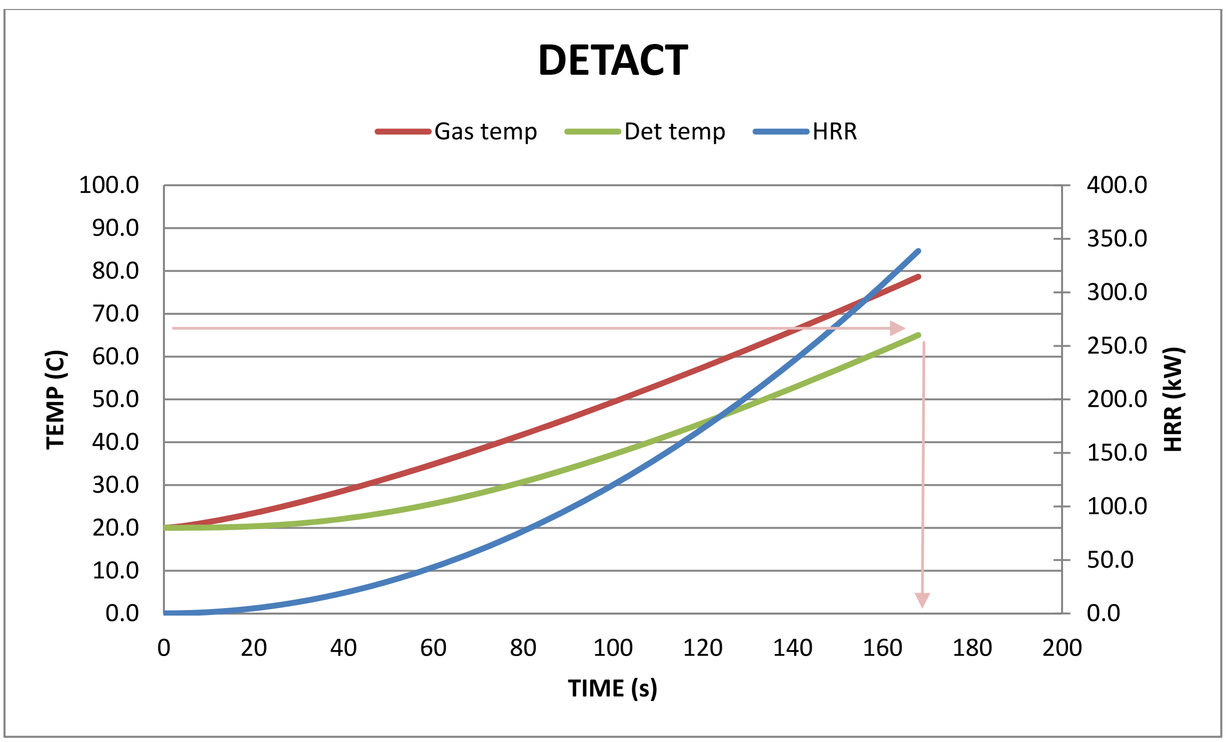


Time: 303 seconds

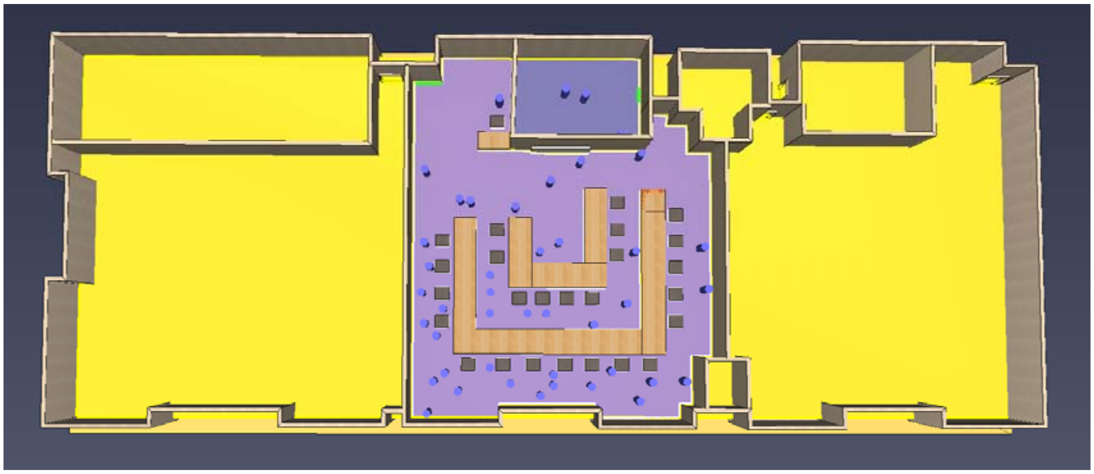
Appendix R. DETACT-QS

Input Parameters	Values	Conversion	Calculated Parameters	Values
Ceiling height (H)	4.2 m	13.7 ft.	R / H	0.238
Radial distance (R)	1.0 m	3.3 ft.	dT(cj) / dT(pl)	0.781
Ambient temperature (To)	20 C	68 F	u(cj) / u(pl)	0.661
Actuation temperature (Td) [a]	20 +68.3 C	68+155 F		
Response time index (RTI) [b]	50 $(m * s)^{1/2}$	91 $(ft * s)^{1/2}$		
Fire growth power (n)	2	----		
Fire growth coefficient (k) [c]	0.012 kW/s^2	----		
Time Step (dt)	2 sec	----		

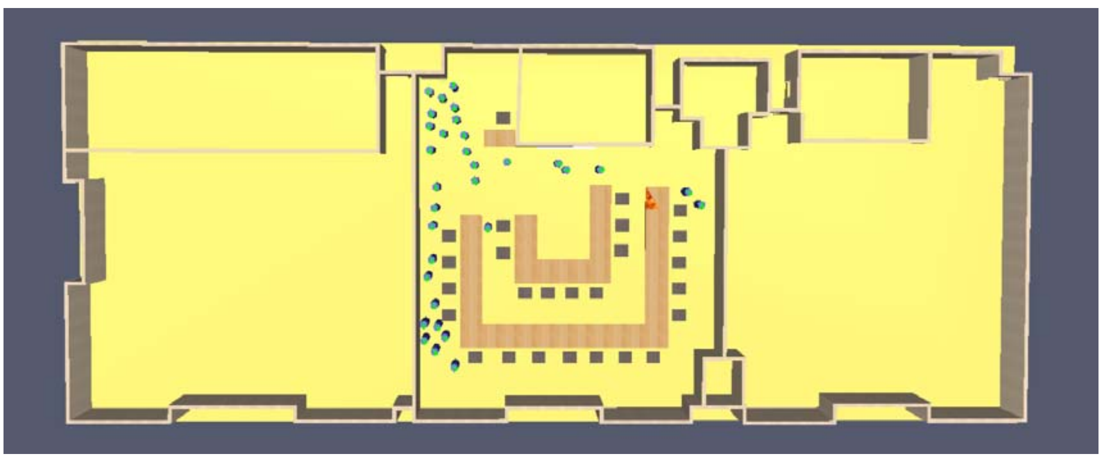
a. Activation Time [F]: Ordinary (135-170) / Intermediate (175-225) / High (250 – 300) / Extra High (325-375) / Very Extra High (400 – 475) / Ultra High (500–650)
b. RTI [$(ft * s)^{1/2}$]: Quick (< 91) / Standard (> 145)
c. Fire Growth Coefficient [$(kW/s)^2$]: Slow (0.003) / Medium (0.012) / Fast (0.047) / Ultrafast (0.400)



Appendix R. Movement Time



Time: 0.0 / 28.0 seconds



Time: 9.3 / 28.0 seconds

Time: 17.8 / 28.0 seconds