Orangeburg Assembly Hall of Jehovah's Witnesses

Orangeburg, South Carolina

Fire Protection & Life Safety Design Analysis

Project Analysis Prepared by:

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Not for Construction -Academic Exercise Only

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Abstract

In partial fulfillment of the requirements for the Degree of Masters of Science in Fire Protection Engineering, a prescriptive and performance-based engineering analysis was performed on the Orangeburg Assembly Hall of Jehovah's Witnesses. The building was recently constructed and completed in 2013 in Orangeburg, South Carolina to serve as a center for education of Jehovah's Witnesses on Biblical principles for daily life. More than 300 congregations throughout Georgia and the Carolinas will use the Assembly Hall for their semi-annual assemblies and conventions, with an estimated annual attendance of 190,000 per year. Prescriptive analyses were conducted based primarily upon the provisions of the 2009 *International Building Code (IBC), International Fire Code (IFC)*, and the 2009 edition of the National Fire Protection Association standard, NFPA 101, *Life Safety Code*. Where required by the referenced building and fire codes, other NFPA codes and standards such as the 2010 editions of NFPA 13, *Automatic Sprinkler Systems Handbook* and NFPA 72, *National Fire Alarm and Signaling Code* were also referenced. Fire protection system analysis included reviewing and establishing a safe means of egress system, fire detection, alarm and notification system, water-based fire suppression system, smoke management system and structural fire protection. Results are provided with respect to each. The performance-based analyses focused primarily upon the ability of occupants to safely escape the building after the onset of various fire events by creating a tenable environment in concert with a smoke management system. The computer fire model, "Fire Dynamics Simulator" (FDS) version 6 produced by the National Institute of Standards and Technology (NIST), was used to estimate the available safe egress time (ASET) of occupants under applicable fire scenarios. The required time needed for safe egress (RSET) was determined based upon calculation methods set forth in the Society of Fire Protection Engineering (SFPE), *Handbook of Fire Protection Engineering* (HBFPE) in conjunction with a computer egress model, "Pathfinder" version 2011 produced by Thunderhead Engineering. Available (ASET) and required safe egress times (RSET) were compared for analysis purposes. It should be noted that these recommendations are considered a best effort and are presumed technically valid for academic purposes only and do not represent the design decisions of the actual building design.

About the Author

Justin Biller is a fire protection engineer experienced in a diverse portfolio of projects across most industry sectors. He currently works as a senior life safety engineer for Carilion Clinic – a not-for-profit healthcare system, where Mr. Biller provides consulting services on the evaluation and administration of fire and life safety practices within a network of hospitals, ambulatory care centers and clinics. With over 13 years of broad discipline experience in the fire protection industry including life safety, building construction, basic and advanced fire suppression, fire alarm/mass notification, and smoke control systems, Mr. Biller's work has been concentrated in the healthcare, industrial and federal markets. As a registered fire protection engineer in Virginia and North Carolina, Mr. Biller uses his in-depth knowledge of building, fire codes, NFPA standards, various design criteria (e.g., TJC, GSA, DoVA, etc.), and understanding of fire phenomena in order to produce well-coordinated, quality fire and life safety designs and practices. Previous to his work with Carilion Clinic, Mr. Biller worked as a fire protection engineering consultant for AECOM – a multi-national A&E firm, as well as a building and fire official for local and state governments.

Acknowledgements

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Table of Contents

1. Fire and Life Safety Design Criteria

(ICC) - International Code Council
- International Building Code (IBC) 2009
- International Fire Code (IFC) 2009
- International Mechanical Code (IMC) 2009
- International Plumbing Code (IPC) 2009
- International Performance Code for Buildings and Facilities (ICCPC) 2009

(NFPA) - National Fire Protection Association Codes and Standards
- NFPA 10, Portable Fire Extinguishers, 2007
- NFPA 13, Installation of Sprinkler Systems, 2007
- NFPA 72, National Fire Alarm and Signaling Code, 2007
- NFPA 80, Fire Doors and other Opening Protectives, 2007
- NFPA 90A, Installation of Air-Conditioning & Ventilating Systems, 2009
- NFPA 92B, Smoke Management Systems in Malls, Atria and Large Spaces, 2005
- NFPA 101, Life Safety Code, 2009
- NFPA 110, Emergency and Standby Power,
- NFPA 220, Types of Building Construction, 2009
- NFPA *Fire Protection Handbook*, 20th Edition (NFPA FPHB)

(SFPE) - Society of Fire Protection Engineers
- SFPE Engineering Guide, *Human Behavior in Fire*, 2003
- SFPE Handbook of Fire Protection Engineering, 4th Edition (SFPE HBFPE)
- SFPE Engineering Guide, *Performance-Based Fire Protection*, 2nd Edition

2. Project Executive Summary

2.1. General Scope of Work

The US Assembly Hall Design Group (USAHDG) is a group of working professionals who provide architectural, engineering and construction administrative services, on a completely voluntary basis, in order to design and construct Assembly Halls of Jehovah's Witnesses throughout the continental United States. The objectives of the group are to provide functional facilities, moderate in design and cost, capable of serving the needs of various circuits and districts of Jehovah's Witnesses during annual circuit assemblies and regional conventions. Since the costs for construction, operation and maintenance of the building are provided solely through voluntary contributions, it is important to make design and construction affordable and efficient. The USAHDG currently standardizes all designs to be of similar size and footprint, with only local slight site modifications as needed. I was recently asked to work on the design team with these other professionals to provide code consulting and act as the design engineer of record for the fire protection systems.

The current design incorporates a simplified main auditorium and platform layout with seating for 2,900 plus. Adjacent support spaces include some office space, main lobby and restrooms, as well as storage, mechanical and electrical rooms. The primary function of the building is to provide meeting space for congregation circuits and districts and is primarily used on Thursday thru Sunday of each week. Congregation circuits meet together biannually, so Assembly Halls are primarily used by circuits of congregations (generally 20 – 22 congregations) in 200 to 300 mile radius around the building. Occupants for the most part will become familiar with the building layout and egress after several years of use. Additional schools of approximately 30 –

50 may take place during the week, but other than caretakers and maintenance volunteers, the building is unoccupied for the large part of most weeks, with primary activity on weekends.

2.2. Summary of Fire Protection Analysis

While not required by local or state provisions, a comprehensive analysis of the current fire and life safety provisions applicable to this facility was conducted in accordance with the 2009 editions of the *International Building Code* (IBC) and NFPA 101, *Life Safety Code* as further delineated in the design criteria above. Original design and construction of this facility was performed under 2006 *International Building Code* (IBC) and earlier editions as State Amended (i.e. South Carolina Building Code had adopted the 2006 editions of all the International Codes), however as egress analysis will detail, changes under 2009 IBC would put current egress configurations out of compliance with most current criteria. IBC 2009 Section 1005.1 revised egress capacity required for doors to 0.2 inches per occupant in fully sprinklered buildings, whereas the 2006 IBC and earlier editions only required 0.15 inches per occupant in fully sprinklered buildings. Based on the analysis of the code criteria outlined in section 1 of this report, the facility is deemed to satisfy the majority of other prescriptive life safety provisions of the code. Section 12.1 will further discuss performance-based options available in both the LSC and the *International Performance Code for Buildings and Facilities* (ICCPC) for alternate egress analysis to satisfy exit capacity issues that would be present had the design met later editions of the code.

3. Building Construction Requirements

3.1. Classification of Occupancy (IBC Chapters 3 -5; See Section 4 for NFPA 101 Occupancy Analysis)

3.1. Classification of Occupancy (IBC Requirements)

3.1.1 Primary Use Groups (IBC Chapter 3)
Group A-3; Assembly Place of Religious Worship

3.1.2 Mixed use and occupancy (IBC Section 508) – Reference Appendix A, *Occupancy Use & Classifications* for additional information.

3.1.2.1 Accessory occupancies (IBC Section 508.2)
Storage spaces (S-1) and the Mechanical/Equipment spaces (F-1) are treated as accessory structures, meeting the limits of 10% aggregate area or less in accordance with 508.2.1 as shown in the table 3.1.2.1 below. As can be seen, approximately only 3% of space would be used to accommodate these accessory spaces, and allowable building areas for each accessory occupancy are considered for Type IIB construction (see section 3.2.1 below), and verification that these areas are under the code allowable area meeting the requirements of IBC sections 508.2.1 and 508.2.3.

Table 3.1.2.1 Accessory Occupancy Summary

Use	Area (ft^2)	Allowable Area IBC Table 503 (ft^2)	Total Building Area (ft^2)	Building Area Percentage (%)
STORAGE ROOMS (S-1)	1,203	17,500	51,583	2
MECHANCIAL ROOMS (F-1)	474	15,500	51,583	1
ELECTRICAL ROOMS (F-1)	281	15,500	51,583	0.6

3.1.2.2 Incidental Use Areas (IBC Section 508.2.5)

Mechanical Room: 1 Hour or Automatic Fire-extinguishing System with smoke-tight construction
Refrigerant Machinery Room: 1 Hour or Automatic Sprinkler System with smoke-tight construction

3.1.2.3 Non-separated occupancies (IBC Section 508.3)

The office spaces will be classified as mixed-use non-separated B/A-3 occupancy. Fire protection systems required by IBC chapter 9 for A-3 use will be provided throughout entire building fire compartment. Building area allowable areas are more restrictive in size for A-3 so analysis will be based on these areas.

3.1.3 Separated occupancies (IBC Section 508.4.4)
Not applicable.

3.2. Allowable Heights & Areas (IBC Table 503)

3.2.1 Area per floor (A-3/B, Non-separated)

Base Allowable Floor Areas, per IBC table 503 summarized in Table 3.2.1 below. Actual Building Area: 51,583 ft^2

Table 3.2.1 Base Allowable Floor Area – Excerpted from IBC Table 503

Type IA: Unlimited > 51,583 ft^2	Type IB: Unlimited > 51,583 ft^2
Type IIA: 15,500 ft^2 < 51,583 ft^2*	Type IIB: 9,500 ft^2 < 51,583 ft^2*
Type IIIA: 14,000 ft^2 < 51,583 ft^2*	Type IIIB: 9,500 ft^2< 51,583 ft^2*
TypeIV: 15,000 ft^2 < 51,583 ft^2*	
Type VA: 11,500 ft^2 < 51,583 ft^2*	Type VB: 6,000 ft^2 < 51,583 ft^2*

*The types indicated in red are not code compliant based on proposed area.

Areas per floor are only allowable for Use Group A-3 with Type IA and Type I-B construction only without additional protection (e.g. open perimeter, sprinkler protection, etc).

3.2.2 Height (A-3/B, Non-separated)
Base Allowable Height and Number of Stories, per IBC table 503 summarized in Table 3.2.2 below . Actual Building Height: 32'-6"

Table 3.2.2 Base Allowable Height – Excerpted from IBC Table 503

Type IA: Unlimited > 1 story/ 32.5 ft.	Type IB: 11 stories/160 ft. > 1 story/ 32.5 ft.
Type IIA: 3 stories/65 ft. > 1 story/ 32.5 ft.	Type IIB: 2 stories/55 ft. > 1 story/ 32.5 ft.
Type IIIA: 3 stories/65 ft. > 1 story/ 32.5 ft.	Type IIIB: 2 stories/55 ft. > 1 story/ 32.5 ft.
Type IV: 3 stories/65 ft. > 1 story/ 32.5 ft.	
Type VA: 2 stories/50 ft. > 1 story/ 32.5 ft.	Type VB:1 stories/40 ft. ≥ 1 story/ 32.5 ft.

Since building is only 1 story, height is not a limiting factor for the type of construction proposed for Use Group A-3 without any additional protective measures.

3.2.3 Height and/or area increases.
3.2.3.1 Height (IBC section 504, 504.2) Fully sprinklered buildings are allowed to extend 1 additional story and/or 20 feet in height, which is summarized in Table 3.2.3.1 below.

Table 3.2.3.1 Modified Allowable Floor Height – Application of IBC 504.2

Type IA: Unlimited > 1 story/ 32.5 ft.	Type IB: 12 stories/180 ft. > 1 story/ 32.5 ft.
Type IIA: 4 stories/85 ft. > 1 story/ 32.5 ft.	Type IIB: 3 stories/75 ft. > 1 story/ 32.5 ft.
Type IIIA: 4 stories/85 ft. > 1 story/ 32.5 ft.	Type IIIB: 3 stories/75 ft. > 1 story/ 32.5 ft.
Type IV: 4 stories/85 ft. > 1 story/ 32.5 ft.	
Type VA: 3 stories/70 ft. > 1 story/ 32.5 ft.	Type VB:2 stories/60 ft. ≥ 1 story/ 32.5 ft.

Since building is only 1 story, height is not a limiting factor for the type of construction proposed for Use Group A-3 without any additional protective measures.

3.2.3.2 Building Area Modifications - (IBC section 506) – Areas increases are allowed for fully automatic sprinkler protection and open frontage area around building perimeter. The following formula can be applied to modify allowable areas which is summarized in Table 3.2.3.2 below.

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

A_a = Allowable building area per story (ft^2).

A_t = Tabular building area per story in accordance with Table 503 (ft^2)

I_f = Area increase factor due to frontage as calculated, per IBC section 506.2

I_f = (F/P – 0.25)*(W/30)

I_f = (550 ft./550 ft. – 0.25)* (30/30) = 0.75

I_s = Area increase factor due to sprinkler protection per NFPA 13 as calculated in accordance with section 506.3. (I_s = 3)

Table 3.2.3.2 Modified Allowable Floor Area – Application of IBC 506

Type IA: Unlimited > 51,583 ft^2	Type IB: Unlimited > 51,583 ft^2
Type IIA: 58,125 ft^2 > 51,583 ft^2	Type IIB: 35,625 ft^2 < 51,583 ft^2*
Type IIIA: 52,500 ft^2 > 51,583 ft^2	Type IIIB: 35,625 ft^2< 51,583 ft^2*
TypeIV: 56,250 ft^2 < 51,583 ft^2*	
Type VA: 43,125 ft^2 < 51,583 ft^2*	Type VB: 22,500 ft^2 < 51,583 ft^2*

*The types indicated in red are not code compliant based on proposed area.

Areas per floor are only allowable for Use Group A-3 with Type IA, Type IB, Type IIA and Type IIIA construction with a full open perimeter and full automatic sprinkler protection.

3.2.3.3 Aggregate Building Area (IBC 506.4)

Aggregate Building Area does not need to be considered for a 1 story building, per IBC section 506.4.

3.2.3.4 Unlimited Area Buildings (IBC 507)

An A-3 assembly building of Type II construction, used for a place of religious worship, would qualify for unlimited area provisions set forth in IBC section 507.6, where it does not have a stage (platform only), full automatic sprinkler protection, and a minimum of 60 open feet around building.

3.2.4 Proposed Construction Type

For compliance purposes, the building could be considered an unlimited building so design will implement Type IIB construction. Building is a steel framed structure that implements steel columns, beams and girders as well as steel roof joists, metal decking and built-up roofing (reference building section included in Appendix C, *Architectural Building Sections*). Interior partitions will be of light gauge cold-formed steel studs with gypsum wallboard finishes. Exterior walls are curtain walls only and do not support the

structural systems; veneers include brick, and exterior insulation and finish systems (EIFS).

3.3. Construction Type (IBC 601, NFPA 101 12.1.6 & 8.2.1.2)

3.3.1 Type IIB construction in accordance with IBC Chapter 6 will be provided. The equivalent construction type in accordance with NFPA 220 is Type II (000) construction.

3.3.2 Fire resistance rating for building elements (IBC Table 601, NFPA 101 A.8.2.1.2, NFPA 220). Values stated in Table 3.3.2 summarized below are minimums for the construction type. Actual rating may be higher per other requirements.

Table 3.3.2 Structural Components

Element	Rating
Primary Structural Frame	0
Exterior Bearing Walls	0
Interior Bearing Walls	0
Exterior Nonbearing Walls and Partitions	IBC Table 602
Interior Nonbearing Walls and Partitions	0
Floor Construction and Secondary Members	0
Roof Contruction and Secondary Members	0

3.3.3 Use of combustible material.
The use of combustible materials is restricted to the applications permitted by IBC Section 603 and NFPA 220.

3.4. Building Separation and Exposure Protection (IBC Table 602)

The minimum fire separation distance is greater than 30 feet for exterior walls to have no fire rating requirement. If the fire separation distance is less than 30 feet but greater than 5 feet, exterior walls will have a 2 hour fire resistance rating for Occupancy Group H and a 1 hour fire resistance rating for Occupancy Group B, S & I. If the fire separation distance is less than 5 feet, exterior walls will have a 3 hour fire resistance rating for Occupancy Group H, a 2 hour fire resistance rating for Occupancy Group S-1, and a 1 hour fire resistance rating for Occupancy Group B, I & S-2. The building has a minimum of 30 feet to any lot line, so 0 hourly rating is required for exterior walls.

3.5. Seismic Protection (IBC 1613)

The IBC classified seismic design category of D requires the consideration of seismic restraints in accordance with ASCE 7 for fire protection systems and emergency electrical systems for lighting and voice evacuation system.

4. Means of Egress (IBC Chapter 10, NFPA 101 Chapter 7)

4.1. Classification of Occupancy (NFPA 101; 6.1.2)

For egress analysis under NFPA 101, occupancy is classified as New Assembly for worship purposes serving greater than 50 occupants. Compliance with 101, chapter 12, is analyzed in addition to meeting provisions for fire and life safety in accordance with IBC.

4.1.2 Multiple Occupancies (NFPA 101, 6.1.14)

In addition to the primary occupancy classification, accessory spaces including office space and mechanical/electrical rooms would include NFPA 101 classifications of Business and Special Purpose Industrial. Exit access of assembly spaces and adjacent accessory occupancy areas traverse same egress paths. As such, exit requirements will be based on the most stringent requirements – in this case Assembly Occupancy, per section 6.1.14.2 and 6.1.14.1.3.

4.2. Occupant load (IBC 1004.1.1; NFPA 101 7.3.1.2)

4.2.1 Occupant load factors per IBC Table 1004.1.1 (SF/person) and NFPA 101, 7.3.1.2 are provided in table 4.2.1 below (Refer also to Appendix A, *Occupancy Use & Classification*s).

Table 4.2.1 Occupant Loads

Use	Area (ft^2)	Occupant Load Factor (ft^2 per person)	Occupant Load
ASSEMBLY SPACE	29,000	Fixed Seating – N/A (Actual # of Seats)	2,966
ASSEMBLY LOBBY SPACE	7,181	15 gross*	479
PLATFORM	1,800	15 net	120
MULTI-PURPOSE ASSEMBLY SPACE (Room 119)	1,800	15 net	120
CONFERENCE ROOM	344	15 net	23
OFFICE SPACE	2,987	100 gross	30
ELECTRICAL SPACE	281	300 gross	1
MECHANICAL SPACE	474	300 gross	2
STORAGE SPACE	1,203	300 gross	5
CORRIDOR SPACE	2,824	100 gross	29
RESTROOM SPACE	3,689	100 gross	37
TOTAL	51,583	-	3,812

*Refer to LSC section 12.1.7.2 and Table A.7.3.1.2. Lobby space is not designed with the intention that it will be occupied by patrons waiting for a proceeding religious service, but should be designed for simultaneous use per LSC section 12.1.2.2. Lobby space was sized similar to a concourse waiting area in an airport terminal, as it is assumed occupants will congregate in less densely fashion than what would be anticipated in a theatre or restaurant waiting area.

4.3. Number of exits (IBC 1021, NFPA 101, 12.2.4, 7.4)

Required: Based on Table 1021.1 and NFPA 101 section 7.4, Occupant loads in all spaces in excess of 1,000 and the aggregate total of the building require a minimum of 4 primary exits.
Provided: 8 primary exits provided for building, 7 secondary exits from individual rooms.
Auditorium has 5 primary exits. Refer to Appendix B for additional information.

4.4. Capacity of means of egress

4.4.1 Capacity factors (IBC 1005.1; NFPA 101, 7.3.3.1)

NFPA 101 section 12.1.2.2 requires exits to be sized sufficient for simultaneous use. Means of egress components will be sized using calculated occupant loads multiplied by the following capacity factors: 0.3 (stairways) and 0.2 (doors, ramps, etc.) in accordance with IBC section 1005.1 and NFPA 101 section 7.3.3.1, but must be a minimal size as stated in table 4.4.1 below.

Table 4.4.1 Exit Capacity

EGRESS COMPONENT	COMPONENT SIZE	EGRESS CLEAR WIDTH	CAPACITY FACTOR	MAXIMUM OCCUPANT LOAD CAPACITY	ACTUAL OCCUPANT LOAD CAPACITY
Door 100	6'-0"	66"	0.2	330	172
Door 100A	6'-0"	66"	0.2	330	172
Door 100B	6'-0"	66"	0.2	330	172
Door 100C	6'-0"	66"	0.2	330	172
Door 100D	6'-0"	66"	0.2	330	164
Door 100E	6'-0"	66"	0.2	330	164
Door 100F	6'-0"	66"	0.2	330	164
Door 100G	6'-0"	66"	0.2	330	164
Door 100H	6'-0"	66"	0.2	330	164
Door 100J	6'-0"	66"	0.2	330	164
Door 100K	6'-0"	66"	0.2	330	164
Door 111A $^{\Psi}$	3'-0"	33"	0.2	165	2
Door 118	6'-0"	66"	0.2	330	371*
Door 118A	6'-0"	66"	0.2	330	371*
Door 118B	6'-0"	66"	0.2	330	371*
Door 118C	6'-0"	66"	0.2	330	371*
Door 119B	3'-0"	33"	0.2	165	60
Door 119C	3-0"	33"	0.2	165	60
Door 120	6'-0"	66"	0.2	330	179
Door 121B $^{\Psi}$	3'-0"	33"	0.2	165	9
Door 128A $^{\Psi}$	3'-0"	33"	0.2	165	2
Door 130A $^{\Psi}$	3'-0"	33"	0.2	165	2
Door 134	6'-0"	66"	0.2	330	179
TOTAL	117'-0"	1287"	-	6,435	3,812

* Exit Capacity is deficient for minimum number required by current code. Equivalency must address this issue, which is discussed in section 12.1 of this document.

Ψ Considered Secondary Exits for individual room egress

4.4.1.1 Aisles, corridors, and ramps – Minimum 44 inches wide (IBC 1018.2 and)

4.4.1.2 Doors – Minimum 32 inches clear width for means of egress doors (1008.1.1); minimum 28 inches clear width for doors to sleeping units (408.3.1); minimum 78 inches in height for doors to sleeping units (1008.1.1).

4.4.1.3 Stairs – Minimum of 44 inches width in accordance with IBC section 1009.1 and NFPA 101 table 7.2.2.2.1.2(B)

4.4.1.4 Assembly Space Main Exit - NFPA 101 section 12.2.3.6.2 and IBC section 1028.2 would require the main entrance/exit to be sized for a minimum of 1/2 the total occupant load. Exit access doors 112 thru 112G are considered the main entrance from the lobby. Half the auditorium exit load is determined to be 1483 (2,996/2). Exit capacity is limited to only 1,320 [(66*4)/0.2] causing a deficient capacity for main assembly exit access. This will need to be addressed in the equivalency egress provisions.

4.4.1.5 All egress components will be sized in capacity such that the loss of any means of egress leaves available at least 50% of the required capacity per NFPA 101 section 7.3.1.1.2.

4.5. Arrangement of means of egress

4.5.1 Remoteness of exits (IBC 1015.2.1, NFPA 101 7.5.1.3): Min. 1/3 of the maximum overall diagonal dimension of the building, area or space to be served including exits, exit access, and exit discharge. Refer to Appendix B, *Prescriptive Code Egress Layout*, for remoteness of exit analysis.

4.5.2 A minimum of 2 exits or exit access doors shall be remote from each area or space required to have 2 or more exits or exit access doors. Additional exits and/or exit access doors shall be located as remote as practicable.

4.5.3 Horizontal exits (IBC 1025, NFPA 101 7.2.4) – horizontal exits are not included in egress concept.

4.5.4 Travel Distance, Common Path of Travel, and Maximum Dead End Limits (IBC 1016, NFPA 101, 7.5.1.5, 7.6) – these are indicated in table 4.5.4 below. As discussed in section 4.1.2 of this analysis, compliance with the strictest egress requirements must be applied to the entire occupancy for mixed occupancy classification. In this case, the assembly requirements would be considered the most stringent and would be applicable for the entire building.

Table 4.5.4, Arrangement of Exits - Extracted data from NFPA 101, section A.7.6 and occupancy chapters 12 "New Assembly", 38 "New Business" and 40 "New Industrial"

Occupancy	Common Path Limit (ft.)	Dead End Limit (ft.)	Travel Distance Limit (ft.)
Assembly	20 serving > 50 occupants 75 serving <50 occupants	20	250
Business	100	50	300
Special Purpose Industrial	100	50	400

4.5.6 Stairways will comply with requirements for new stairs (IBC 1009, NFPA 101 7.2.2.2.1.1(a)). The maximum height between stair landings is 12 ft.

4.5.6.1 Riser Height: Minimum 4 in., Maximum 7 in.; Tread Depth: Minimum 11 in. Stairs must be uniform in dimension with no more than 3/16" variation in riser or tread depth and must be constructed such that treads and landings are free of projections that could cause a tripping hazard.

4.5.6.2 Handrails must be provided on each side of stair, but must be no more than 60" O.C. spacing (i.e. larger width stairs may require center rail). Handrails must be provided at a height between 34" - 38" above the walking surface of the stair tread and must be designed to be grasped firmly (typically a Circular cross section with an outside diameter of not less than 1 ¼" - 2"). Handrails must typically extend at least 12" beyond top riser at the landing or floor level and the depth of one tread beyond the bottom riser (at minimum 11" but to the length of the actual tread). (IBC 1012)

4.6. Discharge from exits (IBC 1027, NFPA 101 7.7)

A minimum of 50% of exits and exit capacities are required to discharge outdoors. Currently all exits discharge directly to public way.

4.7. Egress through intervening spaces (IBC 1003.6 & 1014.2, NFPA 101 7.5.1.2)

Exit access is not allowed to pass through intervening rooms or spaces unless accessory to one or the other, or as designed as a suite of rooms. Corridors will not provide exit access through intervening rooms other than adjoining corridors, lobbies, and other spaces allowed to be open to the corridor.

4.8. Illumination of Means of Egress (IBC 1006.1, NFPA 101 12.2.8 & 7.8)

Illumination of means of egress is required and will be provided within areas all portions of the building.

4.9. Emergency Lighting (IBC 1006.3, NFPA 101 12.2.9.1 & 7.9)

Emergency lighting is required for all portions of the means of egress and will be provided within the project areas.

4.10. Marking of Means of Egress (IBC 1011.1, NFPA 101 7.10.1.2)

Marking of all means of egress with exit signage is required and will be provided in areas in all portions of the building. These exits and exit access are readily marked on Appendix B.

4.11. Locking Arrangements (IBC 1008.1.10, NFPA 101 12.2.2.2.4)

Latches and locks on all primary exit doors and exit access doors serving more than 50 occupants will be provided with panic hardware. No delayed egress or controlled access doors will be incorporated into egress concept.

5. Accessibility

5.1. Accessible Route & Accessible Entrances (IBC 1104)

The accessible route shall be in accordance with IBC section 1104 and ANSI A117.1, 2003.

5.2. Accessible Means of Egress (IBC 1007, NFPA 101 7.5.4)

A minimum of 2 accessible means of egress are required for assembly occupancies. Since building is on ground level, accessible entrances can also serve as accessible means of egress.

6. Assembly Seating Arrangements

6.1 Number of Seats Between Aisles (IBC1028.10.1, NFPA 101 12.2.5.5.4)

Aisles at both ends - Rows of seating served by aisles or doorways at both ends will not exceed 100 seats per row.

6.2 Aisles & Aisle Accessway Width (IBC 1028.10, NFPA 12.2.5.5.5.1) – Also Reference Appendix B, *Prescriptive Code Egress Layout* - Assembly Worksheet

6.2.1 Aisle accessways at both ends (IBC1028.10.1, NFPA 12.2.5.5.4.1) - The 12 in. minimum clear width of aisle accessway shall be increased by 0.3 in. for every seat over a total of 14. Currently some aisle accessways are in excess of this minimum threshold so smoke protected assembly seating must be implemented into the design.

6.2.2 Aisle accessways at one end only (IBC 1028.10.2, NFPA 12.2.5.5.5.1) - The 12 in. minimum clear width of aisle accessway shall be increased by 0.6 in. for every seat over a total of 7. Aisle accessways at one end only are limited to a maximum of 30 feet.

6.2.3 Ramped Aisles (IBC 1028.9, NFPA 12.2.5.6.3) - Aisles serving seats on both sides shall be a minimum of 42 inches.

6.4 Smoke Protected Assembly Seating (SPAS) Provision (IBC 1028.6.2, NFPA 101 12.4.2)

Smoke-protected assembly seating is defined as "seating served by a means of egress that is not subject to smoke accumulation within or under the structure." Smoke-protected assembly seating is analyzed for academic purposes in this egress concept, but will also be used as an equivalency to the deficiencies in egress capacity identified section 4 of this report. SPAS will be achieved by providing an engineered smoke control system that will keep smoke from affecting the occupants during the time needed to evacuate or the space above any occupied area can hold the volume of smoke that is generated during the time needed for occupants to evacuate. Refer to section 11 of this analysis for further details.

6.4.1 Smoke Protected Assembly Seating (SPAS) Reductions (IBC 1028.6.2, NFPA 12.4.2) - reductions in egress capacity and egress parameters, including travel to exits and dead end aisle widths for seating rows are permitted. Table 6.4.1, below is a code comparison showing the various provisions allowed for SPAS and it analyzes the percent reduction associated with these parameters. The limitations on egress width and travel are reduced as a performance measure because it is anticipated, with the removal and control of smoke to a manageable height above occupants, occupants will have longer time to evacuate. As such, large reductions are allowable, as the occupant load significantly increases – this is demonstrated in table 6.4.1.

Table 6.4.1 Smoke Protected Assembly – Extracted form NFPA 101 and IBC requirements

Number of Seats	Smoke Protected Assembly Seating								
	Inches of Clear Width per Seat Served				%		(ft)		
	Stairs & Aisle Steps with handrails within 30 inches	Stairs & Aisle Steps without handrails within 30 inches	Passageways, doorways and ramps not steeper than 1 in 10 slope	Ramps steeper than 1 in 10 in slope	Percent Reduction from Non-Smoke Protected Seating for Stairs & Aisles	Percent Reduction from Non-Smoke Protected Seating - doors, ramps, etc.	Travel Distance Limits*	Dead End Limits	Common Path of Travel
2,000	0.3	0.375	0.22	0.242	0	0	400	30	50
5,000	0.2	0.25	0.15	0.165	33.3	31.82	400	30	50
10,000	0.13	0.163	0.1	0.11	56.7	54.55	400	30	50
15,000	0.096	0.12	0.07	0.077	68	68.18	400	30	50
20,000	0.076	0.095	0.056	0.062	74.7	74.55	400	30	50
≥25,000	0.06	0.075	0.044	0.048	80	80	400	30	50

*Assuming Fully Sprinklered Building

6.5 Life Safety Evaluation (IBC 1028.6.2, NFPA 101 12.1.7.3, 12.4.2.2 & 12.4.1)

A life safety evaluation is required to be performed where an assembly occupant load exceeds 6,000 or when considering provisions for smoke-protected assembly seating. A life safety evaluation is a comprehensive report on the safety precautions during planning that considers various emergencies that could drastically affect the assembly of large crowds that would make them even more vulnerable including natural disasters, medical emergencies, fire hazards and emergencies, and even civil disturbances. It also considers how facility management, event participants, emergency responders, and others interact during a given scenario. Life safety evaluations are required to be prepared by persons having experience with the conditions described and must be approved by the authority having jurisdiction. Reference Section 13 of this report for additional information.

6.6 Platform (IBC 410, NFPA 3.3.246 & 12.4.5)

The main podium used for educational/worship purposes shall be constructed as a platform as defined by both the IBC and NFPA, as combustible contents are very limited and multiple stage curtains are not present. It shall be constructed of non-combustible construction per IBC section 410.4 and NFPA 101 section 12.4.5.1.

7. Passive Fire Protection Features

7.1. Incidental Use and Hazardous Area Separation (IBC 508.2.5, NFPA 101 12.3.2)

The following rooms will be designed with an appropriate level of hazard protection as mentioned below:

Mechanical Room: 1 Hour or Automatic Fire-extinguishing System
Refrigerant Machinery Room: 1 Hour or Automatic Sprinkler System

When making use of automatic sprinkler system, walls must be constructed as a minimum with smoke partitions of substantial construction to limit smoke spread and solid-core doors with self-closing door arrangements for opening protection.

7.2. Fire Rated Separation of Exits and Exit Access

7.2.1 Exit Access Corridors (IBC 1018.1, NFPA 101 12.3.6).

Corridors are required to be separated with fire resistance rated construction as mentioned below, for specific occupancy classifications - this analysis considers building as fully sprinklered:

A-3 use – 0 hour fire rating
B use – 0 hour fire rating
F-1 use – 0 hour fire rating

7.2.2 Exits (IBC 1022, NFPA 101 7.1.3.2).

Exit enclosures are required to have 2-hour fire resistance rating where connecting 4 stories or more; 1-hour fire resistance rating is required for shafts connecting less than 3 stories. Enclosed stairs shall not open onto normally unoccupied space in accordance with section 1022.3. Openings into enclosed stairs are to be limited to only those necessary for maintenance and operation of stair. Currently no enclosed exits are necessary for a single story building.

7.3. Shaft Enclosures (IBC 708, NFPA 101 12.3.1 & 8.6)

Shaft enclosures are required to have 2-hour fire resistance rating where connecting 4 stories or more, and 1-hour fire resistance rating, where otherwise providing connecting multiple floors. Currently no enclosed exits are necessary for a single story building.

7.4. Opening Protectives (IBC 715, NFPA 101 8.3.4)

Openings in fire resistance-rated assemblies will be in accordance with IBC section 715.4, NFPA 101 8.3.4.1, and NFPA 80, as shown in table 7.4.1 below. Only incidental areas protected with smoke partitions are necessary for consideration.

Table 7.4.1 Protective Openings

Component	Walls and Partitions (hr)	Fire Door Assemblies (hr)	Fire Window Assemblies (hr)
Elevator hoistways	2	1 1/2	NP
	1	1	NP
Vertical shafts (including stairways, exits, and refuse chutes)	1	1	NP
	1/2	1/3	NP
Fire barriers	3	3	NP
	2	1 1/2	NP
	1	3/4	3/4
	1/2	1/3	1/3
Horizontal exits	2	1 1/2	NP
Horizontal exits served by bridges between buildings	2	3/4	3/4
Exit access corridors	1	1/3	3/4
	1/2	1/3	1/3
Smoke barriers	1	1/3	3/4
Smoke partitions	0	0	0

8. Interior Finish Requirements

8.1. Wall and Ceiling (IBC 803.9, NFPA 101 12.3.3 & 10.2)

8.1.1 Exits – Class A
8.1.2 Exit access corridors & lobbies – Class A
8.1.3 General assembly areas & other spaces – Class A or B

8.2. Floor Finish (IBC 804.4.1, NFPA 101 12.3.3.5 & 10.2)

Class I or Class II floor finish. The floor finish must not be Class I or Class II in exit enclosures, exit access corridors and spaces not separated from them by walls complying with 18.3.6.1. Carpet and carpet-like interior floor finishes must comply with ASTM D2859, Standard Test Method for Ignition Characteristics of Finished Textile Floor Covering Materials. Floor coverings, other than carpet, must have a critical radiant flux of 0.1 W/cm^2.

9. Fire Extinguishing Systems

9.1. Water-Based Fire Suppression Systems (IBC 903.2.1.3, NFPA 101 12.3.5.2 & 9.7)

Automatic fire sprinkler protection will be provided throughout the facility. The system shall be designed and installed in accordance with NFPA 13 with quick-response sprinklers used throughout all light and ordinary hazard classifications. The system will be a wet-pipe sprinkler system supplied thru one sprinkler zone, under light hazard limitations of 52,000 ft^2 per NFPA 13, section 8.2.1. The system riser will be located in the rear of the building in a mechanical room, adjacent to office spaces; reference Appendix E, *Preliminary Sprinkler System Layout* for further detail on sprinkler layout.

9.2 Water Supply (IBC 903.3.5)

The automatic fire sprinkler system that will be provided throughout the Orangeburg Assembly Hall of Jehovah's Witnesses and will be feed solely by a municipal water supply system in accordance with NFPA 13 section 23.1.8.

9.2.1 Available Water Supply

Initial water supply analysis was based on flow tests, conducted in accordance with NFPA 291 *Recommended Practice for Fire Flow Testing and Marking of Hydrants*, at hydrants identified as H47-59, H47-58, and H47-60. Data for each of these hydrants is indicated below:

H47-59 – Static: 52 psi; Flow: 1060 gpm; Residual: 48 psi
H47-58 – Static: 51 psi; Flow: 1130 gpm; Residual: 48 psi
H47-60 – Static: 51 psi; Flow: 1060 gpm; Residual: 48 psi

Refer to the attached water curve graphical presentation in Appendix D, *Available Water Supply Curves,* for additional information and analysis related to water supply system capabilities.

9.2.2 Backflow Prevention

To protect the potability of the municipal water supply, a new double check backflow preventer will be provided in the first floor mechanical room connected to main riser in accordance with NFPA 13 section 23.1.8.2 and the *International Plumbing Code* (*IPC*), 2009 as referenced by the IBC. A test valve located downstream of the backflow preventer for flow testing the backflow preventer at full system demand flow will be provided.

9.2.3 Available Water at the Base of Riser

Water supply line will be cement lined ductile iron 6" pipe running from municipal connection to base of riser (BOR) for 100 feet. The elevation change from BOR is approximately 2 feet above municipal supply point of connection. Based on anticipated flow, the pressure available resulting from friction and elevation change, at base of riser is 1,060 gpm @ 41 psig residual.

9.3 Sprinkler Design Criteria (NFPA 13, 5.1, 11.2.3)

The majority of the building will be classified as light hazard occupancy. Mechanical, transformer, and electrical rooms will be Ordinary Hazard Group 1. Storage, trash, and

mechanical rooms with fuel-fired equipment will be Ordinary Hazard Group 2. Design densities and flow durations will be as specified in Table 9.3 below.

Table 9.3 Sprinkler Design Criteria Summary

Throughout Facility Unless Otherwise Noted	
Hazard	Light
Design Density	0.10 gpm/SF
Design Area	1500 SF [1,2]
Hose Stream	100 gpm
Duration	30 minutes
Mechanical, Transformer, Electrical Rooms	
Hazard	Ordinary Hazard Group 1
Design Density	0.15 gpm/SF
Design Area	1500 SF [1]
Hose Stream	250 gpm
Duration	60 minutes
Storage, Trash, Mechanical Rooms with Fuel-Fire Equipment	
Hazard	Ordinary Hazard Group 2
Design Density	0.20 gpm/SF
Design Area	1500 SF [1]
Hose Stream	250 gpm
Duration	60 minutes

[1] Design area reductions in accordance with NFPA 13 (2007) chapter 11 will be applied as applicable.
[2] Design area slope increase is required in auditorium sprinkler remote area calculations in accordance with NFPA 13 (2007) chapter 11.

9.3.1 Hydraulic Calculations (NFPA 13, 22.4.4)

During early stages of design, it is critical that a fire protection engineer provide hydraulic calculations demonstrating that the design will provide an adequate water supply for the fire extinguishing systems. The nature of these hydraulic calculations is typically performed during the 35 percent design stage. Calculations must be based on recent water flow test data.
The preliminary design of this system is calculated (see Appendix F, *Preliminary Sprinkler System Calculations*) to analyze water supply and verify adequacy for this automatic sprinkler system. This was performed as a conceptual design (reference 9.3.3 of this document below). It is recognized that the system is anticipated to be laid out as a gridded system, which will provide a more robust use of hydraulics, and it is important to perform several hydraulic calculations to verify system hydraulics are peaked. In addition, it is important to consider the hydraulic demand of the sloped ceiling configuration in the main auditorium. However, during conceptual hydraulic analysis, it was concluded that furthest distance from riser would be analyzed for remote area and is considered conservative for determining water supply adequacy.
The rectangular remote area was determined to be 47 feet long (1.2 *√1500) with a minimum number of 4 sprinklers on each branch line (i.e., 47 ft. /12 ft. mas sprinkler spacing in this layout). Based on the attached calculations, a total demand of **324 gpm @ 44 psig**, including a 100 gpm hose stream allowance, is the anticipated demand. As a result of this analysis, it can

be concluded that municipal water system will be adequate without any additional pressure boost by a stationary fire pump (reference Appendix D, *Available Water Supply Curves,* for additional water supply information related to sprinkler demand).

9.3.2 Seismic Constraints (IBC 1613)

Orangeburg, located approximately 60 – 70 miles from Charleston, SC, is close to significant seismic fault lines. The IBC classified seismic design category of D requires the consideration of seismic restraints for the automatic fire sprinkler system. Lateral bracing and supports will be designed in accordance with NFPA 13.

9.3.3 Conceptual Design – Preliminary Plans (NFPA 13, A.22.1)

NFPA 13, section A.22.1 describes preliminary plans, as those early documents typically prepared by the design professional, in order to formalize the fire sprinkler concept and fire protection strategy.
This section states in part:

> *"Preliminary plans should be submitted for review to the authority having jurisdiction prior to the development of working plans. The preliminary plans can be part of the construction documents submitted in order to obtain a building permit…Preliminary plans should include as much information as is required to provide a clear representation of the hazard to be protected, the system design concept, the proposed water supply configuration, and building construction information pertinent to system layout and detailing."*

The owner's information certificate should be used to obtain a declaration of the intended use of the occupancy to be protected. This certificate was completed and is included in Appendix F, *Preliminary Sprinkler System Calculations*. Conceptual layout of the riser (6" riser with reliable alarm check valve), 4" schedule 40 gridded cross mains, with primarily 1" schedule 40 branch lines. It is proposed that quick response sprinklers are to be provided throughout the majority of the compartment with exception only for mechanical space (reference Appendix E, *Preliminary Sprinkler System Layout* for additional information).

9.3.3 Detailed Design – Working Plans (NFPA 13, 22.1)

Working plans, also called shop drawings, differ from preliminary plans in that they include the details of the project, such as the exact location of sprinklers and the equipment necessary for the operation of the sprinkler system. Shop drawings must include the layout and detail information, as well as the associated hydraulic calculations that show how the work will be fabricated and installed. These documents are to be prepared by a qualified technician, with a minimum of NICET Level III certification, in conformance with the conceptual design provided in the preliminary plans, and these working drawings are to be submitted for approval prior to system installation but after the issuance of a building permit.
The working plans need to include enough information to make sure that all of the rules of NFPA 13 are implemented as applicable. The 46 items listed in 22.1.3 outline the minimum information that needs to be provided to the fire protection engineer in responsible charge of the project in addition to the Authority Having Jurisdiction (AHJ).

9.4 Inspection, Testing & Maintenance (ITM) Criteria (IFC 903.5, 901.6.1; NFPA 25)

An ITM program, as part of operational maintenance, is a critical component in ensuring the overall reliability of a system. ITM programs will discover problems in a system that could result in a failure, and by correcting such problems system failure rates will decrease. This will have the effect of increasing the overall reliability of a fire protection system. This program of ITM will be part of the prepared Operations and Maintenance Manual (O&M manual), which is necessary for buildings designed with a performance-based approach. This will become invaluable through the life cycle of the building in determining an appropriate ITM program, as well boundary conditions and restrictions related to occupancy, fire protection system design, and fuel loading. Reliability for overall sprinkler performance, reported by NFPA, is currently rated at 87 %, based on estimations of an operation rate of sprinkler systems of 91% where fires were large enough to actuate the system and an overall effective rate of 96%. Nearly two-thirds (64%) of sprinkler system failure rates could be attributed to system being shut off, i.e. valve closed or partially closed; other reasons for failure include manual intervention (17%), lack of maintenance (8%), inappropriate equipment for the type of fire (6%), and damaged component (5%). Therefore, regular ITM could immensely impact roughly 83% of reported sprinkler system failures.

NFPA 25 is the primary guiding document for automatic sprinkler system maintenance and care. This standard contains regimens for each components of the system and contains charts, tables and verbiage to guide the user in implementing an appropriate Inspection, Testing and Maintenance (ITM) program. In addition to the prescribed regimens included in NFPA 25, new language in this standard also provides guidance in developing performance based provisions for ITM which could turn out to be either more or less restrictive than the prescriptive schedules listed in the standard. To prepare a performance based approach, one must consider historical test documents of performance for similar installations; as well, performance based maintenance programs will most likely need to be phased in over the life cycle of the building to ensure the reliability of the systems. Historical test data and repair history will assist in developing an estimated failure rate (Figure 3.4.2) and be well vetted among all stake holders including the owner, AHJ, and the design team.

$$FSFR\ t = \frac{NF}{(NC)(t)}$$

Where FSFR = fire system failure rate (failures per year)
NF = number of failures
NC = total number of fire systems inspected or tested
t = time interval of review in years

Figure 9.4.2 Failure Rate Calculation
(Source: Extracted – NFPA 25, 2008, A.4.6.1.1.1)

Routine ITM will address problems associated with water pipe corrosion, deterioration and/or leaking of components including valves, gauges and sprinklers, changes in hazard classification, water supply deterioration, and obstructions to water flow and hydraulics. Proper sprinkler activation and effectiveness depends heavily on the design criteria established when the system was originally designed. When changes in hazard classification occur as a result of the introduction of additional fuel loads, then it is incumbent on the AHJ, the building owner and the fire protection engineer to ensure that the sprinkler system design is adequate for the

needed changes. Of primary concern to the fire protection engineer is an increasing prevalence of Microbiologically Influenced Corrosion (MIC) in fire sprinkler systems. While research into this phenomenon is inconclusive as to the causes and treatment solutions, it is incumbent on the engineer to evaluate the water supply and environmental conditions that may generate conditions that could contribute to MIC in water based fire protection systems. Table 9.4.2, listed below describes the various ITM practices that should be implemented into the buildings maintenance and care program for the automatic sprinkler system.

Table 9.4.2 Sprinkler ITM Requirements Summary

Water-based Suppression Components	Standard Inspection, Testing and Maintenance (ITM) Requirements
City Water Main	Maintained by city. Water should be available at all times. Visual review of connection should be done as part of quarterly testing by the contractor performing the maintenance contract.
Above Ground Piping/Supports The above ground piping includes the riser, the feed main, cross mains and branch lines.	Annual inspection should be done by the contractor performing the maintenance contract. This inspection should cover the review of piping and supports to verify that no hangers are loose or that objects are not being hung from any exposed piping. Additional inspections should be done any time occupancy changes or modifications to the building are done.
Control Valves and Gauges Includes check valves, backflow preventer and drain and test valves.	Valves should all be kept readily accessible and unobstructed so that they can be operated promptly and examined to see that they are open and in good operative condition, turn easily and do not leak. The post indicator valve outside the building by the riser should be open at all times. Periodic inspection is done by the local fire department. Quarterly inspection and testing should be part of the quarterly testing by the contractor performing the maintenance contract. These quarterly inspections and tests should be timed to include the spring and fall tests noted below. A spring inspection should be done after low temperatures have passed. This should include a flow test and review of valve operation. A fall inspection should be conducted of the building envelope to ensure that cold air will not enter to expose the sprinkler system to freezing. Additional inspections should be done any time occupancy changes or modifications to the building are done. Water flow alarm devices, supervisory signals should be tested as part of the quarterly testing by the contractor performing the maintenance contract. A spring inspection should be done after low

	temperatures have passed. This should include a flow test and review of alarm and tamper switch operation. This should be done as part of one of the scheduled quarterly visits by the contractor performing the service contract.
Water Flow Alarm, Supervisory and Tamper Switch Devices	Maintenance staff should visually inspect monthly. Water flow alarm devices, supervisory signals should be tested as part of the quarterly testing by the contractor performing the maintenance contract. A spring inspection should be done after low temperatures have passed. This should include a flow test and review of alarm and tamper switch operation. This should be done as part of one of the scheduled quarterly visits by the contractor performing the service contract.
Signs	Sign information should be inspected annually by the contractor performing the maintenance contract. Additional inspections should be done any time occupancy changes or modifications to the building are done.
Sprinklers	The sprinklers installed in the building are fast-response type and should be tested at 20 years and then every 10 years after. When tested 1 percent of the sprinklers should be tested. Annually inspection of the following items should be done by the contractor performing the maintenance contract. Annual sprinkler inspections should review the following items. 1. Observe and note absence of sprinklers from any rooms. 2. Observe location of sprinklers. Are they under shelves, benches racks or platforms. 3. Do they have proper clearance? Are they obstructed? 4. Deflector distance should conform to NFPA 13. 5. The sprinkler installation should be reviewed. The rating, type and condition of the sprinklers should be reviewed. Sprinklers should be reviewed for corrosion, paint coatings and deposits. Additional inspections should be done any time occupancy changes or modifications to the building are done.
Fire Department Connection	Inspect regularly to make sure caps are in place, threads are in good condition, the ball drip or drain is in order, and the check valve is not leaking.

9.5. Portable Fire Extinguishers (IBC 906.1)

Portable fire extinguisher cabinets will be provided in closed-front, recess-mounted fire extinguisher cabinets of steel construction, sized to accommodate 2.5 gal pressurized water extinguishers to be provided by the owner. Locations will comply with NFPA 10.

10. Fire Detection and Alarm

10.1. Fire Alarm System (IBC 907.2.1, NFPA 101 12.3.4)

A fire alarm system designed in accordance with NFPA 72 is required to supervise the automatic fire extinguishing system, smoke control system, and fire detection equipment. Additionally, performance of the alarm components requires it to provide for occupant, fire department, and operator or police notification of a fire alarm condition; supervisory and trouble signals will be acknowledged locally at the panel and transferred to Central Station monitoring only. Voice evacuation system is required for large occupant assembly occupancies and will be provided throughout building, per IBC section 907.2.1.1 and NFPA 101 section 12.3.4.3.4. Voice evacuation system shall be provided with an emergency backup power supply per IBC section 907.5.2.2.4 and NFPA 110.

10.1.2 Fire Alarm System Features

Features of the fire alarm system design include the following components, installation and operational features (refer also to Appendix J, *Preliminary Fire Alarm System Layout*, for additional installation information):

1. Fire alarm control panel
2. Fire alarm subpanels
3. Fire alarm annunciator panel
4. Fire alarm transmission to the campus main control panel located in Building 1
5. Supervision of sprinkler system alarm and supervisory devices
6. Spot-type photoelectric smoke detectors throughout auditorium compartment
7. Duct smoke detectors in supply and return air ducts for smoke segregation
8. Smoke damper detection devices associated with smoke management system
9. Manual fire alarm stations
10. Audible notification appliances (speakers)
11. Visual notification appliances in publicly accessible areas and mechanical rooms
12. Class B Signaling Line Circuits for Initiating Devices
13. Class B Signaling Line Circuits for Monitoring Modules
14. Class B Notification Appliance Circuits

Mounting Heights for various components are included in Figure 10.1 below.

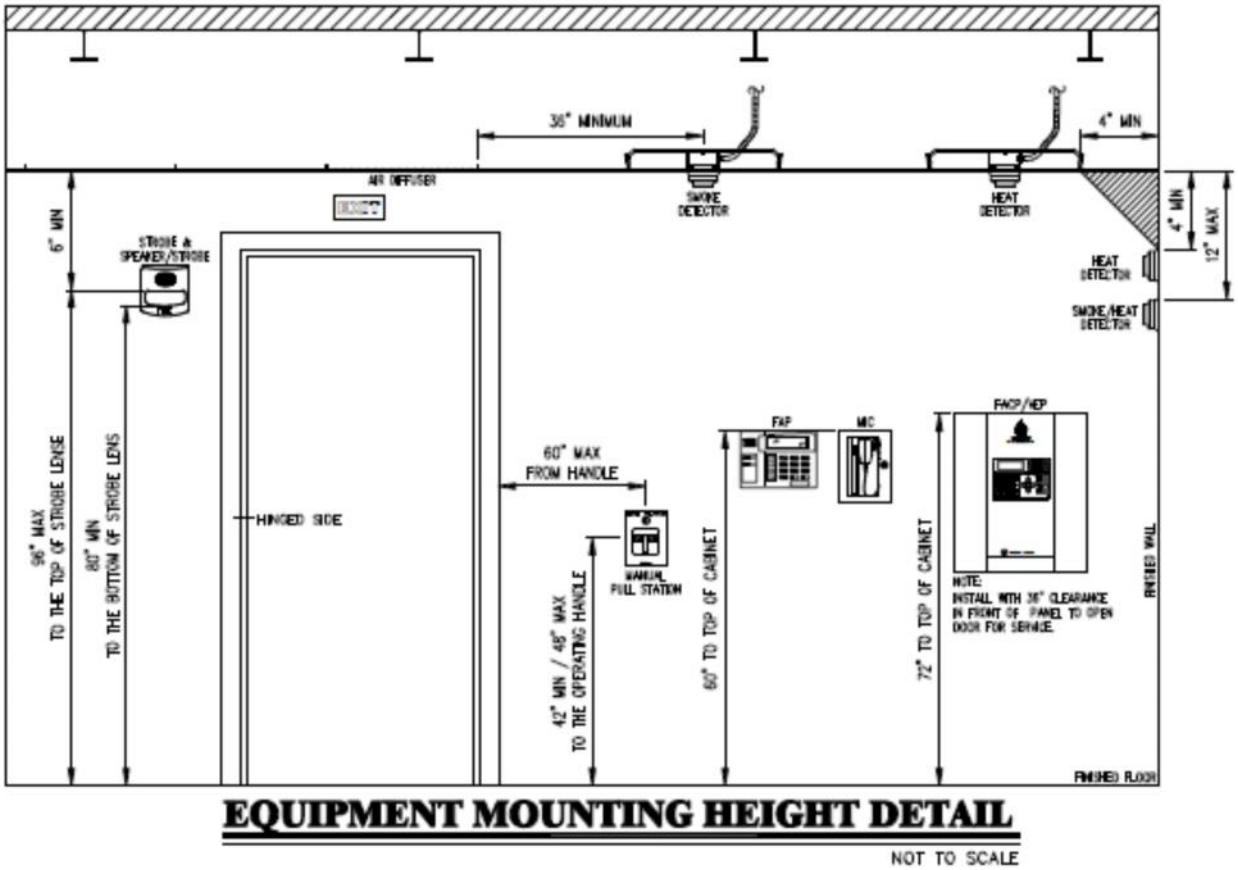


Figure 10.1 Mounting Height Diagram

10.2 Fire Detection Design Criteria (NFPA 72, 17.7)

Fire Detection System

A partial automatic detection system will be provided in the auditorium compartment for activation of the smoke control system in accordance with IBC 909.12. System layout will be performance-based engineering design using the approach found for performance criteria provided in appendix B of NFPA 72 (refer to Appendix L, *DETACT Fire Model – Smoke Detector Activation*, for additional information). Reference sections 3.2.1 through 3.2.3 below for additional information. Additional smoke detection will also be provided at the fire alarm control panel, remote annunciator and NAC power booster panels, per NFPA 72 section 10.15.

Duct-mounted smoke detectors will be provided in accordance with NFPA 90A and the *International Mechanical Code* (IMC). AHU's greater than 2,000 CFM will be provided with detectors in both the supply lines per NFPA 90A and on the return lines per IMC section 606.2.1. Duct-mounted smoke detectors need to be installed to obtain a representative sample of the airstream and in accordance with manufacturer's instructions. This generally entails locating the detector away from duct bends where air flow may be turbulent, per NFPA 72 section 17.7.5.5.1. Duct-mounted smoke detectors will be used for smoke dampers used in the operation of the smoke management system.

10.2.1 Performance Based Design Approach (NFPA 72, Annex B; SFPE HBFPE 4-1)

Prescriptive requirements for heat and smoke detector spacing layout are prescribed in NFPA 72 sections 17.6.3 and 17.7.3. In addition, NFPA 72 sections 17.6.3.8 and 17.7.1 allow spacing

to meet the alternative design methods offered by Annex B of NFPA 72. Spot-type photoelectric smoke detectors are only being installed in auditorium. Since detectors are installed at a height above finished floor of 24 feet, it becomes necessary to use Annex B to determine actual spacing.
In developing performance criteria, it is important to develop anticipated fire scenarios as discussed in NFPA 72, Annex B section B.2.3.1. In general a fire scenario defines the development of a fire and the spread of combustion products throughout a compartment or building. A fire scenario represents a set of fire conditions that are deemed a threat to a building and its occupants and/or contents, and, therefore, should be addressed in the design of the fire protection features of the structure. Fire scenarios are used to evaluate the performance of proposed designs. Consequently, it is critical that all the stakeholders agree, up front, on how a proposed design will be evaluated. This decision prevents the performance evaluation from changing as the design process moves forward. The fire scenario will be used to produce a model of the effects of fire in the building or compartment to be protected. The time at which the fire alarm system is predicted to respond to those fire effects is compared to the time needed to execute the planned response. Thus, the performance of the fire alarm system is evaluated in the context of a set of scenarios, which should be chosen and agreed upon by the stakeholders as representing reasonable worst-case situations. The process of developing a fire scenario is a combination of hazard analysis and risk analysis. The hazard analysis identifies potential ignition sources, fuels, and fire development. Risk is the probability of occurrence multiplied by the consequences of that occurrence. The risk analysis looks at the impact of the fire to the surroundings or target items. The fire scenario should include a description of various conditions, including building characteristics, occupant characteristics, and fire characteristics. Building characteristics include the following:

(1) Configuration (area; ceiling height; ceiling configuration, such as flat, sloped beams; windows and doors, and thermodynamic properties)
(2) Environment (ambient temperature, humidity, background noise, and so forth)
(3) Equipment (heat-producing equipment, HVAC, manufacturing equipment, etc.)
(4) Functioning characteristics (occupied, during times, days, and so forth)
(5) Target locations
(6) Potential ignition sources
(7) Aesthetic or historic preservation considerations

For this performance-based analysis refer to section 12 of this report for a discussion regarding selection and analysis of selected fire scenarios.

10.2.2 DETACT Modeling

The smoke detector response can be assumed when the local smoke density exceeds the detector threshold sensitivity. Smoke detectors are known to exhibit a delay in response referred to as *smoke entry delay,* which is related to the aerodynamic restriction of the outer housing and sensor design. This entry delay can be quantified as related to the detector's *characteristic length L.* The entry delay time is the detector's characteristic length divided by the local flow velocity. The calculations for this method are sufficiently complex that they cannot be done by hand with any degree of accuracy. Thus, methods have been incorporated into several of the fire models in popular use. One, called DETACTQS, is specifically for the estimation of the activation times of heat detectors and sprinklers. DETACT can be used for smoke detectors by applying the optical density to the temperature rise correlation. The correlation of optical density to temperature rise states that there is a direct relationship between the temperature rise and the smoke at a detector. The correlation values are obtained in Annex B of NFPA 72.

10.2.3 Conclusions

The response characteristics of smoke detectors are not well understood. While research suggests a correlation between temperature and optical response exists, there is still a lot of uncertainty as to what that response is. For this analysis, it was assumed that a low-temperature heat detector could be approximated for design purposes. Reference was made to NFPA 72 Tables B.3.2.5 and B.4.7.5.3. The numbers in Table B.4.7.5.3 are estimated based on research by Heskestad and Delichatsios, as indicated in NFPA 72, section B.4.7.5.3. Calculations based on using DETACT model are included in appendix L, *DETACT Fire Model – Smoke Detector Activation.* Calculated results for auditorium smoke detectors indicates that smoke detectors installed at the typical 30 foot maximum spacing arrangement will activate at 63 seconds.

10.3 Notification & Annunciation (NFPA 72, 18.1)

Assembly occupancy notification will be designed for public mode general building evacuation. Strobes will be provided in publicly accessible areas as required. Occupants will be notified through the EVACS with a pre-recorded voice message indicating **"There is an emergency in the building, please proceed to the nearest exit."** Prior to the voice message, a temporal 3 pattern alert tone will sound throughout the building. Simultaneously, strobes will flash in all public areas to indicate an alarm condition to the hearing impaired.
The fire alarm and emergency voice alarm system will transmit both alarm and supervisory signals to a UL listed central station service. The central station service will immediately contact the local fire department to initiate an emergency response. Upon receipt of a supervisory signal, the central station service will contact appropriate building maintenance staff. Trouble signals (e.g., grounds, opens, low battery, loss of primary power, or other abnormal fire alarm/emergency voice alarm condition) will also transmit to the central station service, and will initiate an audio and visual alarm at the fire alarm control panel (reference Appendix I, *Fire Alarm Sequence of Operations Matrix*, for additional information. A remote annunciator panel will be located at the main vestibule lobby to assist in emergency response per NFPA 72 section 10.16 and NFPA 101 section 9.6.6.

10.3.1 Fire Alarm Audibility (NFPA 72, 18.4.3.1)

NFPA 72, section 18.4.3.1 specifies the public audibility requirements for NAC devices to be at least 15 dB above ambient sound level or 5 dB above the maximum sound level having a duration of at least 60 seconds, whichever is greater. This maximum sound pressure parameter is measured at 5 ft above the floor in the area required to be served by the system using the A-weighted scale (dBA). The table below is excerpted from applicable requirements found from NFPA 72, table A.18.4.3. The average and minimum decibel levels required for the various occupancies at this assembly hall are listed in table 10.3.1 below:

Table 10.3.1 Audibility Requirements

Occupancy	Avg. Ambient dBA	Minimum dBA Required
Office Areas	55	70
Assembly Areas	55	70
Storage Areas	55	70
Mechanical Rooms	90	105

10.3.2 Fire Alarm Intelligibility (NFPA 72, 18.4.10)

Voice Intelligibility design is initiated by the establishment of Acoustically Distinguishable

Spaces (ADS), determined by the system designer during the planning and design of a EVAC system, per NFPA 72, section 18.4.10.1.
An ADS is defined by NFPA 72 as:

> "An emergency communication system notification zone, or subdivision thereof, that might be an enclosed or otherwise physically defined space, or that may be distinguished from other spaces because of different acoustical, environmental or use characteristics such as reverberation time and ambient sound pressure level."

Then, in accordance with NFPA 72, section 18.4.10.2, each ADS is to be identified as requiring or not requiring voice intelligibility. Intelligibility is addressed in greater detail in NFPA 72 annex D. It is anticipated that directions in the auditorium space will need to be intelligible; average ambient sound levels are expected to be in a range where intelligible messages can be interpreted. Communication system is considered acceptable if at least 90 percent of the measurement locations within each Acoustically Distinguishable Space (ADS) have a measured STI of not less than 0.45 STI (0.65 CIS) and an average STI of not less than 0.50 STI (0.70 CIS).

Factors in the space that will affect intelligibility are identified below:

1. Signal to noise level - Background noise and ambient sound levels will affect sound distribution; speakers wattage and spacing will directly impact intelligible sound better than just increasing speaker volume.
2. Echoes and reflections - The space configuration and the finish materials used in room or area will impact sound transmission as well as obstructions to speaker transmission.
3. Talker ability - Accents, dialects, diction, and tone of voice will directly impact the ability to understand a message by the listener. For instance, a female voice has been shown to be better understood inside a building.

10.3.3 Fire Alarm Visibility (NFPA 72, 18.5)

NFPA 72, 18.5.4.4 defines the public mode visible appliance spacing in corridors. Section 18.5.4.4.5 indicates that the separation in corridors be not greater than 100 feet between appliances and located not more than 15 feet from the end of a corridor. All service corridors have combination speaker/strobe appliances located at each of two exits and in the center, spaced approximately 80 feet apart and, therefore, meet the 100' spacing requirements.

10.3.4 Emergency Communication System (Mass Notification System; NFPA 72, 24.3.2)

Emergency Communication/Mass Notification systems (ECS/MNS) are enhanced emergency voice communication systems that can be used to broadcast non-fire emergencies including severe weather, chemical spills, terrorist attacks, etc. NFPA 72, chapter 24 sets forth guidelines for the design and installation of emergency communication/mass notification, as well as guidelines for performing risk analysis to determine necessity of a system. Currently there are no code requirements mandating private installations of emergency communication or mass notification systems per NFPA 72 section 24.3.2.

10.3.5 Voltage Drop Calculations (NFPA 72 18.3.2.3; NFPA 70)

Actuation of alarm notification appliances or emergency voice communications, emergency control functions, and annunciation at the protected premises shall occur within 10 seconds after the activation of an initiating device per NFPA 72 section 10.9.2.
NFPA 72, section 18.3.2.3 suggests that NACs require a voltage drop analysis to ensure that all appliances connected to the circuit are within the limits necessary for proper operation. A lump-sum analysis is typically performed which conservatively assumes all appliances are located at

the end of the circuit. The minimum operating voltage of a typical appliance is 16 volts and the minimum operating voltage of a control unit is typically 20.4 volts. The voltage drop analysis is shown in Appendix H, *Preliminary Fire Alarm System Calculations*.

10.4 Fire Alarm System Design Considerations

10.4.1 Seismic Constraints (IBC 1613; ASCE 7, 13.2.2)

Orangeburg, located approximately 60 – 70 miles from Charleston, SC, is close to significant seismic fault lines. The IBC classified seismic design category of D requires the consideration of seismic restraints for the fire alarm system as critical equipment. The component importance factor, Ip, shall be taken as 1.5 for a component required to function for life-safety purposes after an earthquake, including fire protection sprinkler system monitoring. Fire alarm panel requires components to be certified exclusively through shake table testing or experience data.

10.4.2 Fire Alarm Power Supply – Primary & Secondary (IBC 907.6.2; NFPA 101 9.6.1; NFPA 72 10.5)

The secondary power supply capacity must be sized to provide at least 24 hours of power to the NACs in non-alarm condition (stand-by mode) and at the end of that period, be capable of operating all alarm notification appliances used for evacuation or to direct aid to the location of an emergency for 15 minutes because the system is used for EVACS. In addition, battery calculations shall include a 20 percent safety margin to the calculated amp-hour rating per NFPA 72 section 10.5.6.3 (reference Appendix H, *Preliminary Fire Alarm System Calculations* for additional information).

10.4.3 Conceptual Design – Construction Documents (IBC 907.1.1)

The IBC requires construction documents prepared by the registered design professional to be of sufficient clarity to indicate "the location, nature and extent of the work proposed and show in detail that it will conform" to the IBC, IFC, and any local or state amendments. Refer to Appendix J for conceptual design layout.

10.4.4 Detailed Design – Working Plans (IBC 907.1.2, NFPA 72 10.18.1.2)

Working plans, also called shop drawings, differ from preliminary plans in that they include the details of the project, such as the exact location of all devices, appliances and the equipment necessary for the operation of the sprinkler system. Shop drawings must include the layout and detail information, as well as the associated wiring diagrams that show how the work will be fabricated and installed. These documents are to be prepared by a qualified technician, with a minimum of NICET Level III certification, in conformance with the concepts of the construction documents, and are to be submitted for approval prior to system installation but after the issuance of a building permit.

The working plans need to include enough information to make sure that all of the rules of NFPA 72 are met. The 29 items listed in A.10.18.1.2 outline the minimum information that needs to be provided to the fire protection engineer in responsible charge of the project, in addition to the Authority Having Jurisdiction (AHJ).

10.4.5 Operation Matrix (NFPA 72, 10.18.2.3, A.14.6.2.4 (9))

A fire alarm sequence of operation matrix is very useful information for the engineer to provide on the construction documents for the fire alarm design technician and to the AHJ and is required in accordance with NFPA 72 section 10.18.2.3 (4) and A.14.6.2.4(9). Included in appendix I, *Fire Alarm Sequence of Operations Matrix* is the general sequence of operations needed to produce a code compliant system.

10.4.6 Record of Completion & System Commissioning (IFC 907.8, 907.8.2; NFPA 72 10.18.2.1)

Upon completion of the installation, the fire alarm system and all fire alarm components shall be tested in accordance with NFPA 72. NFPA 3, *Recommended Practice for Commissioning Fire Protection Systems*, is not proposed to be used on the project at this time. A record of completion in accordance with NFPA 72 verifying that the system has been installed and tested in accordance with the approved construction documents and shop drawings will be provided by the installing contractor.

10.5 Inspection, Testing & Maintenance (ITM) Criteria (IFC 907.9; NFPA 72 14.2, 14.3, 14.4)

Performance based designs for building fire and life safety design will also incorporate the need for reliable automatic fire alarm systems as part of a balanced fire protection scheme and fulfills one of the vital roles of fire protection to notify and evacuate occupants from hazardous or untenable locations. An ITM program, as part of operational maintenance, is a critical component in ensuring the overall reliability of a system. ITM programs will discover problems in a system that could result in a failure, and by correcting such problems system failure rates will decrease. This will have the effect of increasing the overall reliability of a fire protection system. This program of ITM will be part of the prepared Operations and Maintenance Manual (O&M manual), which is necessary for buildings designed with a performance-based approach. This will become invaluable through the life cycle of the building in determining an appropriate ITM program, as well boundary conditions and restrictions related to occupancy, fire protection system design, and fuel loading.

Also crucially important in the maintenance program established for fire alarm systems is to verify that as-built or record drawings and specifications for every alarm and detection system be retained and updated each time the system is changed. Other information that should be retained includes the manufacturers' literature, sequence of operations, and later bulletins or updates pertaining to any part of the system, which needs to be included in the Operations and Maintenance Manual (O&M manual). Appropriate inspection, testing, and maintenance frequencies for all parts of the system should be determined, as is further discussed below. The maintenance program that is developed should be put in writing, kept on file, and used to schedule the work, preferably in the O&M manual prepared for the building design. Copies of all inspection, testing, and maintenance records should be maintained for the life of the system.

The frequency of the minimum acceptable inspection, testing, and maintenance requirements for fire alarm and detection systems is contained in NFPA 72. It contains the periodic inspection, testing, and maintenance requirements for fire alarm and detection systems. When the recommended inspection, testing, and maintenance are performed, the system and its components are statistically more reliable. Visual inspections, as specified in the fire alarm standard, are to detect conditions that could affect the operation of the fire alarm system. Individual system components require periodic testing, at the frequencies required by NFPA 72, to ensure system reliability.

In addition to the prescribed regimens included in NFPA 72, language in this standard also provides guidance in developing qualitative performance based provisions for ITM which could turn out to be either more or less restrictive than the prescriptive schedules listed in the standard. In section A.14.28 of the current NFPA 72 standard, the primary purpose of such a program is surmised by the following statement: "To establish the requirements and frequencies

at which inspection and testing must be performed to demonstrate an acceptable level of operational reliability."

Table 10.5 Fire Alarm ITM Requirements Summary

Fire alarm & Detection System	Standard Inspection, Testing and Maintenance (ITM) Requirements
Fire Alarm Control Panel (FACP)	Annual inspection should be done by the contractor performing the maintenance contract. This inspection should cover the review of fuses, lamps, and primary power supply. Additional inspections should be done any time occupancy changes or modifications to the building are done. Testing will also be performed annually to verify that station is receiving signals.
Secondary Power - Battery	Semi-annual inspection should be done by the contractor performing the maintenance contract. This inspection should review the condition of nickel-cadmium battery. Voltage testing and discharge testing is necessary annually. .
Fire Emergency voice/alarm communication equipment	Semi-annual inspection should be done by the contractor performing the maintenance contract.
Water Flow Alarm, Supervisory and Tamper Switch Devices	Maintenance staff should visually inspect monthly. Water flow alarm devices, supervisory signals and tamper switches should be tested as part of the quarterly testing by the contractor performing the maintenance contract.
Duct detectors, manual pull stations, and smoke detectors	Semi-annual inspection should be done by the contractor performing the maintenance contract. Initiating devices are necessary to be tested annually to verify working properly.
Remote annunciation	Semi-annual inspection should be done by the contractor performing the maintenance contract. Verify that obstructions are not present to access annunciator. Annual testing to verify signals are received at remote station.

11. Smoke Management

11.1 Smoke Management System for SPAS (IBC 1028.6.2, NFPA 101 12.4.2)

As discussed in section 6 of this analysis, smoke protected assembly seating (SPAS) is provided in assembly occupancies to reduce aisle widths and increase total number of seats available in the space. This system can implement natural venting or mechanized controls to accomplish the design goals of the system. The parameters in which smoke protected seating in assembly spaces can be utilized is summarized below, per NFPA 12.4.2.1:

(1) All enclosed areas with walls and ceilings in buildings or structures containing smoke-protected assembly seating shall be protected with an approved, supervised automatic sprinkler system,
(2) All means of egress serving a smoke-protected assembly seating area shall be provided with smoke-actuated ventilation facilities or natural ventilation, where the ventilation system shall be designed to maintain the level of smoke at not less than 6 ft above the floor of the means of egress. The ventilation system shall be in accordance with NFPA 92B, *Standard for Smoke Management Systems in Malls, Atria, and Large Spaces.*

11.1 Rational Analysis Report

Refer to Appendix K, *Smoke Control Rational Analysis* for full design analysis report supplementing the smoke management system design. Refer to section 12 of this report regarding performance-based aspects of the smoke management system design.

12. Performance Based Aspects - Means of Egress

12.1. Equivalency (IBC 104.10 & 104.11, NFPA 101 1.4 & Chapter 5)

As discussed in NFPA 101, section 4.1.1 one of the primary purposes of the fire and life safety provisions of the code is "to provide an environment for the occupants that is reasonably safe from fire…" There are often times where available technology (e.g. available fire safety analytical tools) makes it financially advantageous to pursue alternate methods that would provide an equivalent level of safety. This alternate design approach, when it is deemed appropriate by the Authority Having Jurisdiction, is permissible in accordance with both model codes for fire and life safety. The International Building Code sets forth the proceeding language:

> **"104.10 Modifications.** Wherever there are practical difficulties involved in carrying out the provisions of this code, the *building official* shall have the authority to grant modifications for individual cases…"
>
> **"104.11 Alternative materials, design and methods of construction and equipment.** The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been *approved*. An alternative material, design or method of construction shall be *approved* where the *building official* finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, *fire resistance*, durability and safety."

NFPA 101 has similar language:

> **"1.4 Equivalency.** Nothing in this *Code* is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this *Code*."

In addition to designing an equivalent exhaust method for a smoke control system, this section of the analysis will also consider an equivalent design method for particular deviations from the IBC and NFPA 101 codes identified in section 4 of this report regarding means of egress:

1. Assembly space is not provided with a minimum of 1/2 exit capacity for main auditorium entrance as indicated in section 4.4.1.4 of this report.
2. Exit capacity is insufficient for main auditorium exits based on the criteria indicated in section 4.4.1 of this report.

These deficiencies will be addressed using performance-based design method employing smoke protected assembly seating (SPAS) for egress analysis and to determine the tenability of occupants until such time that evacuation can be accomplished. This analysis will be documented throughout this section of the design brief.

12.2. Goals & Objectives (ICCPC 602, NFPA 101, 4.1, 4.2)

Project goals identify the desired fire safety performance of a building in qualitative terms. These goals are established in connection to the various stakeholders, but as a minimum, NFPA 101 establishes minimum performance goals that will be met in this design, as follows:

> **"4.1.1 Fire.** A goal of this *Code* is to provide an environment for the occupants that is reasonably safe from fire by the following means: (1)*Protection of occupants not intimate with the initial fire development, ..
> **4.1.3 Crowd Movement.** An additional goal is to provide for reasonably safe emergency crowd movement and, where required, reasonably safe nonemergency crowd movement."

Objectives are established to provide more detail about the intended fire safety performance. The LSC also provides minimum objectives that must be implemented into the design to meet the performance goals, as follows:

> **"4.2.1 Occupant Protection.** A structure shall be designed, constructed, and maintained to protect occupants who are not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place.
> **4.2.2 Structural Integrity.** Structural integrity shall be maintained for the time needed to evacuate, relocate, or defend in place occupants who are not intimate with the initial fire development.
> **4.2.3 Systems Effectiveness.** Systems utilized to achieve the goals of Section 4.1 shall be effective in mitigating the hazard or condition for which they are being used, shall be reliable, shall be maintained to the level at which they were designed to operate, and shall remain operational."

In addition, the ICCPC section 602.2 sets forth an additional fire safety objective as excerpted below:

> "Buildings shall be designed with safeguards against the spread of fire so that no person not directly adjacent or involved in the ignition of a fire shall suffer serious injury or death from a fire and so that the magnitude of the property losses are limited as follows:
> …Performance Group III [i.e. buildings where > 300 people congregate per T303.1] – Mild"

In accordance with NFPA 101, section 4.4.1, meeting the goals and objectives set forth in chapter 4 can be accomplished by either:
(1) Prescriptive-based provisions per NFPA 101, 4.4.2, or
(2) Performance-based provisions per NFPA 101, 4.4.3
As addressed in this analysis portions meet both the prescriptive requirements with several specific performance options related to prescriptive egress analysis. Reference sections 2.2 and 12.1 of this document for additional information.

12.3 Fire Scenarios & Design Fires (SFPE HBFPE ; NFPA FPH ; NFPA 101, 5.5.3)

NFPA 101, as well as the SFPE Engineering Guide, *Performance-Based Fire Protection,* set forth parameters in developing a performance-based approach where the anticipated threats to fire and life safety can be evaluated. In accordance with NFPA 101, section 5.5.3.1, design fire scenarios are to be evaluated using a method acceptable to the authority having jurisdiction and

appropriate for the conditions. Each design fire scenario considered is also required to be as challenging as any that could occur in the building, but realistic, based on the scenario specifications of (1) Initial fire location, (2) Early rate of growth in fire severity, and (3) Smoke generation.

Since scenarios will also be used to model smoke evacuation system, IBC section 909.9 specifically requires that a design fire be determined through a rational analysis by a registered fire protection engineer (reference appendix K, *Smoke Control Rational Analysis* for additional information). To determine the appropriate fire size, an engineering analysis is necessary that takes into account the following elements: fuel (potential burning rates), fuel load (how much), effects included by the fire (smoke particulate size and density), steady or unsteady (burn steadily or simply peak and dissipate) and likelihood of sprinkler activation (based on height and distance from the fire).

12.3.1 Design Fire Scenario 1. Design Fire Scenario 1 is an occupancy-specific fire representative of a typical fire for the occupancy. It explicitly accounts for the following: (a) Occupant activities. (b) Number and location, (c) Room size, (d) Furnishings and contents, (e) Fuel properties and ignition sources, (f) Ventilation conditions, and (g) Identification of the first item ignited and its location.

12.3.2 Design Fire Scenario 2. Design Fire Scenario 2 is an ultrafast-developing fire, in the primary means of egress, with interior doors open at the start of the fire. It addresses the concern regarding a reduction in the number of available means of egress.

12.3.3 Design Fire Scenario 3. Design Fire Scenario 3 is a fire that starts in a normally unoccupied room, potentially endangering a large number of occupants in a large room or other area. It addresses the concern regarding a fire starting in a normally unoccupied room and migrating into the space that potentially holds the greatest number of occupants in the building.

12.3.4 Design Fire Scenario 4. Design Fire Scenario is a fire that originates in a concealed wall or ceiling space adjacent to a large occupied room. It addresses the concern regarding a fire originating in a concealed space that does not have either a detection system or a suppression system and then spreading into the room within the building that potentially holds the greatest number of occupants.

12.3.5 Design Fire Scenario 5. Design Fire Scenario 5 is a slowly developing fire, shielded from fire protection systems, in close proximity to a high occupancy area. It addresses the concern regarding a relatively small ignition source causing a significant fire.

12.3.6 Design Fire Scenario 6. Design Fire Scenario 6 is the most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building. It addresses the concern regarding a rapidly developing fire with occupants present.

12.3.7 Design Fire Scenario 7. Design Fire Scenario is an outside exposure fire. It addresses the concern regarding a fire starting at a location remote from the area of concern and either spreading into the area, blocking escape from the area, or developing untenable conditions within the area.

12.3.8 Design Fire Scenario 8. Design Fire Scenario 8 is a fire originating in ordinary combustibles in a room or area with each passive or active fire protection system independently rendered ineffective. It addresses concerns regarding the unreliability or unavailability of each fire protection system or fire protection feature, considered individually.

12.3.8 Design Fire Scenario Selection

For simplification in this analysis, fire scenario 1 was considered for 2 variations, based on historical data; these scenarios are considered to be prevalent and realistic for the occupancy being analyzed. Figure 12.3.8 below provides statistical data for religious related assembly occupancies. Cooking equipment is not present in the building and intentional fire scenario was not considered for life safety purposes due to fire and security measures that are in place. The interpreted data provides reason to conclude that most arson related fires with religious-related occupancy's occur at times when building is unoccupied. There are many attendants assigned throughout the assembly hall during any event. While not trained as "security guards", all attendants are given instructions on suspicious activity both inside and outside the Assembly Hall and several attendants are assigned to security watch duties during each event. Risk of arson was thus seen to be low. (reference sections 13 and 14 of this document below for additional information); faulty electrical wiring and electrical hazards are considered the most likely scenarios as demonstrated below:

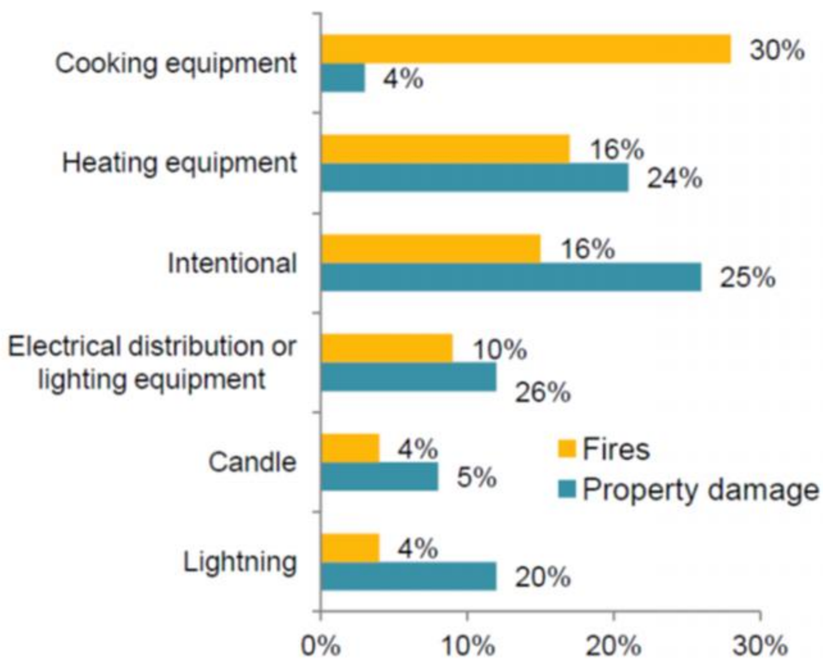


Figure 12.3.8 NFPA Data: Leading Causes of Structure Fires in Religious and Funeral Properties, 2007-2011

12.3.8.1 Polyurethane Foam Fixed Seating in the Auditorium– Faulty Electrical Receptacle Overheating Adjacent to Foam Padding Serving as Ignition Source. In this scenario, an Ultra-fast Growth Fire in the Auditorium Polyurethane Upholstered Seating is considered. Multiple seats are assumed to be ignited based on the formula below (reference appendix M, *Ignition/Fire Growth Calculations – Polyurethane Foam Padding Fixed Seating* for additional information), until a Heat Release Rate (HRR) of 3MW is reached wherein the automatic

sprinkler system actuates; fire is assumed to be steady-state from that point forward and that sprinkler controls fire to a maximum size of 3 MW for the extent of the fire model simulation, (reference appendix L, *DETACT Fire Model – Sprinkler Activation* for additional information).

$$q" = \frac{X_r\, Q"}{4\pi R^2}$$

Where $q"$ = energy radiated per unit time per unit area (W/m^2 or kW/m^2)
X_r = fraction of energy radiated relative to the total energy released
$Q"$ = heat release rate (W or kW)
$4\pi R^2$ = surface area of sphere, where R is the radial distance to the target fuel

Figure 12.3.8.1 (a) – Heat flux formula for Ignition

Each foam padded chair is based on an assumed peak HRR of 270 kW based on a 1985 report by the National Bureau of Standards (now NIST), *Fire Behavior of Upholstered Furniture*, as demonstrated in figure 12.3..8.1 (b) below. The growth of the design fire was based on an Ultra-fast growth fire rate as demonstrated in figure 12.3.8.1 (c), wherein a fire grows in intensity of 1MW HRR at 75 seconds as illustrated in 12.3..8.1 (d) below.

Specimen	Mass (kg)	Combustible (kg)	Style	Frame	Padding	Fabric	Interliner	Peak ṁ (g/s)	Peak q̇ (kW)
T50	16.5		waiting room chair	metal	cotton	PVC	—	NA	<10
T53	15.5	1.9	waiting room chair	metal	PU	PVC	—	13.1	270
T54	27.3	5.8	metal frame loveseat	metal	PU	PVC	—	19.9	370
T75/F20	7.5 (x4)	2.6	stacking chairs (4)	metal	PU	PVC	—	7.2	160

[a] Estimated from mass loss records and assumed Δh_c.
[b] Estimated from doorway gas concentrations.

Figure 12.3.8.1 (b) – Peak Heat Release Rates for Upholstered Furnishing: Source NBS (NIST), 1985

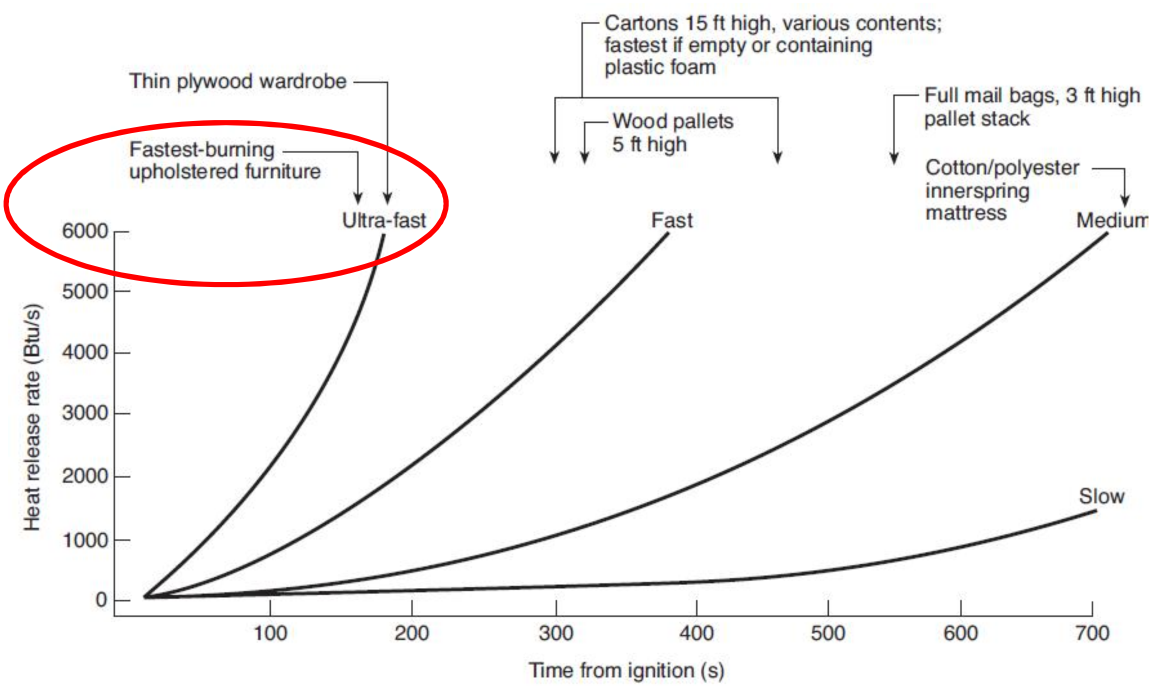


Figure 12.3.8.1 (c) – Heat Release Rate Growth Curves

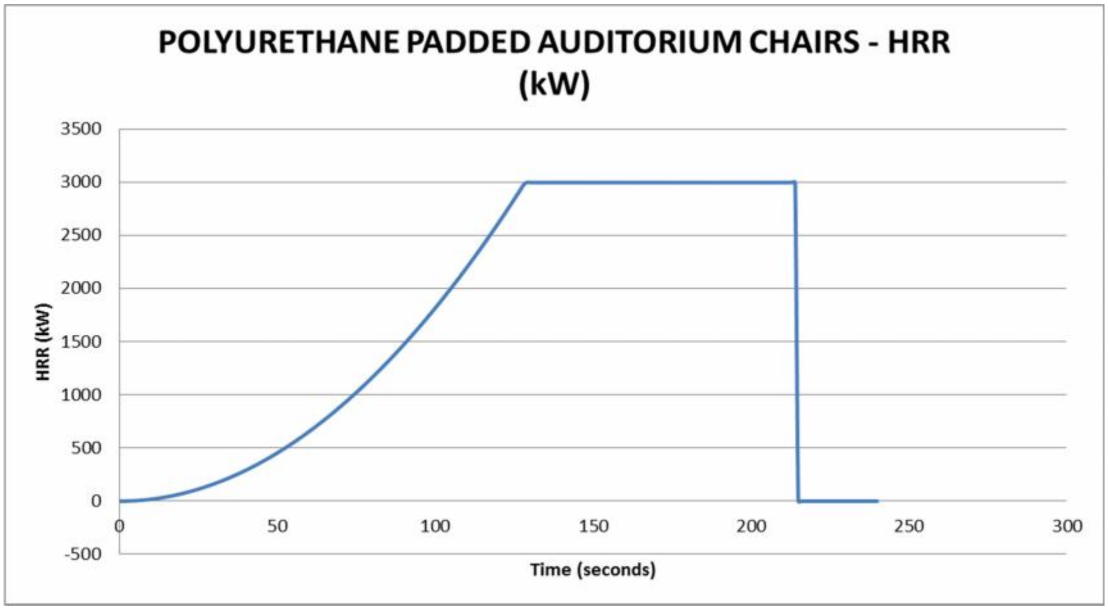


Figure 12.3.8.1 (d) – Heat flux formula for Ignition

The fire environment impact analysis necessary to determine the Available Safe Egress Time (ASET) performed through hazard assessment and fire modeling is demonstrated below in figures 12.3.8.1 (e) thru (i), based on the implementation of a smoke control system (for additional information, reference appendix K, *Smoke Control Rational Analysis)*. Fire modeling input file is documented in appendix N, *Fire Dynamics Simulator (FDS) Design Fire Input.* The process to determine the Required Safe Egress Time (RSET), which can be evaluated with the SFPE *Handbook of Fire Protection Engineering* (SFPE HBFPE) is documented in sections 12.4 -12.7 of this report.

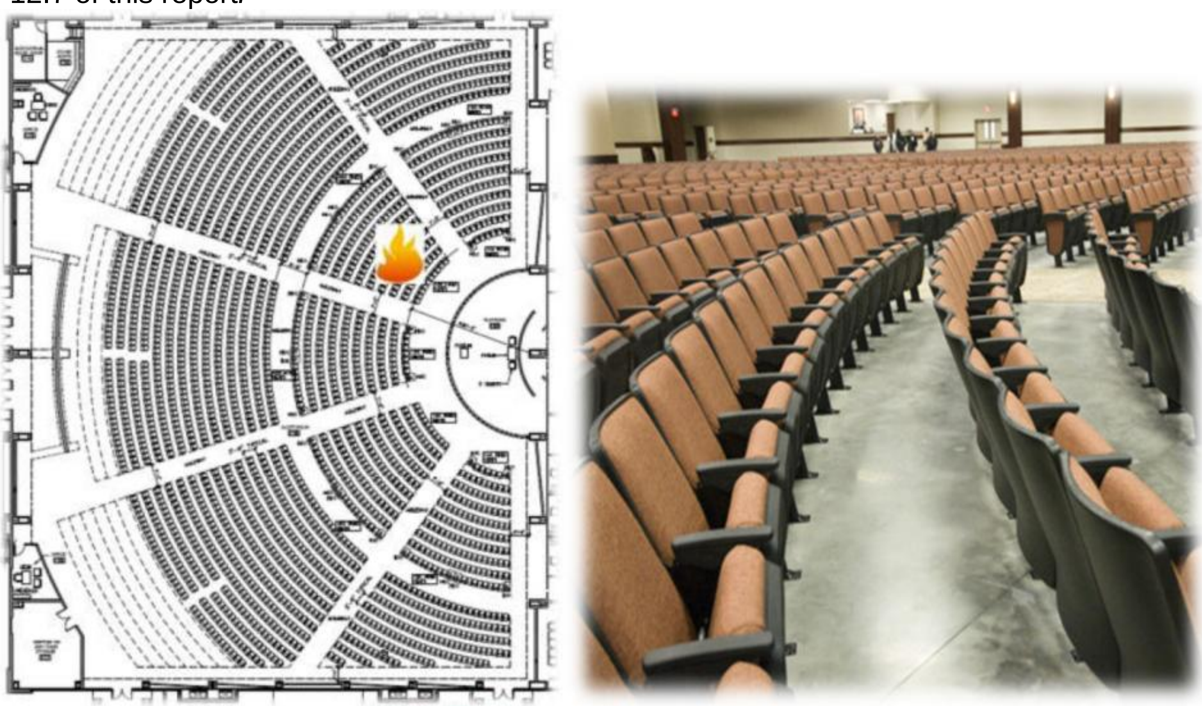


Figure 12.3.8.1 (e) Fire Scenario 1 Location and Conditions

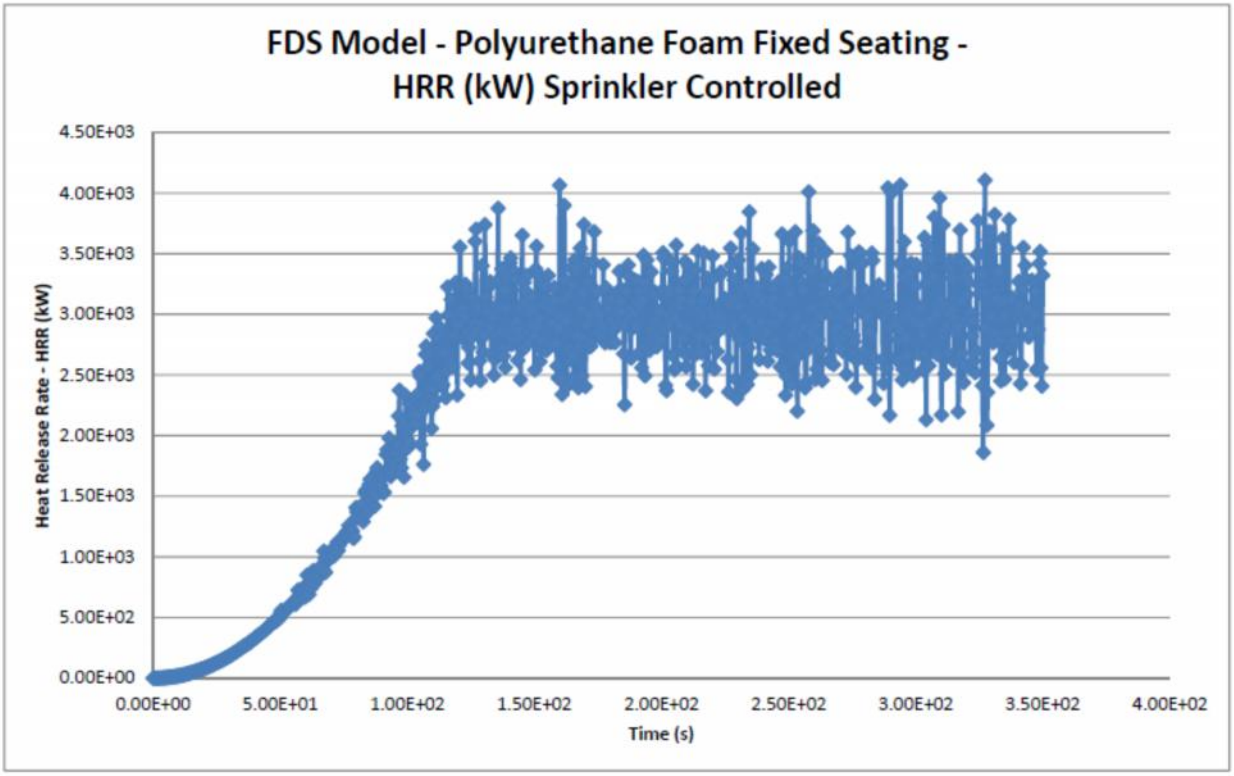


Figure 12.3.8.1 (f) FDS Fire Model Simulation of Ultrafast Growth Fire; Sprinkler Activation @ 3MW HRR Determined by DETACT

Figure 12.3.8.1 (g) FDS Fire Model Simulation – Compartment fire growth and smoke development @ 120 seconds

Figure 12.3.8.1 (h) FDS Fire Model Simulation – Compartment fire growth and smoke development @ 250 seconds

Figure 12.3.8.1 (i) FDS Fire Model Simulation – Compartment fire growth and smoke development @ 350 seconds

The results of the FDS simulation including analyzing the tenability of the compartment are contained within appendix K, *Smoke Control Rational Analysis.*

12.3.8.2 Ignition of a 2 L Hand-sanitizer Station Spill - Ignition Resulted from Adjacent Electrical Receptacle Ignition Source.

Fire scenario 2 is to consider an ultrafast fire in the primary means of egress (reference figure 12.3.8.2.(a) for size and location). The most common alcohol-based hand rubs are typically 60% ethyl alcohol or isopropyl alcohol by volume. This design scenario was considered plausible and relevant, but further modeling & investigation not warranted, as sufficient data is present to support requirements specified in NFPA 101 for hand-sanitizer stations (reference figures 12.3.8.2.(b) and (c) for additional information). Strict adherence to the prescriptive standards in NFPA 101 would achieve appropriate level of fire & life safety. Trained attendants with portable extinguishers could prevent fire growth to adjacent combustibles.

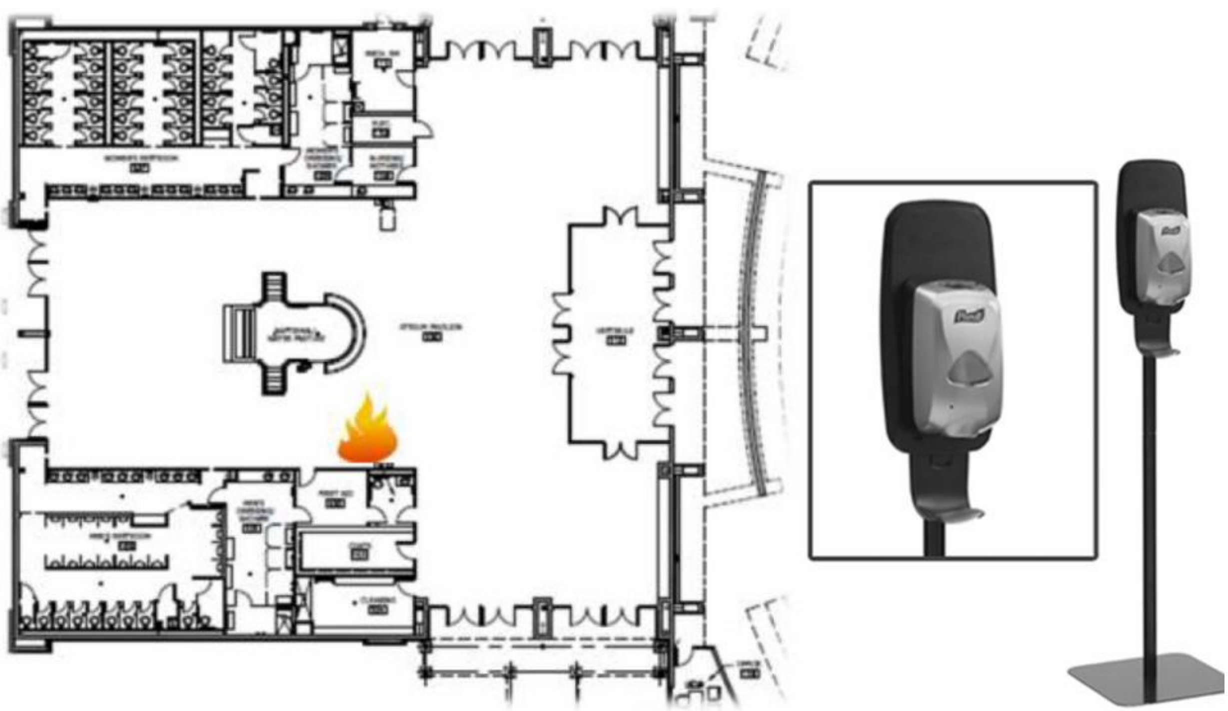


Figure 12.3.8.2 (a) Fire Scenario 2 Location and Considerations

Representative Sample Data: Ignition Source - HRR (kW)	Sample Size (L)	Representative Sample Data Sources
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
200	2	ASHE Modeling Fire Data
80	2	ASHE Modeling Fire Data
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
200	2	ASHE Modeling Fire Data
80	2	ASHE Modeling Fire Data
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
200	2	ASHE Modeling Fire Data
80	2	ASHE Modeling Fire Data
Statistical Data Based on Sample Sources		
Mean	96	
Standard Deviation	59	
Max.	200	
Min.	40	

Figure 12.3.8.2 (b) Summary of Fire Modeling Simulations
Source: Alcohol-Based Hand Rub Solution - Fire Modeling Analysis Report, August 22, 2003 - American Society for Healthcare Engineering (ASHE)

Table 8 - Summary of Fire Model Results

	Fire Size	Temp.	Visibility	Carbon Monoxide	Sprinkler Activation	Ignition of Targets
	kW	ºF	feet	ppm		
Scenario 1-1	100	158	47	13	N	N
	40	135	49	12	N	N
Scenario 1-2	200	247	27	25	Y 64 sec	N
	80	190	19	31	N	N
Scenario 1-3	100	195	30	21	N	N
	40	142	35	16	N	N
Scenario 1-4	200	397	12	56	Y 49 sec	N
	80	190	19	31	Y 195 sec	N
Scenario 1-5	100	150	49	12	N	N
	40	131	68	10	N	N
Scenario 1-6	40	134	18	28	N	N
Scenario 1-7	40	150	18	28	N	N
Scenario 2-1	100	102	90	6	N	N
	40	108	79	7	N	N
Scenario 2-2	200	138	61	10	Y 77 sec	N
	80	117	60	9	Y 251 sec	N

Figure 12.3.8.2 (c) Summary of Fire Modeling Results
Source: Alcohol-Based Hand Rub Solution - Fire Modeling Analysis Report, August 22, 2003 - American Society for Healthcare Engineering (ASHE)

12.4. Human Behavior & Evacuation (SFPE HBFPE 3-12; NFPA FPH 4-1)

Human factors are key to understanding and estimating the responses and general behavior of people evacuating during a fire incident. The areas to consider are addressed in the SFPE *Engineering Guide: Human Behavior in Fire*, which are itemized below:

12.4.1. Occupant characteristics
12.4.2. Human response to cues
12.4.3. Decision making
12.4.4. Movement

12.4.1 Occupant Characteristics (NFPA 101, 5.4.5.1; SFPE HBFPE 3-12; NFPA FPH 4-1)

Occupant characteristics include gender, age, physical capabilities, sensory capabilities, familiarity with the building, past experience and knowledge of emergencies, social and cultural

roles, presence of others, and commitment to activities. To predict human reactions and behaviors during an evacuation, the occupant characteristics of a building's population need to be reviewed to identify the occupant group or groups that are important in the analysis. In performing the evacuation analysis, it may be possible to rely on a single defined occupant group that is recognized as the most critical and is conservatively characterized. However, it may also be necessary to perform additional analysis when several identified occupant groups in a given building are distinguished by their varying characteristics.

Occupant characteristics that may be important include the following, as noted in NFPA 101 annex material:
'The four basic characteristics — sensibility, reactivity, mobility, and susceptibility — comprise a minimum, exhaustive set of mutually exclusive performance characteristics of people in buildings that can affect a fire safety system's ability to meet life safety objectives. The characteristics are briefly described as follows:
(1) Sensibility to physical cues, which is the ability to sense the sounding of an alarm and can also include discernment and discrimination of visual and olfactory cues in addition to auditory emanations from the fire itself,
(2) Reactivity, which is the ability to interpret cues correctly and take appropriate action and can be a function of cognitive capacity, speed of instinctive reaction, or group dynamics; might need to consider reliability or likelihood of a wrong decision, as in situations where familiarity with the premises influences wayfinding,
(3) Mobility (speed of movement), which is determined by individual capabilities, as well as crowding phenomena, such as arching at doorways, and
(4) Susceptibility to products of combustion, which includes metabolism, lung capacity, pulmonary disease, allergies, or other physical limitations that affect survivability in a fire environment.

Other occupant characteristics worth considering regarding the occupant include the (1) Alertness — condition of being awake/asleep, can depend on time of day, (2) Responsiveness — ability to sense cues and react, (3) Commitment — degree to which occupant is committed to an activity underway before the alarm, (4) Focal point — point at which an occupant's attention is focused (e.g., to front of classroom, stage, or server in business environment), (5) Physical and mental capabilities—influence on ability to sense, respond, and react to cues; might be related to age or disability, (6) Role—influence on whether occupant will lead or follow others, (7) Familiarity — influence of time spent in building or participation in emergency training, (8) Social affiliation — extent to which an occupant will act/react as an individual or as a member of a group, (9) Condition over the course of the fire — effects, both physiological and psychological, of the fire and its combustion products on each occupant.'

In the case of this egress evacuation analysis, it was assumed that occupants would react as a group, and did not account for individual limitations. To this end, an appropriate factor of safety must be applied to ensure all occupants of varying capabilities are able to safely evacuate. A conservative safety factor consistent with design parameters is discussed further in section 12.7 of this document.

12.4.2 Pre-movement & Decisions (NFPA 101, 5.4.5.2; SFPE HBFPE 3-12; NFPA FPH 4-1)
How people will respond to cues of fire must be considered in lieu of assuming that people will respond immediately. People generally will not respond within seconds to the initial cues of a fire. The time people will spend receiving the cue, recognizing the cue, and interpreting the cue is called "cue validation time." Estimating or quantifying the cue validation time is one

component of the total human factors to be considered. The cue validation time involves a delay before response that needs to be included in any fire safety analysis and design. This delay time is a component of the decision-making process influenced by notification circumstances. Human behavior and decision take place once cues are recognized and interpreted, including the decision to take no action.
In an egress model as shown in figure 1 below, The SFPE HBFPE designates a distinct delay in occupant movement as "pre-movement time." In discussing pre-movement time, Proulx defines this time in the SFPE HBFE as "the interval between the time at which the alarm signal is given and the time at which the decision is made and the person starts evacuation." The egress model, shown in figure 12.4.2.1 below, further delineates pre-movement time into recognition time and response time. Recognition time is defined as the "interval between the time at which the alarm signal is perceived and the time at which the occupant interprets this signal as indicating a fire/emergency event." The response time is further defined as "the interval between the recognition time and the time at which the first move is made to evacuate the building."

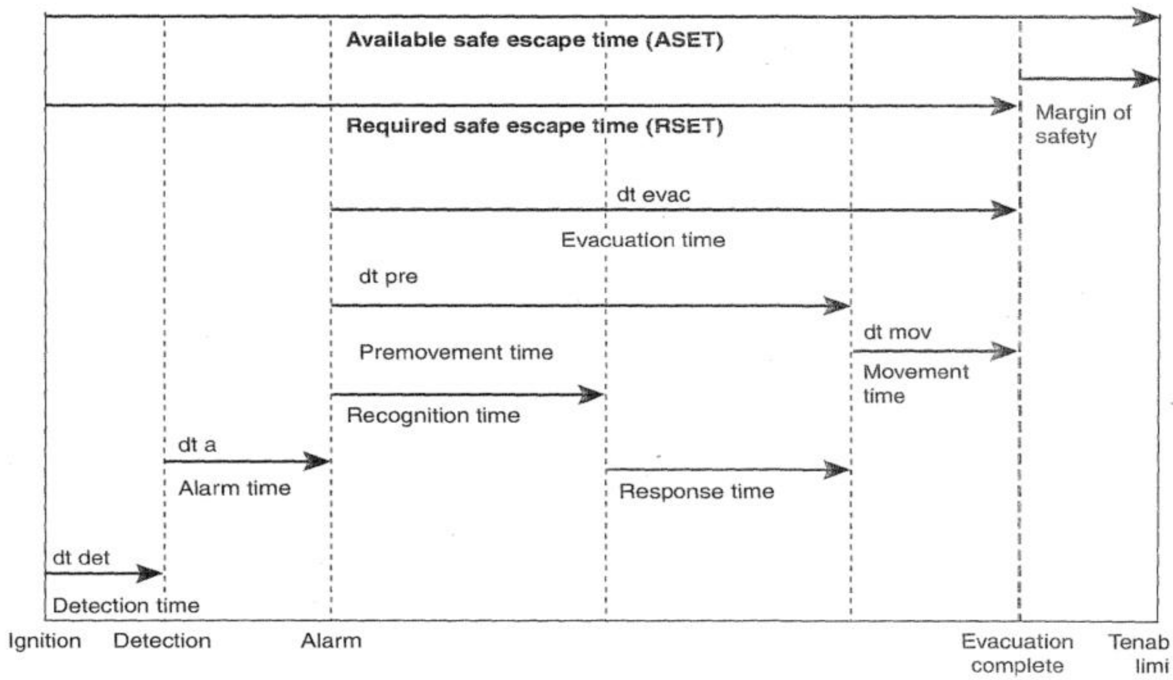


Figure 12.4.2.1 Egress Time Model (Extracted from SFPE Fire Protection Engineering Handbook, figure 312.1)

In the recognition phase, an occupant is anticipated to receive various cues such as a fire alarm signal, the sight and/or smell of smoke, or a warning by others. After receiving such cues, additional time may be needed to further investigate or to seek additional cues for confirmation of an emergency. Following the recognition phase, the response time will extend for an additional period in order for occupants to seek to fight fire with an extinguisher, warn others, gather other family members, retrieve personal items, or call the fire department prior to actual movement. Movement does not begin until such time that the occupant, based on interpreted cues and information makes the decision to reach a place of safety. As Proulx documented through various fire drill studies, depending on the occupancy, pre-movement could be an extended period of time in upwards of 3 – 5 minutes in some cases.

The work of Bryan, also discussed in the SFPE HBFE, further delineates the human factor of decision making into pre-movement times and movement times, highlighting 6 mechanisms an individual will make use of prior to formally deciding to move; figure 12.4.2.2 below illustrates

the relationship of these psychological processes. The pre-movement activities would include recognition, validation, definition and evaluation; commitment and reassessment involve the actual response of an occupant and would be considered under the actual movement to an escape, wherein commitment may be the first action taken to escape and reassessment may take place where first decision was in error. Recognition is a process of identifying the fire cues, whereas validation seeks to validate a cue by confirming perceived items with what he or she knows about the environment as well as the actions of others. Definition follows this natural progression to relate warning cues within the context of their individual surroundings – whether they are in a perceived imminent threat, for instance. Evaluation, in turn, seeks to strategize their individual actions so as to make a decision – escape, defend, adapt, etc.

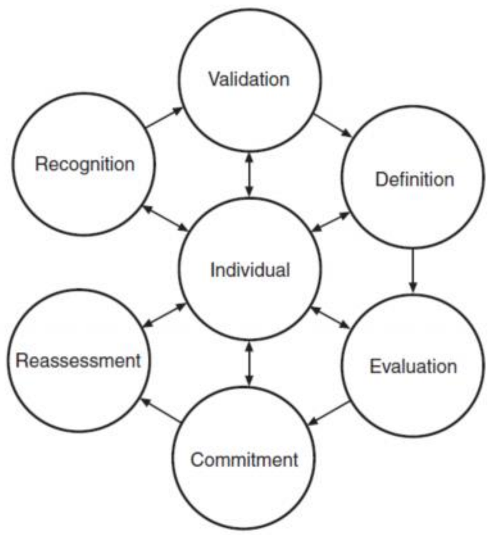


Figure 12.4.2.2 Decision Process of the Individual in a Fire

(Extracted from NFPA Fire Protection Handbook, figure 4.1.5)

12.4.2.1 Reduction of Pre-movement by Design & Operational Features

Since pre-movement of occupants accounts for a significant portion of the total time necessary to safely egress, as determined by the Required Safe Escape Time (RSET), it is important for design professionals to consider various methods, both through design and operationally, to reduce this overall time. The SFPE HBFPE highlights a major contributing factor in reducing pre-movement time is related to "the visual access to other occupants and what goes on in a building." In the case of this assembly occupancy the largest number of occupants are located in an open seating area where occupants can quickly be motivated by others they see who have made the decision to move to safety. Where the building layout is such that "wayfinding" or meandering through a building to determine location is reduced, this can also have a reduction factor in pre-movement times. The large majority of occupants have direct site to an exterior exit, although a psychological factor involved with this occupancy concerns a population who will generally attempt to evacuate through the main entrance where they entered - this phenomena can actually be affected by trained attendants in the audience who would assist in an emergency to move occupants to the closest exit possible. An additional building element that can reduce pre-movement time is the use of a voice evacuation alarm system, in lieu of standard audible alarms which is specified to be provided in the fire alarm system design. The SFPE HBFPE indicates that even more significant is the use of live public address versus the use of pre-recorded messages and as such, prearranged announcements can be made through

the sound system by the program chairman to assist in the orderly evacuation of these occupants. These measures can have a positive effect in reducing the overall pre-movement times for occupants.

12.4.3 Hand Calculation Estimates (NFPA 101, 5.6.2; SFPE HBFPE 3-13; NFPA FPH 4-2)

In accordance with NFPA 101 section 5.6.2, the design professional shall use the assessment methods to demonstrate that the proposed design will achieve the goals and objectives, as measured by the performance criteria, in light of the safety margins and uncertainty analysis, for each scenario, given the assumptions. The movement of occupants considers the period of time after the decision is made to evacuate or relocate. Other factors (smoke in egress paths, familiarity with the building, etc.) might affect the route chosen and therefore, impact the movement calculation. The capacity of exit routes is a function of the effective width, where the "effective width" (W_e) is the width of the component less allowance for a boundary layer. The effective width takes into consideration that people's bodies sway as they walk and so they tend not to use the portions of the egress component nearest an edge.

	Boundary Layer	
Exit Route Element	*in.*	*cm*
Stairways—walls or side of tread	6.0	15
Railings, handrails*	3.5	9
Theater chairs, stadium benches	0.0	0
Corridor, ramp walls	8.0	20
Obstacles	4.0	10
Wide concourses, passageways	Up to 18	46
Door, archways	6.0	15

*Where handrails are present, use the value if it results in a lesse effective width.

Clear width is measured as follows:

1. From wall to wall in corridors or hallways
2. As the width of the treads in stairways
3. As the actual passage width of a door in its open positio
4. As the space between the seats along the aisles of assemb arrangement

Table 12.4.3.1 Boundary Width Figures – NFPA Fire Protection Handbook Table 4.2.4

The effective width can be calculated by subtracting the boundary layer width from the total width. Note that boundary layers exist on both sides of the egress element so the boundary layers on both sides of the element must be considered when determining the total width. Once the effective width of an egress component has been determined, the flow rate through the component can be calculated.

Table 12.4.3.2 Egress Effective Width

EGRESS COMPONENT	COMPONENT SIZE	EGRESS EFFECTIVE WIDTH, W_e (in.)	EGRESS EFFECTIVE WIDTH, W_e (m)
Door 100	6'-0"	54"	1.37 m
Door 100A	6'-0"	54"	1.37 m
Door 100B	6'-0"	54"	1.37 m
Door 100C	6'-0"	54"	1.37 m
Door 100D	6'-0"	54"	1.37 m
Door 100E	6'-0"	54"	1.37 m
Door 100F	6'-0"	54"	1.37 m
Door 100G	6'-0"	54"	1.37 m
Door 100H	6'-0"	54"	1.37 m
Door 100J	6'-0"	54"	1.37 m
Door 100K	6'-0"	54"	1.37 m
Door 111A $^{\Psi}$	3'-0"	27"	0.69 m
Door 118	6'-0"	54"	1.37 m
Door 118A	6'-0"	54"	1.37 m
Door 118B	6'-0"	54"	1.37 m
Door 118C	6'-0"	54"	1.37 m
Door 119B	3'-0"	27"	0.69 m
Door 119C	3-0"	27"	0.69 m
Door 120	6'-0"	54"	1.37 m
Door 121B $^{\Psi}$	3'-0"	27"	0.69 m
Door 128A $^{\Psi}$	3'-0"	27"	0.69 m
Door 130A $^{\Psi}$	3'-0"	27"	0.69 m
Door 134	6'-0"	54"	1.37 m
TOTAL	117'-0"	1,080"	27.43 m

Ψ Considered Secondary Exits for individual room egress

The time it takes an occupant to move from his or her starting point to a location of safety is simply a function of travel speed and distance:

Time (s) = Distance (m) / Speed (m/s)

The calculation method chosen will depend to a great degree on the values needed for the evaluation of a design. There are two principal approaches for estimating the evacuation time for a building. One approach applies a hydraulic analogy, simulating people as fluid particles. Another approach considers the behavioral aspects of the people. In this evacuation calculation, hydraulic flow calculations are implemented to calculate by hand (reference appendix O, *Estimated Evacuation Time Analysis*).

Speed - The NFPA *Fire Protection Handbook* indicates that the evacuation speed of a group is a function of the population density. If the population density is less than about 0.05 person/ft^2 (0.54 person/m^2) of exit route (20 ft^2/person [1.85 m^2/person]), individuals will move at their own pace, independent of the speed of others. If the population density exceeds about 0.35 person/ft^2 (3.8 persons/m^2), no movement will take place until enough of the crowd has passed from the crowded area to reduce the density. Between the density limits of 0.05 and 0.35

person/ft^2 (0.54 and 3.8 persons/m^2), the relationship between speed and density can be considered as a linear function. The equation of this function is:

$$S = k - akD$$

Where,

S = Speed along the line of travel
D = Density (persons/unit area - persons/ft^2 or persons/m^2)
k = Constant, where
$k = k^1$ and a = 2.86 when calculating speed in feet per minute and density in persons per square foot and equates to 275 for corridors, aisles, ramps or doorways, and 212 for stairs with 7/11 stair riser/tread detail,
$k = k^2$ and a = 0.266 when calculating speed in meters per second and density in persons per square meter and equates to 1.40 for corridors, aisles, ramps or doorways, and 1.08 for stairs with 7/11 stair riser/tread detail.

By combining this formula with the additional parameters presented in the NFPA Fire Protection Handbook, the total time for passage (T_p) can be determined as:

$$T_p = P/(1 - aD)kDW_e$$

Where,
T_p = time for passage (T_p is in minutes where F_c is persons/ min; T_p is in seconds where F_c is persons/sec)
P = population in persons,
W_e = effective width,
F_c = Calculated flow where F_s (Specific flow)* W_e

The calculations used for determining the estimated evacuation time are included in Appendix C. The results from this analysis indicate that raw evacuation time is estimated to be **7 minutes** using a conservative flow of 0.28 persons/sec./m to an exit to factor in the elderly and disabled population into mean population. Final analysis of this estimation is considered in section 12.7 of this document under conclusions.

12.5. Tenability Analysis (SFPE HBFPE 2-6; NFPA FPH 3-7; NFPA 101, 5.2.2)
The types of effects that the fire environment can have include reduced visibility, breathing difficulty, fatigue, or incapacitation. Estimating the negative impact of an environment contaminated with smoke and tire gases assumes that occupants are subject to exposure of smoke and toxic gases, which may not be the case for all occupants participating in a building evacuation. Those areas or spaces of a building where smoke and toxic gases may pose an exposure generally require an engineering analysis of the fire development. Fire hazard calculations or mathematical evacuation models can be used to identify both the location of smoke and toxic gas environments in a building, as well as the concentrations or density of the smoke and toxic gas constituents of interest.

A critical criterion of fire safety goals is to maintain tenability for occupants during evacuation. This performance parameter is specified in NFPA 101 section 5.2.2 as excerpted below:

> "*Any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions.*"

The annex material to this section outlines several methods for evaluating tenability. The first method requires a detailed performance criterion that verifies that occupants are not incapacitated by fire effects. The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* describes a process of establishing tenability limits – this is discussed further in section 12.5.1.

The second method is to 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 (1.83 m) above the floor. The timing of such an evacuation means that no occupant is exposed to fire effects. Such an evacuation requires calculation of the locations, movement, and behavior of occupants because fire effects and occupants are separated by moving the occupants, which is further addressed in section 12.5.3. Reference appendix K, *Smoke Control Rational Analysis* for a comprehensive discussion of the tenability analysis, used in this design approach.

12.5.1 Toxicity

Generally, when considering impact of the environment on occupants, a "fractional effective dose" (FED) approach is used. The FED represents the fraction of a potentially lethal exposure to which people may be exposed. The effects of fire products of combustion on humans are complex, with contributions coming from the asphyxiants (e.g. CO, CO2) and irritants (e.g. HCI, SO2) that are roughly additive. The accumulated dose of toxic products can cause incapacitation (loss of consciousness) or death (lethality). The maximum tolerable doses of toxic gases for survival (lethal limits) are approximately twice those for incapacitation.

12.5.2 Visibility or Smoke Obscuration

Higher levels of smoke will obscure visibility and affect way finding and decision making during escape.

12.5.3 Hot Layer Height

An acceptable criterion is that the hot layer does not fall below 6 ft. (1.83 m) in height from the floor. This means that occupants will not have to move through products of combustion (smoke) in making their escape and must be maintained as such during full Available Safe Egress Time (T_{ASET}).

12.6. Computational Modeling (NFPA 101, 5.8.11)

A simulated egress model was also evaluated using the Pathfinder software. The results of this simulation are included in appendix P, *Pathfinder Egress Model*. The model produced results of estimated evacuation times of 2.5 to 3 minutes, compared with hand calculation results of 7 minutes (reference appendix O, *Estimated Evacuation Time Analysis*).

12.6.1 In accordance with NFPA 101, section 5.8.11.2, documentation is required to be provided to verify that the assessment methods have been used validly and appropriately to address the design specifications, assumptions, and scenarios. Information regarding use and validation of this model is also included in Appendix P, *Pathfinder Egress Model*.

12.7. Conclusions (NFPA 101, 5.8.11)

12.7.1 ASET VS RSET TIMELINE ANALYSIS

For an absolute evaluation, the available safe egress time (ASET), obtained using the acceptance criteria for tenability, is compared with the required safe egress time (RSET) obtained using occupant evacuation modeling.

The requirement for occupant safety is:

T_{RSET} (Required Safe Egress Time) < T_{ASET} (Available Safe Egress Time)
Where,

$T_{RSET} = (t_d + t_a + t_p + t_e)$*1.5 (Safety Factor)
$T_{ASET} = t_u$
t_d = time of fire detection
t_P = occupant pre-movement time
t_r = occupant response time
t_e = travel time
t_u = time of untenable conditions

This would result in a T_{RSET} of **18 minutes**, where

t_d = 1 minutes (62 seconds - DETACT Model)
t_a = 1 minutes (60 second maximum, per NFPA 72)
t_P = 3 minutes (SFPE Recommends 3 -5 minutes based on level of assistance & way-finding ability)
t_r = 1 minute (SFPE Recommends this as part of pre-movement time of 3 -5 minutes)
t_e = 7 minutes (SFPE Hand Calculation)

In accordance with NFPA 101, section 5.7, approved safety factors shall be included in the design methods and calculations to reflect uncertainty in the assumptions, data, and other factors associated with the performance-based design.
The safety margin or factor of safety for an absolute analysis is to be **1.5** for the worse credible fire scenario (i.e. RSET x 1.5 < ASET), as discussed in the annex of NFPA 101 A.5.7, as well as IBC section 909.4.6, for duration analysis of smoke management design.

The fire environment impact analysis performed through hazard assessment to determine Available Safe Egress Time (ASET) is previously discussed in section 12.3.8 of this document and the referenced appendices. This process verifies that proposed egress analysis will be acceptable. Refer also to section 18 of this report for final conclusions.

13. Life Safety Evaluation

In accordance with NFPA 101 section 12.4.2.2, in order to make use of the provisions for smoke-protected assembly seating, a facility is subject to a life safety evaluation in accordance with NFPA 101 section 12.4.1, which is implemented in this fire safety management plan.

13.1 Condition Assessment (NFPA 101 12.4.1.2)

Life safety evaluations shall include an assessment of all of the following conditions and related appropriate safety measures:

13.1.1 Nature of the Events and the Participants and Attendees

The primary function of the building is to provide meeting space for congregation circuits and districts and is primarily used on Thursday thru Sunday of each week. Congregation circuits

meet together biannually so Assembly Halls are primarily used by circuits of congregations (generally 20 – 22 congregations) in 200 to 300 mile radius around the building. Events are associated with religious service and occupants are generally alert and awake.

13.1.2 Access and Egress Movement, Including Crowd Density Problems
Egress modeling should be referenced for auditorium density movement. Attendants are to assist in the orderly evacuation of occupants and coordinate special evacuation for disabled occupants.

13.1.3 Medical Emergencies
In the event of a medical emergency, wardens should:

- Quickly check the situation for danger and assess the person's condition
- Alert people nearby and enlist their aid
- If a situation is assessed as life threatening or if there is any doubt, phone 911. Report the location and nature of the medical emergency and request an ambulance immediately
- Administer first aid up to level of training

13.1.4 Fire Hazards
For fire hazards, reference section seven for emergency planning and preparedness
In the event of a sudden explosion attendants will: (having due regard to their own safety)

- Assess the situation, being wary of fallen live wires, spilt flammable/corrosive liquids, the release of hazardous materials or flammable or toxic gases
- Report the explosion to 911
- Send someone to meet the emergency services
- Commence an immediate evacuation of people from the explosion-affected area. Rescue and evacuate injured personnel and conduct a cursory search for trapped victims. Do not enter a building or allow anyone else to enter a building unless it is safe to do so
- Provide first aid to the injured (to level of expertise)
- Fight any small fires that may have been lit as a result of the explosion, but only if is safe to do so and trained to do so
- Cordon off the damaged/danger area and keep onlookers and media away
- Assist the Emergency Services on their arrival

13.1.5 Permanent Structural Systems
Structural system is primarily steel framing and is designed to minimum design standards for wind, seismic, and gravity loading.

13.1.6 Severe Weather Conditions
Building is located approximately 100 miles from eastern coast and is subject to severe weather associated with hurricane force winds. Facility should be evacuated prior to a hurricane moving inland.

13.1.7 Earthquakes
Attendants should instruct persons within their area of responsibility not to leave the building during an earthquake due to falling masonry and glass but to instruct people to take refuge under a desk or table or stand within a doorframe.

After the quake, evacuate to a place which is clear of buildings, trees, and power lines. Be aware of hazards such as fallen live electrical wires or ruptured gas lines. Do not enter a structurally damaged building. Be mindful of the possibility of after-shocks occurring.

13.1.8 Civil or Other Disturbances

If the attendants or assembly overseers become aware of a civil disorder, protest or demonstration occurring inside or in the vicinity of the building they will:

- Contact security and request assistance
- Attempt to restrict access to the building or confine the disaffected group to a specific area by locking doors
- Depending on the event, secure records and other valuable property (if it is safe to do so)
- Withdraw occupants from contact or confrontation with the group
- Remain calm and do not antagonize the group

Armed Intruder in the Building

In the event of an armed intruder, alarms might not be used to evacuate people as the sound may agitate the intruder or may cause uninformed persons to evacuate into the intruders possible field of fire. Attendants may consider sending runners or use alternate methods of advising people in their care. Depending on the event, attendants will have to decide whether to evacuate by an alternate escape route and assembly area or make themselves safe by locking themselves inside a secure area. Respond in any way that will best protect your safety and those in your charge. In all events remain calm and avoid confrontation with the intruder. If this is not possible, do not antagonize the intruder.

Bomb Threat

Until proven otherwise, all threats are to be treated as real. During meeting events the building attendants together with assembly hall overseers should evaluate the threat and consider actions/evacuation. This may be done in conjunction with the police if they are available. The threat may be specific or non-specific as follows:

Specific Threat

In this case the caller will provide a more detailed warning statement, which might describe the type and placement of device, the reason or motive, and /or other additional specific information.

Non-specific threat

In this instance they may make a simple statement to the effect that a device has been placed. Generally very little, if any, additional detail is conveyed before the caller terminates the conversation.

The non-specific threat is more common but neither type of threat can be immediately discredited without investigation. Every threat has to be treated as real until proven otherwise. Depending on the evaluation by the Building warden and management, one of four possible alternatives should be pursued.

If an evacuation is ordered, do not use the fire alarm signals – use the PA facility BUT a search along paths of travel and around assembly areas must be conducted before ordering an evacuation.

Evacuation action

Option 1: Search with partial evacuation - If the threat level is considered moderate, with no reason to believe explosion is imminent, the person who has knowledge might consider partial evacuation retaining only essential staff and search teams. Partial evacuation might also be appropriate where an organization is spread over a wide area: Only those personnel at immediate risk may need to be evacuates initially.

Option 2: Search and evacuation - In this option, occupants remain in–situ during initial search and are evacuated once the presence of a suspicious article is confirmed. Normally this option would be adopted in a low threat assessment scenario because otherwise the implication is that persons would be exposed to the effects of a device if it functioned.
Doors and windows should be left open and occupants should be required to remove all personal belongings, e.g., handbags, briefcases, etc., when evacuating. This will facilitate the identification of suspect objects.

Option 3: Evacuate immediately - When the risk is high or when search is precluded due to the extreme short notice of the threat, the person who has the knowledge has no option other than to evacuate as quickly and as safely as possible.
If the decision to evacuate without a search is made then the following points must be considered:

13.1.9 Hazardous Materials Incidents Within and Near the Facility
In the event of a hazardous material spill:

- If safe to do so, identify the hazardous material for correct response purposes. Phone 911 to report the location and, if known, the identity of the hazardous material released
- Evacuate from the affected area. Assist injured personnel
- Proceed to the designated assembly area for the building
- Do not allow any person to re-enter an area affected by hazardous material
- Do not allow any person to eat or smoke until decontamination has taken place

13.1.10 Relationships Among Facility Management, Event Participants, Emergency Response Agencies, and Others Having a Role In the Events Accommodated In the Facility
The assembly hall overseers are assisted by attendants appointed for each seating section or floor area. The attendants are responsible for the coordination of building evacuations, including the following:

- Ascertaining the nature of the emergency and determining appropriate actions
- Ensuring that the appropriate emergency service has been notified
- Initiating evacuation procedures and control entry to the affected area
- Ensuring the progress of the evacuation and any action taken is recorded in an incident log
- Briefing the emergency services upon arrival on type, scope and location of the emergency and the status of the evacuation and, thereafter, act on the senior officer's instructions

On hearing the fire alarm sounding or on being advised of an emergency situation, the attendants shall immediately:

- Ensure the relevant emergency service has been called
- Proceed to the fire indicator panel & commence evacuation procedures

• Inform the affected section using the PA system or runner and initiate a search or instigate designated actions

If a fire / or emergency has been found, the attendants must:

• Evacuate the building immediately (if not already under way)
• Meet the emergency services on arrival and inform them of the situation

If no fire / emergency is found, the attendants must:

• Inform occupants of the false alarm
• Meet the emergency service on arrival and inform them of the situation

13.2 Building System Assessment (NFPA 101 12.4.1.3)

Life safety evaluations shall include assessments of both building systems and management features upon which reliance is placed for the safety of facility occupants and such assessments shall consider scenarios appropriate to the facility.

Emergency Exits

Continuously illuminated exit signs identify emergency exit locations from all sections within buildings. These lead directly or indirectly to open space.

Emergency Lighting

Emergency lighting is installed in strategic locations throughout building. In the event of failure of the mains power supply, the emergency lights should activate almost instantaneously and last from 1 to 2 hours.

Air Conditioning

The building's ducted air conditioning system will shut down automatically on the operation of the duct detection activation and initiation of fire alarm supervisory signal.

Fire Alarm System

The building is equipped with an automatic fire detection and alarm system, which is connected directly to Fire and Rescue Services. Smoke and thermal detectors are positioned strategically throughout building. These fire system components must remain unobstructed at ALL times.

Activation of the alarm will:

• Sound the alarm throughout the premises.
• Summon the Fire Department.
• Shutdown the air conditioning system
• Operate smoke exhaust system

Automatic Sprinkler System

The building is equipped throughout with an automatic sprinkler system intended to control fire growth and spread. System operation will automatically transmit an alarm signal to the building fire alarm system for building evacuation.

Portable Fire Extinguishers

Portable fire extinguishers are located in easily identifiable locations throughout the premises. Know their locations and suitability for use on various types of fires (e.g.) electrical, flammable liquids, ordinary combustibles. Extinguishers are only suitable to use on fires in their incipient stages (small or beginning). Before you use a fire extinguisher, you must know:

• What fuel is burning
• What type of fire extinguisher is suitable for that type of fire

• How to operate the extinguisher
Fire extinguishers are grouped into four classes:
Type Category Use on following fire types
1. Water Class A (combustible Solids) Wood, Cloth, Plastics, Paper
2. Foam Class B (flammable Liquids) Petrol, Oil, Paint
3. CO2 Class C (flammable Gases) Methane, Propane, Butane, Electrical equipment
4. Dry chemical Class D (combustible Metals) Magnesium, Aluminum
5. Dry chemical Class E (combustible Solids), All Class A, B and C fires (flammable liquids) (electrically energized) and around the burning object

14. Emergency Planning & Preparedness

An emergency evacuation plan (EEP) is a written document required by the IFC chapter 4. The purpose of an EEP is to facilitate and organize student, staff, and faculty actions during workplace emergencies.

The elements of the plan must include, but are not limited to:

- Means of reporting fires and other emergencies.
- Evacuation procedures and emergency escape route assignments.
- Medical emergencies.
- Assisting disabled occupants.
- Procedures to account for all occupants after an emergency evacuation has been completed.
- Procedures to be followed by student, staff, and faculty who remain to operate critical plant operations before they evacuate.
- Roles and responsibilities of building occupants, attendants, and outside contractors.
- Training requirements for building occupants as well as attendants
- Names or job titles of persons who can be contacted for further information or explanation of duties under the plan.

The following plan will serve as the building EEP
Purpose: The Internal emergency response plan is designed to facilitate the safe evacuation of all occupants from the assembly hall in the event of fire or other internal emergency.

<u>Evacuation Procedures:</u>

1. **<u>Supervision during the Emergency:</u>**
   a. The attendants will supervise the evacuation of the building.
   b. The attendants will assist in ensuring evacuation and report to the Building Coordinator any persons missing or unaccounted for.

c. Re-entry into the building after a fire shall only be upon authorization by the Police or Fire Department.

2. Person discovering a fire:

a. Recruit assistance from persons in vicinity if possible to:
   i. Pull Fire alarms at nearest box. These alarms will automatically sound alarms throughout the building.
   ii. Call 911 report name, location, description of emergency,
   iii. If trained, use fire extinguishers to aid in evacuation and to confine the area of the fire
   iv. Remove victims in the immediate area of the fire
   v. Confine fire by closing doors and windows in vicinity of fire

3. **All Occupants:**

a. All building occupants will exit the building upon announcement by the attendants or sounding of the fire alarm.
b. Close doors, corridor doors, and windows in the vicinity.
c. Assist all injured or disabled persons from the building.
d. Report to the appropriate assembly area. If designated assembly area is involved with smoke, report to one of the other designated assembly areas. Remain with and listen to instructions from the Area Steward.
e. Assembly areas are determined by the exit location of the building:

4. **Attendant responsibilities**:

a. Identify Alternates to aid in clearing rooms, including restrooms, of assigned area. If possible, shut off air handling units in assigned area.
b. Direct persons to assigned exits and assembly areas.
c. Verify assigned area is evacuated.
d. Check all persons in assembly area and identify missing persons.
e. Report missing person(s) presumed to be in the building to Police or Fire Department.
f. Remain in assembly area until receiving instructions from Police or Fire Department to re-enter building.
g. If Assembly area becomes unsafe, relocate as a group to another assembly area.
h. Select an attendant in same location to serve as back up should attendant be absent.

5. Evacuation:

Develop evacuation and attendant area assignment chart similar to as noted below.

	STAGE	
FRONT LEFT Sam Robinson Bo Montgomery	**FRONT CENTER** Mike Pizza Ron Denson	**FRONT RIGHT** Carl Chappell Matthew Cornett
MIDDLE LEFT John Gillespie Kenneth Biller	**MIDDLE CENTER** Kyle Lafolatte Steve Waller	**MIDDLE RIGHT** Trevor Baker Gary Hudson
REAR LEFT James Bearden Ken Newberry	**REAR CENTER** Dennis Baker Justin Biller	**REAR RIGHT** Ed Dixon Ben Henderson
DOORS LEFT Brady Furrow Courtney Jackson		**DOORS RIGHT** Mark Waller Ken Colvin

Medical Emergency

Your actions during the first minutes of an emergency can be critical. As a general rule, you should phone 911 and ask for assistance whenever someone is seriously ill or hurt.

If in doubt, call for assistance - **Medical Emergency - 911**

Provide as much information regarding the injury and the exact location of the emergency:

- What is your emergency?
- How many people are injured?
- Where is the victim located? Building, floor and room number, etc.
- What number are you calling from?
- What is happening now?

One of the most dangerous threats to a seriously injured victim is unnecessary movement. Moving the victim can cause additional injury and pain and complicate recovery.

An injured person should only be moved if there are immediate life-threatening dangers.

Additionally, if you are trained and providing first aid, always follow safety precautions for your safety, electrical hazards, blood-borne pathogens, etc.

Location of Automated External Defibrillators (AED): (1) Located at first aid desk.

General Fire Alarm

You will hear a **loud, three pulse tone horn** sounding throughout the building and see **emergency strobe lights flashing**.

Stop all work - Take your primary evacuation route to the nearest exit and leave the building. Follow illuminated EXIT signs to fire rated staircases or exits.

Once outside the building, immediately report to your **evacuation meeting site** and await further instructions from your **Evacuation Monitor.**

Your Evacuation Monitor will notify you at your evacuation meeting site when it is safe to re-enter the building. **Do not re-enter the building until you are told to do so.**

RELOCATE	When you discover a fire, RELOCATE people in IMMEDIATE danger if it is safe to do so
ALARM	Activate the nearest pull box ALARM along your exit route alert other occupants and the Fire Department.
CONFINE	Close doors, windows, and other openings to CONFINE fire if it is safe to do so.
EVACUATE	Evacuate the building by following the exit signs to the nearest door or stairwell. Once outside the building, immediately report to your designated evacuation meeting site and await instructions from your Evacuation Monitor.

Occupants with Disabilities

If a mobility impaired person(s) is located in the building on a floor that is not accessible directly to the outside, the following procedures should be followed.

- **Emergency response personnel will be responsible for evacuating disabled persons.**
- **If necessary move the person horizontally away from the danger or to safe place of refuge such as an office**.

- **All attendants shall immediately report the location of disabled occupants to the responding emergency personnel.**

- The attendants will report to emergency response personnel any people remaining in the building and any other information pertinent to the situation.

Evacuation Meeting Site

Meeting sites are designated by building management largely due to their accessibility and distance from the building. A building may have multiple meeting sites depending on its size, number of exits, number of buildings, occupants and events held in the facility.

Meeting sites provide a method to:

- Keep occupants safe from hazards
- Allow easier building access for emergency responders
- Allow information to be distributed more easily
- Account for occupants

Refer to the posted evacuation map for your specific work area and be familiar with your primary and secondary exit routes.

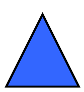
The emergency evacuation meeting site(s) are shown on the site plan to follow.

Fire Protection Systems

Fire extinguishers should only be used by people who have been trained or are knowledgeable of how they work.

Multi-purpose type fire extinguishers can be found in fire extinguisher cabinets throughout the building. While occupants are never expected to fight a fire, when used correctly, under limited circumstances, a fire extinguisher may provide an escape route from a small fire.

Site Map

	Meeting Location(s)
	**Primary Meeting Location:** The primary meeting location is the adjacent parking lot. Move at least 100 feet away from the building.
	**Secondary Meeting Location:** Grassy area behind tree line

LEARN TO P-A-S-S

PULL	Pull the pin or ring.
AIM	Aim the extinguisher nozzle at the base of the fire.
SQUEEZE	Squeeze or press the handle.
SWEEP	Sweep from side to side slowly at the base of the fire.

Fire extinguisher is limited to train personnel ONLY.

Fire Prevention

Generally, the best way to prevent fire is to minimize its potential through the observation of safe work practices and housekeeping. Refer to section 17 for more detailed fire safety practices.

Common sense and periodic inspections will help to detect and prevent hazardous conditions. You should observe the following basic guidelines:

- Keep storage areas neat and clean. Avoid accumulating excessive amounts of paper products.
- Do not store combustible items such as paper and cardboard against electrical panels, in telephone closets, stairwells, and corridors.
- Do not store flammable or combustible fluids or gases outside designated flammable storage or safety cabinets.
- Maintain electrical appliances in good working order.
- Periodically check for potential electrical hazards such as frayed cords, broken plugs, and overloaded electrical outlets. Avoid using extension cords.
- Make sure all electrical appliances and cords are approved by the Underwriters Laboratory (UL).
- Do not block or obstruct hallways or exit doors. Keep fire doors closed—do not block/hold open.
- Refrain from stacking items too high or close to sprinkler heads, 18 inches of clearance must be maintained. Do not hang anything from the sprinkler pipes or sprinkler heads.
- Do not use space heaters. These units are a major cause of building fires and their use is not authorized within the building

Hazardous Materials

Location of Hazardous Materials: Small amounts of hazardous materials may accumulate for cleaning solvents, hand sanitizers, etc. **Additional Comments:** Majority of the hazardous materials are stored in storage closets.

15. Operation & Maintenance Procedures

15.1 Reference section 9.4 of this document for sprinkler O & M Procedures.
15.2 Reference section 10.4 of this document for fire alarm O & M Procedures.

16. Fire Protection Safeguards during Construction & Alterations

During periods of construction, the following safeguards will be implemented in accordance with IBC chapter 33, IFC chapter 14 and NFPA 241:

16.1. Fire Protection System Continuity

Provide temporary but equivalent fire alarm and detection systems for use when a fire system is impaired.

16.2. Fire Protection System Impairments

Where sprinkler system is turned off to facilitate connection of newly completed sections of piping, procedures for impairment of automatic sprinkler system are to comply with the provisions outlined in NFPA 25, chapter 15. Procedures during any system impairment lasting more than 4 hours shall include provisions for establishing a fire watch, control ignition sources and/or shutdown hazardous processes (i.e., hotwork, smoking, etc.), expedite connection work, and ensure that fire protection is properly placed back into service. Where fire protection is regularly turned off and on for connection purposes, sprinkler control valves must be checked at the end of each work shift to ensure proper protection is in service.

16.3. Construction Demising Barriers

All occupied areas will be separated from demolition, renovation, or construction activities by temporary smoke-tight construction partitions of gypsum board or other approved non-combustible or limited-combustible material. Partitions will be full height, extending through suspended ceilings to the floor slab or roof deck above and will be one-hour fire rated, unless sprinklers are installed and are operational on both sides of the temporary partition whereupon the partition may be permitted to terminate at the ceiling in accordance with NFPA 241. Where the ceiling on one side of the temporary construction barrier has been removed, the temporary wall would need to go to the deck above.

16.4. Construction Fire Prevention Practices

Procedures for storage, housekeeping, and debris removal practices that reduce the building's flammable and combustible fire load to the lowest feasible level.

16.5. Roles and Responsibilities of Contractors

The senior on-site manager, foreman or supervisor of contracted employees who are required to work inside the building must ensure that the elements of the emergency evacuation program are communicated to the contractor prior to the start of work at the building.

Other responsibilities of contractors may include, but are not limited to:

- Contractors must review the emergency maps that indicate exit routes in all areas of the building where they will be working.
- Contractors must be aware of the location of nearby fire pull stations and emergency exits and never remove or tamper with fire safety equipment.
- Notify owner of potential fire hazards in their work area.
- Notify owner of any fires or incidents that have occurred as a result of the work being performed.
- Contractors must adhere to all applicable requirements for the safe handling and storage of hazardous and flammable substances.
- If hot work (i.e. welding, cutting or brazing) is being performed, contractors are expected to comply with all applicable Federal OSHA regulations and local requirements for fire watches, permits, and notifications.
- Contractors must ensure that their vehicles and equipment do not limit safe and efficient access to and egress from the building.

17. Fire Safety Checklist

The following checklist can be referenced for assessing various fire hazards and to implement strategies for eliminating hazards.

17.1. Emergency Lighting/Egress Lighting

- Does the facility have emergency egress lighting with battery back-up capability?
- Are the emergency egress lights routinely cleaned, inspected, and tested on a monthly basis?
- Is the emergency lighting adequate or does it need improvement to provide adequate emergency egress illumination?
- Does storage, furnishings, or decorations obscure the emergency egress lights?
- Is remote egress lighting installed on the exterior of the facility at all designated exit locations?
- If emergency egress lighting is provided through a generator, is the generator routinely serviced, exercised, and are maintenance records current and available for review?
- Are emergency generators regularly tested per NFPA 110?

17.2. Fire Extinguishers

- Does the facility have the proper number and type of fire extinguishers?
- Are the fire extinguishers mounted in visible locations to which the occupants have access?

- Are the fire extinguishers routinely visually inspected on a monthly basis?
- Are the fire extinguishers pinned and sealed to prevent accidental discharge?
- Are the Inspection tags and the inspection checked and initialed on a monthly basis?
- When was the last hydrostatic inspection on the fire extinguisher cylinders?
- Are the fire extinguishers in compliance with NFPA 10?
- Are facility personnel properly trained in the emergency use of fire extinguishers?

17.3. Exit Signs/Means of Egress

- Do all means of egress routes have proper exit signage with directional arrows (if required)?
- Are the exit signs illuminated at all times?
- Do the exit signs have battery back-up in case of power failure?
- Does storage, furnishings, or decorations obscure the exit signs?
- Are the exit Lights routinely cleaned, inspected, and tested on a monthly basis?
- Do additional exit signs need to be installed to adequately direct evacuation in the event of an emergency?

17.4. Exit/Egress Doors

- Do all means of egress doors readily open from the side which egress is to be made without a key, special knowledge or effort?
- Do exit/egress doors have prohibited locking mechanisms such as special fasteners, chains, or deadbolts?
- Are all doors, passageways, and stairways that are not a means of egress, nor provide a means of egress, properly identified (labeled) so as not to be mistaken for a means of egress?
- Area all exit/egress doors properly maintained?
- In rooms where chairs or tables and chairs are utilized, do aisles have a minimum clear width of 44 inches (>50 occupants) or 36 inches (<=50 occupants)?
- Do chairs, tables, or other objects obstruct aisles?
- Are doors blocked by storage of materials?

17.5. Fire Rated Doors/Walls/Assemblies

- Are all fire-resistant rated assemblies being maintained? If previously damaged, altered, or penetrated, have these rated assemblies been properly repaired and restored according to the Fire and Building Code requirements?
- Are all fire-rated doors being adequately maintained, including all associated hardware necessary for proper operation?
- Are unapproved and prohibited hold-open devices such as wedges, doorstops, rocks, rope, etc., being used to keep fire doors/smoke and smoke barrier doors open?
- Are automatic closure devices (smoke detectors) used in conjunction with some fire door assemblies cleaned, inspected, and tested on an annual basis?
- Do all of your fire-rated doors swing and close from the full-open position and latch automatically?
- Does the closure mechanism exert enough force to close and latch the door form any partially open position?
- Is a written record of the results of the inspection and testing being maintained and made available to the fire marshal inspector?

- Are fusible links being properly maintained and inspected? If the fusible links were found painted, corroded, damaged, or loaded with foreign materials, have they been replaced with new links?

17.6. Storage of Materials (Including Flammable/ Combustible Liquids)

- Has good housekeeping been made a priority, with all materials, processes, and storage being kept in a neat and orderly fashion on both the interior and exterior of the building?
- Are materials/goods being stored too close to the ceiling? (18" clearance to sprinklers)
- Is the storage of materials or commodities blocking access to fire protection systems or equipment (Blocked sprinkler control valves, blocked standpipe connections, blocked fire extinguisher cabinets)?
- Is the storage of materials significantly reducing aisle widths?
- Is combustible/flammable storage blocking access to electrical service cabinets? (30" clearance required)
- Are materials being stored on stairwell landings, or on stairs?
- Are combustible/flammable material being stored under stairwells?
- Are materials being stored within 36" of a gas-fired appliance (water heater, furnace, etc.)?
- Is storage blocking sprinkler control valves, inspectors test valves, or gas valves/meters?
- Are all flammable liquids being stored in approved flammable liquids cabinets?
- Is gasoline being stored in approved safety cans inside of flammable liquids cabinets?
- Are all containers properly labeled as to the contents?
- Are gasoline-powered items being stored inside the facility with fuel in the tanks?
- Is smoking and open flames prohibited in areas where combustible or flammable liquids are stored?
- Are "NO SMOKING" signs posted?

17.7. Hazardous Materials/Pressure Cylinders/Containers

- Are all compressed gas cylinders in storage or service properly secured (chained) to prevent falling or being knocked over or according to requirements listed in NFPA 50, NFPA 50A, and NFPA 99?
- Are incompatible chemicals being stored together or in alphabetical order?
- Are protective caps or valve protection devices in place on compressed gas cylinders?
- Are Material Safety Data Sheets (MSDS) being kept on file for each chemical used at your facility?
- Are MSDS sheets kept together in a readily accessible location identifiable to the Fire Department?
- Are all outside storage containers properly labeled as to the contents contained therein?
- Are outside hazardous materials storage areas adequately protected from truck/vehicle traffic?

17.8. Electrical Considerations

- Does the facility have bare bulbs, exposed wiring, outlet/junction box cover plates missing, altered circuit breaker panels, or unlabeled electrical panels?
- Are all protective covers or globes in place on light fixtures?
- Are light duty extension cords (zip cords) being used in office, vending, or kitchen areas?
- Are extension cords being utilized in lieu of permanent wiring?
- Are ground fault circuit interrupters in use near sinks or areas prone to potential electrical shock?
- Does the wiring in the facility comply with NFPA 70 (National Electrical Code)?
- In areas containing hazardous atmospheres, is the electrical service explosion proof in accordance with NFPA 70, National Electrical Code?
- Are tamper devices installed on fire alarm system circuit breakers?

17.9. Fire Alarm Systems

- Is your system current, centrally monitored, and meeting the requirements under NFPA 72 (National Fire Alarm Code)?
- Is your system maintained and inspected on a regular basis? Are all devices, including horns, bells, and strobes listed by location on the inspection report?
- Are the annunciation panels in a location readily accessible to the Fire Marshal Inspector?
- Are the installed detection devices tested on at least an annual basis? Are all smoke detectors tested per NFPA 72 for sensitivity?

17.10. Fire Suppression Systems

- Do your systems meet NFPA standards associated with each particular system or system component?
- Is the fire suppression system maintained, inspected, cleaned, and tested at least annually?
- Are maintenance and testing records maintained at the facility available for review by the Fire Marshal Inspector?
- Have alterations been made to the facility (interior room additions, mezzanines, storage areas, etc.) which defeats the currently installed system or which may not provide adequate protection?
- Due to changes in your facility operations, are additional fire suppression systems required to provide adequate protection for your facility?
- Do you have fire suppression systems that are in locations subject to freezing temperatures?
- Does your company secure (lock and chain) or monitor (electronic tamper switches) all fire suppression system valves including post indicator valves?
- Are spare sprinkler heads / wrench present in a cabinet near the sprinkler risers?

17.11. Fire Lanes/Fire Hydrants/Fire Department Connections

- Are the Fire Lane areas properly identified with signs and striping on the pavement?
- Are there storage items, trash containers, storage containers, or vehicles blocking access to fire hydrants, Fire Department Connections or Fire lanes?

- Does the facility have landscaping, fencing, or other items that would interfere with Fire Department Access in an emergency?
- Are your fire hydrants serviced annually by a licensed fire protection contractor to ensure proper operation? Fire hydrants require annual preventive maintenance if they are to work properly. Will the hydrant caps turn freely?

18. Conclusions & Recommendations

18.1. Conclusions

The Orangeburg Assembly Hall of Jehovah's Witnesses was analyzed in the applicable prescribed criteria in section 1 of this report. The various prescriptive-based design requirements established in the building, fire and life safety codes were documented throughout various sections of this report and a description of various building functions and systems were discussed.

The performance-based analysis addressed code deficiencies if the building was designed to a later edition of various codes and standards through the application of smoke-protected assembly seating (SPAS), not part of the original design. Based upon the estimated total evacuation time and the performance of the smoke management system, occupants of this facility are expected to have sufficient time to evacuate, prior to conditions becoming untenable (reference figure 18.1 below). FDS fire modeling also established that tenable conditions were maintained with a reduction in overall exhaust rate from an exhaust rate of 21,125 cfm (9.97 m^3/s) determined algebraically to an exhaust rate of 10,595 cfm (5 m^3/s). This can significantly reduce initial installation and construction costs as well as long-term operating and maintenance (O&M) life cycle costs. Finally, while the prescriptive egress analysis identified several egress capacity issues associated with doors in the auditorium, FDS fire modeling established that this could be overcome by equivalency that sufficient time was available for occupants to properly evacuate.

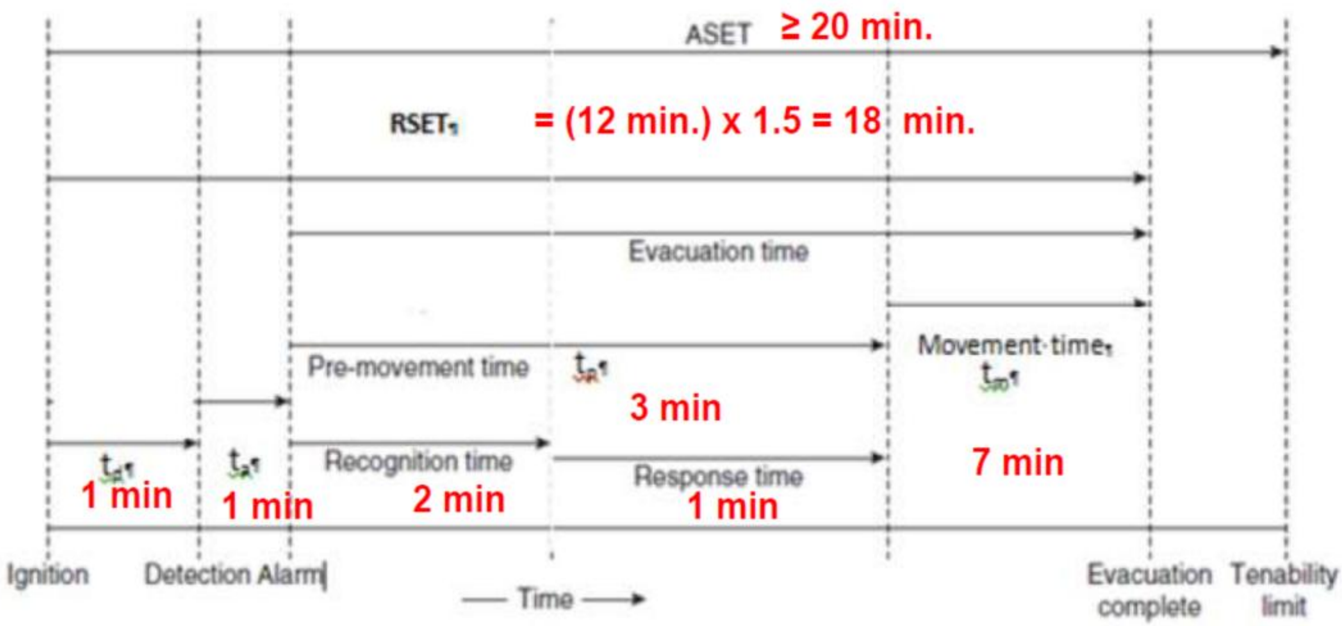


Figure 18.1 ASET/RSET Analysis

18.2. Recommendations

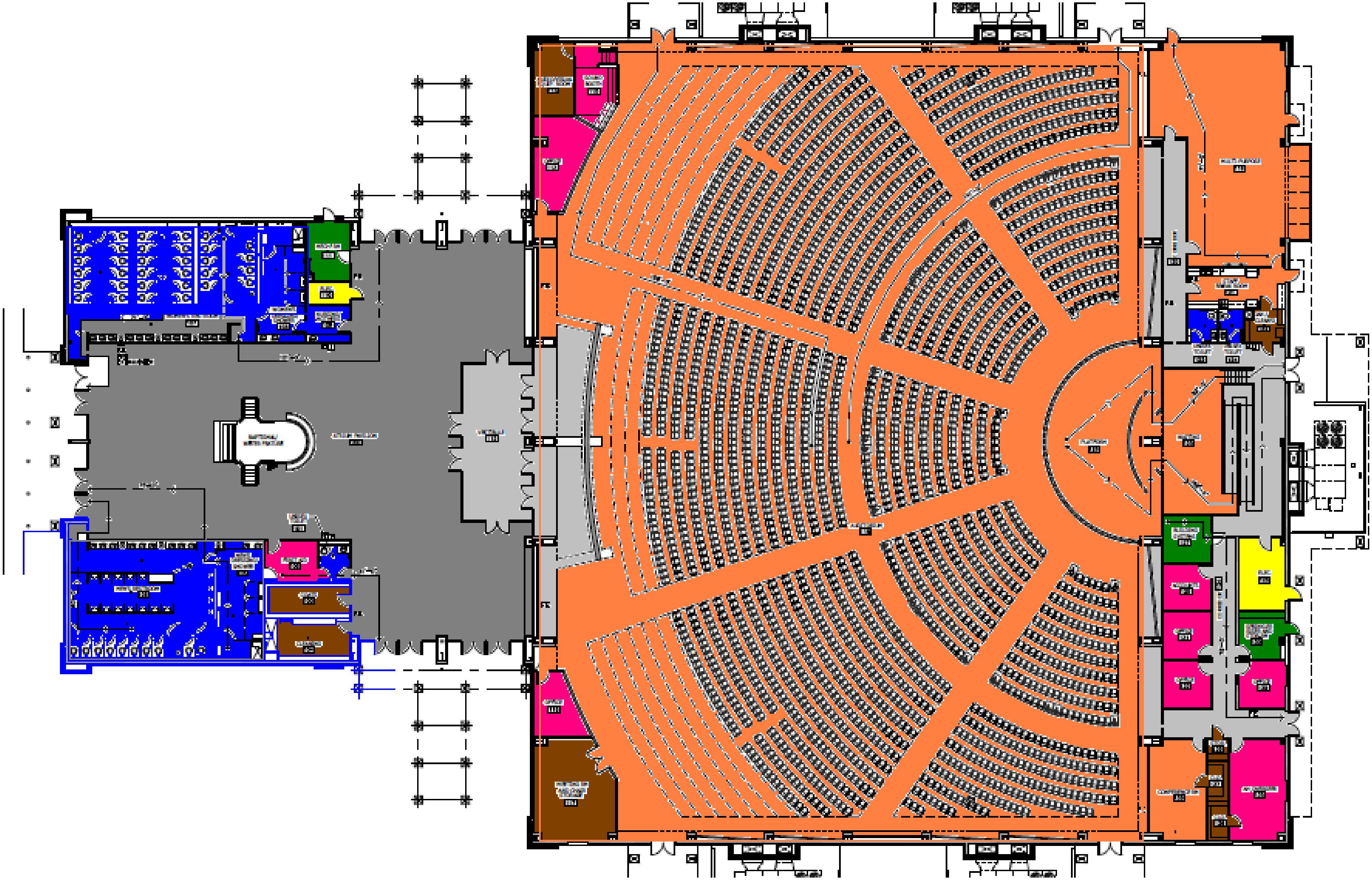
In order for this design approach to be appropriately implemented, the following recommendations shall serve as the basis of initiation and ongoing maintenance:

- Fire Protection System Initial Integrated Testing & Commissioning
- Fire Protection System Regular Inspection, Testing & Maintenance (ITM)
- Ongoing Review of Evacuation Plan & Fire Management Plans
- Regularly Review & Update Life Safety Evaluation for Assembly Seating
- Regular Training for Auditorium Attendants on Fire Evacuation Plan

Appendices

Appendix A - Occupancy Use & Classifications
Appendix B - Prescriptive Code Egress Layout
Appendix C - Architectural Building Sections
Appendix D - Available Water Supply Curves
Appendix E - Preliminary Sprinkler System Layout
Appendix F - Preliminary System Calculations
Appendix G - Proposed Sprinkler Material Cut Sheet Examples
Appendix H - Preliminary Fire Alarm System Calculations - Voltage Drop, Battery Size
Appendix I – Fire Alarm Sequence of Operations Matrix
Appendix J - Preliminary Fire Alarm System Layout
Appendix K - Smoke Control Rational Analysis
Appendix L - DETACT Fire Model – Sprinkler Activation & Smoke Detection Activation
Appendix M – Ignition/Fire Growth Calculations – Polyurethane Foam Padding Fixed Seating
Appendix N - Fire Dynamics Simulator (FDS) Design Fire Input
Appendix O - Estimated Evacuation Time Analysis
Appendix P - Pathfinder Egress Model
Appendix Q - Slide Show Presentation

Appendix A - Occupancy Use & Classifications



OCCUPANCY & USE CLASSIFICATIONS – ASSEMBLY HALL OF JEHOVAH'S WITNESSES – SHEET LS.1

ASSEMBLY SPACE	ELECTRICAL SPACE	RESTROOM SPACE	OFFICE SPACE	STORAGE SPACE	MECHANICAL SPACE	ASSEMBLY LOBBY SPACE	CORRIDOR SPACE

APPENDIX A OCCUPANCY & USE CLASSIFICATIONS - SHEET LS.1

Appendix B - Prescriptive Code Egress Layout

ASSEMBLY EGRESS WIDTH SUB-WORKSHEET

Is the occupant load of a Group A occupancy over 300 persons? yes (Yes or No) If yes, see Section 1008.1

Is the assembly seating area smoke-protected? yes (Yes or No)

If **yes**, then an evaluation per NFPA 101 shall be submitted with the plans and the egress widths shall be based not IBC Table 1008.5.2 minimums. All of the requirements of Sections 1008.5.2.1, 1008.5.2.2, and 1008.5.2.3 must be met, or else it is not smoke-protected seating.

If **no**, then use the following requirements from Section 1008.5.1 as listed below.

Clear width of aisles and other means of egress for non-smoke-protected seating shall be per cases 1 through 6 below. *(Indicate which formula is being used.)*

Where **W** = Required width in **inches per occupant**
R = Riser height in inches (from tread to tread)

Case 1 – Where **R** ≤ 7.0” Then **W = 0.3** (Formula 10-1)

Case 2 – Where **R** > 7.0” Then **W = 0.3 + 10(R – 7.0”)(0.005)** (Formula 10-2)

Case 3 – Where egress requires stair descent without a handrail within a horizontal distance of 30” and **R** ≤ 7.0”, then add 0.075” additional width per occupant
Then **W = 0.375** = 0.3 + 0.075 (Formula 10-3)

Case 4 – Where egress requires stair descent without a handrail within a horizontal distance of 30” and **R** > 7.0”, then add the 0.075” additional width per occupant plus a factor
Then **W = 0.375 + 10(R – 7.0”)(0.005)** (Formula 10-4)

Case 5 – Where ramped means of egress > 1:12 slope Then **W = 0.22** (Formula 10-5)

Case 6 – Where level or ramped means of egress ≤ 1:12 slope, Then **W = 0.20** (Formula 10-6)

Note that for outdoor smoke-protected assembly seating, the width may meet the lesser of clear width of Section 1008.5.3 or the Table 1008.5.2 requirement serving the same number of seats.

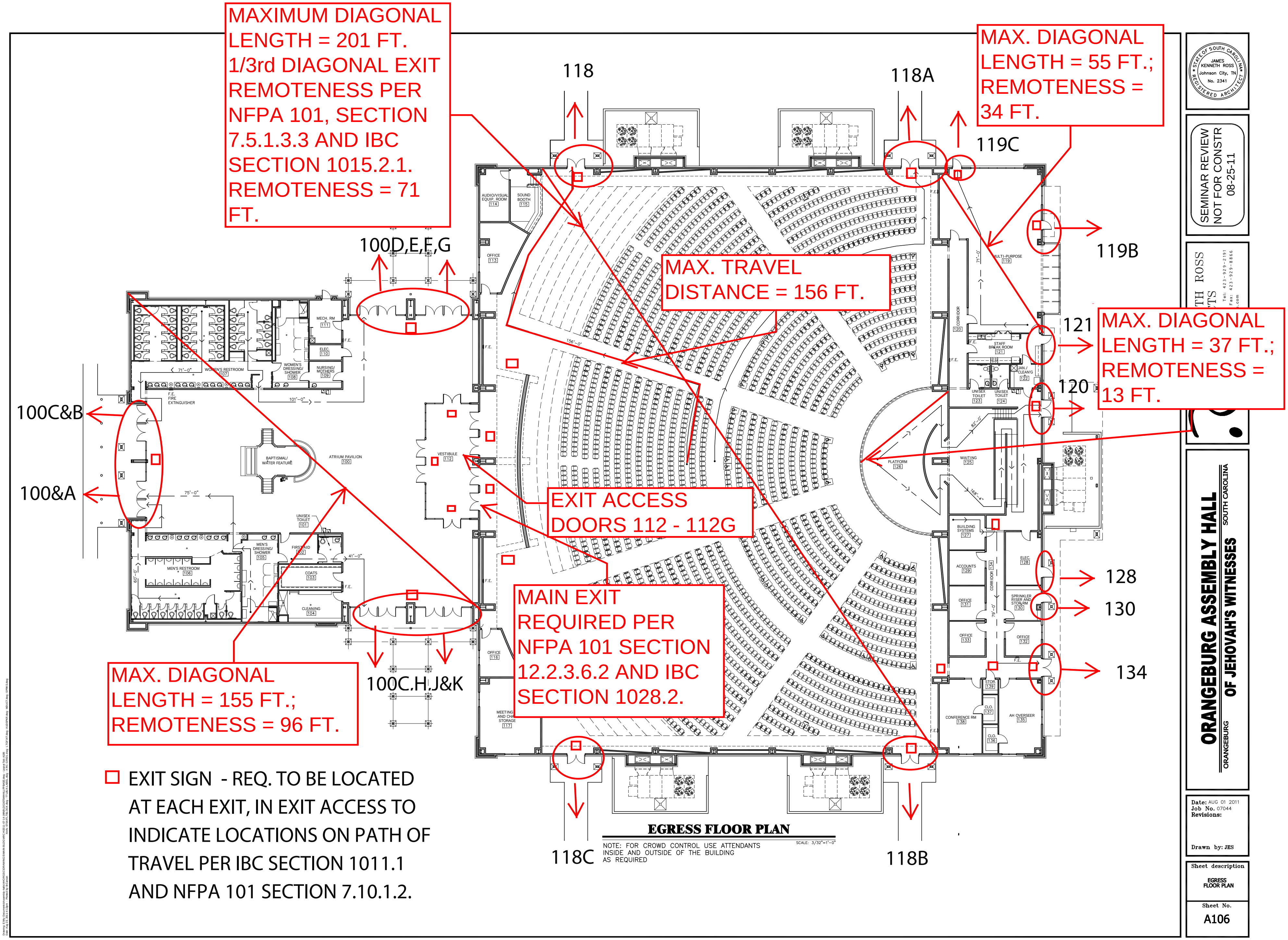
Case 7 – Where outdoor smoke-protected seating using stairs Then **W = 0.08** (Formula 10-7)

Case 8 – Where outdoor smoke-protected seating using ramps, corridors, tunnels or vomitories
Then **W = 0.06** (Formula 10-8)

NOTE THAT MINIMUM AISLE WIDTHS PER SECTIONS 1008.7.1, 1008.7.2, 1008.7.3, AND 1008.7.4 MUST ALSO ALWAYS BE PROVIDED. **These widths include:**

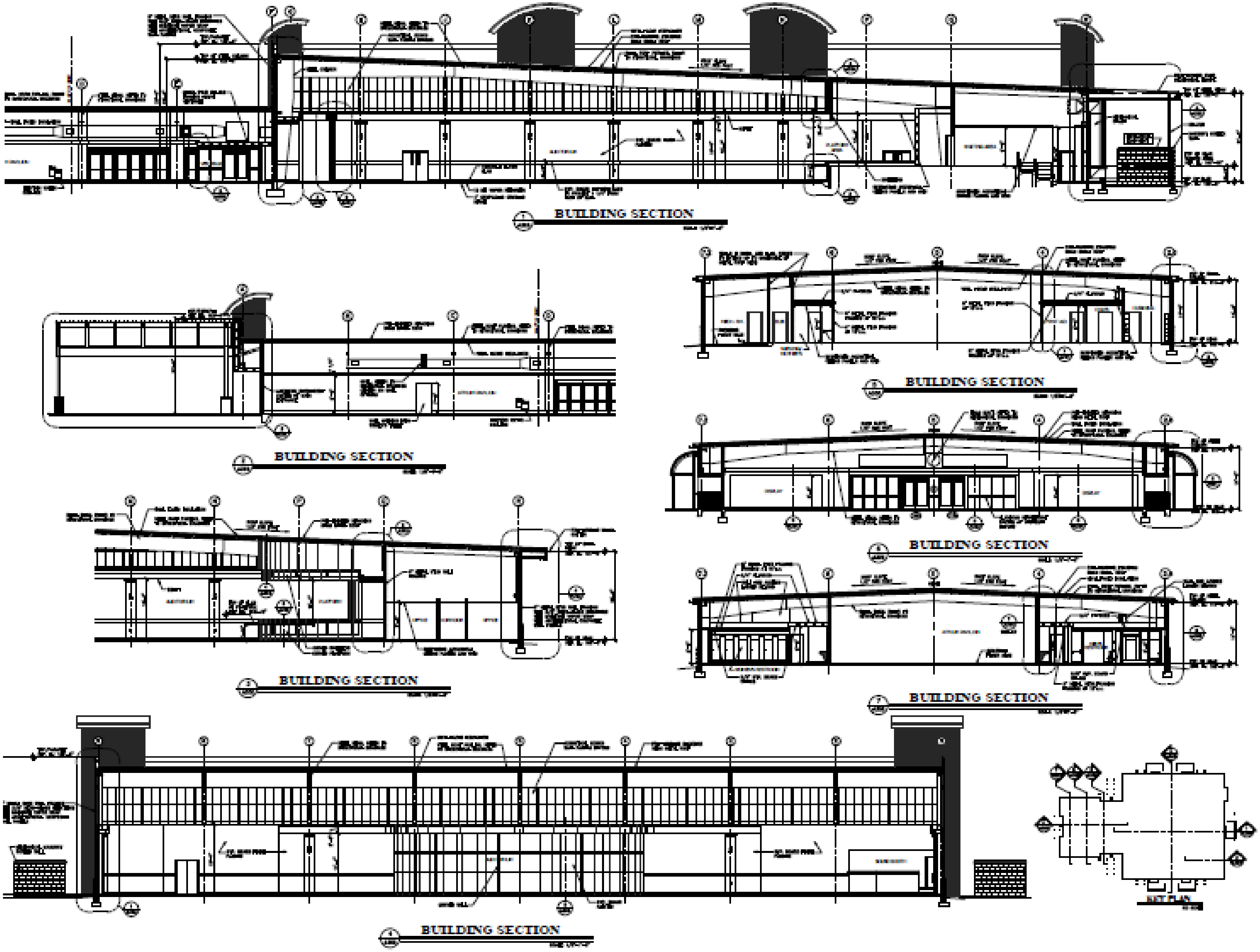
42” aisle for level or ramp with seats both sides
36” aisle for level or ramp with seats on both sides if under 50 seats
36” aisle for level or ramp with seats one side
23” clear to handrail serving aisle stair less than 5 rows on one side

48” for aisle stairs with seats on both sides
36” aisle stair w/seats both sides if < 50 seats
36” for aisle stairs with seats one side
23” clear to handrail dividing an aisle stair



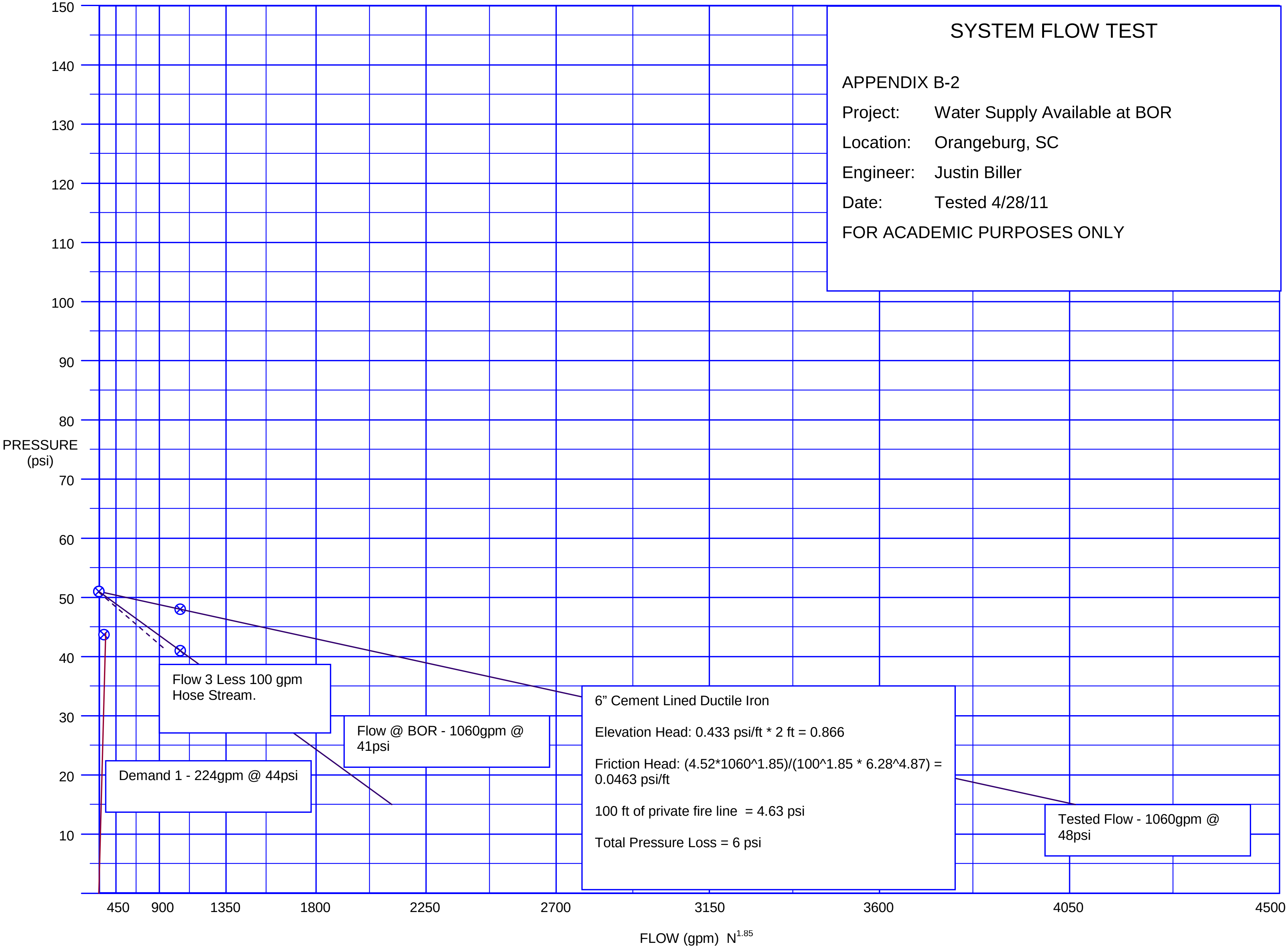
APPENDIX B PRESCRIPTIVE CODE EGRESS LAYOUT SHEET LS.2

Appendix C - Architectural Building Sections

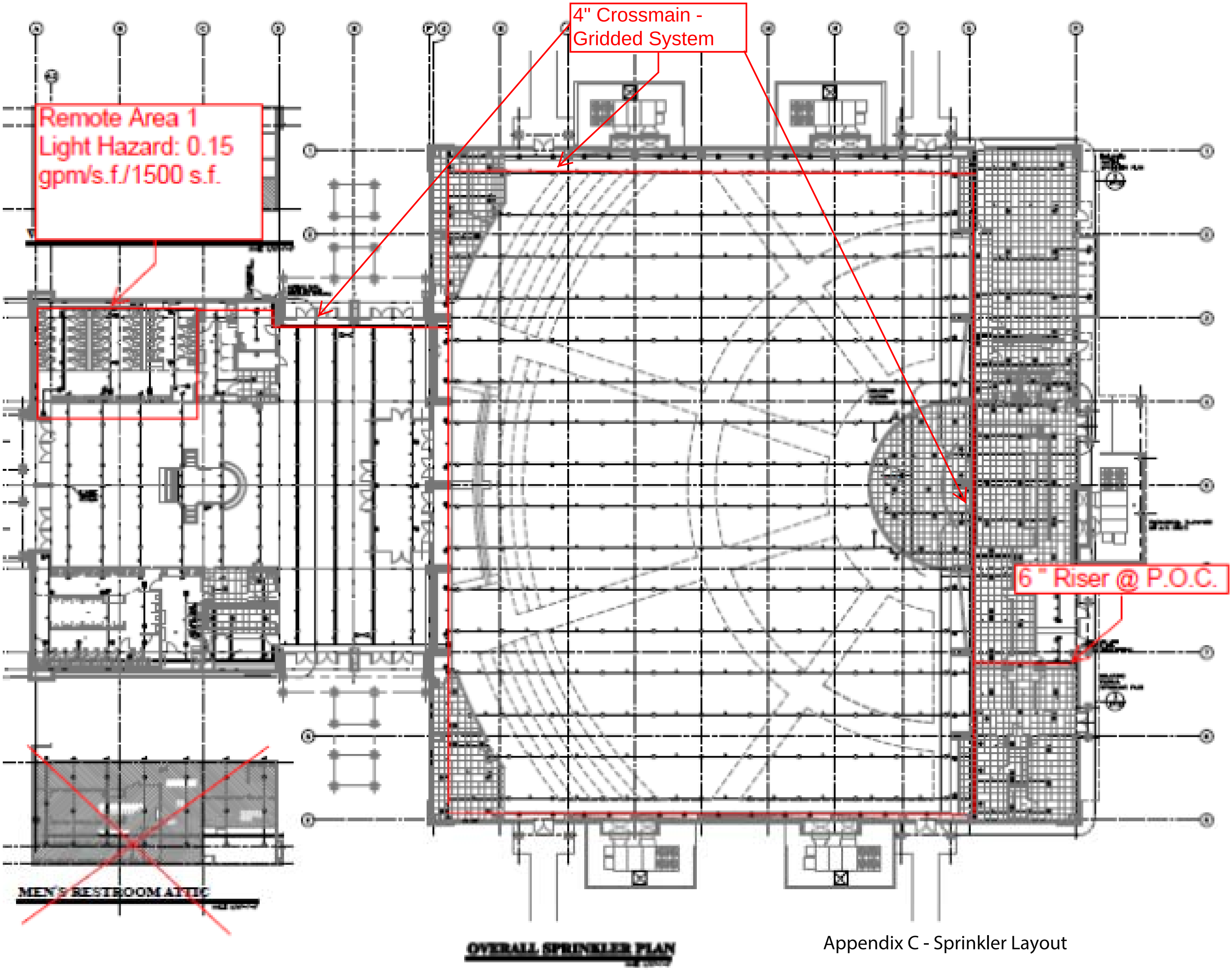


Appendix B - Building Sections

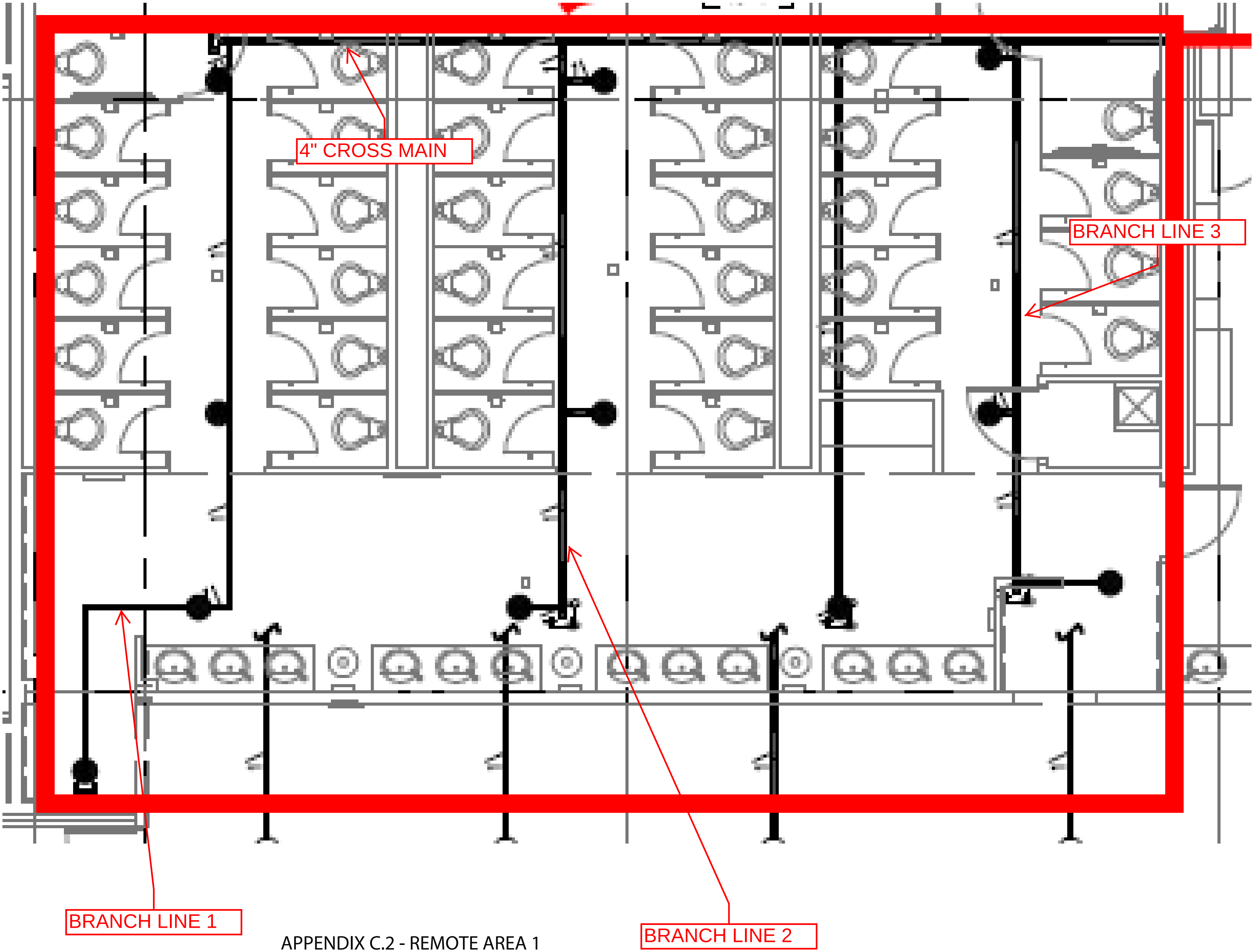
Appendix D - Available Water Supply Curves


SYSTEM FLOW TEST
APPENDIX B-2
Project: Water Supply Available at BOR
Location: Orangeburg, SC
Engineer: Justin Biller
Date: Tested 4/28/11
FOR ACADEMIC PURPOSES ONLY
PRESSURE (psi)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
450
900
1350
1800
2250
2700
3150
3600
4050
4500
FLOW (gpm) N^1.85
Flow 3 Less 100 gpm Hose Stream.
Flow @ BOR - 1060gpm @ 41psi
Demand 1 - 224gpm @ 44psi
6” Cement Lined Ductile Iron
Elevation Head: 0.433 psi/ft * 2 ft = 0.866
Friction Head: (4.52*1060^1.85)/(100^1.85 * 6.28^4.87) = 0.0463 psi/ft
100 ft of private fire line = 4.63 psi
Total Pressure Loss = 6 psi
Tested Flow - 1060gpm @ 48psi

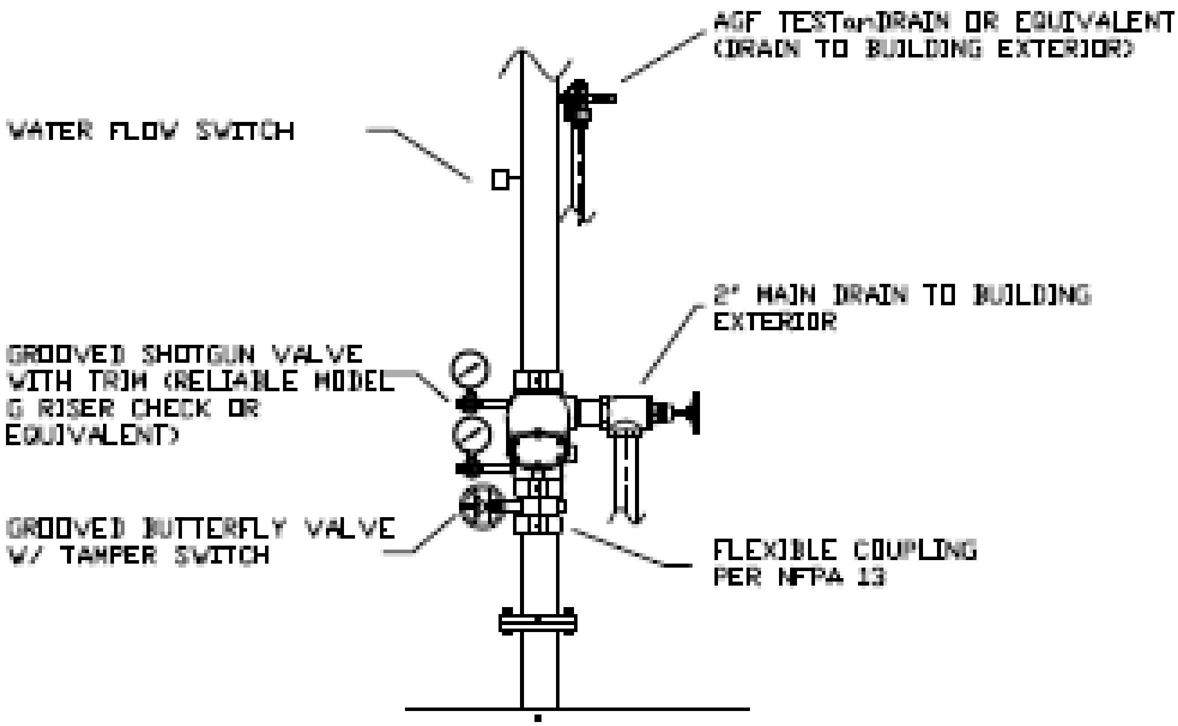
Appendix E - Preliminary Sprinkler System Layout



Appendix C - Sprinkler Layout



APPENDIX C.2 - REMOTE AREA 1

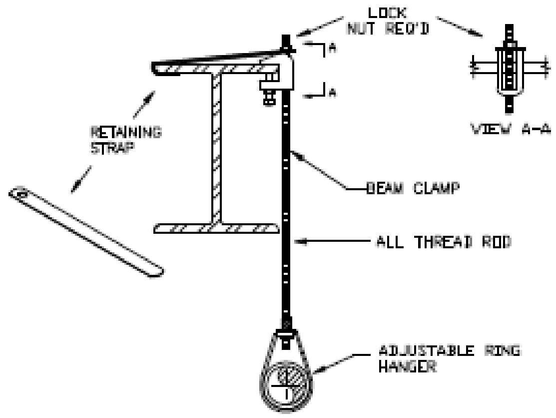


RISER DETAIL

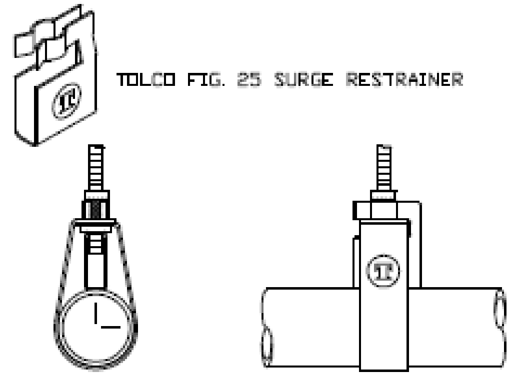
NOT TO SCALE

SPRINKLER HEAD LEGEND

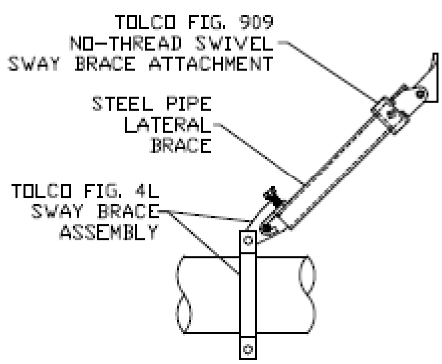
◉	102	(1/2",K=5.6)	WHITE RECESSED PENDENT
○	272	(1/2",K=5.6)	UPRIGHT
●	77	(1/2",K=5.6)	WHITE CONCEALED PENDENT

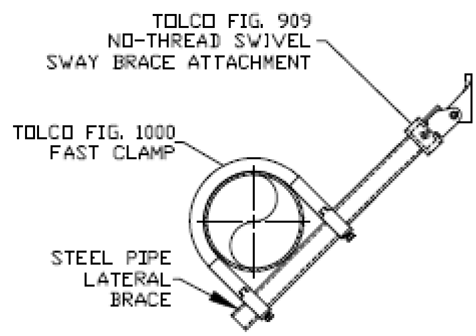


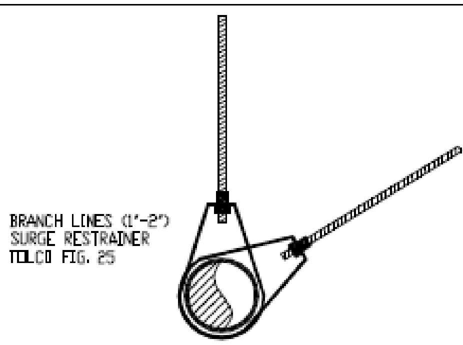
TOP BEAM CLAMP, ROD, AND RING



TOLCO FIG. 25 IS DESIGNED TO BE USED TO RESTRAIN THE UPWARD MOVEMENT OF PIPE AS IT OCCURS DURING SPRINKLER HEAD ACTIVATION OR SEISMIC ACTIVITY







END OF LINE & LATERALLY RESTRAINT DETAIL

NO SCALE

2 -- 3/8" A.T.R.
2 -- 1" - 2 1/2" Swivel Ring (TOLCO FIG. 200)
1 -- Swivel Attachment (TOLCO FIG. 75)

(INSTALL AT END OF ALL LINES, SEE PLAN FOR ADDITIONAL LOCATIONS)

Appendix F - Preliminary System Calculations

OWNER'S INFORMATION CERTIFICATE

Name/address of property to be protected with sprinkler protection Orangburg SC Assembly Hall of Jehovah's Witnesses

Owner Orangeburg Assembly Hall Committee

Existing or planned construction is:

- ☒ Fire resistive or noncombustible
- ☐ Wood frame or ordinary (masonry walls with wood beams)
- ☐ Unknown

Is the system installation intended for one of the following special occupancies:

Aircraft hangar	☐ Yes	☒ No	Airport terminal	☐ Yes	☒ No
Fixed guideway transit system	☐ Yes	☒ No	Aircraft engine test facility	☐ Yes	☒ No
Race track stable	☐ Yes	☒ No	Power plant	☐ Yes	☒ No
Marine terminal, pier, or wharf	☐ Yes	☒ No	Water-cooling tower	☐ Yes	☒ No

If the answer to any of the above is "yes," the appropriate NFPA standard should be referenced for sprinkler density/area criteria.

Indicate whether any of the following special materials are intended to be present:

Flammable or combustible liquids	☐ Yes	☒ No	Compressed or liquefied gas cylinders	☐ Yes	☒ No
Aerosol products	☐ Yes	☒ No	Liquid or solid oxidizers	☐ Yes	☒ No
Nitrate film	☐ Yes	☒ No	Organic peroxide formulations	☐ Yes	☒ No
Pyroxylin plastic	☐ Yes	☒ No	Idle pallets	☐ Yes	☒ No

If the answer to any of the above is "yes," describe type, location, arrangement, and intended maximum quantities. ____________

Indicate whether the protection is intended for one of the following specialized occupancies or areas:

Spray area or mixing room	☐ Yes	☒ No	Commercial cooking operation	☐ Yes	☒ No
Solvent extraction	☐ Yes	☒ No	Class A hyperbaric chamber	☐ Yes	☒ No
Laboratory using chemicals	☐ Yes	☒ No	Cleanroom	☐ Yes	☒ No
Oxygen–fuel gas system for welding or cutting	☐ Yes	☒ No	Incinerator or waste-handling system	☐ Yes	☒ No
			Linen-handling system	☐ Yes	☒ No
Acetylene cylinder charging	☐ Yes	☒ No	Industrial furnace	☐ Yes	☒ No
Production or use of compressed or liquefied gases	☐ Yes	☒ No	Water-cooling tower	☐ Yes	☒ No

If the answer to any of the above is "yes," describe type, location, arrangement, and intended maximum quantities. ____________

Will there be any storage of products over 12 ft (3.6 m) in height? ☐ Yes ☒ No

If the answer is "yes," describe product, intended storage arrangement, and height. ____________

Will there be any storage of plastic, rubber, or similar products over 5 ft (1.5 m) high except as described above? ☐ Yes ☒ No

If the answer is "yes," describe product, intended storage arrangement, and height. ____________

I certify that I have knowledge of the intended use of the property and that the above information is correct.

Signature of owner's representative or agent ____________ Date ____________

Name of owner's representative or agent completing certificate *(print)* ____________

Relationship and firm of agent *(print)* ____________

Project name: Orangeburg Assembly Hall - Preliminary Calculation Date: 3.14.12

Step No.	Nozzle Ident and Location	Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure		Notes	
		q				L	10	C=	120	Pt	9.0	Pt		k=	5.6
1	1 BL1			1.049	1 Elbow	F	1			Pe		Pv			q =0.1*168 = 16.8 gpm
		Q	16.8			T	11	pf	0.094	Pf	1.0	Pn		Pt=	$(16.8 gpm/5.6)^2$ = psi
		q	17.7			L		C=	120	Pt	10.0	Pt		k=	5.6
2	2			1.049		F				Pe		Pv		q=	k*√P
		Q	34.5			T	10	pf	0.358	Pf	3.6	Pn			
		q	20.7			L		C=	120	Pt	13.6	Pt		k=	5.6
3	3			1.38		F				Pe		Pv		q=	k*√P
		Q	55.2			T	10	pf	0.224	Pf	2.2	Pn			
		q	22.3			L	10	C=	120	Pt	15.9	Pt		k=	5.6
4	4			1.61		F				Pe		Pv		q=	k*√P
		Q	77.5			T	10	pf	0.198	Pf	2.0	Pn			
	to	q	23.6			L	3	C=	120	Pt	17.8	Pt		k=	5.6
5	5 CM			1.61	1 Tee	F	8			Pe		Pv		q=	k*√P
		Q	101.1			T	11	pf	0.324	Pf	3.6	Pn			
	Equivalent	q				L		C=		Pt	21.4	Pt		K =	Q/√P
6	K BL1					F				Pe		Pv		**K =**	**21.87**
		Q				T		pf		Pf		Pn			
	CM to	q				L	14	C=	120	Pt	30.9	Pt			
7	BL2			4.026		F				Pe		Pv			
		Q	101.1			T	14	pf	0.004	Pf	0.1	Pn			
	Equivalent	q	122.2			L		C=		Pt	31.0	Pt		K=	21.97
10	Flow					F				Pe		Pv			
	BL2	Q	223.3			T		pf		Pf		Pn			
	CM to	q			1 90 ELB	L	350	C=	120	Pt	31.0	Pt			
11	BOR			4.026	1 CK VLV	F	24			Pe	6.5	Pv			
		Q	223.3		1 GT VLV	T	374	pf	0.016	Pf	6.0	Pn			
		q	100.0			L		C=		Pt	43.5	Pt			324 GPM @ 44 psi
						F				Pe		Pv			
		Q	323.3			T		pf		Pf		Pn			
		q				L		C=		Pt		Pt			
						F				Pe		Pv			
		Q				T		pf		Pf		Pn			
		q				L		C=		Pt		Pt			
						F				Pe		Pv			
		Q				T		pf		Pf		Pn			
		q				L		C=		Pt		Pt			
						F				Pe		Pv			
		Q				T		pf		Pf		Pn			
		q				**L**		**C=**		**Pt**		**Pt**			
						F				**Pe**		**Pv**			
		Q				**T**		**pf**		**Pf**		**Pn**			

Appendix G - Proposed Sprinkler Material Cut Sheet Examples

Model E3 High Pressure Alarm Check Valve 4" (100mm), 6" (150mm), 165 mm & 8" (200mm)

Bulletin 410 Rev. F

Features

1. 300 psi (20,7 bar) ratings. Factory tested hydrostatically to 600 psi (41,4 bar).
2. Grooved seat design ensures positive water flow alarm operation.
3. Precision retard chamber minimizes false alarms under variable pressure conditions.
4. External by-pass minimizes false alarms under all supply pressure conditions.
5. Grooved inlet and outlet connections. Less weight than flange valves.
6. Vertical and horizontal trims available.
7. Three compact galvanized trim styles available:
   - Individual part trim
   - Segmentally assembled trim
   - Factory trimmed valve
8. TestANDrain® valve with pressure relief, optional:
   - Exercises the clapper with alarm test.
   - Functions like the Inspector's Test Port with greater convenience.

Description

The Reliable Model E3 Alarm Valve activates the water flow alarm device in wet pipe sprinklers systems. The design allows for installation under both variable and constant supply pressure conditions. When water flows in the sprinkler system due to the operation of one or more automatic fire sprinklers, the alarm valve opens, allowing continuous flow of water into the system and transmittal of water pressure to electrical and/or mechanical water flow alarm devices.

Approvals & Listings

1. Listed by Underwriters Laboratories, Inc. and Certified by UL for Canada (cULus).
2. Approved by FM Research (FM).
   - When used with the Model E3 trim sets.
   - Optional TestANDrain® Valve is not FM Approved.
3. Scientific Services Laboratory (SSL, Australia). 100mm, 165mm & 200mm.
4. NYC MEA 258-93-E
5. Conforms to EN 12259-2 metric sizes only (CE).
6. Loss Prevention Certification Board (LPCB) Approved.

Ordering Information – Specify:

- Valve size – 4" (100mm) or 6" (150mm), or 165mm or 8" (200mm).
- Type of trim – Constant Pressure or Variable Pressure.
- Style of trim – Individual parts trim, segmentally assembled trim, or factory trimmed valve.
- Additional Equipment – Mechanical sprinkler alarm and pressure alarm switch must be separately ordered.

Operation

Variable Pressure

The Reliable Model E3 High Pressure Alarm Valve in it's closed and open positions is shown in Figures 1 and 2. The closed position is maintained as long as the water pressure in the sprinkler system piping above the alarm valve is greater than, or equal to, the supply pressure. A flow of water in the system piping, resulting from the discharge through one or more fused automatic sprinklers, causes the clapper to rise off its grooved seat and permits water from the supply to enter the system for distribution on the fire.

Water now flows through the uncovered groove and alarm line into the retard chamber. Once the retard chamber is filled the water flow activates the mechanical and electrical alarms (Figs. 3 & 4).

Virtually all sprinkler system piping contains confined air. If a water hammer or pressure surge occurs in the supply line, the increased pressure will compress the confined air and cause the alarm valve clapper to lift intermittently which may result in false alarms. The Reliable Model E3 Alarm Valve minimizes false alarms under these conditions by two features:

a. The by-pass connection with check valve (Figs. 3 & 4) allows pressure surges from the supply to by-pass the alarm valve clapper. An excess system pressure is thus created which steadies the clapper. Should a heavy surge unseat the clapper and permit water to flow into the alarm line, the retarding chamber then comes into action.
b. Two Drain Orifice restrictions on the supply side of the Retard Chamber allow intermittent flow to be drained before the Chamber fills and activates the alarms.

Constant Pressure

The operation of the Model E3 Alarm Valve in installations where the water pressure is constant is the same as described above, with this exception: The retard chamber is not required and water passing through the groove in the alarm valve seat flows directly to activate the mechanical and electrical alarms.

Valve Description

1. Rated working pressure: 300 psi (20,7 bar).
2. Factory hydrostatic test pressure: 600 psi (41,4 bar).
3. End and trim connections:
   - Threaded openings per ANSI B 2.1 or ISO 7/1 R.
   - Grooves per ANSI/AWWA C606.
4. Color: Black.
   Red (E3A*)
   Red (Metric)

Groove Dimensions in Inches (mm)					
Valve Size	Inlet and Outlet Dia.	Groove Dia.	Groove Width	Face To Groove Dim.	Valve Type
4 (100)	4.500 (114)	4.334 (110.1)	3/8 (9.5)	5/8 (16)	E3 & E3A*
6 (150)	6.625 (168)	6.455 (164.0)	3/8 (9.5)	5/8 (16)	E3
6 (165)	6.500 (165)	6.330 (160.8)	3/8 (9.5)	5/8 (16)	E3A
8 (200)	8.625 (219)	8.441 (214.0)	7/16 (11)	3/4 (19)	E3 & E3A*

*"A" Designates valves made for Australia.

5. Face to Face Dimension:
   - For the 4" (100mm) valve – 11¾" (299mm).
   - For the 6" (150mm) valve – 13½" (343mm).
   - For the 8" (200mm) valve – 14½" (368mm).

Model E3 Trim Description

The basic trims for the Reliable Model E3 High Pressure Alarm Valve (Figs. 3 & 4), are arranged for rapid, easy and compact attachment, and serve as connection points to Reliable alarm and other devices. They also act as a means for testing the operation of the alarm devices without causing the system to operate. The Model E3 high pressure alarm valves are available in two trims and may be installed in the vertical or horizontal position in the main supply to the wet pipe system:

- Constant Pressure Closed Drain – Retard chamber not required. This trim set is used where water supply pressure does not vary such as a gravity tank. The mechanical sprinkler alarm line automatically drains to the 2" (50mm) main drain line.
- Variable Pressure Closed Retard Chamber Drain – Retard chamber required. This trim set is used where water supply pressures vary. The retard chamber and mechanical sprinkler alarm line are drained through a closed, checked connection to the 2" (50mm) main drain line. Only one drain connection is required.

Note:

- The trim set permits both vertical and horizontal installation.
- A TestANDrain® valve segment is optional, to be purchased separately, as a replacement to the valve (Figs. 3 & 4).

Model E3 High Pressure Alarm Valve (Fig. 1 & 2)

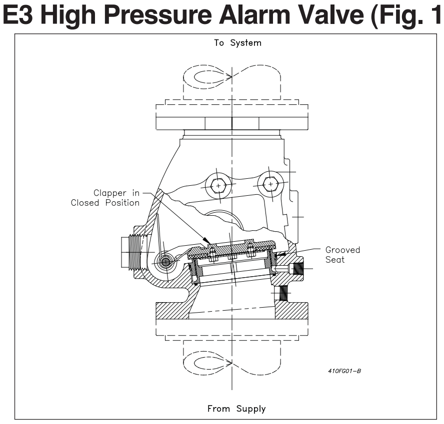


Fig. 1 Closed Position

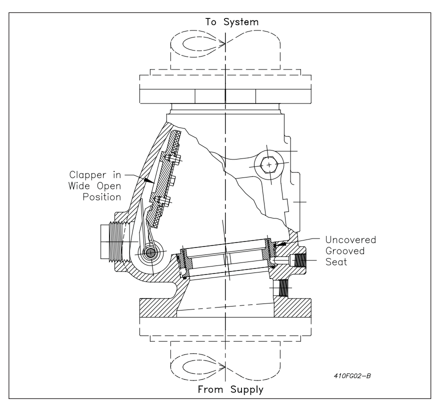


Fig. 2 Open Position

E-3 Vertical and Horizontal Trims:

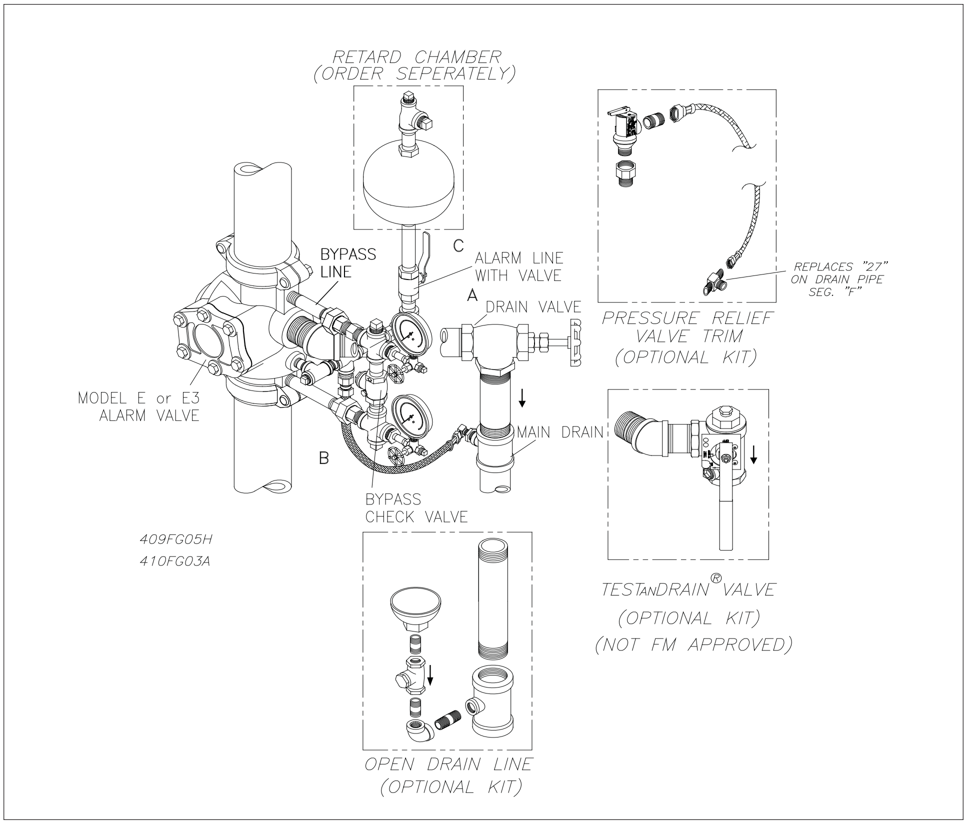


Fig. 3 - E3 Vertical Trim

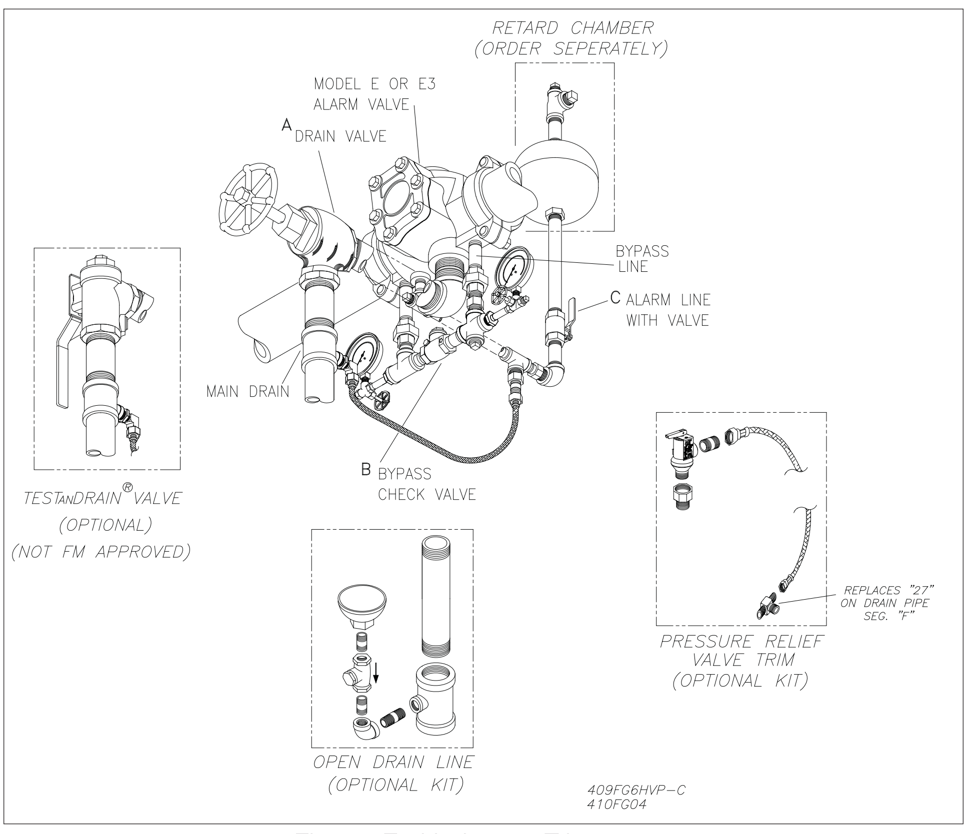


Fig. 4 - E3 Horizontal Trim

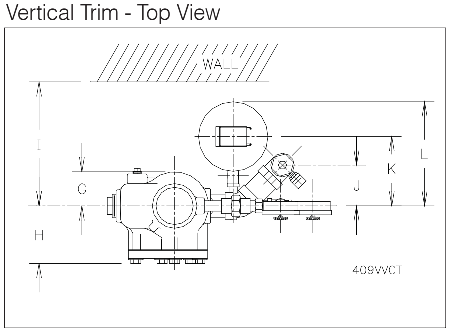
Model E3 Vertical & Horizontal Trim Illustrations

Installation dimension in Inches (mm)

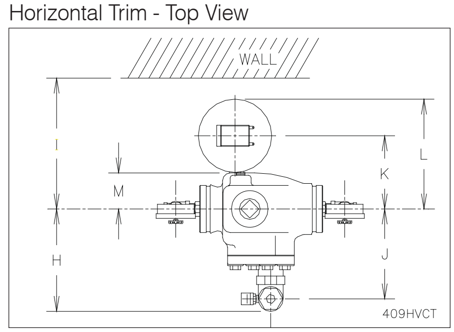
Valve	A	B	C	D	E	F	G	H	I	J	K	L	M
4” (100mm)	7” (178)	10½” (267)	16½” (419)	6” (152)	16¾” 426)	15” (381)	3½” (89)	5¾” (146)	12” (305)	4½” (114)	6½” (165)	10” (254)	8¼” (210)
6” (150mm) (165mm)	7” (194)	11½” (292)	17½” (445)	7” (178)	15¼” (387)	16½” (419)	4¼” (108)	7” (178)	12” (305)	4½” (114)	6½” (165)	10” (254)	6¾” (172)
8” (200mm)	7” (194)	11½” (292)	17½” (445)	7” (178)	15¼” (387)	16½” (419)	4¼” (108)	7” (178)	12” (305)	4½” (114)	6½” (165)	10” (254)	6¾” (172)

Installation must be made with 300 psi (20,7 bar) minimum rated grooved couplings, such as the Star® Fittings Model C-2 LW. To mate with ANSI Class 250 or Class 300 Flanges, use listed grooved flanged adapters having appropiate pressure rating.

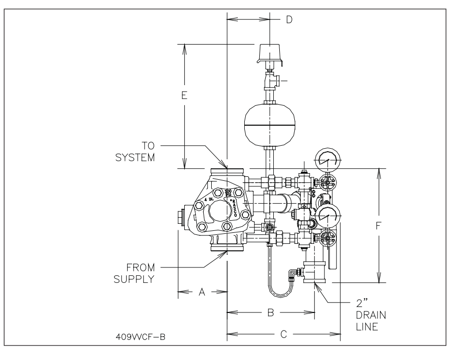
Variable Pressure
Vertical Trim - Top View



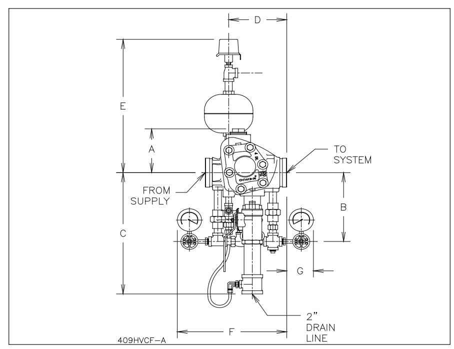
Variable Pressure
Horizontal Trim - Top View



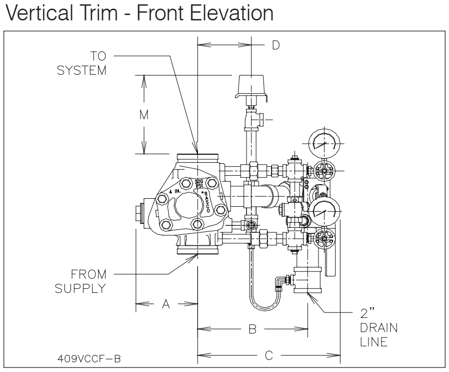
Variable Pressure
Vertical Trim - Front Elevation



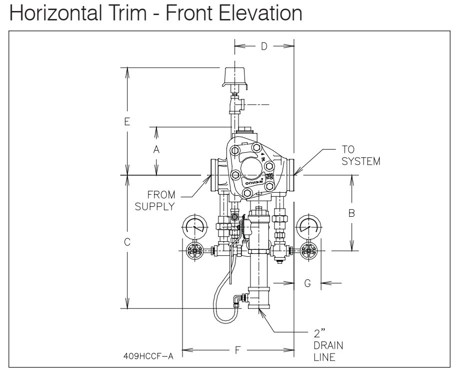
Variable Pressure
Horizontal Trim - Front Elevation



Constant Pressure
Vertical Trim - Front Elevation



Constant Pressure
Horizontal Trim - Front Elevation



The equipment presented in this bulletin is to be installed in accordance with the latest published Standards of the National Fire Protection Association, Factory Mutual Research Corporation, or other similar organizations and also with the provisions of governmental codes or ordinances whenever applicable. Productsmanufactured and distributed by Reliable have been protecting life and property for over 80 years, and are installed and serviced by the most highly qualified and reputable sprinkler contractors located throughout the United States, Canada and foreign countries.

Manufactured by

Reliable®

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Series TY-FRB — 2.8, 4.2, 5.6, and 8.0 K-factor Upright, Pendent, and Recessed Pendent Sprinklers Quick Response, Standard Coverage

General Description

The Series TY-FRB, 2.8, 4.2, 5.6, and 8.0 K-factor, Upright and Pendent Sprinklers described in this data sheet are quick response - standard coverage, decorative 3 mm glass bulb type spray sprinklers designed for use in light or ordinary hazard, commercial occupancies such as banks, hotels, shopping malls, etc.

The recessed version of the Series TY-FRB Pendent Sprinkler, where applicable, is intended for use in areas with a finished ceiling. It uses either a two-piece Style 10 (1/2 inch NPT) or Style 40 (3/4 inch NPT) Recessed Escutcheon with 1/2 inch (12,7 mm) of recessed adjustment or up to 3/4 inch (19,1 mm) of total adjustment from the flush pendent position, or a two-piece Style 20 (1/2 inch NPT) or Style 30 (3/4 inch NPT) Recessed Escutcheon with 1/4 inch (6,4 mm) of recessed adjustment or up to 1/2 inch (12,7 mm) of total adjustment from the flush pendent position. The adjustment provided by the Recessed Escutcheon reduces the accuracy to which the fixed pipe drops to the sprinklers must be cut.

Corrosion resistant coatings, where applicable, are utilized to extend the life of copper alloy sprinklers beyond that which would otherwise be obtained when exposed to corrosive atmospheres. Although corrosion resistant coated sprinklers have passed the standard corrosion tests of the applicable approval agencies, the testing is not representative of all possible corrosive atmospheres. Consequently, it is recommended that the end user be consulted with respect to the suitability of these coatings for any given corrosive environment. The effects of ambient temperature, concentration of chemicals, and gas/chemical velocity, should be considered, as a minimum, along with the corrosive nature of the chemical to which the sprinklers will be exposed.

An intermediate level versions of the Series TY-FRB Pendent Sprinklers are detailed in Technical Data Sheet TFP356, and Sprinkler Guards are detailed in Technical Data Sheet TFP780

IMPORTANT

Always refer to Technical Data Sheet TFP700 for the "INSTALLER WARNING" that provides cautions with respect to handling and installation of sprinkler systems and components. Improper handling and installation can permanently damage a sprinkler system or its components and cause the sprinkler to fail to operate in a fire situation or cause it to operate prematurely.

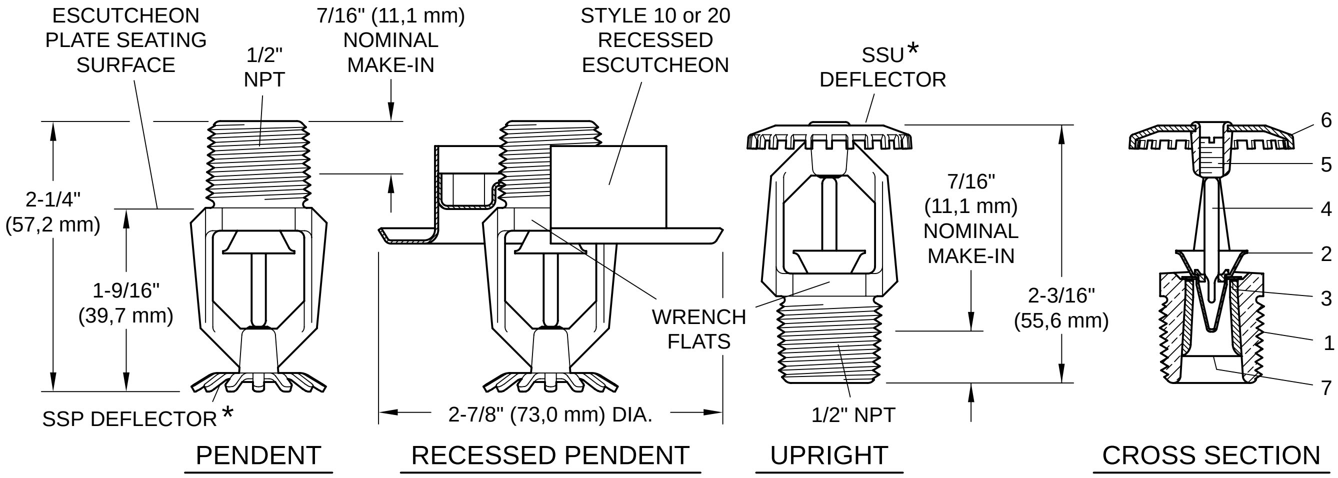
WARNINGS

The Series TY-FRB Sprinklers described herein must be installed and maintained in compliance with this document, as well as with the applicable standards of the National Fire Protection Association, in addition to the standards of any other authorities having jurisdiction. ***Failure to do so may impair the performance of these devices.***

The owner is responsible for maintaining their fire protection system and devices in proper operating condition. The installing contractor or sprinkler manufacturer should be contacted with any questions.

Model/Sprinkler Identification Numbers

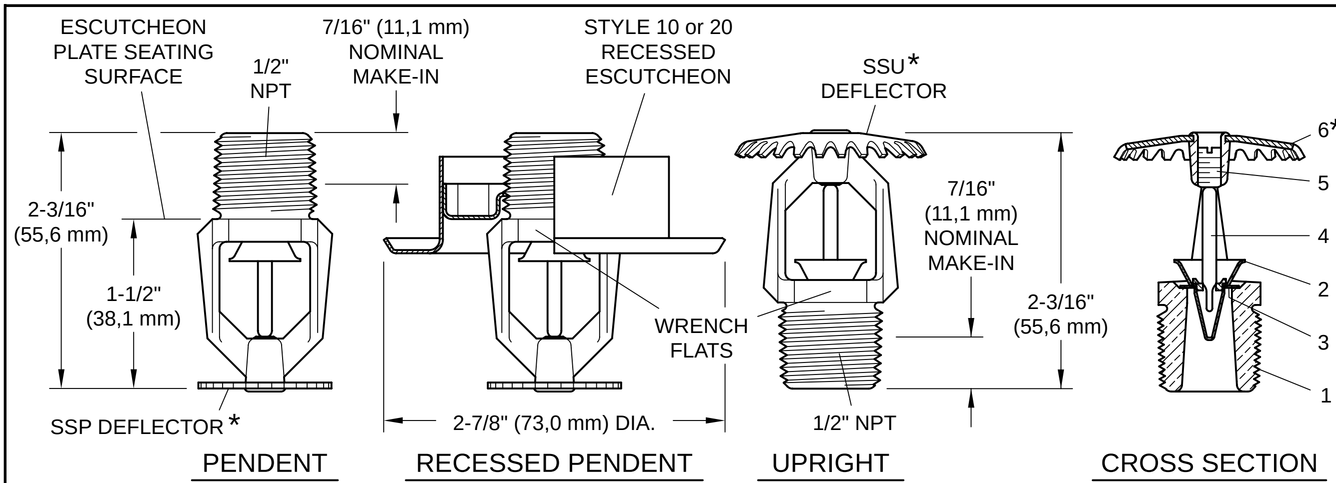
TY1131 -	**Upright**	**2.8K, 1/2"NPT**
TY1231 -	**Pendent**	**2.8K, 1/2"NPT**
TY2131 -	**Upright**	**4.2K, 1/2"NPT**
TY2231 -	**Pendent**	**4.2K, 1/2"NPT**
TY3131 -	**Upright**	**5.6K, 1/2"NPT**
TY3231 -	**Pendent**	**5.6K, 1/2"NPT**
TY4131 -	**Upright**	**8.0K, 3/4"NPT**
TY4231 -	**Pendent**	**8.0K, 3/4"NPT**
TY4831-	**Upright**	**8.0K, 1/2"NPT**
TY4931-	**Pendent**	**8.0K, 1/2"NPT**



1 - Frame
2 - Button
3 - Sealing Assembly
4 - Bulb
5 - Compression Screw
6 - Deflector
7 - Bushing

* Temperature rating is indicated on deflector or adjacent to orifice seat on frame.

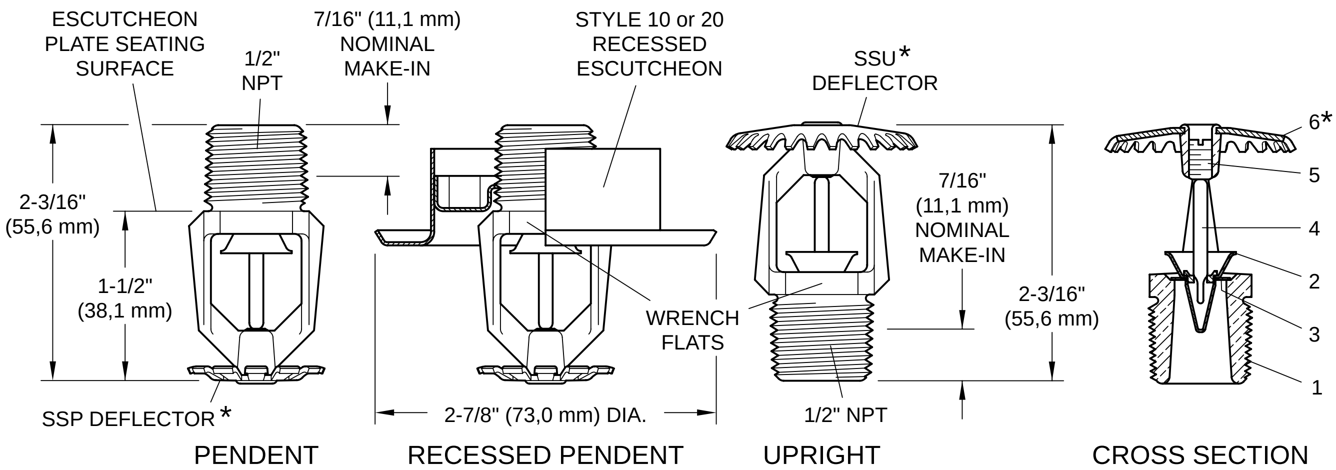
FIGURE 1
QUICK RESPONSE SERIES TY-FRB UPRIGHT (TY1131) AND PENDENT (TY1231) SPRINKLERS
2.8 K-FACTOR, 1/2 INCH NPT



1 - Frame
2 - Button
3 - Sealing Assembly
4 - Bulb
5 - Compression Screw
6 - Deflector

* Temperature rating is indicated on deflector or adjacent to orifice seat on frame.

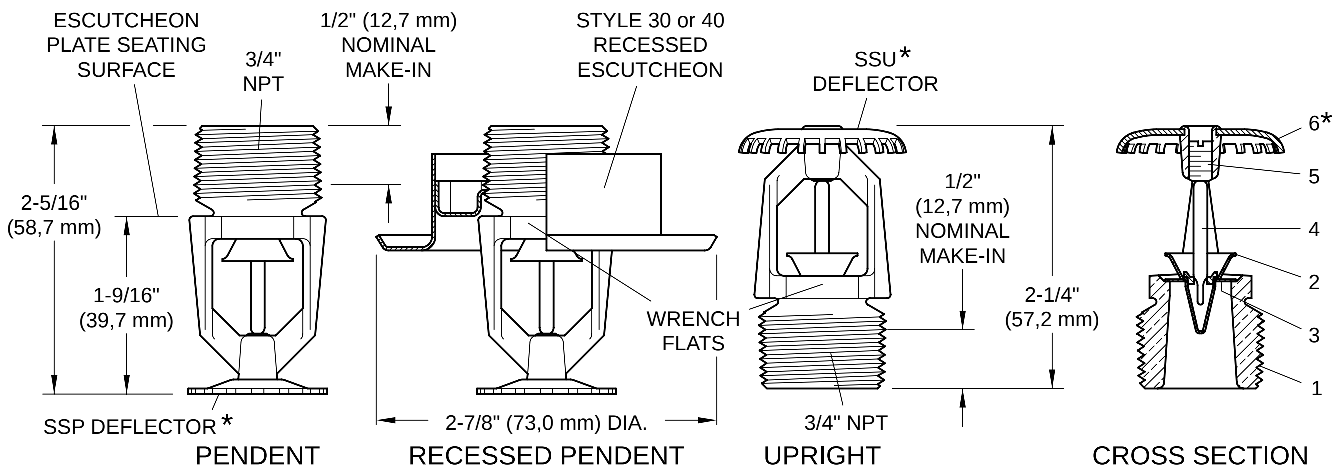
FIGURE 2
QUICK RESPONSE SERIES TY-FRB UPRIGHT (TY2131) AND PENDENT (TY2231) SPRINKLERS
4.2 K-FACTOR, 1/2 INCH NPT



1 - Frame
2 - Button
3 - Sealing Assembly
4 - Bulb
5 - Compression Screw
6 - Deflector

* Temperature rating is indicated on deflector or adjacent to orifice seat on frame.

FIGURE 3
QUICK RESPONSE SERIES TY-FRB UPRIGHT (TY3131) AND PENDENT (TY3231) SPRINKLERS
5.6 K-FACTOR, 1/2 INCH NPT



1 - Frame
2 - Button
3 - Sealing Assembly
4 - Bulb
5 - Compression Screw
6 - Deflector

* Temperature rating is indicated on deflector or adjacent to orifice seat on frame.

FIGURE 4
QUICK RESPONSE SERIES TY-FRB UPRIGHT (TY4131) AND PENDENT (TY4231) SPRINKLERS
8.0 K-FACTOR, 3/4 INCH NPT

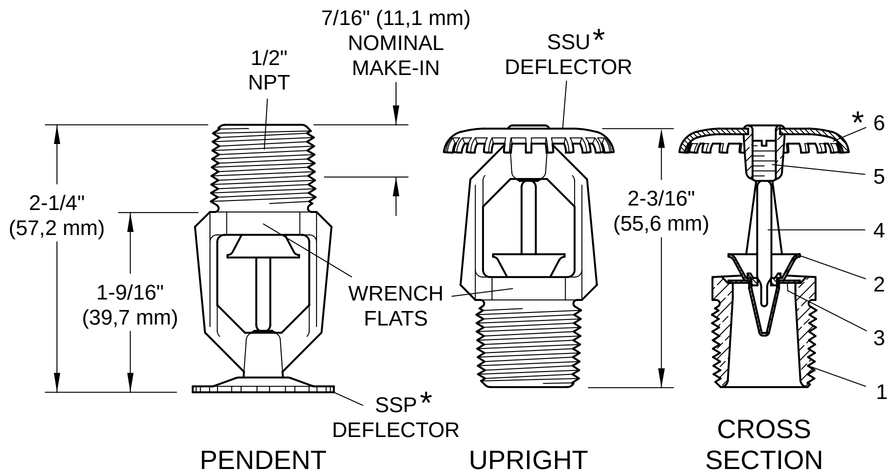


FIGURE 5
QUICK RESPONSE SERIES TY-FRB UPRIGHT (TY4831) AND PENDENT (TY4931) SPRINKLERS
8.0 K-FACTOR, 1/2 INCH NPT

Technical Data

Approvals
UL and C-UL Listed.
FM, LPCB, and NYC Approved.
(Refer to Table A and B for complete approval information including corrosion resistant status.)

Maximum Working Pressure
Refer to Table C.

Discharge Coefficient
K = 2.8 GPM/psi$^{1/2}$ (40,3 LPM/bar$^{1/2}$)
K = 4.2 GPM/psi$^{1/2}$ (60,5 LPM/bar$^{1/2}$)
K = 5.6 GPM/psi$^{1/2}$ (80,6 LPM/bar$^{1/2}$)
K = 8.0 GPM/psi$^{1/2}$ (115,2 LPM/bar$^{1/2}$)

Temperature Ratings
Refer to Table A and B

Finishes
Sprinkler: Refer to Table A and B.
Recessed Escutcheon: White Coated, Chrome Plated, or Brass Plated.

Physical Characteristics
Frame . . . . Bronze
Button . . . . Brass/Copper
Sealing Assembly . . . .
. . . . . Beryllium Nickel w/Teflon†
Bulb . . . . Glass
Compression Screw . . . . . Bronze
Deflector . . . . Copper/Bronze
Bushing (K=2.8) . . . . Bronze

Operation

The glass Bulb contains a fluid which expands when exposed to heat. When the rated temperature is reached, the fluid expands sufficiently to shatter the glass Bulb, allowing the sprinkler to activate and water to flow.

Design Criteria

The Series TY-FRB Pendent and Upright Sprinklers are intended for fire protection systems designed in accordance with the standard installation rules recognized by the applicable Listing or Approval agency (e.g., UL Listing is based on the requirements of NFPA 13, and FM Approval is based on the requirements of FM's Loss Prevention Data Sheets). Only the Style 10, 20, 30, or 40 Recessed Escutcheon, as applicable, is to be used for recessed pendent installations.

† DuPont Registered Trademark

K	TYPE	TEMP.	BULB LIQUID	SPRINKLER FINISH (See Note 7) NATURAL BRASS	CHROME PLATED	WHITE*** POLYESTER
2.8 1/2" NPT	**PENDENT (TY1231) and UPRIGHT (TY1131)**	135°F/57°C	Orange	1, 2, 3, 5		
		155°F/68°C	Red			
		175°F/79°C	Yellow			
		200°F/93°C	Green			
		286°F/141°C	Blue			
	RECESSED PENDENT (TY1231)* Figure 6	135°F/57°C	Orange	1, 2, 5		
		155°F/68°C	Red			
		175°F/79°C	Yellow			
		200°F/93°C	Green			
	RECESSED PENDENT (TY1231) Figure 7**	135°F/57°C	Orange			
		155°F/68°C	Red			
		175°F/79°C	Yellow			
		200°F/93°C	Green			
4.2 1/2" NPT	**PENDENT (TY2231) and UPRIGHT (TY2131)**	135°F/57°C	Orange	1, 2		
		155°F/68°C	Red			
		175°F/79°C	Yellow			
		200°F/93°C	Green			
		286°F/141°C	Blue			
	RECESSED PENDENT (TY2231)* Figure 8	135°F/57°C	Orange			
		155°F/68°C	Red			
		175°F/79°C	Yellow			
		200°F/93°C	Green			
	RECESSED PENDENT (TY2231) Figure 9**	135°F/57°C	Orange			
		155°F/68°C	Red			
		175°F/79°C	Yellow			
		200°F/93°C	Green			

NOTES:
1. Listed by Underwriters Laboratories, Inc. (UL) as Quick Response Sprinklers.
2. Listed by Underwriters Laboratories, Inc. for use in Canada (C-UL) as Quick Response Sprinklers.
3. Approved by Factory Mutual Research Corporation (FM) as Quick Response Sprinklers.
5. Approved by the City of New York under MEA 354-01-E.
7. Where Polyester Coated Sprinklers are noted to be UL and C-UL Listed, the sprinklers are UL and C-UL Listed as Corrosion Resistant Sprinklers.
* Installed with Style 10 (1/2" NPT) or Style 40 (3/4" NPT) 3/4" Total Adjustment Recessed Escutcheon, as applicable.
** Installed with Style 20 (1/2" NPT) or Style 30 (3/4" NPT) 1/2" Total Adjustment Recessed Escutcheon, as applicable.
*** Frame and Deflector only. Listings and approvals apply to color (Special Order).
N/A: Not Available

TABLE A
LABORATORY LISTINGS AND APPROVALS
2.8 AND 4.2 K-FACTOR SPRINKLERS

<table>
<tr><th colspan="4"></th><th colspan="4">SPRINKLER FINISH (See Note 8)</th></tr>
<tr><th>K</th><th>TYPE</th><th>TEMP.</th><th>BULB LIQUID</th><th>NATURAL BRASS</th><th>CHROME PLATED</th><th>WHITE*** POLYESTER</th><th>LEAD COATED</th></tr>
<tr><td rowspan="13">5.6
1/2"
NPT</td><td rowspan="5">PENDENT (TY3231) and UPRIGHT (TY3131)</td><td>135°F/57°C</td><td>Orange</td><td rowspan="5" colspan="3">1, 2, 3, 4, 5, 6, 7</td><td rowspan="5">1, 2, 3, 5</td></tr>
<tr><td>155°F/68°C</td><td>Red</td></tr>
<tr><td>175°F/79°C</td><td>Yellow</td></tr>
<tr><td>200°F/93°C</td><td>Green</td></tr>
<tr><td>286°F/141°C</td><td>Blue</td></tr>
<tr><td rowspan="4">RECESSED PENDENT (TY3231)* Figure 10</td><td>135°F/57°C</td><td>Orange</td><td rowspan="4" colspan="3">1, 2, 4, 5</td><td rowspan="4">N/A</td></tr>
<tr><td>155°F/68°C</td><td>Red</td></tr>
<tr><td>175°F/79°C</td><td>Yellow</td></tr>
<tr><td>200°F/93°C</td><td>Green</td></tr>
<tr><td rowspan="4">RECESSED PENDENT (TY3231)** Figure 11</td><td>135°F/57°C</td><td>Orange</td><td rowspan="4" colspan="2">1, 2, 3, 4, 5</td><td rowspan="4">1, 2, 4, 5</td><td rowspan="4">N/A</td></tr>
<tr><td>155°F/68°C</td><td>Red</td></tr>
<tr><td>175°F/79°C</td><td>Yellow</td></tr>
<tr><td>200°F/93°C</td><td>Green</td></tr>
<tr><td rowspan="13">8.0
3/4"
NPT</td><td rowspan="5">PENDENT (TY4231) and UPRIGHT (TY4131)</td><td>135°F/57°C</td><td>Orange</td><td rowspan="5" colspan="3">1, 2, 3, 4, 5, 6, 7</td><td rowspan="5">1, 2, 5</td></tr>
<tr><td>155°F/68°C</td><td>Red</td></tr>
<tr><td>175°F/79°C</td><td>Yellow</td></tr>
<tr><td>200°F/93°C</td><td>Green</td></tr>
<tr><td>286°F/141°C</td><td>Blue</td></tr>
<tr><td rowspan="4">RECESSED PENDENT (TY4231)* Figure 12</td><td>135°F/57°C</td><td>Green</td><td rowspan="4" colspan="3">1, 2, 4, 5</td><td rowspan="4">N/A</td></tr>
<tr><td>155°F/68°C</td><td>Orange</td></tr>
<tr><td>175°F/79°C</td><td>Red</td></tr>
<tr><td>200°F/93°C</td><td>Yellow</td></tr>
<tr><td rowspan="4">RECESSED PENDENT (TY4231)** Figure 13</td><td>135°F/57°C</td><td>Orange</td><td rowspan="4" colspan="3">1, 2, 3, 4, 5</td><td rowspan="4">N/A</td></tr>
<tr><td>155°F/68°C</td><td>Red</td></tr>
<tr><td>175°F/79°C</td><td>Yellow</td></tr>
<tr><td>200°F/93°C</td><td>Green</td></tr>
<tr><td rowspan="5">8.0
1/2"
NPT</td><td rowspan="5">PENDENT (TY4931) and UPRIGHT (TY4831)</td><td>135°F/57°C</td><td>Orange</td><td rowspan="5" colspan="3">1, 2, 4, 5, 6</td><td rowspan="5">1, 2, 5</td></tr>
<tr><td>155°F/68°C</td><td>Red</td></tr>
<tr><td>175°F/79°C</td><td>Yellow</td></tr>
<tr><td>200°F/93°C</td><td>Green</td></tr>
<tr><td>286°F/141°C</td><td>Blue</td></tr>
</table>

NOTES:
1. Listed by Underwriters Laboratories, Inc. (UL) as Quick Response Sprinklers.
2. Listed by Underwriters Laboratories, Inc. for use in Canada (C-UL) as Quick Response Sprinklers.
3. Approved by Factory Mutual Research Corporation (FM) as Quick Response Sprinklers.
4. Approved by the Loss Prevention Certification Board (LPCB Ref. No. 007k/04) as Quick Response Sprinklers; however, the LPCB does not rate the thermal sensitivity of recessed sprinklers.
5. Approved by the City of New York under MEA 354-01-E.
6. VdS Approved (For details contact Tyco Fire & Building Products, Enschede, Netherlands, Tel. 31-53-428-4444/Fax 31-53-428-3377).
7. Approved by the Loss Prevention Certification Board (LPCB Ref. No. 094a/06) as Quick Response Sprinklers.
8. Where Polyester Coated and Lead Coated Sprinklers are noted to be UL and C-UL Listed, the sprinklers are UL and C-UL Listed as Corrosion Resistant Sprinklers. Where Lead Coated Sprinklers are noted to be FM Approved, the sprinklers are FM Approved as a Corrosion Resistant Sprinklers.

* Installed with Style 10 (1/2" NPT) or Style 40 (3/4" NPT) 3/4" Total Adjustment Recessed Escutcheon, as applicable.
** Installed with Style 20 (1/2" NPT) or Style 30 (3/4" NPT) 1/2" Total Adjustment Recessed Escutcheon, as applicable.
*** Frame and Deflector only. Listings and approvals apply to color (Special Order).
N/A: Not Available

TABLE B
LABORATORY LISTINGS AND APPROVALS
5.6 AND 8.0 K-FACTOR SPRINKLERS

<table>
<tr><th colspan="2"></th><th colspan="4">SPRINKLER FINISH</th></tr>
<tr><th>K</th><th>TYPE</th><th>NATURAL BRASS</th><th>CHROME PLATED</th><th>WHITE POLYESTER</th><th>LEAD COATED</th></tr>
<tr><td rowspan="2">2.8
1/2"
NPT</td><td>PENDENT (TY3231)
and
UPRIGHT (TY3131)</td><td colspan="3" rowspan="2">175 PSI (12,1 BAR)</td><td rowspan="2">N/A</td></tr>
<tr><td>RECESSED PENDENT
(TY323)</td></tr>
<tr><td rowspan="2">4.2
3/4"
NPT</td><td>PENDENT (TY4231)
and
UPRIGHT (TY4131)</td><td colspan="3" rowspan="2">175 PSI (12,1 BAR)</td><td rowspan="2">N/A</td></tr>
<tr><td>RECESSED PENDENT
(TY4231)</td></tr>
<tr><td rowspan="2">5.6
1/2"
NPT</td><td>PENDENT (TY3231)
and
UPRIGHT (TY3131)</td><td colspan="3" rowspan="2">250 PSI (17,2 BAR)
OR
175 PSI (12,1 BAR)

(SEE NOTE 1)</td><td>175 PSI (12,1 BAR)</td></tr>
<tr><td>RECESSED PENDENT
(TY3231)</td><td>N/A</td></tr>
<tr><td rowspan="2">8.0
3/4"
NPT</td><td>PENDENT (TY4231)
and
UPRIGHT (TY4131)</td><td colspan="3" rowspan="2">175 PSI (12,1 BAR)</td><td>175 PSI (12,1 BAR)</td></tr>
<tr><td>RECESSED PENDENT
(TY4231)</td><td>N/A</td></tr>
<tr><td>8.0
1/2"
NPT</td><td>PENDENT (TY4931)
and
UPRIGHT (TY4831)</td><td colspan="3">175 PSI (12,1 BAR)</td><td>175 PSI (12,1 BAR)</td></tr>
</table>

NOTES:
1. The maximum working pressure of 250 psi (17,2 bar) only applies to the Listing by Underwriters Laboratories Inc. (UL); the Listing by Underwriters Laboratories, Inc. for use in Canada (C-UL); and , the Approval by the City of New York.

TABLE C, MAXIMUM WORKING PRESSURE

Installation

The Series TY-FRB Sprinklers must be installed in accordance with the following instructions:

NOTES

Do not install any bulb type sprinkler if the bulb is cracked or there is a loss of liquid from the bulb. With the sprinkler held horizontally, a small air bubble should be present. The diameter of the air bubble is approximately 1/16 inch (1,6 mm) for the 135°F/57°C to 3/32 inch (2,4 mm) for the 286°F/141°C temperature ratings.

A leak tight 1/2 inch NPT sprinkler joint should be obtained with a torque of 7 to 14 ft.lbs. (9,5 to 19,0 Nm). A maximum of 21 ft. lbs. (28,5 Nm) of torque may be used to install sprinklers with 1/2 NPT connections. A leak tight 3/4 inch NPT sprinkler joint should be obtained with a torque of 10 to 20 ft.lbs. (13,4 to 26,8 Nm). A maximum of 30 ft.lbs. (40,7 Nm) of torque is to be used to install sprinklers with 3/4 NPT connections. Higher levels of torque may distort the sprinkler inlet and cause leakage or impairment of the sprinkler.

Do not attempt to make-up for insufficient adjustment in the escutcheon plate by under- or over-tightening the sprinkler. Readjust the position of the sprinkler fitting to suit.

The **Series TY-FRB Pendent and Upright Sprinklers** must be installed in accordance with the following instructions.

Step 1. Pendent sprinklers are to be installed in the pendent position, and upright sprinklers are to be installed in the upright position.

Step 2. With pipe thread sealant applied to the pipe threads, hand tighten the sprinkler into the sprinkler fitting.

Step 3. Tighten the sprinkler into the sprinkler fitting using only the W-Type 6 Sprinkler Wrench (Ref. Figure 14). With reference to Figures 1, 2, 3, 4, and 5, the W-Type 6 Sprinkler Wrench is to be applied to the sprinkler wrench flats.

The **Series TY-FRB Recessed Pendent Sprinklers** must be installed in accordance with the following instructions.

Step A. After installing the Style 10. 20, 30, or 40 Mounting Plate, as applicable, over the sprinkler threads and with pipe thread sealant applied to the pipe threads, hand tighten the sprinkler into the sprinkler fitting.

Step B. Tighten the sprinkler into the sprinkler fitting using only the W-Type 7 Recessed Sprinkler Wrench (Ref. Figure 15). With reference to Figure 1, 2, 3, and 4, the W-Type 7 Recessed

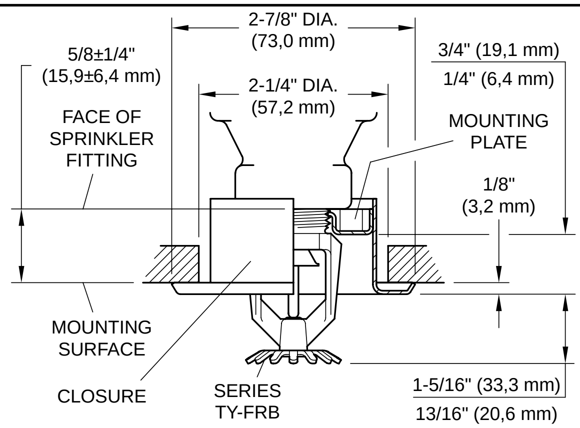


FIGURE 6
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 3/4 INCH TOTAL ADJUSTMENT
STYLE 10 RECESSED ESCUTCHEON
2.8 K-FACTOR, 1/2 INCH NPT

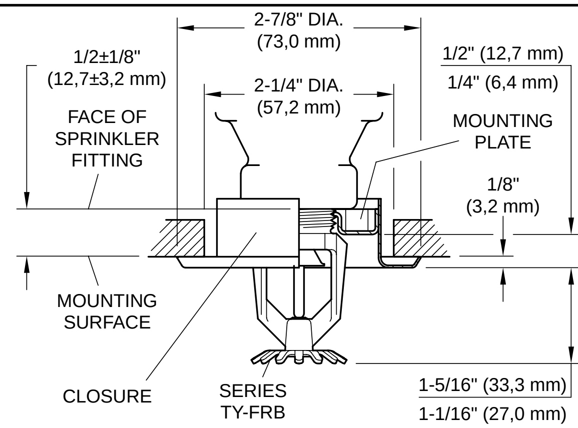


FIGURE 7
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 1/2 INCH TOTAL ADJUSTMENT
STYLE 20 RECESSED ESCUTCHEON
2.8 K-FACTOR, 1/2 INCH NPT

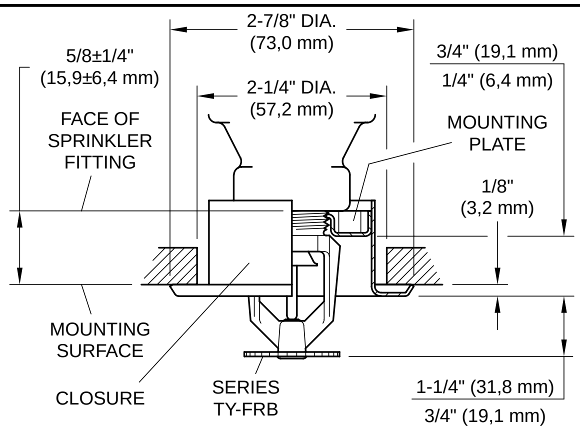


FIGURE 8
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 3/4 INCH TOTAL ADJUSTMENT
STYLE 10 RECESSED ESCUTCHEON
4.2 K-FACTOR, 1/2 INCH NPT

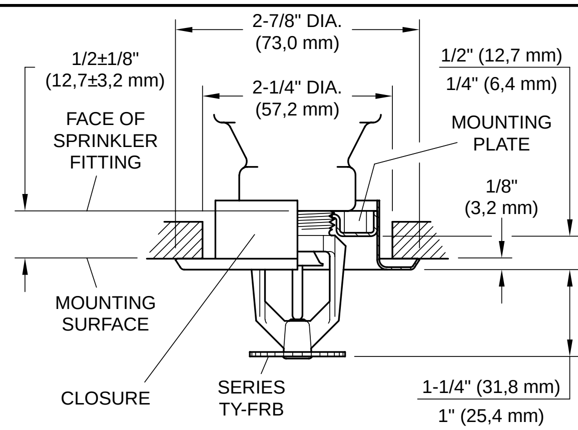


FIGURE 9
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 1/2 INCH TOTAL ADJUSTMENT
STYLE 20 RECESSED ESCUTCHEON
4.2 K-FACTOR, 1/2 INCH NPT

Sprinkler Wrench is to be applied to the sprinkler wrench flats.

Step C. After the ceiling has been installed or the finish coat has been applied, slide on the Style 10, 20, 30, or 40 Closure over the Series TY-FRB Sprinkler and push the Closure over the Mounting Plate until its flange comes in contact with the ceiling.

Care and Maintenance

The Series TY-FRB Sprinklers must be maintained and serviced in accordance with the following instructions:

NOTES

Before closing a fire protection system main control valve for maintenance work on the fire protection system that it controls, permission to shut down the affected fire protection system must be obtained from the proper authorities and all personnel who may be affected by this action must be notified.

The owner must assure that the sprinklers are not used for hanging of any objects; otherwise, non-operation in the event of a fire or inadvertent operation may result.

Absence of an escutcheon, which is used to cover a clearance hole, may delay the time to sprinkler operation in a fire situation.

Sprinklers that are found to be leaking or exhibiting visible signs of corrosion must be replaced.

Automatic sprinklers must never be painted, plated, coated or otherwise altered after leaving the factory. Modified sprinklers must be replaced. Sprinklers that have been exposed to corrosive products of combustion, but have not operated, should be replaced if they cannot be completely cleaned by wiping the sprinkler with a cloth or by brushing it with a soft bristle brush.

Care must be exercised to avoid damage to the sprinklers - before, during, and after installation. Sprinklers damaged by dropping, striking, wrench twist/slippage, or the like, must be replaced. Also, replace any sprinkler that has a cracked bulb or that has lost liquid from its bulb. (Ref. Installation Section).

Frequent visual inspections are recommended to be initially performed for corrosion resistant coated sprinklers, after the installation has been com-

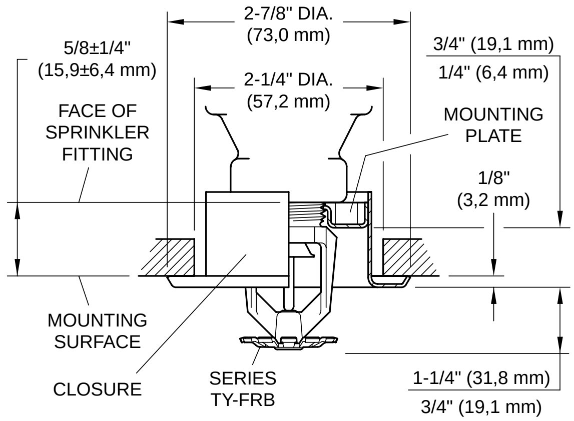


FIGURE 10
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 3/4 INCH TOTAL ADJUSTMENT
STYLE 10 RECESSED ESCUTCHEON
5.6 K-FACTOR, 1/2 INCH NPT

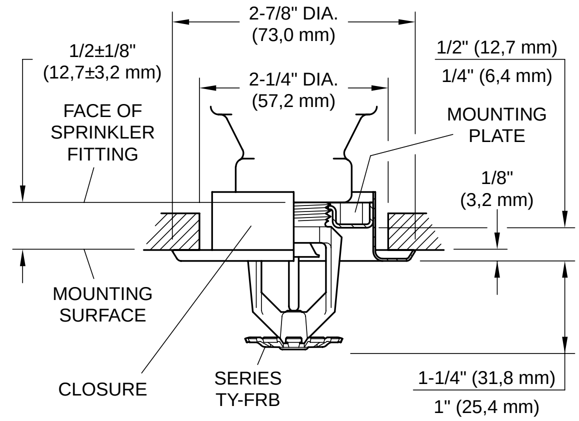


FIGURE 11
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 1/2 INCH TOTAL ADJUSTMENT
STYLE 20 RECESSED ESCUTCHEON
5.6 K-FACTOR, 1/2 INCH NPT

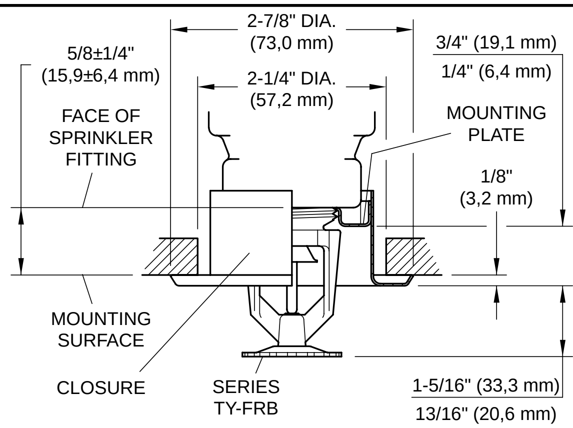


FIGURE 12
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 3/4 INCH TOTAL ADJUSTMENT
STYLE 40 RECESSED ESCUTCHEON
8.0 K-FACTOR, 3/4 INCH NPT

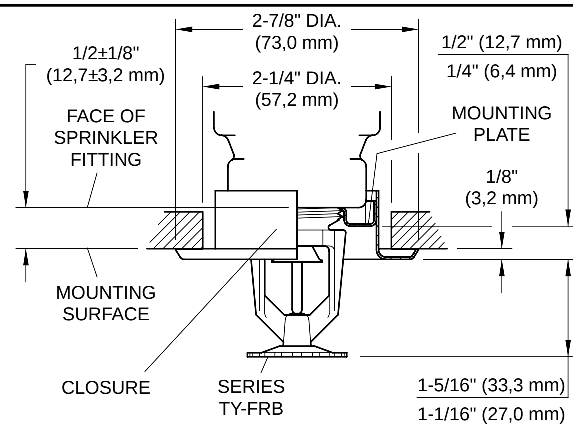


FIGURE 13
SERIES TY-FRB RECESSED PENDENT
WITH TWO-PIECE 1/2 INCH TOTAL ADJUSTMENT
STYLE 30 RECESSED ESCUTCHEON
8.0 K-FACTOR, 3/4 INCH NPT

pleted, to verify the integrity of the corrosion resistant coating. Thereafter, annual inspections per NFPA 25 should suffice; however, instead of inspecting from the floor level, a random sampling of close-up visual inspections should be made, so as to better determine the exact sprinkler condition and the long term integrity of the corrosion resistant coating, as it may be affected by the corrosive conditions present.

The owner is responsible for the inspection, testing, and maintenance of their fire protection system and devices in compliance with this document, as well as with the applicable standards of the National Fire Protection Association (e.g., NFPA 25), in addition to the standards of any other authorities having jurisdiction. The installing contractor or sprinkler manufacturer should be contacted relative to any questions.

It is recommended that automatic sprinkler systems be inspected, tested, and maintained by a qualified Inspection Service in accordance with local requirements and/or national codes.

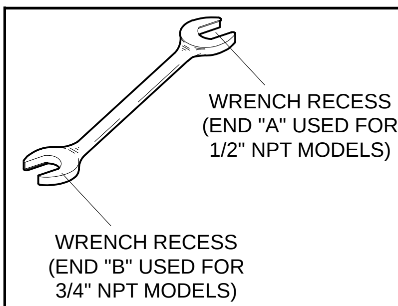


FIGURE 14
W-TYPE 6 SPRINKLER
WRENCH

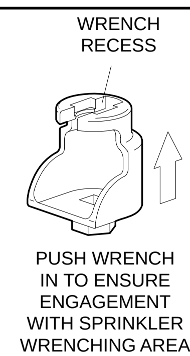


FIGURE 15
W-TYPE 7 RECESSED
SPRINKLER WRENCH

P/N 57 — XXX — X — XXX

		MODEL/SIN
330	2.8K UPRIGHT (1/2"NPT)	TY1131
331	2.8K PENDENT (1/2"NPT)	TY1231
340	4.2K UPRIGHT (1/2"NPT)	TY2131
341	4.2K PENDENT (1/2"NPT)	TY2231
370	5.6K UPRIGHT (1/2"NPT)	TY3131
371	5.6K PENDENT (1/2"NPT)	TY3231
390	8.0K UPRIGHT (3/4"NPT)	TY4131
391	8.0K PENDENT (3/4"NPT)	TY4231
360	8.0K UPRIGHT (1/2"NPT)	TY4831
361	8.0K PENDENT (1/2"NPT)	TY4931

	SPRINKLER
1	NATURAL BRASS
4	WHITE POLYESTER
3	WHITE (RAL9010)*
9	CHROME PLATED
7	LEAD COATED

	TEMPERATURE RATING
135	135°F/57°C
155	155°F/68°C
175	175°F/79°C
200	200°F/93°C
286	286°F/141°C

* Eastern Hemisphere sales only.

TABLE D
PART NUMBER SELECTION
SERIES TY-FRB PENDENT AND UPRIGHT SPRINKLERS

Limited Warranty

Products manufactured by Tyco Fire & Building Products (TFBP) are warranted solely to the original Buyer for ten (10) years against defects in material and workmanship when paid for and properly installed and maintained under normal use and service. This warranty will expire ten (10) years from date of shipment by TFBP. No warranty is given for products or components manufactured by companies not affiliated by ownership with TFBP or for products and components which have been subject to misuse, improper installation, corrosion, or which have not been installed, maintained, modified or repaired in accordance with applicable Standards of the National Fire Protection Association, and/or the standards of any other Authorities Having Jurisdiction. Materials found by TFBP to be defective shall be either repaired or replaced, at TFBP's sole option. TFBP neither assumes, nor authorizes any person to assume for it, any other obligation in connection with the sale of products or parts of products. TFBP shall not be responsible for sprinkler system design errors or inaccurate or incomplete information supplied by Buyer or Buyer's representatives.

In no event shall TFBP be liable, in contract, tort, strict liability or under any other legal theory, for incidental, indirect, special or consequential damages, including but not limited to labor charges, regardless of whether TFBP was informed about the possibility of such damages, and in no event shall TFBP's liability exceed an amount equal to the sales price.

The foregoing warranty is made in lieu of any and all other warranties, express or implied, including warranties of merchantability and fitness for a particular purpose.

This limited warranty sets forth the exclusive remedy for claims based on failure of or defect in products, materials or components, whether the claim is made in contract, tort, strict liability or any other legal theory.

This warranty will apply to the full extent permitted by law. The invalidity, in whole or part, of any portion of this warranty will not affect the remainder.

Ordering Procedure

When placing an order, indicate the full product name. Refer to the Price List for complete listing of Part Numbers.

Contact your local distributor for availability.

Sprinkler Assemblies with NPT Thread Connections:
Specify: (Specify Model/SIN), Quick Response, (specify K-factor), (specify temperature rating), Series TY-FRB (specify Pendent or Upright) Sprinkler with (specify type of finish or coating), P/N (specify from Table D).

Recessed Escutcheon:
Specify: Style (10, 20, 30, or 40) Recessed Escutcheon with (specify*) finish, P/N (specify*).

* Refer to Technical Data Sheet TFP770.

Sprinkler Wrench:
Specify: W-Type 6 Sprinkler Wrench, P/N 56-000-6-387.

Specify: W-Type 7 Sprinkler Wrench, P/N 56-850-4-001.

Appendix H - Preliminary Fire Alarm System Calculations - Voltage Drop, Battery Size

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FIRELITE MS-9200UDLS BATTERY CALCULATIONS

FOR

AHORGSC Assembly Hall of Jehovah's Witnesses

TABLE A-1
CALCULATING THE AC BRANCH CIRCUIT:

The FIRELITE MS-9200UDLS requires connection to a separate, dedicated AC branch circuit (120VAC), which must be labled **FIRE ALARM**. No other equipment may be powered from the fire alarm branch circuit. The branch circuit wire must run continuously, witho

DEVICE	NUMBER OF DEVICES	x	CURRENT DRAW (AMPS)	=	TOTAL CURRENT
MS-9200UDLS	1		3		3
AL300ULXB	0	x	1.45	=	0
CHG-75	0		2.05		0
CHG-120	0		2		0
TOTAL A.C. BRANCH CURRENT (IN AMPS) REQUIRED				=	**3**

TABLE A-2
BATTERY SIZING CALCULATION -

The following calculation provides the size of batteries (in amp/hours) required to meet the standby

SECONDARY STANDBY LOAD		0.441	AMPS
The amount of power that must be supplied by the batteries during non-alarm conditions.	FOR	**24**	**HOURS**
	=	10.58892	STANDBY AMP/HOURS
SECONDARY ALARM LOAD		5.163	AMPS
The amount of power that must be supplied by the batteries during an alarm conditions.	FOR	**15**	**MINUTES**
	=	1.291	ALARM AMP/HOURS

TOTAL AMP/HOUR LOAD	11.87972
MULTIPLY BY DERATING FACTOR	1.2
TOTAL AMP/HOUR	**14.256**
BATTERY SIZE PROVIDED	18.0
SPARE CAPACITY	**21%**

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TABLE A-3

CALCULATING THE SYSTEM CURRENT DRAW -

AHORGSC Assembly Hall of Jehovah's Witnesses

CATEGORY	COLUMN 1 PRIMARY, NON-FIRE ALARM CURRENT (AMPS)					COLUMN 2 PRIMARY, FIRE ALARM CURRENT (AMPS)					COLUMN 3 SECONDARY, NON-FIRE ALARM CURRENT (AMPS)				
Basic System	1	x	0.300	=	0.3000	1	x	0.3250	=	0.3250	1	x	0.255	=	0.2550
ANNUNCIATOR MODULES	⇨ circuit fed from TB8 and/or 9, terminals 1 & 2 - power fed from TB1, terminals 1 & 2														
AFM-16ATF / AFM-32AF	0	x	0.040	=	0.000	0	x	0.056	=	0.000	0	x	0.040	=	0.000
ACM-16ATF / ACM-32AF	0	x	0.040	=	0.000	0	x	0.056	=	0.000	0	x	0.040	=	0.000
AEM-16AT / AEM-32AF	0	x	0.002	=	0.000	0	x	0.018	=	0.000	0	x	0.002	=	0.000
AFM-16AF	0	x	0.025	=	0.000	0	x	0.065	=	0.000	0	x	0.025	=	0.000
LCD-80F	0	x	0.064	=	0.000	0	x	0.064	=	0.000	0	x	0.025	=	0.000
ANN-80	2	x	0.040	=	0.080	2	x	0.040	=	0.080	2	x	0.040	=	0.080
LDM-32F	0	x	0.040	=	0.000	0	x	0.056	=	0.000	0	x	0.040	=	0.000
LDM-E32F	0	x	0.002	=	0.000	0	x	0.018	=	0.000	0	x	0.002	=	0.000
PDACT-2UD	1	x	0.093	=	0.093	1	x	0.136	=	0.136	1	x	0.093	=	0.093
			SUBTOTAL	=	0.173			SUBTOTAL	=	0.216			SUBTOTAL	=	0.173
SLC LOOP DEVICES	⇨ circuit fed from TB10, terminals 1 & 3 and 2 & 4														
BG-12LX	4	x	0.000230	=	0.000920	4	x	0.000230	=	0.000920	4	x	0.000230	=	0.000920
MMF-301	1	x	0.000375	=	0.000375	1	x	0.000375	=	0.000375	1	x	0.000375	=	0.000375
MMF-300	2	x	0.000350	=	0.000700	2	x	0.005000	=	0.010000	2	x	0.000350	=	0.000700
MDF-300	2	x	0.000750	=	0.001500	2	x	0.006400	=	0.012800	2	x	0.000750	=	0.001500
CMF-300	2	x	0.000350	=	0.000700	2	x	0.006500	=	0.013000	2	x	0.000350	=	0.000700
CRF-300	7	x	0.000230	=	0.001610	7	x	0.006500	=	0.045500	7	x	0.000230	=	0.001610
MMF-302	0	x	0.000270	=	0.000000	0	x	0.005100	=	0.000000	0	x	0.000270	=	0.000000
I300	2	x	0.000400	=	0.000800	2	x	0.005000	=	0.010000	2	x	0.000400	=	0.000800
AD-350	0	x	0.000310	=	0.000000	0	x	0.010000	=	0.000000	0	x	0.000310	=	0.000000
SD355(T)	12	x	0.000300	=	0.003600	12	x	0.000300	=	0.003600	12	x	0.000300	=	0.003600
H355(R-)	1	x	0.000300	=	0.000300	1	x	0.000300	=	0.000300	1	x	0.000300	=	0.000300
D350PL(R-)	9	x	0.000300	=	0.002700	9	x	0.000300	=	0.002700	9	x	0.000300	=	0.002700
			SUBTOTAL	=	0.0132			SUBTOTAL	=	0.0992			SUBTOTAL	=	0.0132
TWO / FOUR WIRE DETECTORS	⇨ device power fed from TB1, terminals 3 & 4														
D350PL(R-)	0	x	0.02600	=	0.000000	0	x	0.08700	=	0.000000	0	x	0.026000	=	0.000000
			SUBTOTAL	=	0.0000			SUBTOTAL	=	0.0000			SUBTOTAL	=	0.0000
OPTIONAL MODULES	⇨ module power fed from on-board plug-in														
RTM-8F (Note 4)	0	x	0.009	=	0.000	0	x	0.146	=	0.000	0	x	0.009	=	0.000
4XTM	0	x	0.005	=	0.000	0	x	0.011	=	0.000	0	x	0.005	=	0.000
Municipal Box						0	x		=	0.000					
Reverse Polarity Outputs Used	0	x	0.005	=	0.000	0	x	0.005	=	0.000	0	x	0.005	=	0.000
NOTIFICATION APPLIANCES	⇨ refer to Table A-3 for circuit & power terminal designations														
TOTAL ALARM LOAD FROM TABLE A-5									=	4.523					
COLUMN LOAD TOTALS (IN AMPS)			(Note 1)		0.486			(Note 2)		5.1632			(Note 3)		0.441
			Primary Non-Alarm					**Primary Alarm**					**Secondary Non-Alarm**		

NOTES FOR TABLE A-3 :

1) **Calculation Column 1** - The primary supply current load that the control panel must support during a non-fire alarm condition, with AC power applied. This current draw cannot exceed 0.6A.

2) **Calculation Column 2** - The primary supply current load that the control panel must support during a fire alarm condition, with AC power applied. This current draw cannot exceed 6A.

3) **Calculation Column 3** - The standby current drawn from the batteries in a non-fire alarm condition during a loss of AC power.

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TABLE A-4
NOTIFICATION APPLIANCE CIRCUITS:
AHORGSC Assembly Hall of Jehovah's Witnesses

ON-BOARD NAC's		CIRCUIT CONFIGURATION (LOADS ARE REPRESENTED IN AMPS)									VOLTAGE DROP ANALYSIS	
CKT. #	LOCATION	DEVICE TYPE	Cd	QTY	x	DEVICE LOAD	=	TOTAL LOAD	MAXIMUM LOAD	SPARE CAPACITY	TOTAL CIRCUIT LENGTH	WIRE SIZE : 14 AWG CIR. MILLS : 4110 VOLTAGE DROP
1	Serves Auditorium & Offices	Wall Strobe	15	3	x	0.071	=	1.335	2.5	47%	450	18.47
		Wall Strobe	30	1		0.096						
		Wall Strobe	75	1		0.153						
		Ceiling Strobe	15	2		0.071						
		Ceiling Strobe	30	1		0.096						
		Ceiling Strobe	75	3		0.153						
		Ceiling Strobe	95	1		0.176						
	circuit fed from TB3, terminals 1&4											
2	Serves Auditorium	Wall Strobe	110	1	x	0.195	=	1.561	2.5	38%	450	18.15
		Ceiling Strobe	30	1		0.096						
		Ceiling Strobe	75	6		0.153						
		Ceiling Strobe	95	2		0.176						
	circuit fed from TB4, terminals 1&4											
3	Serves Auditorium	Ceiling Strobe	75	2	x	0.153	=	0.658	2.5	74%	200	19.98
		Ceiling Strobe	95	2		0.176						
	circuit fed from TB3, terminals 2&3											
4	Serves Auditorium & Offices	Wall Strobe	15	2	x	0.071	=	0.969	2.5	61%	350	19.31
		Ceiling Strobe	30	2		0.096						
		Ceiling Strobe	75	3		0.153						
		Ceiling Strobe	95	1		0.176						
	circuit fed from TB4, terminals 2&3											
OFF-BOARD NAC's												
[illegible] NAC					x		=	0.000	2	100%		0.00
[illegible] NAC								0.000	2	100%		0.00
TOTAL ALARM LOAD (IN AMPS) REQUIRED : NOTE: REMAINING POWER SUPPLY ALARM LOAD(IN AMPS) : 1.338								**4.523**	SPARE CAPACITY FOR EACH NAC IS DEPENDANT UPON VOLTAGE DROP AND THE AVAILABLE ALARM LOAD		REFER TO MANUFACTURERS OPERATING VOLTAGE RANGE.	

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Fire-Lite FCPS-24FS6 Notification Applicance Circuit Panel Battery Calculations	Project Title:	AHORGSC Assembly Hall of Jehovah's Witnesses
	NACP Designation:	NACP
	Location:	Electric Room 110

1. **Primary AC Power Load: 3.2 Amps @ 120 Volts AC**

This power load represents the peak AC load requirements of the FCPS-24FS6, which occurs when in ALARM and simultaneously charging depleted batteries.

2. **Standby Load Calculations**

Category	Device	Qty	x	Load	=	Total Load	
Basic System	FCPS-24FS6	1	x	0.065	=	0.065	Amps
Annunciator	n/a	0	x	0	=	0	Amps
Smoke Detector	n/a	0	x	0	=	0	Amps
Power Supervision Relay	n/a	0	x	0	=	0	Amps
TOTAL LOAD					=	**0.065**	**Amps**

3. **Battery Sizing Calculations:**

The following calculation provides the size of batteries (in amp/hours) required to meet the standby and alarm durations either specified in the contract documents or as required by NFPA-72:

STANDBY LOAD

This load represents the maximum current draw when primary AC power fails.

	0.065	AMPS
FOR	**24**	**HOURS**
=	1.56	STANDBY AMP/HOURS

ALARM LOAD

This load represents the maximum current draw when the system is in ALARM condition and the maximum device load allowed with all notification devices in operation.

	6.000	AMPS
FOR	**15**	**MINUTES**
	0.250	
=	1.500	ALARM AMP/HOURS

TOTAL AMP/HOUR LOAD	3.060
MULTIPLY BY DERATING FACTOR	1.2
TOTAL AMP/HOURS REQUIRED	**3.672**
BATTERY SIZE PROVIDED	7.0
SPARE CAPACITY	**48%**

Notes:

1) The FCPS can accommodate batteries from 7.0 Amp/Hour to 18.0 Amp/Hour in size.

2) Up to 9.0 Amp/Hour batteries can be installed in the FCPS cabinet.

3) Batteries from 12.0 Amp/Hour to 18.0 Amp/Hour can be installed in the BB-17F battery box. The battery box can be mounted up to 20 feet away from the FCPS.

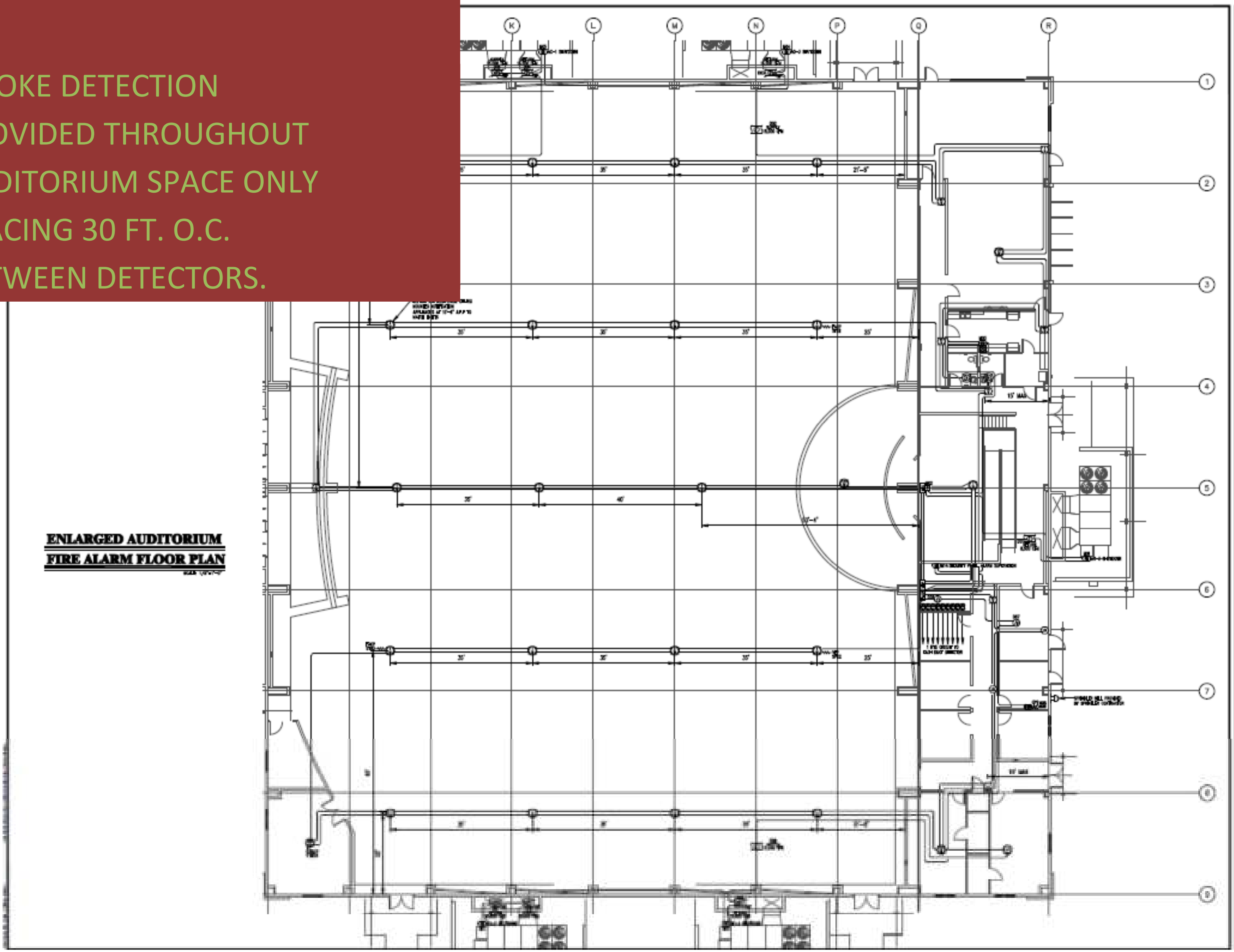
Appendix I – Fire Alarm Sequence of Operations Matrix

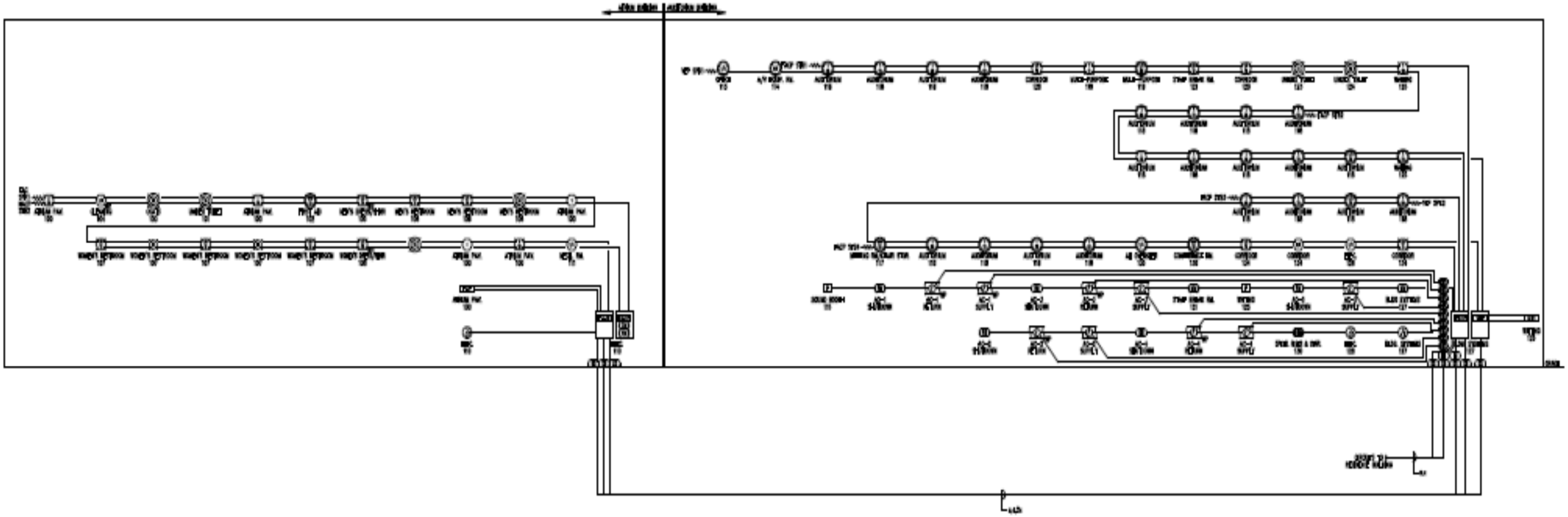
		CONTROL PANEL						TRANSMIT ALARM			AUXILIARY FUNCTION				NOTIFY		
		ACTUATE COMMON ALARM SIGNAL INDICATOR	ACTUATE AUDIBLE ALARM SIGNAL	ACTUATE COMMON SUPERVISORY SIGNAL INDICATOR	ACTUATE AUDIBLE SUPERVISORY SIGNAL	ACTUATE COMMON TROUBLE SIGNAL INDICATOR	ACTUATE AUDIBLE COMMON TROUBLE SIGNAL	TRANSMIT FIRE ALARM SIGNAL TO SUPERVISORY STATION	TRANSMIT SUPERVISORY SIGNAL TO SUPERVISING STATION	TRANSMIT TROUBLE SIGNAL TO SUPERVISING STATION	SHUT-DOWN ASSOCIATED AIR HANDLER UNIT (HVAC)	ACTIVATE SMOKE CONTROL SYSTEM	RELEASE MAGNETICALLY HELD-OPEN DOORS	ACTUATE EVACUATION SIGNALS	FIRE ALARM SIGNAL TO CENTRAL STATION	SUPERVISORY SIGNAL TO CENTRAL STATION	TROUBLE SIGNAL TO CENTRAL STATION
	SYSTEM INPUT	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	MANUAL PULL STATIONS	•	•					•					•	•	•		
2	AUDITORIUM SMOKE DETECTOR	•	•					•					•	•	•		
3	DUCT SMOKE DETECTOR	•	•					•			•	•	•	•	•		
4	WATER FLOW SWITCH - SPRINKLER SYSTEM	•	•					•					•	•	•		
5	TAMPER SWITCH - SPRINKLER SYSTEM			•	•				•							•	
6	TAMPER SWITCH - PIV/BACKFLOW SUPERV.			•	•				•							•	
7	INCOMING FIRE LINE SUPERVISORY CONN.			•	•				•							•	
8	FIRE ALARM AC POWER FAILURE			•	•				•								•
9	FIRE ALARM SYSTEM LOW BATTERY					•	•			•							•
10	OPEN CIRCUIT					•	•			•							•
11	GROUND CIRCUIT					•	•			•							•
12	CIRCUIT SHORT					•	•			•							•

FIRE ALARM SEQUENCE OF OPERATIONS

Appendix J - Preliminary Fire Alarm System Layout

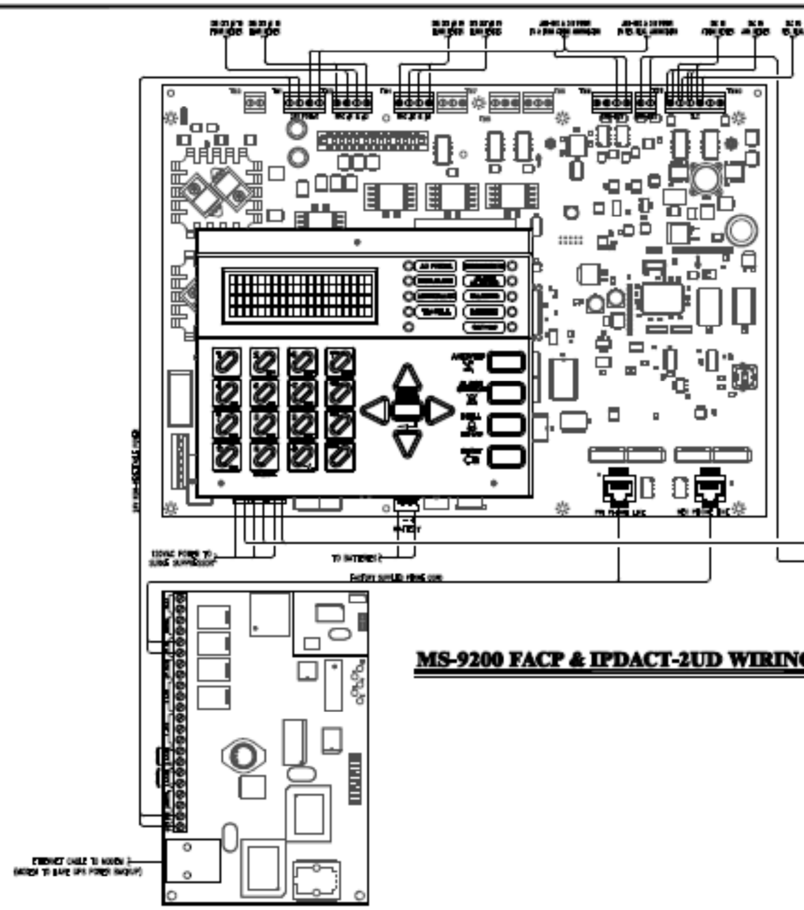
SMOKE DETECTION PROVIDED THROUGHOUT AUDITORIUM SPACE ONLY SPACING 30 FT. O.C. BETWEEN DETECTORS.





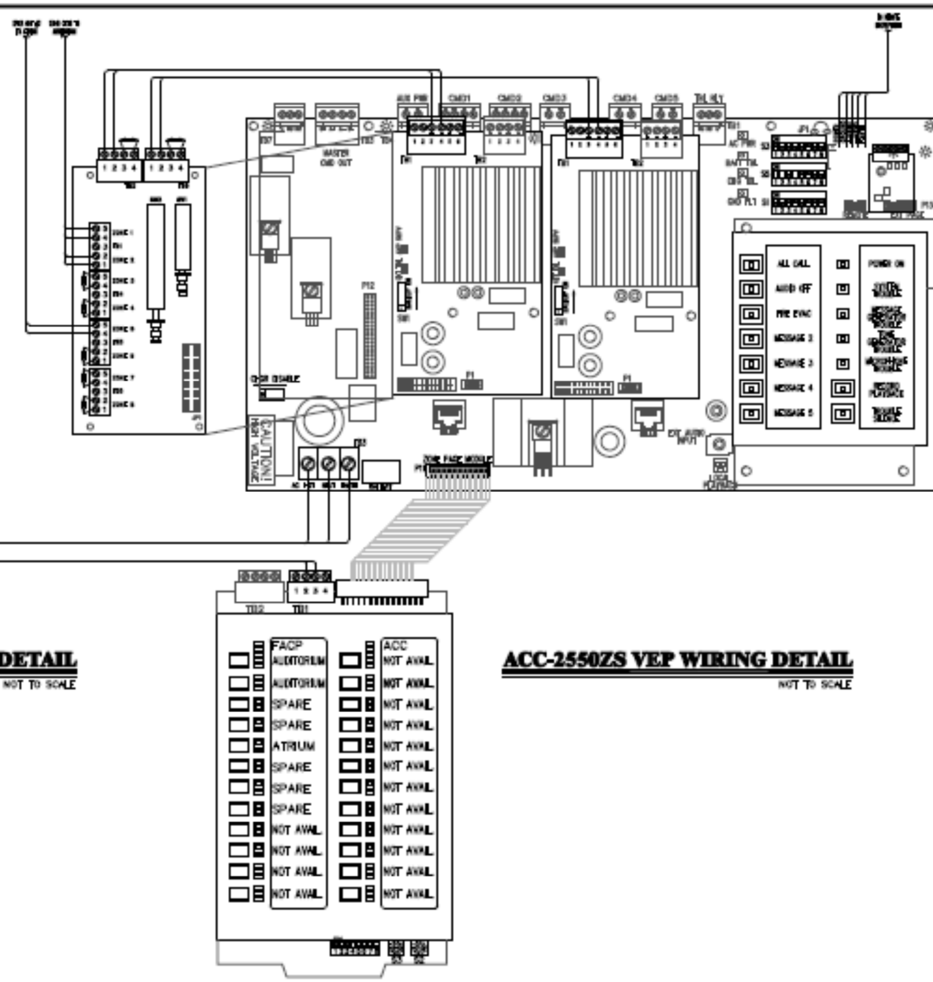
FIRE ALARM RISER DIAGRAM

NOT TO SCALE



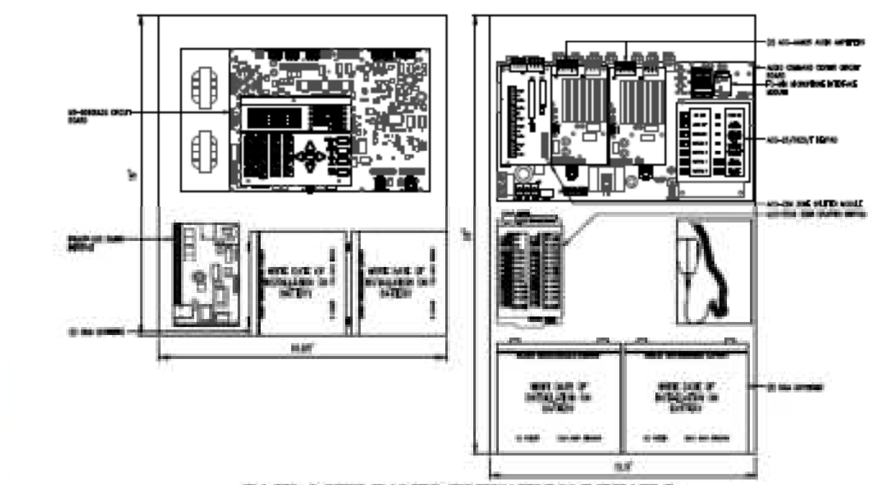
MS-9200 FACP & IPDACT-2UD WIRING DETAIL

NOT TO SCALE



ACC-2550ZS VEP WIRING DETAIL

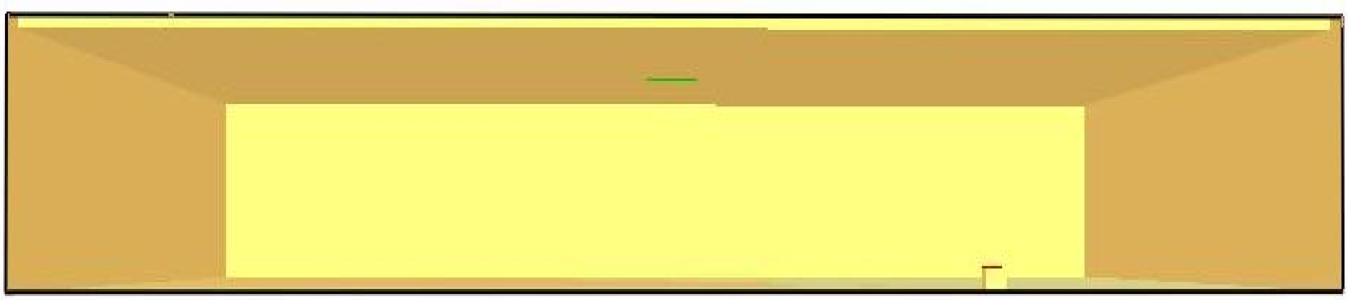
NOT TO SCALE



FACP & VEP PANEL ELEVATION DETAILS

NOT TO SCALE

Appendix K - Smoke Control Rational Analysis



SMOKE MANAGEMENT RATIONAL ANALYSIS REPORT

FIRE PROTECTION & LIFE SAFETY ANALYSIS

APPENDIX K

March 21, 2014

TABLE OF CONTENTS

INTRODUCTION

This report is to document the analysis and determine the necessary exhaust rate for an auditorium (large space) smoke-protected seating arrangement entailing an automatic smoke control system to provide an acceptable level of fire and life safety for building occupants. This analysis report is intended to describe the overall approach to the smoke management system for this project. The project is being designed in accordance with the prescriptive and performance requirements established for a rational analysis. As this report will indicate, the aforementioned calculations and analyses are conducted in accordance with the 2009 *International Building Code* (IBC) and referenced engineering standards. Of primary concern for this analysis, is the implementation of NFPA 92B, *Standard for Smoke Management Systems in Malls, Atria, and Large Spaces,* 2005. The building HVAC system should be balanced to the parameters of this report and tested for pressure differentials. Each individual involved in the design of this smoke management system must be registered or licensed in their particular branch of engineering (i.e., mechanical and fire protection engineering) or architecture, and will be responsible for the elements of the smoke control system in their area of responsibility.

KEY DEFINITIONS

The following words and terms shall, for the purposes of this analysis and as used elsewhere, have the meanings shown herein.

Dedicated Smoke-Control System. Smoke-control systems and components that are installed for the sole purpose of providing smoke control, and upon activation these systems operate specifically to perform the smoke-control function. They include components that do not function under normal building operating conditions, such as stair pressurization fans or smoke control dampers that operate specifically to perform the smoke control function upon smoke control system activation.

End-To-End Verification. A self-testing method that provides positive confirmation that the desired result (e.g., airflow or damper position) has been achieved when a controlled device has been activated, such as during smoke control mode, testing, or manual override operations. The intent of end-to-end verification goes beyond determining whether a circuit fault exists, but instead ascertains whether the desired end result is achieved. True end-to-end verification therefore, requires a comparison of the desired operation to the actual end result.

Nondedicated Smoke-Control Systems. Smoke-control systems and components that share components with some other system(s), such as the building HVAC system, and upon activation cause the HVAC system to change its mode of operation in order to achieve the smoke-control objectives.

Smoke-Control Mode. A predefined operational configuration of a system or device for the purpose of smoke control.

Smoke-Control System. An engineered system that utilizes a combination of passive barriers, mechanical equipment and automatic detection and/or suppression to inhibit smoke movement from the event zone to other smoke zones.

APPLICABLE CODE SECTIONS & REFERENCES

To meet both jurisdictional requirements of design and construction, the following applicable design criteria is used as a basis for the design, installation, approvals and operational maintenance discussed in this analysis:

International Code Council (ICC)
International Building Code (IBC), 2009
International Fire Code (IFC), 2009

National Fire Protection Association (NFPA)
NFPA 70, National Electric Code, 2008
NFPA 72, National Fire Alarm and Signaling Code, 2007
NFPA 90A, Installation of Air-Conditioning and Ventilating Systems, 2009
NFPA 92B, Smoke Management Systems in Malls, Atria, and Large Spaces*,* 2005
NFPA 101, Life Safety Code, 2009

The smoke management system will be designed using the exhaust method for smoke control in accordance with NFPA 92B, IBC/IFC section 909 and generally accepted and well-established principles of engineering as required by IBC section 909.2. In order to comply with the requirements in the NFPA 92B and IBC/IFC, the following guidelines are also referenced:

A Guide to Smoke Control in the 2006 IBC, Dr. John H. Klote, P.E., and Douglas H. Evans, P.E., 2007, International Code Council (ICC)

Handbook of Smoke Control Engineering, 2012 Dr. John H. Klote, P.E., Dr. James A. Milke, P.E., Et. Al., 2002, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), Society of Fire Protection Engineers (SFPE), International Code Council (ICC) and National Fire Protection Association (NFPA)

Commissioning Smoke Management Systems, ASHRAE Guideline 5–RA 2012, 2012 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE)

In accordance with IBC 1028.6.2 and NFPA 101 12.4.2**,** Smoke-Protected Assembly Seating (SPAS) is defined as “seating served by a means of egress that is not subject to smoke accumulation within or under the structure.” Smoke-protected assembly seating is being used in the building design egress concept and this will be achieved by providing an engineered smoke control system that will keep smoke from affecting the occupants during the time needed to evacuate or the space above any occupied area can hold the volume of smoke that is generated during the time needed for occupants to evacuate. The smoke control system will be designed and installed in accordance with IBC Section 909 as the guiding document for design.

> **Section 909 Smoke Control Systems.** Section 909 of the IBC on Smoke Control Systems requires a passive or mechanical smoke control system to provide tenable conditions where implementing the exhaust method.

Section 909.4 Analysis.   Section 909.4 of the IBC on Smoke Control Systems requires building systems and construction used for smoke control to be based on a rational analysis in accordance with well-established principles of engineering, the IBC and other pertinent design code criteria. At a minimum, the analysis must address the following:

- Stack Effect (IBC 909.4.1)
- Temperature (IBC 909.4.2)
- Wind Effects (IBC 909.4.3)
- HVAC System Effects (IBC 909.4.4)
- Climatic Effects (IBC 909.4.5)
- Duration of Operation (IBC 909.4.6)

Section 909.8 Exhaust Method. Section 909.8 of the IBC on Smoke Control systems only allows this design method when approved by the building and/or fire official in lieu of implementing the pressurization method required by IBC section 909.6 as primary smoke control method. The primary application of the exhaust method is in large spaces, such as auditoriums. Where the exhaust method is employed, the smoke control system is to be designed in accordance with NFPA 92B.

Section 909.8.1 Smoke layer. Section 909.8.1 of the IBC on Smoke Control systems requires the design criteria to be used when applying NFPA 92B for the exhaust method is to maintain the smoke layer interface at least 6 feet (1.83 m) above any walking surface that is considered part of the required egress within the particular smoke zone (e.g., auditorium) for a specified duration required by IBC section 909.4.6.

In addition to the performance based design provisions permitted under Section 104.11, the IBC provides specific requirements for the analysis in selecting the design fire (Sub-sections 909.9.1-909.9.4) and treatment of the physics governing weather and building dynamics (Sub-sections 909.4.1-909.4.6) as follows:

Section 909.9 Design fire. Section 909.9 of the IBC on Smoke Control systems establishes that the design fire be determined through a rational analysis by a registered design professional with experience in the area of fire protection engineering including fire dynamics and life safety systems with working knowledge of mechanical systems.

Section 909.9.1 Factors considered.   Section 909.9.1 of the IBC on Smoke Control systems provides detail on the factors that should be taken under consideration when determining the design fire size. To determine the appropriate fire size, an engineering analysis is necessary that takes into account the following elements: fuel (potential burning rates), fuel load (how much), effects included by the fire (smoke particulate size and density), steady or unsteady (burn steadily or simply peak and dissipate) and likelihood of sprinkler activation (based on height and distance from the fire).

> **Section 909.4.6 Duration of Operation.** Section 909.9.1 of the IBC on Smoke Control systems establishes criteria for operation of smoke control for 20 minutes or 1.5 times the calculated egress time, whichever is less, as a minimum time for evacuation or relocation. The code provides for the calculation of evacuation time needs to include delays with notification and the start of evacuation (i.e., pre-movement time, etc.), as well as applying a 1.5 safety factor to this analysis for final duration determination, but not to exceed 20 minutes.

Finally, IBC Section 909.8 requires that the smoke control system using the exhaust method shall be designed in accordance with NFPA 92B. That standard provides detailed methodologies for assisting in the design of large-space auditorium seating smoke management systems with the purpose specified as follows:

> **Section 1.2 Purpose.** Section 1.2 of NFPA 92B for atria smoke management systems establishes the rationale for providing smoke management systems to maintain a tenable environment for the required time for evacuation and manage the migration of smoke to adjacent spaces.

RATIONALITY

IBC section 909.4 requires that systems and building construction used for smoke control be based on a rational analysis in accordance with well-established principles of engineering. At a minimum, the analysis must address the following:

- Stack Effect (IBC 909.4.1)
- Temperature (IBC 909.4.2)
- Wind Effects (IBC 909.4.3)
- HVAC System Effects (IBC 909.4.4)
- Climatic Effects (IBC 909.4.5)
- Duration of Operation (IBC 909.4.6)
- Passive Systems (IBC 909.4.5)
- Smoke Boundary Construction (IBC 909.4.5)

The sections below discuss these issues and the consideration given in the rational analysis for the engineering approach to this system design.

Stack Effect

The IBC and NFPA 92B require the design of smoke control systems consider the phenomenon known as stack effect, so that it will not adversely affect the smoke management system design. The stack effect becomes more pronounced as the height of the space increases. With a one story building, stack effect is assumed to be negligible.

Temperature Effects of Fire
When using the exhaust method, the expansion of hot gases needs to be accounted for in determining the virtual origin, smoke layer depth and exhaust rate. This is determined both algebraically and through the use of fire modeling in this design.

Wind Effects
This is a tightly constructed building and it is assumed that wind effects will have negligible effect on operation of the smoke control system.

HVAC System Effects
HVAC system design and ducts implemented in the smoke control system will be non-dedicated to decrease the overall costs of construction and to improve overall system reliability.

Climatic Effects
Changes in outside air temperature and humidity will have negligible effect on the smoke control system. This is due to the narrow range of temperature fluctuations expected outside compared to the high temperature of a fire, and the single story construction will minimize temperature induced stack effects.

Duration of Operation
As required by IBC section 909.4.6, the smoke control system will be capable of continued operation after detection of a fire event for not less than 20 minutes.

Passive Systems
Smoke exhaust system will rely on the building construction to create compartment size. While compartment walls are of non-rated construction, they are of substantial construction to limit the growth and spread of fire from the auditorium smoke zone of fire origin.

TENABILITY CRITERIA

The temperature, visibility, radiant flux and smoke toxicity tenability limits will serve as design criterion on which to base minimum level of safety for an atrium smoke control system using the performance-based approach allowable under the *International Building Code (IBC), 2009* section 909.8 for designs implementing the Exhaust Method and *NFPA 92B*. These tenability limits should be evaluated at a height of 6 feet (1.8 m) above the finished floor level in accordance with IBC Section 909.8.1 for the smoke layer interface. Temperature, visibility, and radiant flux must be considered, and a life safety strategy must provide tenable conditions for a duration that enables safe evacuation of building occupants. The design criterion is summarized below in figure 1 and is discussed in greater detail below.

Tenability Limitation Criteria	Criteria Justification
Visibility Must Remain Above 10 m at 1.8 m (6 ft.) Walking Surface	*SFPE Fire Protection Engineering Handbook, Visibility and Human Behavior in Fire Smoke*
Temperature Must Remain Below 66° C at 1.8 m (6 ft.) Walking Surface	Figure 6.1 of the *Handbook of Smoke Control Engineering, Heat Tolerance for Humans at Rest, Naked with Low Air Movement*
Carbon Monoxide Concentration Must Remain Below 1,400 ppm at 1.8 m (6 ft.) Walking Surface	*Handbook of Smoke Control Engineering*

FIGURE 1, TENABILITY CRITERIA

Exposure to Heat/Temperature

Heat exposure to an occupant occurs as a result of both convective and radiative heat transfer. Convective heat transfer can occur through contact with smoke as product of combustion, whereas thermal radiation occurs with direct contact from flames or hot smoke. In accordance with Figure 6.1 of the *Handbook of Smoke Control Engineering, Heat Tolerance for Humans at Rest, Naked with Low Air Movement,* a person can tolerate a continuous exposure to humid air at 150ºF (66ºC) for approximately 20 minutes. In situations where a sustained hot smoke layer has been developed, it is possible that the hot smoke layer can radiate heat down to the evacuating occupants. Consideration is given to this possibility by calculating the upper layer temperature required to impart a critical radiant heat flux upon the occupants. Figure 6.2 of the Handbook of Smoke Control Engineering, *Tolerance of Human Skin to Thermal Radiation* indicates that an incident radiant flux, greater than 1.7 kW/m², would cause pain on the exposed skin of an occupant with any prolonged exposure.

Visibility

Occupants attempting to exit the facility must also be provided with sufficient visibility in order to evacuate. Since most occupants of the building will likely be only moderately familiar with the building layout and exact location of emergency exits, it is necessary for the smoke management system to provide suitable visibility levels. Estimates of visibility through smoke can be made using the following equation:

$$S=C/K$$

Where,
C is a non-dimensional constant
K is the light extinct coefficient
S is the visibility through the smoke (m)

K varies with the density of smoke particulate and a mass specific extinction coefficient, as determined in the following equation.

$$K = K_m \rho Y_S$$

The C parameter is specified according to the object being viewed through the smoke. For these analyses C is specified as 8 since the exit signs in the building will be the light emitting type. As discussed by Jin in the *SFPE Fire Protection Engineering Handbook, Visibility and Human Behavior in Fire Smoke*, proposed allowable smoke visibility that permits safe escape ranges from approximately 4 feet (1.2 m) to 66 feet (20.12 m), depending on the nature of the space and the awareness level of the occupants. For purposes of this analysis, an auditorium where occupants are semi-familiar with their surroundings can be analyzed at 32.8 ft. (10 m).

Toxicity & Fractional Effective Dosing (FED)

Carbon monoxide (CO) exposure is considered to account for the majority of fire fatalities as indicated in the *Handbook of Smoke Control Engineering,* but hyperventilation and Oxygen (O_2) depletion can also occur as a result of Carbon dioxide (CO_2) exposure. A fractional effective dose (FED) model was developed for use to determine incapacitation and lethality with a maximum determined exposure at 1.8 m (6 ft.) of 1,400 ppm. FED is based on a lethal dose (LD) of combustion products to 50% of test specimens over a specified time period. Since smoke must be sufficiently diluted for visibility, a simplified FED model can be practical to determine smoke toxicity levels using the following formula:

$$FED = \frac{Kt}{2.303\ S\delta_m LD}$$

Where,
K = Proportionality constant
(8 illuminated signs, 3 for reflected light)
t = Exposure time, minutes (minutes)
S = Visibility during exposure, ft. (m)
δ_m = Mass optical density, $ft^2/lb.$ (m^2/g)
LD = Lethal dose from test data

NFPA 92B CALCULATIONS

Initial calculations were performed using the methods outlined in NFPA 92B. For the exhaust method, an axisymmetric plume fire was studied. The smoke layer interface is designed to be 6 feet above the walking surface of the floor area, keeping smoke and hot gases above this level. Using the empirical model presented in these algebraic calculations, tenable conditions are assumed to be maintained through a deterministic approach in NFPA 92B. The table below details the inputs and results from calculations performed in accordance with the exhaust method on NFPA 92B. The calculations include determining the functions of the following formulas:

Step 1 Design fire: $Q_c = \chi Q_T$, where $\chi = 0.7$, per NFPA 92 5.5.1.3

Step 2 Determine Height of First Indication of Smoke with No Smoke Exhaust Opening

$$\frac{z}{H} = 1.11 - 0.28 \ln \frac{\frac{tQ^{\frac{1}{3}}}{H^{\frac{4}{3}}}}{\frac{A}{H^2}}$$

Step 3 Determine Limiting Elevation for an Axisymmetric Plume

$$z_L = 0.533 Q_c^{2/5}$$

Step 4 Determine the Mass Rate of Smoke Production, where $z > z_L$

$$m = 0.071 Q_c^{\frac{1}{3}} z^{\frac{5}{3}} + 0.0042 Q_c$$

Step 5 Determine the Smoke Layer Temperature

$$T_s = T_o + \frac{K_s Q_c}{m C_p}$$

Step 6 Determine the Volumetric Flow Rate

$$V = \frac{m}{\rho}$$

$$\rho = \frac{P_{atm}}{RT}$$

SMOKE CONTROL DESIGN CALCULATIONS & RESULTS

Algebraic equations are provided at the end of this document for reference purposes; the table below summarizes results of these hand calculations.

FIGURE 2, 92B ALGEBRAIC HAND CALCULATIONS

Axisymmetric Plume
Q = 3,000 kW
Qc = 2,100 kW
Z = 6 ft (1.83 m)
Z_L = 11.5 ft (3.54 m)
Smoke Temperature = 451°F (233 °C)
Exhaust Rate (V) = 21,125 cfm (9.97 m^3/s)

FIGURE 3, RESULTS SUMMARY OF 92B CALCULATIONS

FIRE DYNAMICS SIMULATOR (FDS) MODELING

In addition to performing algebraic equations, fire modeling is used to analyze a performance based approach. This approach is allowed under NFPA 92B, section 5.1.3 mentioned below and Appendix F of this document provides guidance for use of Compartment Fire Models.

> **Section 5.1.3* Compartment Fire Models.** Section 5.1.3 of NFPA 92B for large space auditorium smoke management systems requires compartment fire models to be either zone fire models or computational fire dynamics (CFD) modeling.

The proposed performance-based design relies on computer fire/smoke modeling to justify that the mechanical smoke control system proposed provides a level of fire life safety that satisfies the intent of the IBC. This analysis considers design fire scenario 1 (reference Section 12 of the Fire & Life Safety Design Analysis) in determining the overall exhaust rated needed to maintain a tenable environment for sufficient time period to evacuate. A performance-based fire safety approach is allowed under the International Building Code, as set forth the proceeding language:

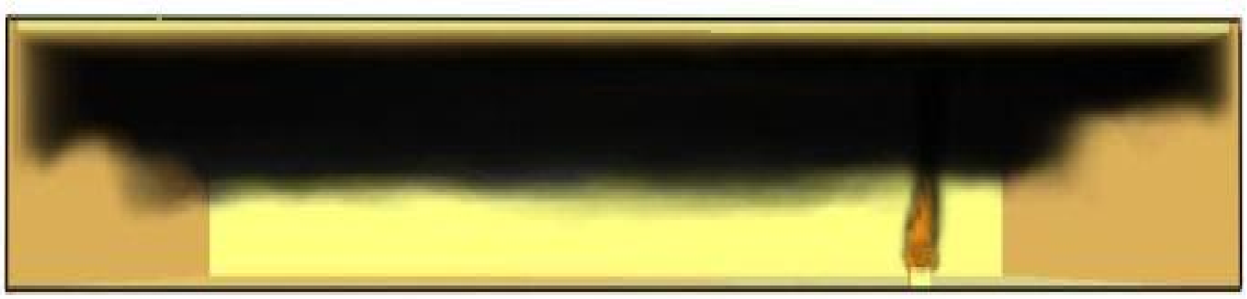
> **"104.10 Modifications.** Wherever there are practical difficulties involved in carrying out the provisions of this code, the *building official* shall have the authority to grant modifications for individual cases…"

"104.11 Alternative materials, design and methods of construction and equipment. The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been *approved*. An alternative material, design or method of construction shall be *approved* where the *building official* finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, *fire resistance*, durability and safety."

In the performance-based approach to the design of an auditorium (large space) smoke control system, an ASET/RSET analysis will be conducted. The Available Safe Egress Time (ASET) is the time lapse between fire ignition and growth to the creation of an untenable environment. ASET is determined through fire modeling using a computational fluid dynamic analysis using the Fire Dynamics Simulator (FDS), version 6, developed by the National Institute of Standards (NIST) – reference appendix N, *Fire Dynamics Simulator (FDS) Design Fire Input,* in the *Fire and Life Safety Analysis Design Report* for additional information. The Required Safe Egress Time (RSET) for this scenario was considered to be a minimum of 18 minute duration, as established by the IBC as 1.5 Safety Factor applied to the calculated egress time of 12 minutes.

The time at which conditions become untenable (ASET) is time wherein smoke particulates and heat, calculated by FDS exceeds pre-established tenability criteria. Tenability criteria for determining ASET as discussed previously in this report is summarized in the Results section and compared with FDS Modeling Results.

Compartment Fire Growth & Smoke Spread @ 120s



Compartment Fire Growth & Smoke Spread @ 250s

Compartment Fire Growth & Smoke Spread @ 350s

FIGURE 4, COMPARTMENT FIRE GROWTH & SMOKE SPREAD

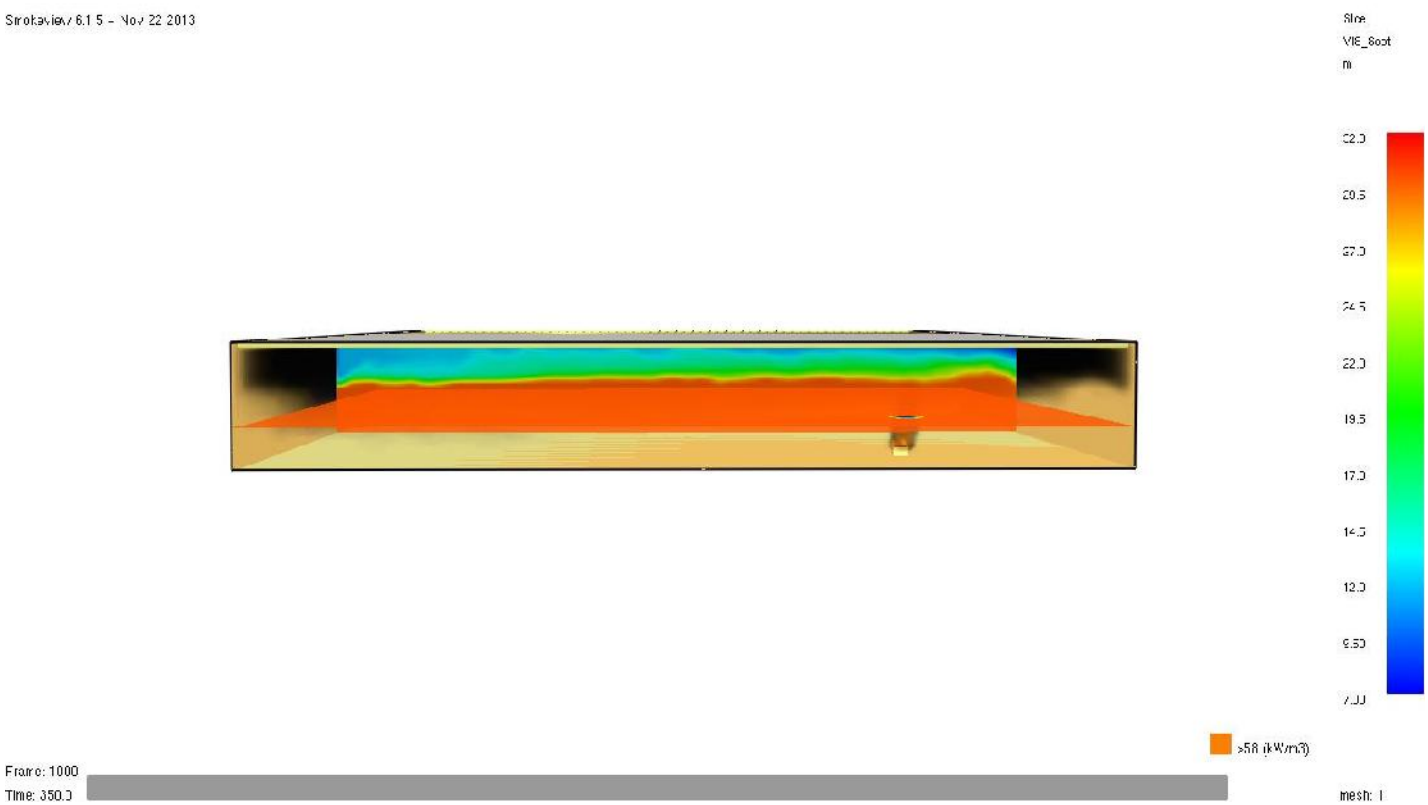


FIGURE 5, FDS MODEL – SOOT VISIBILITY, 32 M @ 1.83 M HEIGHT

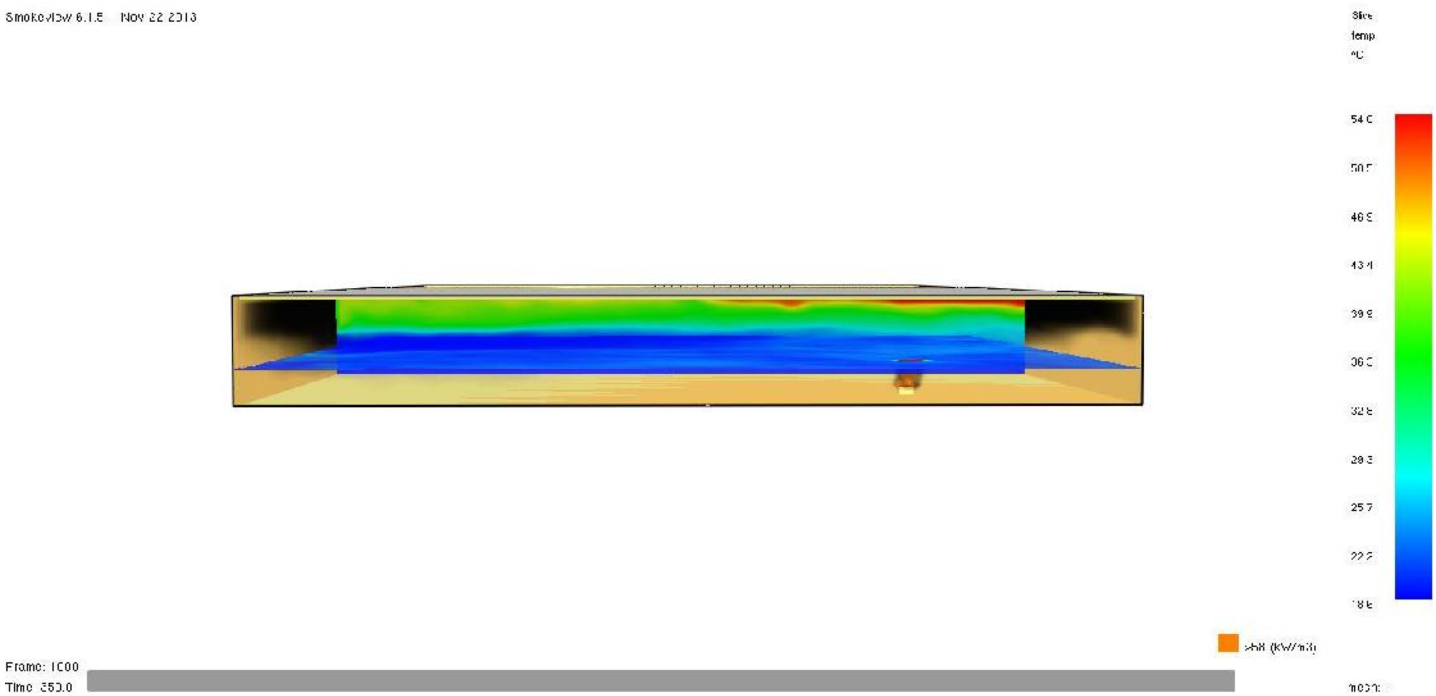


FIGURE 6, FDS MODEL – COMPARTMENT TEMPERATURES, 18.6 °C @ 1.83 M HEIGHT

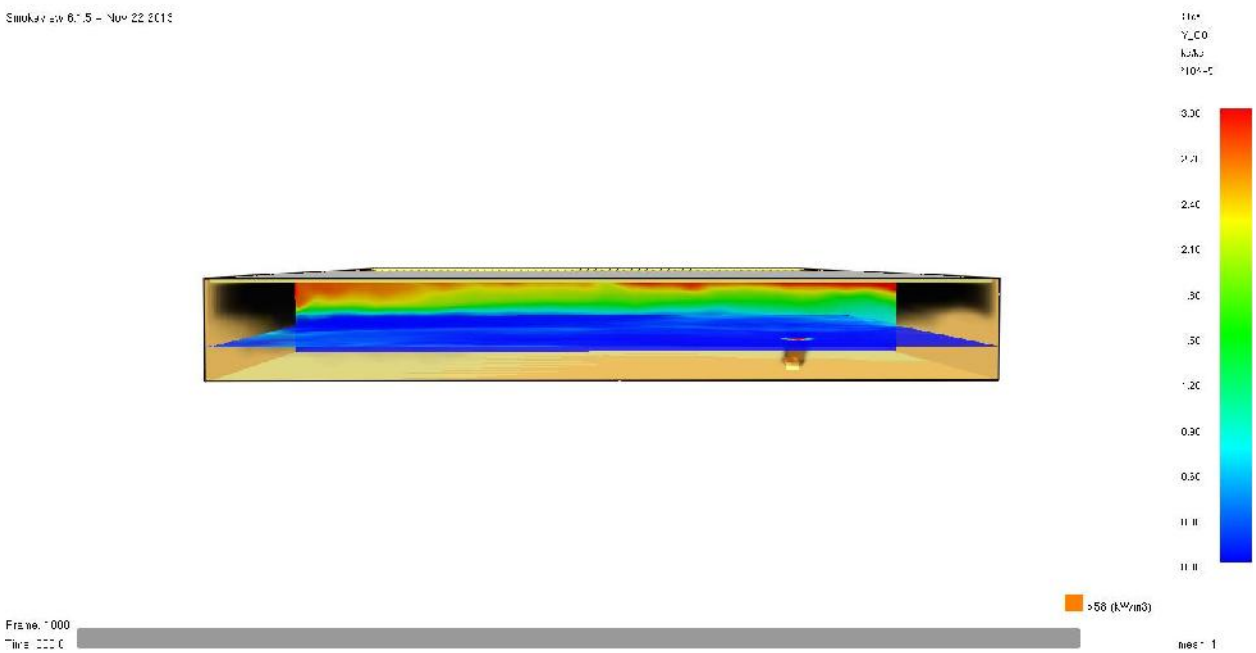


FIGURE 7, FDS MODEL – CO MASS CONCENTRATIONS, 0.000003 KG/KG CO YIELD @ 1.83 M HEIGHT

The Exhaust rate for a 9 m^2 smoke control vent was modeled at 5 m^3/s, or 10,595 cfm and maintained tenable conditions as summarized below.

RESULTS

As summarized below, FDS fire modeling established that tenable conditions were maintained with a reduction in overall exhaust rate from an exhaust rate of 21,125 cfm (9.97 m^3/s) determined algebraically to an exhaust rate of 10,595 cfm (5 m^3/s). This can significantly reduce initial installation and construction costs as well as long-term operating and maintenance (O&M) life cycle costs.

Tenability Limitation Criteria	FDS Modeling Results
Visibility must remain above 4 m at 1.83 m walking surface	Visibility maintained above 10 m at 1.83 m walking surface
Temperature must remain below 66° C at 1.83 m walking surface	Temperature maintained below 66° C at 1.83 m walking surface
Carbon monoxide concentration must remain below 1,400 ppm at 1.83 m walking surface	Carbon monoxide concentration is maintained below 1,400 ppm at 1.83 m walking surface

FIGURE 8, FDS MODEL SUMMARY

SMOKE CONTROL COMMISSIONING

Prior to commissioning the smoke control system, detailed system testing needs to be developed in concert with the special inspector and the design team. The testing criteria should be reviewed by the AHJ to confirm that methods of testing are acceptable. This document must provide a detailed method of testing and documenting the pass/fail criteria of each test demonstrating that each component of the smoke control system functions as intended by the design. The smoke control system shall be inspected and tested in accordance with the IBC/IFC 909.3, 909.10 through 909.19, Chapter 8 of NFPA 92B, ASHRAE Guideline 5, and is described below:

- Each individual fire alarm initiating device which activates any portion of the smoke control system must be verified to provide all applicable output functions in accordance with IBC 909.18.7. Each detection device must also be tested in accordance with 909.18.1.
- Power systems shall automatically transfer to full standby power in accordance with IBC and NFPA 70.
- The pressure difference across door shall not exceed a 30-pound force to set the door in motion in accordance with IBC Section 1008.1.2.

Smoke control systems are to be inspected and tested by special inspector in accordance with IBC 909.18 and this standard. The role of the special inspector is to review the installation for conformance with the approved design approach and code. Individuals serving as the Special Inspector are to be a

Fire Protection Engineer, registered by the appropriate state licensure board as a Professional Engineer (P.E.) with the qualifications outlined in IBC Section 909.18.8.2.

MECHANICAL SMOKE CONTROL ACTIVATION

Controls for each zone of the smoke control system will be provided at the Firefighter's Control Panel located in the central control station. All components shall be listed and installed using a methodology appropriate to ensure the prescribed survivability as follows:

- Equipment including fans, ducts, and dampers in accordance with IBC section 909.10.
- Primary and secondary power systems in accordance IBC section 909.11.
- Detection and control systems in accordance with IBC section 909.12.
- Control air tubing in accordance with IBC section 909.13.
- Marking and identification in accordance with IBC section 909.14.
- Firefighter's smoke control panel in accordance with IBC section 909.16.
- System response time in accordance with IBC section 909.17.
- Acceptance testing in accordance with IBC section 909.18

Upon the specific sprinkler zone water flow device or smoke detector initiation, the smoke control system will activate. The smoke compartment has been aligned with sprinkler zones to only activate system if sprinkler flow is within the detention compartment. Manual fire alarm pull stations will not activate the smoke control system.

SYSTEM IMPLEMENTATION REQUIREMENTS

This section is not intended to indicate all requirements listed in Section 909 and NFPA 92B chapter 6, but is intended to highlight those areas of design where coordination is necessary to provide a system design that is code compliant, as required by IBC sections 909.10 through 909.18.

IBC 909.10 EQUIPMENT

All equipment including, but not limited to, ducts, and any dampers, will be suitable for their intended use and will be the probable temperatures for which these components may be exposed. Proper listings for this equipment need to be obtained and submitted with the design or submitted during the Construction Phase prior installation.

Duct construction and fans construction is to be capable of withstanding the probable temperatures and pressures to which they are expected to be exposed to as determined by the formula below.

$$T_s = \frac{Q_c}{mc} + (T_a)$$

where:
c = Specific heat of smoke at smoke layer temperature (kJ/kg K)
m = Exhaust rate (kg/s)
Q_c = Convective heat output of fire (kW)
T_a = Ambient Temperature (K)
T_s = Smoke Temperature (K)

Ducts will be tested to 1.5 times the maximum design pressure in accordance with nationally accepted practices. The maximum leakage of duct will not exceed 5 percent of the design flow after installation. Outside air inlets/outlets will be located so as not to expose exhaust outlets into the building. IBC section 909.10.5 requires belt-driven fans to have 1.5 times the number of belts required for the design duty, where the minimum number of belts is two. Calculations and manufacturer's fan curves are to be included as part of the documentation for the design. Motors driving these fans are required to have a minimum service factor of 1.15.

Duct smoke detectors in supply ducts will automatically shut down the related fan. Where part of a smoke control system, a manual override will be provided at the FSCP. Dampers that are part of smoke control system are to be listed for their intended use.

IBC 909.11 POWER SYSTEMS

Smoke control systems are required to be provided with primary and secondary power as required by IBC section 909.11. Power must be automatic and should occur within 60 seconds failure of primary power. Other response times listed in Section 909.11 apply after the power transfer is complete. The system will be capable of withstanding power outages and has a continuous power supply or uninterruptible power supply for all components of the system that require volatile memory. A power surge protector will be included for those elements of the management system that are susceptible to power surges.

IBC 909.12 DETECTION AND CONTROL SYSTEMS

All control systems (input and output) must be supervised in accordance with IBC section 909.12. Positive confirmation of actuation, testing, manual override, device mechanisms, and the presence of power downstream of all disconnects shall be provided. Fans that are

for smoke management will be monitored with pressure sensors or load sensing current sensors to verify air flow. The supervision of the system will be indicated at the fire fighter's control panel, which must be UUKL listed for smoke control equipment. All wiring, regardless of voltage, will be fully enclosed within continuous raceways.

IBC 909.13 CONTROL AIR TUBING

Control air tubing for pneumatic control equipment comprising any part of the mechanical smoke control system shall be sized of hard drawn copper using installation methods and joining/termination methods in accordance with Section 909.13.1 Approved non-metallic tubing may be used inside originating or terminating enclosures in accordance with the exception to Section 909.13.1. Isolation valves shall be provided to separate tubing serving the mechanical smoke control system from other services or a dedicated tubing system shall be provided for the smoke control equipment.

IBC 909.14 MARKING AND IDENTIFICATION

During the construction phase, the detection and control systems are required to be clearly marked at all junctions, accesses, and terminations. This marking is to be approved for its use by the Fire Department and in accordance with generally accepted practice.

IBC 909.15 CONTROL DIAGRAMS

Identical control diagrams that depict the devices in the system identifying their location and functions will be current and kept within the building control center after construction, along with file copies for the Fire and Building Departments.

IBC 909.16 FIREFIGHTER'S CONTROL PANEL (FSCP)
The FSCP is a system that provides visual status indication and manual overriding capability over smoke-control systems and equipment. This is also referred to as the Fire Fighters' Smoke-Control Station (FSCS) in NFPA 92. The purpose of the FSCP is for fire department use during an emergency. This panel will be provided in accordance with IBC Sections 909.12 and 909.16, and incorporate standards listed in this section.

Priority and control. The FSCP will have the highest priority control over all smoke-control systems and equipment, whether or not the automatic fire alarm system has been activated. The panel will be designed to enable Fire Department personnel who may be unfamiliar with the specific system the ability to reconfigure the status of each smoke zone as deemed necessary during an emergency.

Smoke Detector for Panel. The FSCP will be provided with a smoke detector within 15 feet of the panel (measured horizontally), in accordance with NFPA 72.

Panel Colors. The FSCP shall consist of a white background and generally depict significant smoke barriers by single black lines, appearing as a general section view of the building. The image shall sufficiently illustrate all smoke zones in the building without providing the level of detail common to architectural elevation or section views.

Air Flow. A clear indication of the direction of airflow and the relationship of components will be displayed. Status indicators shall be provided for all smoke control equipment, annunciated by fan and zone, and by pilot-lamp-type indicators as follows:
1. Fans, *dampers* and other operating equipment in their normal status—WHITE.
2. Fans, *dampers* and other operating equipment in their off or closed status—RED.
3. Fans, *dampers* and other operating equipment in their on or open status—GREEN.
4. Fans, *dampers* and other operating equipment in a fault status—YELLOW/AMBER.

Panel Indicators- Equipment and Status. The general location of each smoke control system component, including fans, ducts and dampers, that is controlled or annunciated by the panel will be depicted on the panel.

Fans, Ducts and Dampers. Fans, major ducts, dampers, and zoning within the building that are portions of the smoke control system will be shown connected to their respective ducts or dedicated fans with clear indication of direction of airflow.

Equipment Status Indicators. Indicators as required by IBC Sections 909.16.will be provided for each individually monitored piece of equipment.
The FSCP will have manual operation of all components being controlled for the smoke control system (i.e., control actions of those switches will have the highest priority of any control point within the building, other than those required to be safety items by NFPA 70).

IBC 909.17 RESPONSE TIME
The smoke control activation will be initiated immediately after receipt of the appropriate automatic or manual activation command. The components will be activated in the sequence necessary to prevent physical damage of the equipment and the total response time for the individual components to achieve their desired operating as indicated below:

- Control air valves - 10 seconds maximum
- Smoke damper closing - 15 seconds maximum

- Smoke damper opening 15 seconds maximum
- Fans starting or energizing - 15 seconds maximum
- Fans stopping or de-energizing- 10 seconds maximum
- Fan volume modulation - 30 seconds maximum
- Pressure control modulation- 15 seconds maximum
- Temperature control safety override - 10 seconds maximum
- Positive indication of system status - 15 seconds maximum

The total response time will not exceed 60 seconds, in accordance with standard practice.

IBC 909.18 ACCEPTANCE TESTING CRITERIA

Operational Testing Witnessed. Operational testing is to be conducted in accordance with applicable sections of the SI Test Procedures by a qualified individual. Each control sequence of the smoke control systems must minimally include the following:

- Manual control of smoke control system equipment serving select smoke-control zones shall be demonstrated.
- Manual activation of equipment via FSCP while the system is in normal status; may result in transmission of trouble signal to FACP.
- Trouble signal transmitted to FACP when FSCP manual control set to OFF or CLOSED position while system is in normal status.
- Correct automatic system operation via a minimum of one of each type of initiating device (i.e. smoke detector, waterflow switch, manual station) and sequence of operation serving each smoke-control zone.
- Manual control via FSCP when system is active to activate inactive system components and disable active system components.
- For each sequence of operations, visual confirmation that controlled components in associated active zones have assumed the correct operating condition for the type of alarm initiating device and the location of initiating device. Proper annunciation shall be confirmed also at the FSCP.
- Self-test abort. The system must demonstrate that upon initiation of an alarm, it will properly abort the self-test and initiate the programmed smoke control sequence of operation.
- Return all override switches to their "Auto" position.

SMOKE CONTROL SYSTEM SPECIAL INSPECTOR

Testing and Inspection. Smoke control systems are to be inspected and tested by special inspector in accordance with IBC 909.18 and this standard. The role of the special inspector is to review the installation for conformance with the approved design approach and code.

Special Inspector Qualifications. Smoke control special inspection qualifications are outlined in IBC Section 909.18.8.2 and 1704.16.2. Both sections indicate that agencies are to have expertise in mechanical and fire protection engineering and certification as an air balancer. The combination of persons, agencies or firms can vary, but the qualifications must include all of the disciplines prescribed.

Agency Requirements. Agencies serving as the SIA must have a Registered (P.E.) overseeing the special inspection process. The combination of persons, agencies or firms can vary, but the qualifications of the team providing special inspections must include at a minimum all of the disciplines prescribed in IBC 909.18.8.2.

Individual Requirements. Individuals serving as the SI are to be a Registered (P.E.) Fire Protection, Mechanical, or Electrical Engineer with the qualifications outlined in IBC Section 909.18.8.2. A P.E. with smoke management commissioning experience may serve as the SI to coordinate and verify all components of the smoke-control system within his or her area of expertise. The SI is required to provide a certificate of compliance in accordance with this document.

Air Flow and Pressure Testing. All airflow and pressure testing must be done by an approved Associated Air Balance Council (AABC), National Environmental Balancing Bureau (NEBB), or Testing Adjusting, and Balancing Bureau (TABB) agency. If this company is hired by the installing contractor or responsible for the balancing of the system, the SI must witness all required special inspection testing.

PERIODIC OPERATION AND MAINTENANCE

Record Modifications. Changes as a result of final installation, testing, or a change to the system design must be documented in the special inspection report, prepared in accordance with IBC Section 909.18.8.3. Record drawings must include an accurate depiction of risers, raceway, conduit, all wire runs, cable identification, conduit size, location of junction boxes, terminal boxes, sources of power, devices, sensors, equipment, controlled equipment (motor starters, fans, pumps, valves, dampers, etc.).

Routine Maintenance and Testing. The system must be maintained in accordance with the manufacturer’s instructions and IFC sections 909.12, and 909.20.1 - 909.20.5.

The written record described in IFC Section 909.20.2 is to be maintained with the routine maintenance and operational program in reverse chronological order, beginning with the most recent completed report.

Weekly Self-Test. Automatic weekly self-tests must be conducted and documented for smoke control systems (IBC 909.12). Such testing must include end-to-end verification. The fire alarm or smoke management panel shall exercise system components once per week and receive positive confirmation that the component operated properly. For fans, the self-test typically involves turning on the fan just long enough to bring them up to speed and receive positive confirmation of airflow. For dampers, the self-test typically involves cycling the damper into both the open and closed positions and receiving positive confirmation of each position via contact switches. The duration of the self-test shall be adequate to allow the system to detect a fault condition in the event an affected system component did not function properly.

Self-Test Failure. During the self-test, should any device malfunction, a “FAULT” indication on the associated equipment on the FSCP is required as part of the IBC 909.12 mandated audible, visual and printed report. A trouble signal shall be transmitted to the fire alarm monitoring agency. The self-test procedure and output shall be printed and maintained in the fire control room and accessible to inspection agencies.

Ongoing Records of System Testing and Inspection described in IFC 909.20 are to be maintained for review upon request by the AHJ as described below:

- Elements of the smoke control system found to not conform to the detailed design report or testing program shall be clearly identified as to what the issue is, the date it is discovered, how it was resolved and the date it is resolved (if applicable).

- Dampers controlled by the smoke control system, whether monitored by the FSCP or not, shall be visually inspected and maintained a minimum of every 4 years in accordance with NFPA 90A and the manufacturer's recommendation.

Smoke Control Record Documents. The following items must be maintained current for the life of the building:

- Approved control diagrams must be kept accessible for the life of the building and must be updated when changes are made to the building.
- Plans showing the devices and equipment which make up the smoke control system. This will include control diagrams in accordance with IBC 909.15, all smoke barriers, applicable initiating devices, controllers, fire alarm control panel, fire-fighter's smoke control panel, facility temperature controls, control wiring or tubing, isolation valves, relays, doors, dampers, fans, all supervision devices.
- Every device must have a distinct identifying address. For purposes of this requirement, BFD will accept the detailed design drawings, provided all of the devices listed above are shown, and no extraneous equipment other than fire alarm devices.
- A detailed event matrix (each device must be identified by individual address exactly as it is shown on the control diagram plans above);
- Documents describing the proper operation and maintenance requirements of each component of the smoke control system, including fan curves for the smoke control fans in the building.
- Maintenance logs and quarterly testing logs.
- The approved smoke control Detailed Design Report.
- UUKL panel self-test printouts.

NFPA 92B HAND CALCULATIONS

Determinant	Equation	Solution		Parameters		Notes
Mass Consumption (Steady)	$m = \frac{Q\Delta t}{H_c}$	m =	150.63	Q =	3000	HRR (kW)
Mass Consumption (t-squared)	$m = \frac{333\Delta t^3}{H_c t_g^2}$	m =	#DIV/0!	tg =		growth time (seconds)
First Indication of Smoke for No Exhaust Condition (Steady)	$\frac{z}{H} = 1.11 - 0.28 \ln\left(\frac{\frac{tQ^{1/3}}{H^{4/3}}}{\frac{A}{H^2}}\right)$	z =	2.21	t =	1200	duration of fire (seconds)
First Indication of Smoke for No Exhaust Condition (t-squared)	$\frac{z}{H} = 0.91\left(\frac{t}{t_g^{2/5} H^{4/5}\left(\frac{A}{H^2}\right)^{3/5}}\right)^{-1.45}$	z =	#DIV/0!	Hc =	23900	Heat of Combustion (kJ/kg)
Balcony Spill Plume Equation	$m = 0.36(QW^2)^{1/3}(z_b + 0.25H)$	m =	0.00	H =	7.5	Ceiling Height (m)
Mass rate of smoke production z <zl	$z \le z_l,\ m = 0.0208 Q_c^{3/5} z$	m =	6.96	A =	3604.44	Cross sectional area of atrium space (sq. m.)
Mass rate of smoke production (kg/s) z >zl	$z > z_l,\ m = \left(0.022 Q_c^{1/3} z^{5/3}\right) + 0.0042 Q_c$	m =	**9.88**	zb =	1.83	Height above the floor to the smoke layer interface (m)
Axisymmetric Plume diamter (m)	$d_p = K_d \cdot z$	dp =	0.55	W =		smoke layer interface (m)
Smoke Layer Temperature (°C)	$T_s = T_o + \frac{K_s Q_c}{m C_p}$	Ts =	232.64	zl =	3.54	Limiting elevation (m)
Maximum volumetric flow rate without plugholing at Ts (m^3/s)	$V_{\max} = 4.16\gamma d^{5/2}\left(\frac{T_s - T_o}{T_o}\right)^{1/2}$	Vmax =	519.19	Qc =	2100	Convective portion HRR

Density of smoke (kg/m^3)	$\rho = \frac{P_{atm}}{RT}$	ρ=	0.70	Kd =	0.25	
						(Assume beam detection)
Volumetric rate of smoke exhaust (m^3/s)	$V = \frac{m}{\rho}$	**V =**	**9.97**	Ks =	1	
						NFPA 92 section 5.5.5.1
Exhaust Inlets Needed	**V/Vmax (Round Any Fraction Up)**	**No. =**	**0.02**	Cp =	1	kJ/kg Specific Heat
Exhaust Inlet Ratio - 5.6.7	d/Di > 2 O.K.	Check	2.84	To =	20	Degrees C (Ambient)
Exhaust Vent Separation Distance (m)	$S_{min} = 0.9V_e^{1/2}$	**Smin =**	**20.51**	Y =	0.5	Exhaust location factor
				d=	5.67	Depth of smoke layer below exhaust inlet (m)
				Patm =	101325	Atmospheric pressure (Pa)
				T	505.64	Absolute Temp. of Smoke (K)
				Di =	2	
				a =	**2**	**Vent Length**
				b=	**2**	**Vent Width**
	$F = F_r + \frac{5.2(WA)\Delta P}{2(W-d)}$	Fr = (lb)	7.96	F =	30	Door opening Force (lb)
				W =	3	Door width (ft)
				A =	21	Door area (ft^2)
				ΔP =	0.37	Pressure Difference across doors (i
				d =	0.25	

Table A.4.4.2.2 Maximum Pressure Differences Across Doors

Door-Closer Force* (lbf)	Door Width (in. w.g.)† 32 in.	36 in.	40 in.	44 in.	48 in.
6	0.45	0.40	0.37	0.34	0.31
8	0.41	0.37	0.34	0.31	0.28
10	0.37	0.34	0.30	0.28	0.26
12	0.34	0.30	0.27	0.25	0.23
14	0.30	0.27	0.24	0.22	0.21

For SI units, 1 lbf = 4.4 N; 1 in. = 25.4 mm; 0.1 in. w.g. = 25 Pa.
Notes:
(1) Total door-opening force is 30 lbf.
(2) Door height is 7 ft.
(3) The distance from the doorknob to the knob side of the door is 3 in.

Appendix L - DETACT Fire Model – Sprinkler Activation & Smoke Detection Activation

CHAPTER 11. ESTIMATING SMOKE DETECTOR RESPONSE TIME

Version 1805.0

The following calculations estimate smoke detector response time.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW	947.82
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	23.19	ft	7.07
Height of Ceiling above Top of Fuel (H)	24.50	ft	7.47
Activation Temperature of the Smoke Detector ($T_{activation}$)	83.00	°F	28.33
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$	
Ambient Air Temperature (T_a)	70.00	°F	21.11
			294.11
Convective Heat Release Rate Fraction (χ_c)	0.70		
Plume Leg Time Constant (C_{pl}) (Experimentally Determined)	0.67		
Ceiling Jet Lag Time Constant (C_{cj}) (Experimentally Determined)	1.2		
Temperature Rise of Gases Under the Ceiling (ΔT_c) for Smoke Detector to Activate	18.00	°F	10

r/H = 0.95

Calculate

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

This method assume smoke detector is a low RTI device with a fixed activation temperature

Where $t_{activation}$ = detector activation time (sec)

RTI = detector response time index $(m\text{-}sec)^{1/2}$

u_{jet} = ceiling jet velocity (m/sec)

T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

$T_{activation}$ = activation temperature of detector (°C)

Ceiling Jet Temperature Calculation

$T_{jet} - T_a = 16.9 (Q_c)^{2/3}/H^{5/3}$ for $r/H \le 0.18$

$T_{jet} - T_a = 5.38 (Q_c/r)^{2/3}/H$ for $r/H > 0.18$

Where T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

Q_c = convective portion of the heat release rate (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the detector (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c Q$

Where Q_c = convective portion of the heat release rate (kW)

Q = heat release rate of the fire (kW)

χ_c = convective heat release rate fraction

Q_c = **700** kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.95 r/H > 0.15

>0.15	15.42	<0.15	46.70

$T_{jet} - T_a$ = 5.38 ((Qc/r)^2/3)/H

$T_{jet} - T_a$ = 15.42

T_{jet} = **36.53** (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96 (Q/H)^{1/3}$ for $r/H \le 0.15$

$u_{jet} = (0.195 Q^{1/3} H^{1/2})/r^{5/6}$ for $r/H > 0.15$

Where u_{jet} = ceiling jet velocity (m/sec)

Q = heat release rate of the fire (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.95 r/H > 0.15		
>0.15	1.04	<0.15	4.91

u_{jet} = (0.195 Q^1/3 H^1/2)/r^(5/6)

u_{jet} = **1.044** m/sec

Smoke Detector Response Time Calculation

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ =	**3.09 sec**	**Answer**

NOTE: If $t_{activation}$ = "NUM" Detector does not activate

METHOD OF MOWRER

References: *Mowrer, F., "Lag Times Associated With Fire Detection and Suppression," Fire Technology, August 1990, p. 244.*

$t_{activation} = t_{pl} + t_{cj}$

Where $t_{activation}$ = detector activation time (sec)

t_{pl} = transport lag time of plume (sec)

t_{cj} = transport lag time of ceiling jet (sec)

Transport Lag Time of Plume Calculation

$t_{pl} = C_{pl}\ (H)^{4/3}/(Q)^{1/3}$

Where t_{pl} = transport lag time of plume (sec)

C_{pl} = plume lag time constant

H = height of ceiling above top of fuel (m)

Q = heat release rate of the fire (kW)

t_{pl} = **0.98** sec

Transport Lag Time of Ceiling Jet Calculation

$t_{cj} = (r)^{11/6}/(C_{cj})\ (Q)^{1/3}\ (H)^{1/2}$

Where t_{cj} = transport lag time of ceiling jet (sec)

C_{cj} = ceiling jet lag time constant

r = radial distance from the plume centerline to the detector (m)

H = height of ceiling above top of fuel (m)

Q = heat release rate of the fire (kW)

t_{cj} = **1.10** sec

Smoke Detector Response Time Calculation

$t_{activation} = t_{pl} + t_{cj}$

$t_{activation}$ =	**2.08 sec**	**Answer**

METHOD OF MILKE

References: *Milke, J., "Smoke Management for Covered Malls and Atria," Fire Technology, August 1990, p. 223.*
NFPA 92B, "Guide for Smoke Management Systems in Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

$t_{activation} = X\, H^{4/3}/Q^{1/3}$

Where $t_{activation}$ = detector activation time (sec)
$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$
H = height of ceiling above top of fuel (ft)
Q = heat release rate from steady fire (Btu/sec)

Where $Y = \Delta T_c\, H^{5/3} / Q^{2/3}$
ΔT_c = temperature rise of gases under the ceiling for smoke detector to activate (°F)

Before estimating smoke detector response time, stratification effects can be calculated. NFPA 92B, 2000 Edition, Section A.3.4 provides following correlation to estimate smoke stratification in a compartment.

$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$

Where H_{max} = the maximum ceiling clearance to which a plume can rise (ft)
Q_c = convective portion of the heat release rate (Btu/sec)
$\Delta T_{f\text{->}c}$ = difference in temperature due to fire between the fuel location and ceiling level (°F)

Convective Heat Release Rate Calculation

$Q_c = Q\,\chi_c$

Where Q_c = convective portion of the heat release rate (Btu/sec)
Q = heat release rate of the fire (Btu/sec)
χ_c = convective heat releas rate fraction

Q_c = **663.47** Btu/sec

Difference in Temperature Due to Fire Between the Fuel Location and Ceiling Level

$\Delta T_{f\text{->}c} = 1300\ Q_c^{2/3} / H^{5/3}$

Where $\Delta T_{f\text{->}c}$ = difference in temperature due to fire between the fuel location and ceiling level (°F)

Q_c = convective portion of the heat release rate (Btu/sec)

H = ceiling height above the fire source (ft)

$\Delta T_{f\text{->}c}$ = **478.50** °F

Smoke Stratification Effects

$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$

H_{max} = **24.55** ft

In this case the highest point of smoke rise is estimated to be **24.55** ft

Thus, the smoke would be expected to reach the ceiling mounted smoke detector.

$\mathbf{Y = \Delta T_c\ H^{5/3} / Q^{2/3}}$

Y = **38.55**

$\mathbf{X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6}$

X = **0.68**

Smoke Detector Response Time Calculation

$t_{activation} = X\ H^{4/3}/Q^{1/3}$

$t_{activation}$ =	**4.95** sec	**Answer**

Summary of Results

Calculation Method	Smoke Detector Response Time (sec)
METHOD OF ALPERT	3.09
METHOD OF MOWRER	2.08
METHOD OF MILKE	4.95

NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook 19th Edition, 2003, method described in Fire Technology, 1990, and NFPA 92B, "Guide for Smoke Management Systems in Malls, Atria, and Large Areas," 2000 Edition, Section A.3.4. Calculations are based on certain assumptions and

CHAPTER 11. ESTIMATING SMOKE DETECTOR RESPONSE TIME

Version 1805.0

The following calculations estimate smoke detector response time.

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Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$	
Ambient Air Temperature (T_a)	70.00	°F	21.11
			294.11
Convective Heat Release Rate Fraction (χ_c)	0.70		
Plume Leg Time Constant (C_{pl}) (Experimentally Determined)	0.67		
Ceiling Jet Lag Time Constant (C_{cj}) (Experimentally Determined)	1.2		
Temperature Rise of Gases Under the Ceiling (ΔT_c) for Smoke Detector to Activate	18.00	°F	10

r/H = 0.95

Calculate

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln\ (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

This method assume smoke detector is a low RTI device with a fixed activation temperature

Where $t_{activation}$ = detector activation time (sec)

RTI = detector response time index $(m\text{-}sec)^{1/2}$

u_{jet} = ceiling jet velocity (m/sec)

T_{jet} = ceiling jet temperature (°C)

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$T_{activation}$ = activation temperature of detector (°C)

Ceiling Jet Temperature Calculation

$T_{jet} - T_a = 16.9\ (Q_c)^{2/3}/H^{5/3}$ for $r/H \le 0.18$

$T_{jet} - T_a = 5.38\ (Q_c/r)^{2/3}/H$ for $r/H > 0.18$

Where T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

Q_c = convective portion of the heat release rate (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the detector (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\ Q$

Where Q_c = convective portion of the heat release rate (kW)

Q = heat release rate of the fire (kW)

χ_c = convective heat release rate fraction

Q_c = **700** kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.95 r/H > 0.15

>0.15	15.42	<0.15	46.70

$T_{jet} - T_a$ = 5.38 ((Qc/r)^2/3)/H

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T_{jet} = **36.53** (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ for $r/H \le 0.15$

$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ for $r/H > 0.15$

Where u_{jet} = ceiling jet velocity (m/sec)

Q = heat release rate of the fire (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H =		0.95 r/H > 0.15		
	>0.15	1.04	<0.15	4.91

u_{jet} = (0.195 Q^1/3 H^1/2)/r^(5/6)

u_{jet} = **1.044** m/sec

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$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ =	**3.09 sec**	**Answer**

NOTE: If $t_{activation}$ = "NUM" Detector does not activate

METHOD OF MOWRER

References: *Mowrer, F., "Lag Times Associated With Fire Detection and Suppression," Fire Technology, August 1990, p. 244.*

$t_{activation} = t_{pl} + t_{cj}$

Where $t_{activation}$ = detector activation time (sec)

t_{pl} = transport lag time of plume (sec)

t_{cj} = transport lag time of ceiling jet (sec)

Transport Lag Time of Plume Calculation

$t_{pl} = C_{pl}\ (H)^{4/3}/(Q)^{1/3}$

Where t_{pl} = transport lag time of plume (sec)

C_{pl} = plume lag time constant

H = height of ceiling above top of fuel (m)

Q = heat release rate of the fire (kW)

t_{pl} = **0.98** sec

Transport Lag Time of Ceiling Jet Calculation

$t_{cj} = (r)^{11/6}/(C_{cj})\ (Q)^{1/3}\ (H)^{1/2}$

Where t_{cj} = transport lag time of ceiling jet (sec)

C_{cj} = ceiling jet lag time constant

r = radial distance from the plume centerline to the detector (m)

H = height of ceiling above top of fuel (m)

Q = heat release rate of the fire (kW)

t_{cj} = **1.10** sec

Smoke Detector Response Time Calculation

$t_{activation} = t_{pl} + t_{cj}$

$t_{activation}$ =	**2.08 sec**	**Answer**

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References: *Milke, J., "Smoke Management for Covered Malls and Atria," Fire Technology, August 1990, p. 223.*

NFPA 92B, "Guide for Smoke Management Systems in Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

$t_{activation} = X\ H^{4/3}/Q^{1/3}$

Where $t_{activation}$ = detector activation time (sec)

$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$

H = height of ceiling above top of fuel (ft)

Q = heat release rate from steady fire (Btu/sec)

Where $Y = \Delta T_c\ H^{5/3} / Q^{2/3}$

ΔT_c = temperature rise of gases under the ceiling for smoke detector to activate (°F)

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Where H_{max} = the maximum ceiling clearance to which a plume can rise (ft)

Q_c = convective portion of the heat release rate (Btu/sec)

$\Delta T_{f\text{->}c}$ = difference in temperature due to fire between the fuel location and ceiling level (°F)

Convective Heat Release Rate Calculation

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Where Q_c = convective portion of the heat release rate (Btu/sec)

Q = heat release rate of the fire (Btu/sec)

χ_c = convective heat releas rate fraction

Q_c = **663.47** Btu/sec

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Where $\Delta T_{f\text{->}c}$ = difference in temperature due to fire between the fuel location and ceiling level (°F)

Q_c = convective portion of the heat release rate (Btu/sec)

H = ceiling height above the fire source (ft)

$\Delta T_{f\text{->}c}$ = **478.50** °F

Smoke Stratification Effects

$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$

H_{max} = **24.55** ft

In this case the highest point of smoke rise is estimated to be **24.55** ft

Thus, the smoke would be expected to reach the ceiling mounted smoke detector.

$Y = \Delta T_c\ H^{5/3} / Q^{2/3}$

Y = **38.55**

$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$

X = **0.68**

Smoke Detector Response Time Calculation

$t_{activation} = X\ H^{4/3}/Q^{1/3}$

$t_{activation}$ = 4.95 sec **Answer**

Summary of Result

Calculation Method	Smoke Detector Response Time (sec)
METHOD OF ALPERT	3.09
METHOD OF MOWRER	2.08
METHOD OF MILKE	4.95

NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook 19th Edition, 2003, method described in Fire Technology, 1990, and NFPA 92B, "Guide for Smoke Management Systems in Malls, Atria, and Large Areas," 2000 Edition, Section A.3.4. Calculations are based on certain assumptions and

Appendix M – Ignition/Fire Growth Calculations – Polyurethane Foam Padding Fixed Auditorium Seating

ΔT=	1	s	Ao (m^2) =	2	Ho (m^2)=	2	Hc =	23900	kJ/kg	m (kg) =	22	q" min for ignition=	6	kW/m^2	Ro =	0.1

t	α	αt^2	HRR (max)	HRRf	HRR	mf	mf (fl)	MLR	m	q"	Ign.	t(2)	at^2 (2)	HRR (2)	Total HRR	mf (2)	mf (fl) 2	MLR (2)	m
0	0.182	0	3000	4243	0	0		0	22	0		0	0	0	0	0		0	22
1	0.182	0.182	3000	4243	0.1818	0		8E-06	22	1.1E-05		0	0	0	0.18176	0		0	22
2	0.182	0.727	3000	4243	0.727	0		3E-05	22	4.3E-05		0	0	0	0.72704	0		0	22
3	0.182	1.636	3000	4243	1.6358	0		7E-05	22	9.8E-05		0	0	0	1.63584	0		0	22
4	0.182	2.908	3000	4243	2.9082	0		1E-04	22	0.00017		0	0	0	2.90816	0		0	22
5	0.182	4.544	3000	4243	4.544	0		2E-04	22	0.00027		0	0	0	4.544	0		0	22
6	0.182	6.543	3000	4243	6.5434	0		3E-04	22	0.00039		0	0	0	6.54336	0		0	22
7	0.182	8.906	3000	4243	8.9062	0		4E-04	22	0.00053		0	0	0	8.90624	0		0	22
8	0.182	11.63	3000	4243	11.633	0		5E-04	22	0.00069		0	0	0	11.6326	0		0	22
9	0.182	14.72	3000	4243	14.723	0		6E-04	22	0.00088		0	0	0	14.7226	0		0	22
10	0.182	18.18	3000	4243	18.176	0		8E-04	22	0.00108		0	0	0	18.176	0		0	22
11	0.182	21.99	3000	4243	21.993	0		9E-04	22	0.00131		0	0	0	21.993	0		0	22
12	0.182	26.17	3000	4243	26.173	0		0.001	22	0.00156		0	0	0	26.1734	0		0	22
13	0.182	30.72	3000	4243	30.717	0		0.001	22	0.00183		0	0	0	30.7174	0		0	22
14	0.182	35.62	3000	4243	35.625	0		0.001	22	0.00213		0	0	0	35.625	0		0	22
15	0.182	40.9	3000	4243	40.896	0		0.002	22	0.00244		0	0	0	40.896	0		0	22
16	0.182	46.53	3000	4243	46.531	0		0.002	22	0.00278		0	0	0	46.5306	0		0	22
17	0.182	52.53	3000	4243	52.529	0		0.002	22	0.00314		0	0	0	52.5286	0		0	22
18	0.182	58.89	3000	4243	58.89	0		0.002	22	0.00351		0	0	0	58.8902	0		0	22
19	0.182	65.62	3000	4243	65.615	0		0.003	22	0.00392		0	0	0	65.6154	0		0	22
20	0.182	72.7	3000	4243	72.704	0		0.003	22	0.00434		0	0	0	72.704	0		0	22
21	0.182	80.16	3000	4243	80.156	0		0.003	22	0.00478		0	0	0	80.1562	0		0	22
22	0.182	87.97	3000	4243	87.972	0		0.004	22	0.00525		0	0	0	87.9718	0		0	22
23	0.182	96.15	3000	4243	96.151	0		0.004	22	0.00574		0	0	0	96.151	0		0	22
24	0.182	104.69	3000	4243	104.69	0.00		0.00	21.96	0.01		0.00	0.00	0.00	104.69	0.00		0.00	22.00
25	0.182	113.60	3000	4243	113.60	0.00		0.00	21.96	0.01		0.00	0.00	0.00	113.60	0.00		0.00	22.00
26	0.182	122.87	3000	4243	122.87	0.01		0.01	21.95	0.01		0.00	0.00	0.00	122.87	0.00		0.00	22.00

27	0.182	132.50	3000	4243	132.50	0.01	0.01	21.95	0.01	0.00	0.00	0.00	132.50	0.00	0.00	22.00
28	0.182	142.50	3000	4243	142.50	0.01	0.01	21.94	0.01	0.00	0.00	0.00	142.50	0.00	0.00	22.00
29	0.182	152.86	3000	4243	152.86	0.01	0.01	21.93	0.01	0.00	0.00	0.00	152.86	0.00	0.00	22.00
30	0.182	163.58	3000	4243	163.58	0.01	0.01	21.93	0.01	0.00	0.00	0.00	163.58	0.00	0.00	22.00
31	0.182	174.67	3000	4243	174.67	0.01	0.01	21.92	0.01	0.00	0.00	0.00	174.67	0.00	0.00	22.00
32	0.182	186.12	3000	4243	186.12	0.01	0.01	21.91	0.01	0.00	0.00	0.00	186.12	0.00	0.00	22.00
33	0.182	197.94	3000	4243	197.94	0.01	0.01	21.90	0.01	0.00	0.00	0.00	197.94	0.00	0.00	22.00
34	0.182	210.11	3000	4243	210.11	0.01	0.01	21.90	0.01	0.00	0.00	0.00	210.11	0.00	0.00	22.00
35	0.182	222.66	3000	4243	222.66	0.01	0.01	21.89	0.01	0.00	0.00	0.00	222.66	0.00	0.00	22.00
36	0.182	235.56	3000	4243	235.56	0.01	0.01	21.88	0.01	0.00	0.00	0.00	235.56	0.00	0.00	22.00
37	0.182	248.83	3000	4243	248.83	0.01	0.01	21.87	0.01	0.00	0.00	0.00	248.83	0.00	0.00	22.00
38	0.182	262.46	3000	4243	262.46	0.01	0.01	21.86	0.02	0.00	0.00	0.00	262.46	0.00	0.00	22.00
39	0.182	276.46	3000	4243	276.46	0.01	0.01	21.84	0.02	0.00	0.00	0.00	276.46	0.00	0.00	22.00
40	0.182	290.82	3000	4243	290.82	0.01	0.01	21.83	0.02	0.00	0.00	0.00	290.82	0.00	0.00	22.00
41	0.182	305.54	3000	4243	305.54	0.01	0.01	21.82	0.02	0.00	0.00	0.00	305.54	0.00	0.00	22.00
42	0.182	320.62	3000	4243	320.62	0.01	0.01	21.81	0.02	0.00	0.00	0.00	320.62	0.00	0.00	22.00
43	0.182	336.07	3000	4243	336.07	0.01	0.01	21.79	0.02	0.00	0.00	0.00	336.07	0.00	0.00	22.00
44	0.182	351.89	3000	4243	351.89	0.01	0.01	21.78	0.02	0.00	0.00	0.00	351.89	0.00	0.00	22.00
45	0.182	368.06	3000	4243	368.06	0.02	0.02	21.76	0.02	0.00	0.00	0.00	368.06	0.00	0.00	22.00
46	0.182	384.60	3000	4243	384.60	0.02	0.02	21.75	0.02	0.00	0.00	0.00	384.60	0.00	0.00	22.00
47	0.182	401.51	3000	4243	401.51	0.02	0.02	21.73	0.02	0.00	0.00	0.00	401.51	0.00	0.00	22.00
48	0.182	418.78	3000	4243	418.78	0.02	0.02	21.71	0.02	0.00	0.00	0.00	418.78	0.00	0.00	22.00
49	0.182	436.41	3000	4243	436.41	0.02	0.02	21.69	0.03	0.00	0.00	0.00	436.41	0.00	0.00	22.00
50	0.182	454.40	3000	4243	454.40	0.02	0.02	21.67	0.03	0.00	0.00	0.00	454.40	0.00	0.00	22.00
51	0.182	472.76	3000	4243	472.76	0.02	0.02	21.65	0.03	0.00	0.00	0.00	472.76	0.00	0.00	22.00
52	0.182	491.48	3000	4243	491.48	0.02	0.02	21.63	0.03	0.00	0.00	0.00	491.48	0.00	0.00	22.00
53	0.182	510.56	3000	4243	510.56	0.02	0.02	21.61	0.03	0.00	0.00	0.00	510.56	0.00	0.00	22.00
54	0.182	530.01	3000	4243	530.01	0.02	0.02	21.59	0.03	0.00	0.00	0.00	530.01	0.00	0.00	22.00
55	0.182	549.82	3000	4243	549.82	0.02	0.02	21.57	0.03	0.00	0.00	0.00	549.82	0.00	0.00	22.00
56	0.182	570.00	3000	4243	570.00	0.02	0.02	21.54	0.03	0.00	0.00	0.00	570.00	0.00	0.00	22.00
57	0.182	590.54	3000	4243	590.54	0.02	0.02	21.52	0.04	0.00	0.00	0.00	590.54	0.00	0.00	22.00
58	0.182	611.44	3000	4243	611.44	0.03	0.03	21.49	0.04	0.00	0.00	0.00	611.44	0.00	0.00	22.00
59	0.182	632.71	3000	4243	632.71	0.03	0.03	21.47	0.04	0.00	0.00	0.00	632.71	0.00	0.00	22.00
60	0.182	654.34	3000	4243	654.34	0.03	0.03	21.44	0.04	0.00	0.00	0.00	654.34	0.00	0.00	22.00

61	0.182	676.33	3000	4243	676.33	0.03	0.03	21.41	0.04	0.00	0.00	0.00	676.33	0.00	0.00	22.00
62	0.182	698.69	3000	4243	698.69	0.03	0.03	21.38	0.04	0.00	0.00	0.00	698.69	0.00	0.00	22.00
63	0.182	721.41	3000	4243	721.41	0.03	0.03	21.35	0.04	0.00	0.00	0.00	721.41	0.00	0.00	22.00
64	0.182	744.49	3000	4243	744.49	0.03	0.03	21.32	0.04	0.00	0.00	0.00	744.49	0.00	0.00	22.00
65	0.182	767.94	3000	4243	767.94	0.03	0.03	21.29	0.05	0.00	0.00	0.00	767.94	0.00	0.00	22.00
66	0.182	791.75	3000	4243	791.75	0.03	0.03	21.25	0.05	0.00	0.00	0.00	791.75	0.00	0.00	22.00
67	0.182	815.92	3000	4243	815.92	0.03	0.03	21.22	0.05	0.00	0.00	0.00	815.92	0.00	0.00	22.00
68	0.182	840.46	3000	4243	840.46	0.04	0.04	21.19	0.05	0.00	0.00	0.00	840.46	0.00	0.00	22.00
69	0.182	865.36	3000	4243	865.36	0.04	0.04	21.15	0.05	0.00	0.00	0.00	865.36	0.00	0.00	22.00
70	0.182	890.62	3000	4243	890.62	0.04	0.04	21.11	0.05	0.00	0.00	0.00	890.62	0.00	0.00	22.00
71	0.182	916.25	3000	4243	916.25	0.04	0.04	21.07	0.05	0.00	0.00	0.00	916.25	0.00	0.00	22.00
72	0.182	942.24	3000	4243	942.24	0.04	0.04	21.03	0.06	0.00	0.00	0.00	942.24	0.00	0.00	22.00
73	0.182	968.60	3000	4243	968.60	0.04	0.04	20.99	0.06	0.00	0.00	0.00	968.60	0.00	0.00	22.00
74	0.182	995.32	3000	4243	995.32	0.04	0.04	20.95	0.06	0.00	0.00	0.00	995.32	0.00	0.00	22.00
75	0.182	1022.4	3000	4243	1022.40	0.04	0.04	20.91	0.06	0.00	0.00	0.00	1022.40	0.00	0.00	22.00
76	0.182	1049.8	3000	4243	1049.85	0.04	0.04	20.87	0.06	0.00	0.00	0.00	1049.85	0.00	0.00	22.00
77	0.182	1077.7	3000	4243	1077.66	0.05	0.05	20.82	0.06	0.00	0.00	0.00	1077.66	0.00	0.00	22.00
78	0.182	1105.8	3000	4243	1105.83	0.05	0.05	20.77	0.07	0.00	0.00	0.00	1105.83	0.00	0.00	22.00
79	0.182	1134.4	3000	4243	1134.36	0.05	0.05	20.73	0.07	0.00	0.00	0.00	1134.36	0.00	0.00	22.00
80	0.182	1163.3	3000	4243	1163.26	0.05	0.05	20.68	0.07	0.00	0.00	0.00	1163.26	0.00	0.00	22.00
81	0.182	1192.5	3000	4243	1192.53	0.05	0.05	20.63	0.07	0.00	0.00	0.00	1192.53	0.00	0.00	22.00
82	0.182	1222.2	3000	4243	1222.15	0.05	0.05	20.58	0.07	0.00	0.00	0.00	1222.15	0.00	0.00	22.00
83	0.182	1252.1	3000	4243	1252.14	0.05	0.05	20.52	0.07	0.00	0.00	0.00	1252.14	0.00	0.00	22.00
84	0.182	1282.5	3000	4243	1282.50	0.05	0.05	20.47	0.08	0.00	0.00	0.00	1282.50	0.00	0.00	22.00
85	0.182	1313.2	3000	4243	1313.22	0.05	0.05	20.42	0.08	0.00	0.00	0.00	1313.22	0.00	0.00	22.00
86	0.182	1344.3	3000	4243	1344.30	0.06	0.06	20.36	0.08	0.00	0.00	0.00	1344.30	0.00	0.00	22.00
87	0.182	1375.7	3000	4243	1375.74	0.06	0.06	20.30	0.08	0.00	0.00	0.00	1375.74	0.00	0.00	22.00
88	0.182	1407.5	3000	4243	1407.55	0.06	0.06	20.24	0.08	0.00	0.00	0.00	1407.55	0.00	0.00	22.00
89	0.182	1439.7	3000	4243	1439.72	0.06	0.06	20.18	0.09	0.00	0.00	0.00	1439.72	0.00	0.00	22.00
90	0.182	1472.3	3000	4243	1472.26	0.06	0.06	20.12	0.09	0.00	0.00	0.00	1472.26	0.00	0.00	22.00
91	0.182	1505.2	3000	4243	1505.15	0.06	0.06	20.06	0.09	0.00	0.00	0.00	1505.15	0.00	0.00	22.00
92	0.182	1538.4	3000	4243	1538.42	0.06	0.06	19.99	0.09	0.00	0.00	0.00	1538.42	0.00	0.00	22.00
93	0.182	1572.0	3000	4243	1572.04	0.07	0.07	19.93	0.09	0.00	0.00	0.00	1572.04	0.00	0.00	22.00
94	0.182	1606.0	3000	4243	1606.03	0.07	0.07	19.86	0.10	0.00	0.00	0.00	1606.03	0.00	0.00	22.00

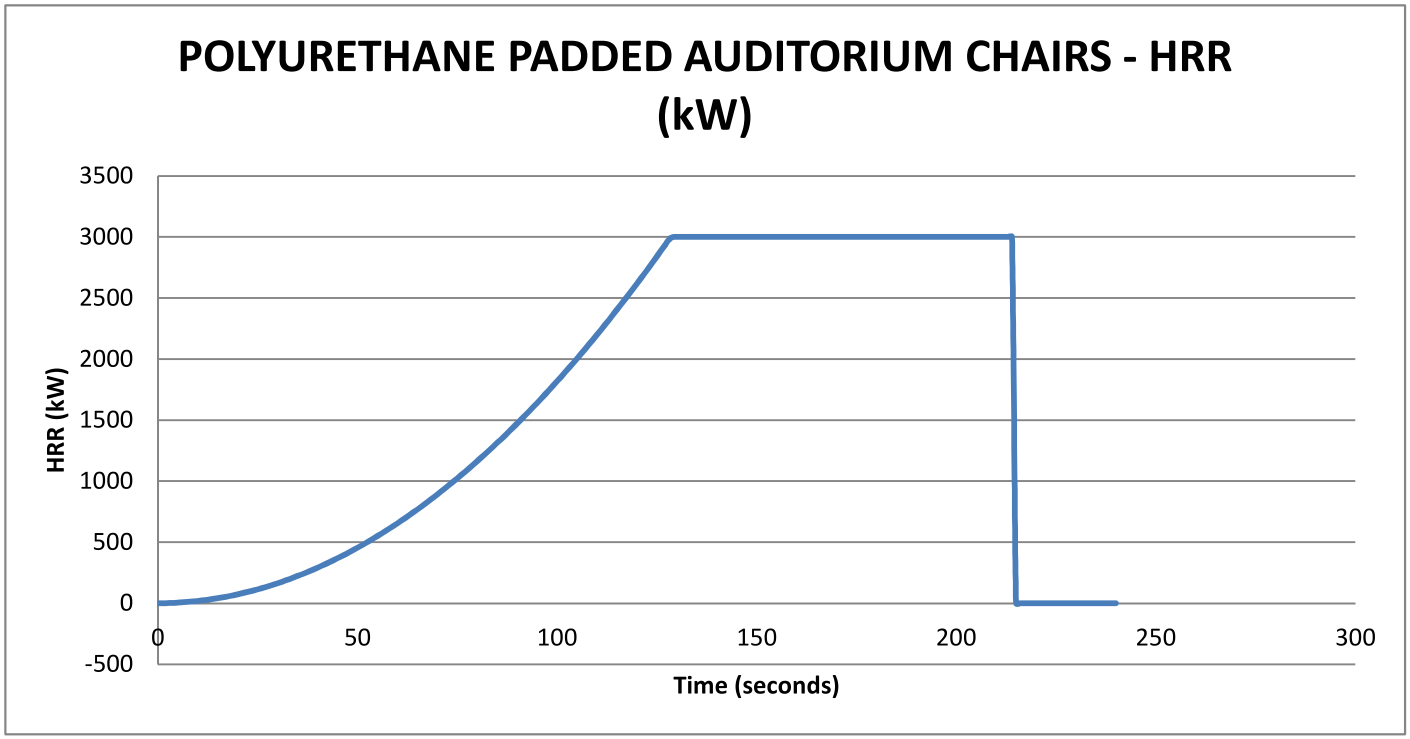
95	0.182	1640.4	3000	4243	1640.38	0.07		0.07	19.79	0.10	0.00	0.00	0.00	1640.38	0.00		0.00	22.00
96	0.182	1675.1	3000	4243	1675.10	0.07		0.07	19.72	0.10	0.00	0.00	0.00	1675.10	0.00		0.00	22.00
97	0.182	1710.2	3000	4243	1710.18	0.07		0.07	19.65	0.10	0.00	0.00	0.00	1710.18	0.00		0.00	22.00
98	0.182	1745.6	3000	4243	1745.62	0.07		0.07	19.58	0.10	0.00	0.00	0.00	1745.62	0.00		0.00	22.00
99	0.182	1781.4	3000	4243	1781.43	0.07		0.07	19.50	0.11	0.00	0.00	0.00	1781.43	0.00		0.00	22.00
100	0.182	1817.6	3000	4243	1817.60	0.08		0.08	19.43	0.11	0.00	0.00	0.00	1817.60	0.00		0.00	22.00
101	0.182	1854.1	3000	4243	1854.13	0.08		0.08	19.35	0.11	0.00	0.00	0.00	1854.13	0.00		0.00	22.00
102	0.182	1891.0	3000	4243	1891.03	0.08		0.08	19.27	0.11	0.00	0.00	0.00	1891.03	0.00		0.00	22.00
103	0.182	1928.3	3000	4243	1928.29	0.08		0.08	19.19	0.12	0.00	0.00	0.00	1928.29	0.00		0.00	22.00
104	0.182	1965.9	3000	4243	1965.92	0.08		0.08	19.11	0.12	0.00	0.00	0.00	1965.92	0.00		0.00	22.00
105	0.182	2003.9	3000	4243	2003.90	0.08		0.08	19.02	0.12	0.00	0.00	0.00	2003.90	0.00		0.00	22.00
106	0.182	2042.3	3000	4243	2042.26	0.09		0.09	18.94	0.12	0.00	0.00	0.00	2042.26	0.00		0.00	22.00
107	0.182	2081.0	3000	4243	2080.97	0.09		0.09	18.85	0.12	0.00	0.00	0.00	2080.97	0.00		0.00	22.00
108	0.182	2120.0	3000	4243	2120.05	0.09		0.09	18.76	0.13	0.00	0.00	0.00	2120.05	0.00		0.00	22.00
109	0.182	2159.5	3000	4243	2159.49	0.09		0.09	18.67	0.13	0.00	0.00	0.00	2159.49	0.00		0.00	22.00
110	0.182	2199.3	3000	4243	2199.30	0.09		0.09	18.58	0.13	0.00	0.00	0.00	2199.30	0.00		0.00	22.00
111	0.182	2239.5	3000	4243	2239.46	0.09		0.09	18.49	0.13	0.00	0.00	0.00	2239.46	0.00		0.00	22.00
112	0.182	2280.0	3000	4243	2280.00	0.10		0.10	18.39	0.14	0.00	0.00	0.00	2280.00	0.00		0.00	22.00
113	0.182	2320.9	3000	4243	2320.89	0.10		0.10	18.29	0.14	0.00	0.00	0.00	2320.89	0.00		0.00	22.00
114	0.182	2362.2	3000	4243	2362.15	0.10		0.10	18.19	0.14	0.00	0.00	0.00	2362.15	0.00		0.00	22.00
115	0.182	2403.8	3000	4243	2403.78	0.10		0.10	18.09	0.14	0.00	0.00	0.00	2403.78	0.00		0.00	22.00
116	0.182	2445.8	3000	4243	2445.76	0.10		0.10	17.99	0.15	0.00	0.00	0.00	2445.76	0.00		0.00	22.00
117	0.182	2488.1	3000	4243	2488.11	0.10		0.10	17.89	0.15	0.00	0.00	0.00	2488.11	0.00		0.00	22.00
118	0.182	2530.8	3000	4243	2530.83	0.11		0.11	17.78	0.15	0.00	0.00	0.00	2530.83	0.00		0.00	22.00
119	0.182	2573.9	3000	4243	2573.90		0.28	0.28	17.50	0.15	0.00	0.00	0.00	2573.90		0.28	0.28	21.72
120	0.182	2617.3	3000	4243	2617.34		0.28	0.28	17.22	0.16	0.00	0.00	0.00	2617.34		0.28	0.28	21.43
121	0.182	2661.1	3000	4243	2661.15		0.28	0.28	16.93	0.16	0.00	0.00	0.00	2661.15		0.28	0.28	21.15
122	0.182	2705.3	3000	4243	2705.32		0.28	0.28	16.65	0.16	0.00	0.00	0.00	2705.32		0.28	0.28	20.87
123	0.182	2749.8	3000	4243	2749.85		0.28	0.28	16.37	0.16	0.00	0.00	0.00	2749.85		0.28	0.28	20.59
124	0.182	2794.7	3000	4243	2794.74		0.28	0.28	16.08	0.17	0.00	0.00	0.00	2794.74		0.28	0.28	20.30
125	0.182	2840.0	3000	4243	2840.00		0.28	0.28	15.80	0.17	0.00	0.00	0.00	2840.00		0.28	0.28	20.02
126	0.182	2885.6	3000	4243	2885.62		0.28	0.28	15.52	0.17	0.00	0.00	0.00	2885.62		0.28	0.28	19.74
127	0.182	2931.6	3000	4243	2931.61		0.28	0.28	15.24	0.17	0.00	0.00	0.00	2931.61		0.28	0.28	19.45
128	0.182	2978.0	3000	4243	2977.96		0.28	0.28	14.95	0.18	0.00	0.00	0.00	2977.96		0.28	0.28	19.17

129	0.182	3024.7	3000	4243	3000.00	0.28	0.28	14.67	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	18.89
130	0.182	3071.7	3000	4243	3000.00	0.28	0.28	14.39	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	18.61
131	0.182	3119.2	3000	4243	3000.00	0.28	0.28	14.10	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	18.32
132	0.182	3167.0	3000	4243	3000.00	0.28	0.28	13.82	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	18.04
133	0.182	3215.2	3000	4243	3000.00	0.28	0.28	13.54	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	17.76
134	0.182	3263.7	3000	4243	3000.00	0.28	0.28	13.26	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	17.47
135	0.182	3312.6	3000	4243	3000.00	0.28	0.28	12.97	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	17.19
136	0.182	3361.8	3000	4243	3000.00	0.28	0.28	12.69	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	16.91
137	0.182	3411.5	3000	4243	3000.00	0.28	0.28	12.41	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	16.63
138	0.182	3461.4	3000	4243	3000.00	0.28	0.28	12.12	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	16.34
139	0.182	3511.8	3000	4243	3000.00	0.28	0.28	11.84	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	16.06
140	0.182	3562.5	3000	4243	3000.00	0.28	0.28	11.56	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	15.78
141	0.182	3613.6	3000	4243	3000.00	0.28	0.28	11.28	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	15.49
142	0.182	3665.0	3000	4243	3000.00	0.28	0.28	10.99	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	15.21
143	0.182	3716.8	3000	4243	3000.00	0.28	0.28	10.71	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	14.93
144	0.182	3769.0	3000	4243	3000.00	0.28	0.28	10.43	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	14.65
145	0.182	3821.5	3000	4243	3000.00	0.28	0.28	10.15	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	14.36
146	0.182	3874.4	3000	4243	3000.00	0.28	0.28	9.86	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	14.08
147	0.182	3927.7	3000	4243	3000.00	0.28	0.28	9.58	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	13.80
148	0.182	3981.3	3000	4243	3000.00	0.28	0.28	9.30	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	13.51
149	0.182	4035.3	3000	4243	3000.00	0.28	0.28	9.01	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	13.23
150	0.182	4089.6	3000	4243	3000.00	0.28	0.28	8.73	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	12.95
151	0.182	4144.3	3000	4243	3000.00	0.28	0.28	8.45	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	12.67
152	0.182	4199.4	3000	4243	3000.00	0.28	0.28	8.17	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	12.38
153	0.182	4254.8	3000	4243	3000.00	0.28	0.28	7.88	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	12.10
154	0.182	4310.6	3000	4243	3000.00	0.28	0.28	7.60	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	11.82
155	0.182	4366.8	3000	4243	3000.00	0.28	0.28	7.32	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	11.53
156	0.182	4423.3	3000	4243	3000.00	0.28	0.28	7.03	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	11.25
157	0.182	4480.2	3000	4243	3000.00	0.28	0.28	6.75	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	10.97
158	0.182	4537.5	3000	4243	3000.00	0.28	0.28	6.47	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	10.69
159	0.182	4595.1	3000	4243	3000.00	0.28	0.28	6.19	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	10.40
160	0.182	4653.1	3000	4243	3000.00	0.28	0.28	5.90	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	10.12
161	0.182	4711.4	3000	4243	3000.00	0.28	0.28	5.62	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	9.84
162	0.182	4770.1	3000	4243	3000.00	0.28	0.28	5.34	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	9.55

163	0.182	4829.2	3000	4243	3000.00	0.28	0.28	5.05	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	9.27
164	0.182	4888.6	3000	4243	3000.00	0.28	0.28	4.77	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	8.99
165	0.182	4948.4	3000	4243	3000.00	0.28	0.28	4.49	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	8.71
166	0.182	5008.6	3000	4243	3000.00	0.28	0.28	4.21	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	8.42
167	0.182	5069.1	3000	4243	3000.00	0.28	0.28	3.92	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	8.14
168	0.182	5130.0	3000	4243	3000.00	0.28	0.28	3.64	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	7.86
169	0.182	5191.2	3000	4243	3000.00	0.28	0.28	3.36	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	7.58
170	0.182	5252.9	3000	4243	3000.00	0.28	0.28	3.07	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	7.29
171	0.182	5314.8	3000	4243	3000.00	0.28	0.28	2.79	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	7.01
172	0.182	5377.2	3000	4243	3000.00	0.28	0.28	2.51	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	6.73
173	0.182	5439.9	3000	4243	3000.00	0.28	0.28	2.23	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	6.44
174	0.182	5503.0	3000	4243	3000.00	0.28	0.28	1.94	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	6.16
175	0.182	5566.4	3000	4243	3000.00	0.28	0.28	1.66	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	5.88
176	0.182	5630.2	3000	4243	3000.00	0.28	0.28	1.38	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	5.60
177	0.182	5694.4	3000	4243	3000.00	0.28	0.28	1.09	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	5.31
178	0.182	5758.9	3000	4243	3000.00	0.28	0.28	0.81	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	5.03
179	0.182	5823.8	3000	4243	3000.00	0.28	0.28	0.53	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	4.75
180	0.182	5889.0	3000	4243	3000.00	0.28	0.28	0.25	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	4.46
181	0.182	5954.6	3000	4243	3000.00	0.28	0.28	-0.04	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	4.18
182	0.182	6020.6	3000	4243	3000.00	0.28	0.28	-0.32	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	3.90
183	0.182	6087.0	3000	4243	3000.00	0.28	0.28	-0.60	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	3.62
184	0.182	6153.7	3000	4243	3000.00	0.28	0.28	-0.89	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	3.33
185	0.182	6220.7	3000	4243	3000.00	0.28	0.28	-1.17	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	3.05
186	0.182	6288.2	3000	4243	3000.00	0.28	0.28	-1.45	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	2.77
187	0.182	6356.0	3000	4243	3000.00	0.28	0.28	-1.73	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	2.48
188	0.182	6424.1	3000	4243	3000.00	0.28	0.28	-2.02	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	2.20
189	0.182	6492.6	3000	4243	3000.00	0.28	0.28	-2.30	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	1.92
190	0.182	6561.5	3000	4243	3000.00	0.28	0.28	-2.58	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	1.64
191	0.182	6630.8	3000	4243	3000.00	0.28	0.28	-2.87	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	1.35
192	0.182	6700.4	3000	4243	3000.00	0.28	0.28	-3.15	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	1.07
193	0.182	6770.4	3000	4243	3000.00	0.28	0.28	-3.43	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	0.79
194	0.182	6840.7	3000	4243	3000.00	0.28	0.28	-3.71	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	0.50
195	0.182	6911.4	3000	4243	3000.00	0.28	0.28	-4.00	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	0.22
196	0.182	6982.5	3000	4243	3000.00	0.28	0.28	-4.28	0.18	0.00	0.00	0.00	3000.00	0.28	0.28	-0.06

197	0.182	7053.9	3000	4243	3000.00		0.28	0.28	-4.56	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-0.34
198	0.182	7125.7	3000	4243	3000.00		0.28	0.28	-4.85	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-0.63
199	0.182	7197.9	3000	4243	3000.00		0.28	0.28	-5.13	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-0.91
200	0.182	7270.4	3000	4243	3000.00		0.28	0.28	-5.41	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-1.19
201	0.182	7343.3	3000	4243	3000.00		0.28	0.28	-5.69	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-1.48
202	0.182	7416.5	3000	4243	3000.00		0.28	0.28	-5.98	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-1.76
203	0.182	7490.1	3000	4243	3000.00		0.28	0.28	-6.26	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-2.04
204	0.182	7564.1	3000	4243	3000.00		0.28	0.28	-6.54	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-2.32
205	0.182	7638.5	3000	4243	3000.00		0.28	0.28	-6.83	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-2.61
206	0.182	7713.2	3000	4243	3000.00		0.28	0.28	-7.11	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-2.89
207	0.182	7788.2	3000	4243	3000.00		0.28	0.28	-7.39	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-3.17
208	0.182	7863.7	3000	4243	3000.00		0.28	0.28	-7.67	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-3.46
209	0.182	7939.5	3000	4243	3000.00		0.28	0.28	-7.96	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-3.74
210	0.182	8015.6	3000	4243	3000.00		0.28	0.28	-8.24	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-4.02
211	0.182	8092.1	3000	4243	3000.00		0.28	0.28	-8.52	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-4.30
212	0.182	8169.0	3000	4243	3000.00		0.28	0.28	-8.81	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-4.59
213	0.182	8246.3	3000	4243	3000.00		0.28	0.28	-9.09	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-4.87
214	0.182	8323.9	3000	4243	3000.00		0.28	0.28	-9.37	0.18	0.00	0.00	0.00	3000.00		0.28	0.28	-5.15
215	0.182	8401.9	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
216	0.182	8480.2	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
217	0.182	8558.9	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
218	0.182	8638.0	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
219	0.182	8717.4	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
220	0.182	8797.2	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
221	0.182	8877.3	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
222	0.182	8957.9	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
223	0.182	9038.7	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
224	0.182	9120.0	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
225	0.182	9201.6	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
226	0.182	9283.6	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
227	0.182	9365.9	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
228	0.182	9448.6	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
229	0.182	9531.7	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15
230	0.182	9615.1	3000	4243	0.00	0.00		0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00		0.00	-5.15

231	0.182	9698.9	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
232	0.182	9783.1	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
233	0.182	9867.6	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
234	0.182	9952.5	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
235	0.182	10038	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
236	0.182	10123	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
237	0.182	10209	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
238	0.182	10296	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
239	0.182	10382	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15
240	0.182	10469	3000	4243	0.00	0.00	0.00	-9.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.15



Assume first chair is ignited at time = 0, with subsequent ignition of additional chairs.

$$\dot{Q}_m = 1500 A_o \sqrt{H_o}$$ (

where

$\dot{Q}_m$ = Maximum total energy release rate (kJ/sec or kW)

A_o = Total opening area (m^2)

H_o = Opening height (m)

$$\dot{m}_f = \frac{\dot{Q}}{\Delta H_c}$$ (fu

$$\dot{m}_f = 0.1 A_o \sqrt{H_o}$$

$$\dot{q}'' = \frac{X_r \dot{Q}}{4\pi R^2}$$

Where:

$\dot{Q}''$ = energy radiated per unit time per unit area (W/m^2 or kW/m^2)

X_r = fraction of energy radiated relative to the total energy released

$\dot{Q}$ = heat release rate (W or kW)

$4\pi r^2$ = surface area of sphere, where r is the radial distance to the target fuel

Appendix N - Fire Dynamics Simulator (FDS) Design Fire Input

NOTE: You should always perform a grid sensitivity analysis and verify the grid resolution yourself. This calculator should only be used as a guide / rule of thumb!

Enter the x, y, z dimensions (meters) and your expected HRR

X_{min} 0 X_{max} 96
Y_{min} 0 Y_{max} 62
Z_{min} 0 Z_{max} 8

Heat Release Rate (Q) 3000 kW

Density (ρ_∞) 1.204 kg / m^3

Specific Heat (c_p) 1.005 kJ / kg-K

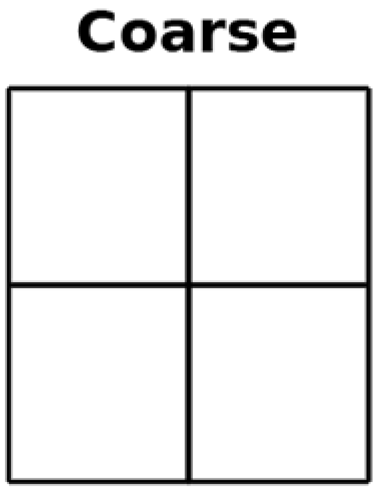
Ambient Temperature (T_∞) 293 K

Gravity (g) 9.81 m / s^2

Calculate suggested cell sizes »

To use the old MESH Size Calculator, click here

The characteristic fire diameter D^* is 1.488



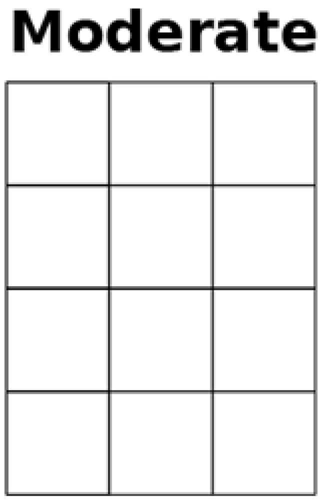
When $D^*/dx = 4$: the suggested coarse cell size is 37.2 cm

Your MESH line for FDS is:

&MESH IJK=270,180,24, XB=0,96,0,62,0,8 /

You entered:
X_{min}: 0 X_{max}: 96
Y_{min}: 0 Y_{max}: 62
Z_{min}: 0 Z_{max}: 8
dx: 0.372

Your actual dx(es) are 0.356 0.344 0.333 (meters)
Your distances are 96 62 8 (meters)
Your total number of cells is 1,166,400



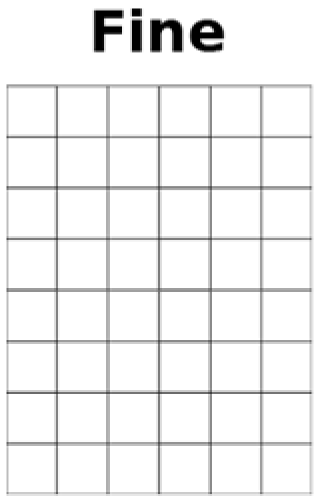
When $D^*/dx = 10$: the suggested moderate cell size is 14.88 cm

Your MESH line for FDS is:

&MESH IJK=648,432,54, XB=0,96,0,62,0,8 /

You entered:
X_{min}: 0 X_{max}: 96
Y_{min}: 0 Y_{max}: 62
Z_{min}: 0 Z_{max}: 8
dx: 0.149

Your actual dx(es) are 0.148 0.144 0.148 (meters)
Your distances are 96 62 8 (meters)
Your total number of cells is 15,116,544



When $D^*/dx = 16$, the suggested fine cell size is 9.3 cm

Your MESH line for FDS is:

&MESH IJK=1080,675,90, XB=0,96,0,62,0,8 /

You entered:
X_{min}: 0 X_{max}: 96
Y_{min}: 0 Y_{max}: 62
Z_{min}: 0 Z_{max}: 8
dx: 0.093

Your actual dx(es) are 0.089 0.092 0.089 (meters)
Your distances are 96 62 8 (meters)
Your total number of cells is 65,610,000

```
&HEAD CHID='Fire_Scenario_1',TITLE='Fire_Scenario_1' /

&MESH IJK=270,180,24 XB=0.0,96.0, 0.0, 62.0, 0.0, 8.0/

&TIME T_END=350.00 /

&REAC FUEL        = 'POLYURETHANE'
      FYI         = 'C_6.3 H_7.1 N O_2.1, NFPA Handbook, Babrauskas'
      SOOT_YIELD = 0.01
      CO_YIELD    = 0.01
      N           = 1.0
      C           = 6.3
      H           = 7.1
      O           = 2.1  /

&SURF ID='BURNER',
      COLOR='RED',
      HRRPUA=3000
      TAU_Q=-120.00/


&MATL ID             = 'GYPSUM PLASTER'
      FYI            = 'Quintiere, Fire Behavior'
      CONDUCTIVITY   = 0.48
      SPECIFIC_HEAT = 0.84
      DENSITY        = 1440. /

&MATL ID='CONCRETE'
      FYI             = 'NBSIR 88-3752 - ATF NIST Multi-Floor Validation'
      SPECIFIC_HEAT   = 1.04
      CONDUCTIVITY    = 1.8
      DENSITY         = 2280. /


&SURF ID          = 'CONCRETE'
      MATL_ID     = 'CONCRETE'
      COLOR       = 'SILVER'
      THICKNESS   = 0.1 /


&MATL ID          = 'CARPET PILE'
      FYI          = 'Assumed'
      CONDUCTIVITY          = 0.16
      SPECIFIC_HEAT         = 2.0
      DENSITY               = 750.
      N_REACTIONS           = 1
      NU_SPEC               = 1.
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Appendix O - Estimated Evacuation Time Analysis

ESTIMATED EVACUATION TIME					
Exit Component	W_e Effective Width (m)	Max. Specific Flow F_s (persons/sec/m)	Calculated Flow F_c (persons/sec.)	Density D (persons/m^2)	Max. Flow F_s (persons/sec/m) NFPA FPH T. 4.2.8 or Calculated F_s
Door 100	1.37	0.90	1.23	2.94	0.90
Door 100A	1.37	0.90	1.23	2.94	0.90
Door 100B	1.37	0.90	1.23	2.94	0.90
Door 100C	1.37	0.90	1.23	2.94	0.90
Door 100D	1.37	0.90	1.23	2.94	0.90
Door 100E	1.37	0.90	1.23	2.94	0.90
Door 100F	1.37	0.90	1.23	2.94	0.90
Door 100G	1.37	0.90	1.23	2.94	0.90
Door 100H	1.37	0.90	1.23	2.94	0.90
Door 100J	1.37	0.90	1.23	2.94	0.90
Door 100K	1.37	0.90	1.23	2.94	0.90
Door 111A $^{\Psi}$	0.69	-	-	-	-
Door 118	1.37	1.09	1.49	1.1	1.09
Door 118A	1.37	1.09	1.49	1.1	1.09
Door 118B	1.37	1.09	1.49	1.1	1.09
Door 118C	1.37	1.09	1.49	1.1	1.09
Door 119B	0.69	0.81	0.56	0.72	0.81
Door 119C	0.69	0.81	0.56	0.72	0.81
Door 120	1.37	0.14	0.19	0.1	0.14
Door 121B $^{\Psi}$	0.69	-	-	-	-
Door 128A $^{\Psi}$	0.69	-	-	-	-
Door 130A $^{\Psi}$	0.69	-	-	-	-
Door 134	1.37	0.14	0.19	0.1	0.14
Door 112	1.37	1.09	1.49	1.1	1.09
Door 112A	1.37	1.09	1.49	1.1	1.09
Door 112B	1.37	1.09	1.49	1.1	1.09
Door 112C	1.37	1.09	1.49	1.1	1.09
Door 112D	1.37	1.09	1.49	1.1	1.09
Door 112E	1.37	1.09	1.49	1.1	1.09
Door 112F	1.37	1.09	1.49	1.1	1.09
Door 112G	1.37	1.09	1.49	1.1	1.09
Vestibule 112	4.47	1.09	4.87	1.1	1.09
Corridor 134	1.4	0.81	1.14	0.72	0.81
Platform Stair	0.81	0.62	0.50	0.71	0.62

$F_s = (1 - a\,D)/k\,D$

Ψ Considered Secondary Exits for individual room egress

	ESTIMATED EVACUATION TIME								
Space to Evacuate	Population	Max. Flow F_s (persons/sec/m) NFPA FPH T. 4.2.8	Travel Speed Public Places Density is factor (m/sec) NFPA FPH T.4.2.3	Total We Effective Width (m)	Travel Distance to Exit (m)	Time to move to door (sec)	Time to move to door (min.)	Time to move thru door (sec)	Time to move to door (min.)
Auditorium	2966	1.09	0.28	10.96	48.00	171.43	2.86	248.28	4.14
Lobby	479	0.90	0.28	15.07	16.00	57.14	0.95	35.32	0.59
Total Evacuation Time (min.) - Auditorium Worst Case								7.00	

$T_p = P/(1 - aD)kDW_e$

Where,

T_p = time for passage (T_p is in minutes where F_c is persons/ min; T_p is in seconds where F_c is persons/sec)

P = population in persons,

W_e = effective width,

F_c = Calculated flow where F_s (Specific flow)* W_e

Travel time to Exit: Tp = Distance (m)/Speed (m/s)

Speed to exit consider dense population in assembly space based on NFPA FPH Table 4.2.3

Assumptions:
Population will use all exits in the optimum balance & population is uniformly distributed
All occupants begin to evacuate at the same time, with no delay accounted for in the calculation
Specific flow from NFPA Fire Protection Handbook Table 4.2.8 is maximum speed to consider
Group was considered as a whole, individual limitations were not accounted for in calculation
Occupants in Lobby are expected to evacuate prior auditorium occupants reaching Lobby (compare lobby total egress time to auditorium travel time to exit)
Accessory office and multipurpose areas were not calculated, as auditorium is assumed worst case
Travel speed of 0.28 m/sec is conservative approach to factor in elderly and disabled population into mean population

Appendix P - Pathfinder Egress Model

Pathfinder Egress Model of Orangeburg Assembly Hall
Model Selected: Pathfinder – Thunderhead Engineering, www.thunderheadeng.com

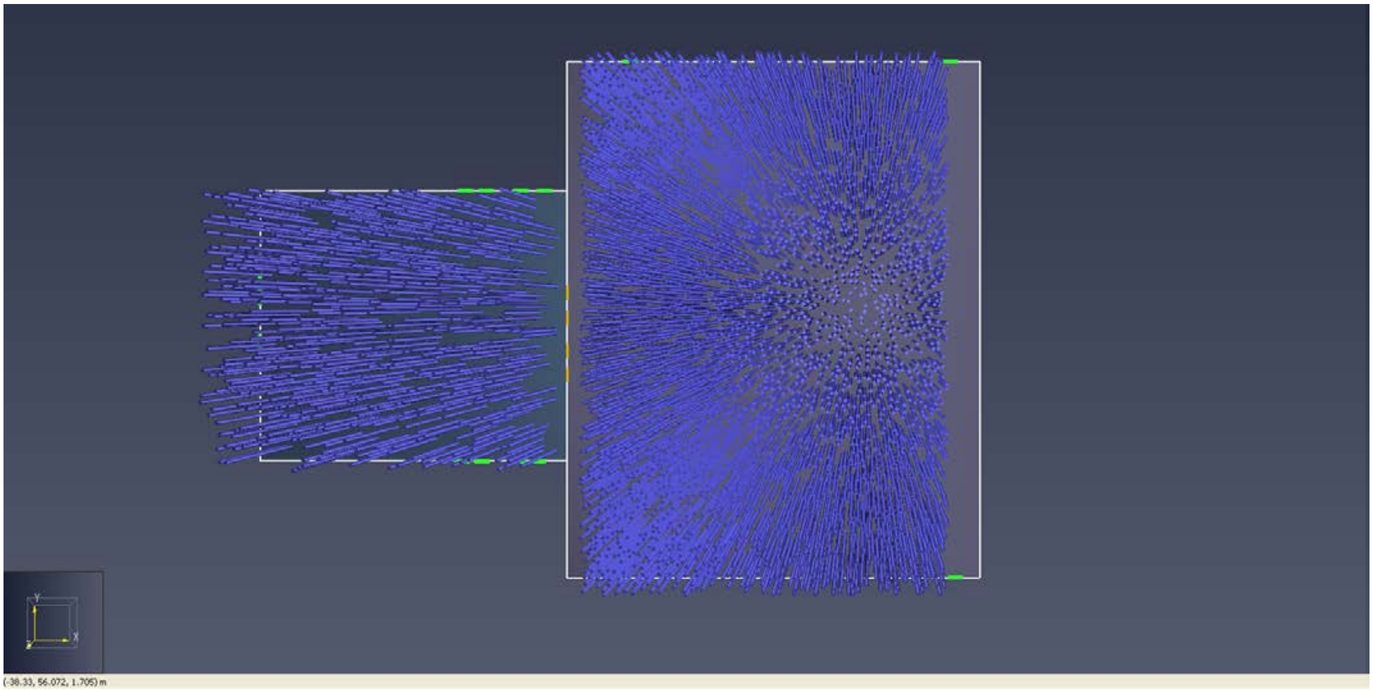
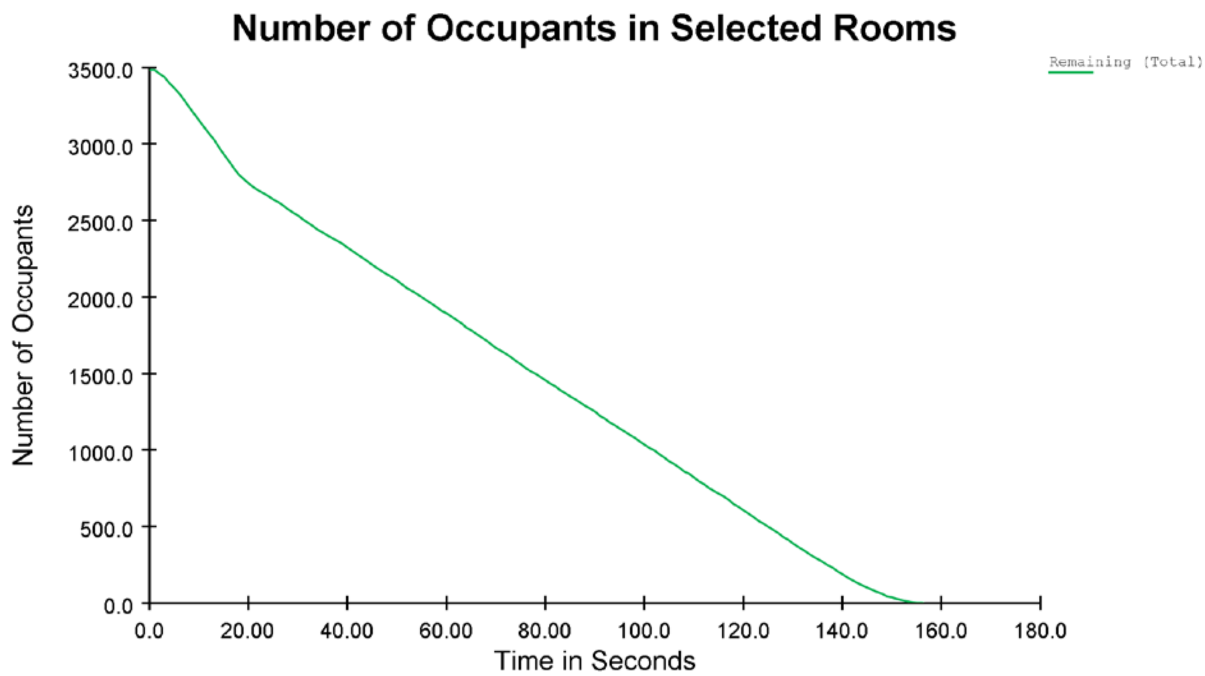
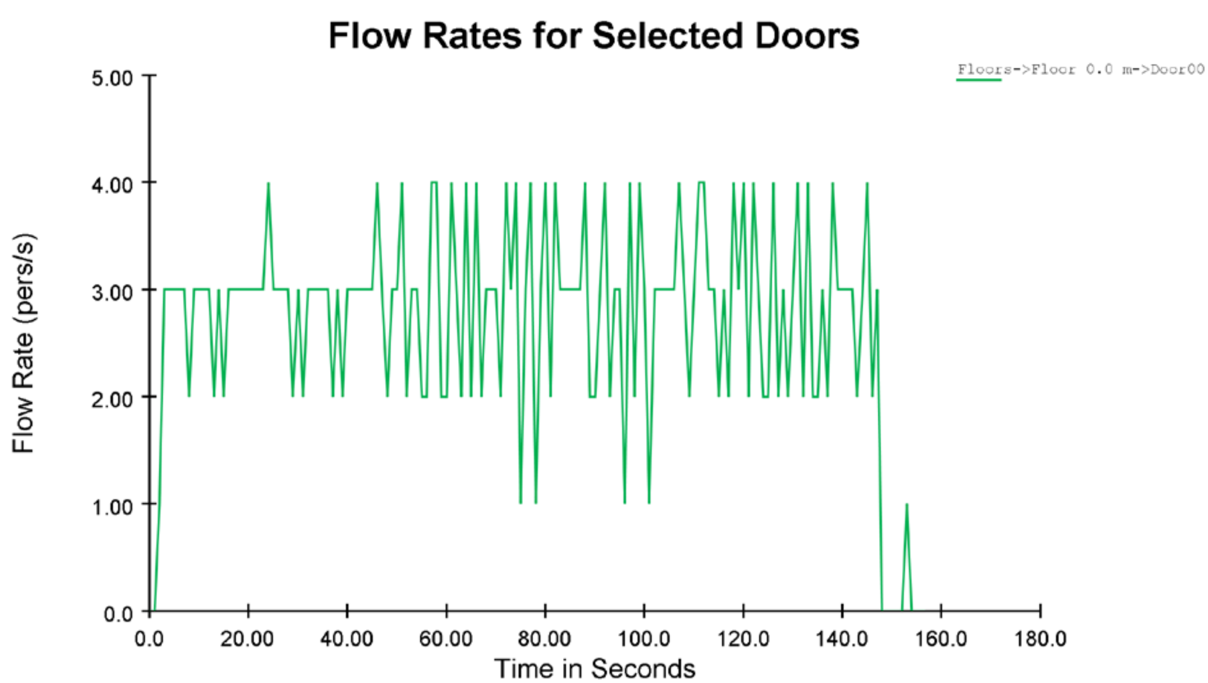


Figure 1 – Graphic Interface of Simple Floor Model Layout of Main Auditorium and Main Lobby Configuration (Steering Mode)

Simulation: Egress Model
Mode: **Steering**
[Components] All: 22
[Components] Doors: 20
Triangles: 54
Occupants: 3482
Startup Time: 0.2s
CPU Time: 160.8s

ROOM/DOOR	FIRST IN (s)	LAST OUT (s)	TOTAL USE (pers)	FLOW AVG. (pers/s)
Floors->Floor 0.0 m->Room00	0.00	152.60	2966	
Floors->Floor 0.0 m->Room01	0.00	156.33	1835	
Floors->Floor 0.0 m->Door00	1.88	152.60	421	2.79
Floors->Floor 0.0 m->Door01	2.68	148.93	403	2.76
Floors->Floor 0.0 m->Door02	2.45	143.63	408	2.89
Floors->Floor 0.0 m->Door03	1.63	149.58	415	2.81
Floors->Floor 0.0 m->Door04	4.55	143.18	321	2.32
Floors->Floor 0.0 m->Door05	5.15	137.98	356	2.68
Floors->Floor 0.0 m->Door06	6.70	137.50	342	2.61
Floors->Floor 0.0 m->Door07	4.63	145.50	300	2.13
Floors->Floor 0.0 m->Door08	1.10	152.53	407	2.69
Floors->Floor 0.0 m->Door09	1.98	151.63	342	2.29
Floors->Floor 0.0 m->Door10	1.63	122.08	56	0.46
Floors->Floor 0.0 m->Door11	1.30	18.73	47	2.70
Floors->Floor 0.0 m->Door12	1.35	21.35	48	2.40
Floors->Floor 0.0 m->Door13	1.75	19.95	49	2.69
Floors->Floor 0.0 m->Door14	1.35	19.58	49	2.69
Floors->Floor 0.0 m->Door15	1.38	18.58	50	2.91
Floors->Floor 0.0 m->Door16	1.45	20.85	50	2.58
Floors->Floor 0.0 m->Door17	1.95	20.50	48	2.59
Floors->Floor 0.0 m->Door18	1.78	155.58	306	1.99
Floors->Floor 0.0 m->Door19	1.23	156.33	383	2.47
SUMMARY	0.00	156.33	2966	


Number of Occupants in Selected Rooms
Remaining (Total)
Number of Occupants
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
0.0
20.00
40.00
60.00
80.00
100.0
120.0
140.0
160.0
180.0
Time in Seconds


Flow Rates for Selected Doors
Floors->Floor 0.0 m->Door00
Flow Rate (pers/s)
5.00
4.00
3.00
2.00
1.00
0.0
0.0
20.00
40.00
60.00
80.00
100.0
120.0
140.0
160.0
180.0
Time in Seconds

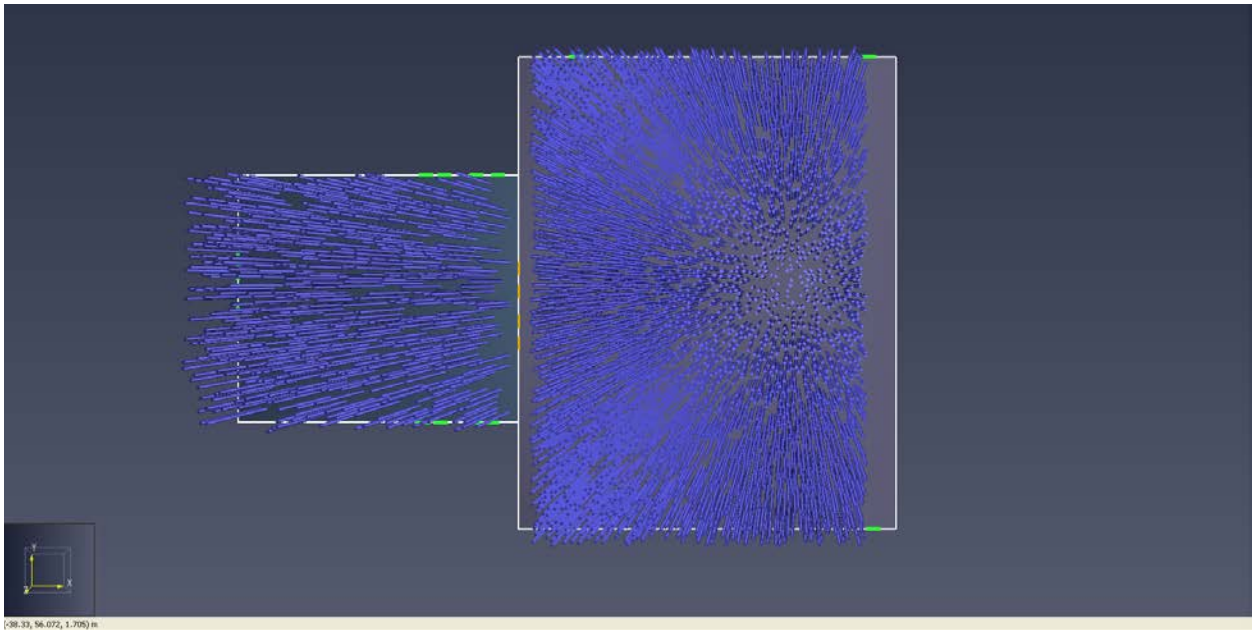
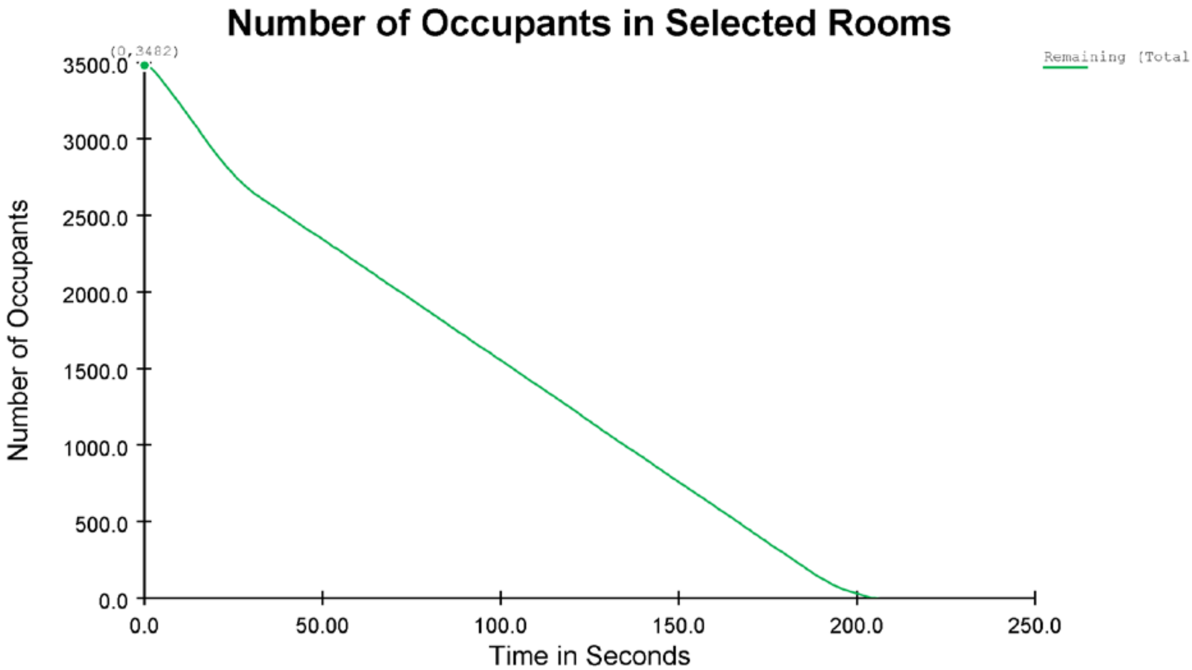
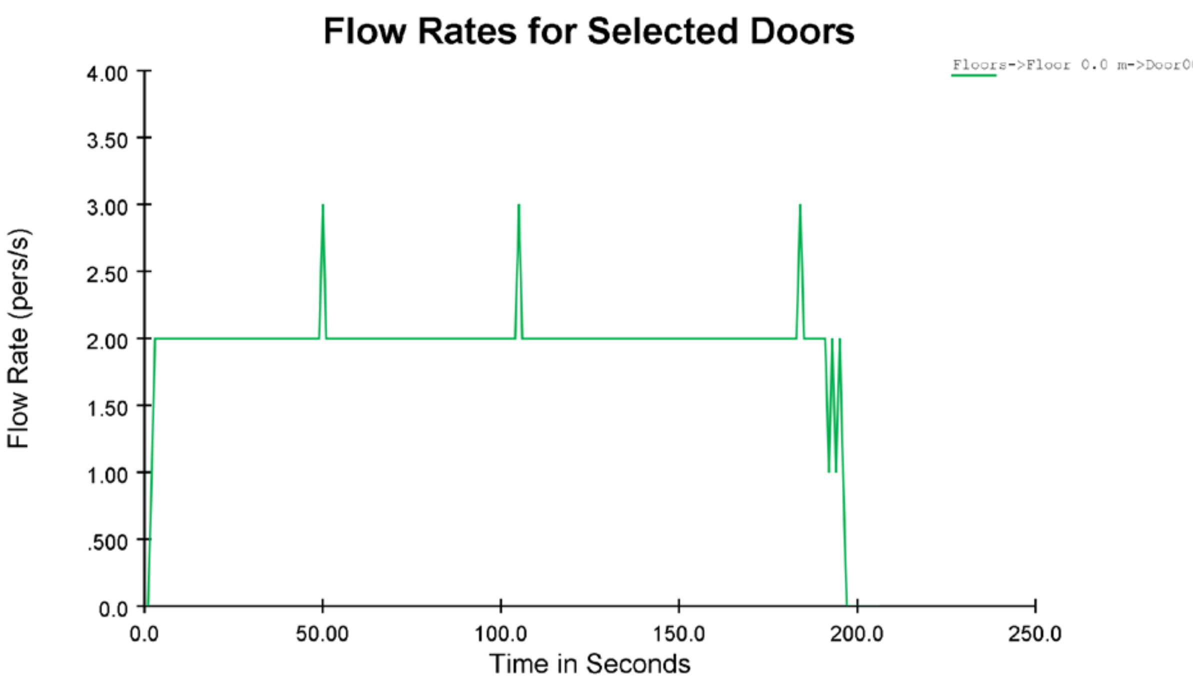


Figure 2 – Graphic Interface of Simple Floor Model Layout of Main Auditorium and Main Lobby Configuration (SFPE Mode)

Simulation: Egress Model
Mode: **SFPE (Prevent Collisions)**
[Components] All: 22
[Components] Doors: 20
Triangles: 54
Occupants: 3482
Startup Time: 0.1s
CPU Time: 149.6s

ROOM/DOOR	FIRST IN (s)	LAST OUT (s)	TOTAL USE (pers)	FLOW AVG. (pers/s)
Floors->Floor 0.0 m->Room00	0.00	204.60	2966	
Floors->Floor 0.0 m->Room01	0.00	205.75	1904	
Floors->Floor 0.0 m->Door00	1.90	195.38	389	2.01
Floors->Floor 0.0 m->Door01	3.03	204.60	405	2.01
Floors->Floor 0.0 m->Door02	2.73	192.23	378	1.99
Floors->Floor 0.0 m->Door03	1.73	203.88	406	2.01
Floors->Floor 0.0 m->Door04	4.93	197.08	379	1.97
Floors->Floor 0.0 m->Door05	5.58	180.08	338	1.94
Floors->Floor 0.0 m->Door06	6.18	174.83	322	1.91
Floors->Floor 0.0 m->Door07	5.05	192.85	349	1.86
Floors->Floor 0.0 m->Door08	0.85	205.75	411	2.01
Floors->Floor 0.0 m->Door09	1.75	196.63	378	1.94
Floors->Floor 0.0 m->Door10	1.38	134.15	41	0.31
Floors->Floor 0.0 m->Door11	1.08	29.05	55	1.97
Floors->Floor 0.0 m->Door12	1.10	29.28	56	1.99
Floors->Floor 0.0 m->Door13	1.50	22.98	41	1.91
Floors->Floor 0.0 m->Door14	1.10	22.18	43	2.04
Floors->Floor 0.0 m->Door15	1.15	29.00	56	2.01
Floors->Floor 0.0 m->Door16	1.23	30.53	59	2.01
Floors->Floor 0.0 m->Door17	1.73	24.90	41	1.77
Floors->Floor 0.0 m->Door18	1.53	195.13	330	1.70
Floors->Floor 0.0 m->Door19	1.03	202.88	393	1.95
SUMMARY	0.00	**205.75**	2966	


Number of Occupants in Selected Rooms
(0,3482)
Remaining (Total)
Number of Occupants
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
0.0
50.00
100.0
150.0
200.0
250.0
Time in Seconds


Flow Rates for Selected Doors
Floors->Floor 0.0 m->Door00
Flow Rate (pers/s)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.500
0.0
0.0
50.00
100.0
150.0
200.0
250.0
Time in Seconds

Model Suitability – Model Selected: Pathfinder 2011

The suitability of a particular model for use in determining and properly displaying occupant evacuation is primarily a matter of choice. The particular model, though, must be evaluated to ensure the proper application of the model is implemented – this evaluation would include considering the model validation, limitations, availability, costs, particular features and capabilities. The SFPE *Fire Protection Engineering Handbook-Third Edition* included a series of questions related to evacuation models that are still relevant to model selection and pose areas of concern that must be considered when deciding what the most appropriate model for a particular project and task should be. These questions are related below, and are answered based on considering the use of Pathfinder 2011 software, produced by Thunderhead Engineering.

Evacuation Model Type

Is the model based on optimization, simulation, or risk assessment?
Pathfinder is a simulation model that can simulate some human behaviors.

Is the type of model suitable for the application?
Yes, pathfinder will produce suitable results for interpretation.

What are the limitations of the model with respect to the application?
Pathfinder currently only simulates movement to exits. It does not integrate results from a fire model or model the effects of toxicity to the occupants. Dynamic geometry is only partially supported such as elevators, whereas opening/closing doors, escalators, etc. are not supported. Elevators are only supported in evacuation-only circumstances.

Enclosure Representation

Is the model based on a fine network or a course network?
Pathfinder is a continuous network model. It simulates occupant movement in a 3D triangulated mesh designed to match the real dimensions of the building. The occupants are not tied to a specific cell.

How are different spaces and areas within spaces represented?
Walls and other impassable areas are represented as gaps in the navigation mesh. Rooms are modeled as open space on which occupants can freely travel.

How are connections between spaces represented?
Doors are represented as special navigation mesh edges and provide a mechanism for joining rooms and tracking occupant flow. Doors can be thick where they are representing the area between two rooms, or thin when representing adjoining rooms. Stairways are represented as special navigation mesh edges and triangles. Each stairway implicitly defines two doors. The number of steps, tread width, tread height, and width of the stairs are controlled by two stair tools.

How are obstructions within a space represented?
Obstructions are modeled as holes in the navigation geometry. Holes can be created with an arbitrary polygonal shape or as a thick wall.

How do these representations influence the model results?
Occupant movement speed in a stairway is reduced by a factor of their level travel speed.

How many nodes, connections, and obstructions can the model handle?
There are no known capacity limits specified.

How are the data entered to represent spaces, connections, and obstructions?
Pathfinder can automatically import geometry from 2D and 3D DXF files, FDS, and PyroSim, or building parameters may be manually input using a drawing feature. Floors are the primary method of

organization. They are simply groups in which rooms, doors, stairs, exits, images, and imported 2D geometry can be placed.

Population Perspective

Does the model use a global or an individual perspective?
Pathfinder is an agent-based simulator -- each occupant uses a set of individual parameters and makes decisions independently throughout the course of the simulation.

If the perspective is global, what general characteristics of the population are represented?
N/A

If the perspective is individual, what individual characteristics of the population are represented?
The movement technique used in steering mode is based on inverse steering behaviors, derived from the work of Craig Reynolds and Heni Ben Amoir. This steering technique allows agents to evaluate the cost of moving in a particular direction. At each time step, agents move in the direction that minimizes the overall cost.

How are the individual or global characteristics of the population entered in the model?
Pathfinder uses an occupant profile system that allows the user to specify the speed, initial delay, and size distributions across groups of occupants. Also, each occupant has a size parameter which is the diameter of the circle representing this occupant. Each parameter can be set to a constant value, a uniform distribution between two values, or a Normal distribution. There are also several options to occupant placement.

Behavioral Perspective

What type of behavioral perspective does the model employ— none, implicit, rule-based, functional analogy based, or artificial intelligence-based?
Artificial intelligence – simple human behavior is simulated in the evacuation. User can select one of two modes – SFPE or Steering. The SFPE mode uses the set of assumptions presented in the SFPE Handbook. The mechanism that controls the simulation is the door queue. Steering mode is more dependent on collision avoidance and occupant interaction for the final answer and often gives answers more similar to experimental data than the SFPE mode. Door queues will be formed naturally as dictated by the occupant density.

How does the model treat people-people interactions and their effects on behavior?
Rather than modeling occupants on a grid or as particles in a flow field, Pathfinder moves occupants in continuous 3D space.

How does the model treat people-enclosure interactions and their effects on behavior?
Each occupant belongs to a profile that controls speed, initial delay, size, and appearance. Profiles allow each of these characteristics to be constant or generated at simulation time based on uniform or normal distributions.

How does the model treat people-environment interactions and their effects on behavior?
At each time step, every agent examines the surrounding environment and takes action based on its own conditions and goals. Occupants make no attempt to optimize door exiting loads. The occupants always tend to move towards nearest exit regardless of any queuing that may be occurring.

How does the model address physiological factors that influence decision making?
Occupants can also be assigned to use specific exits to help simulate varying levels of familiarity with a building.

How does the model address sociological factors that influence decision making?
Pathfinder does not provide support for complex behaviors such as family grouping decisions.

Model Validation

Has the model been validated? If so, how, and to what extent?

Yes, in the NIST technical report 1680 *A Review of Building Evacuation Models, 2nd Edition,* Pathfinder was among the models evaluated and indicated that this particular model had been validated by "validation against code requirements (C), validation against fire drills or other people movement experiments/trials (FD), validation against literature on past evacuation experiments (flow rates, etc) (PE), and validation against other models (OM)."

How has the model validation been reported?

Additional validation information can be found on author's website:
http://www.thunderheadeng.com/downloads/pathfinder/verification_validation_2009_1_0417.pdf

Model Implementation

Has the model been implemented on a computer?

Yes, Pathfinder can be used on personal computers with 32 or 64 bit microprocessors. Pathfinder includes a graphical user interface that is used primarily to create and run simulation models.

What computer platforms does the model support?

Model is for PC hardware with Microsoft operating platform.

Model Support

Is the model currently supported by the author(s)?

Yes, currently by the Author of the model -Thunderhead Engineering
Product Support: support@thunderheadeng.com
Information: www.thunderheadeng.com
Sales and Fax: 1-785-770-8511

Is the model supported by another agency?

No; initial work was partially funded by a grant from the National Science Fund, but it is a proprietary based software that is supported for profit.

Is the model still being developed? If so, how are users notified of upgrades?

Yes, upgrades are implemented typically annually. Upgrades can be found on thunderhead engineering website: www.thunderheadeng.com.

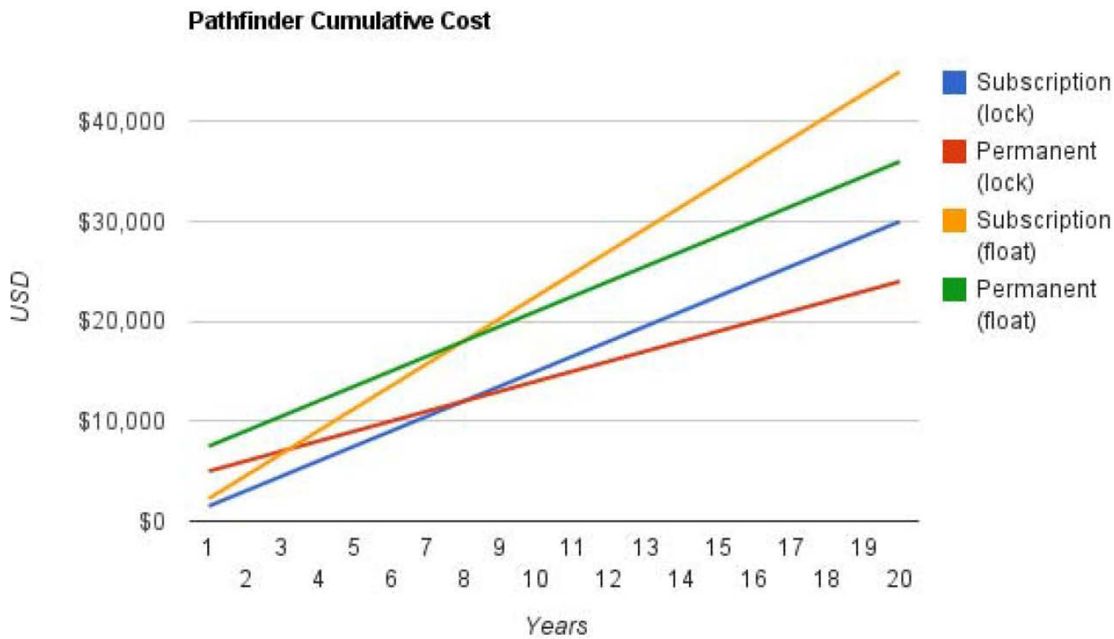
Model Costs

What is the initial cost of the model?

The first year would cost $5000 for a single node-locked perpetual license. The subscription license is $1500 per year and includes upgrades and support also. But, with this license, the software will stop working 365-days after activation. (See chart below for cost comparison prepared by Thunderhead Engineering)

What are the ongoing costs for upgrades, support, and maintenance?

Maintenance and support are provided in the first year as part of the fee. After the first year, the maintenance fee of $1000 would be paid annually to continue to receive support and upgrades for your license. (See chart below for cost comparison prepared by Thunderhead Engineering)



Appropriateness to Task

What inputs does the model require of the user? Are these available?

Pathfinder requires basic building dimensional information to include locations and sizes of internal features such as corridors, doors, rooms, obstructions, and stairs.

Does the model consider elements needed for the task at hand, for example, speed of movement, impact of: (1) density on speed, (2) queuing or other congestion, (3) merging of flows, (4) pre-movement decisions, and (5) decisions/actions during movement?

These features are appropriate to model estimated egress times for the task. Pre-movement behaviors are only considered in the sense that the user can specify a delay time before the occupant begins to evacuate. The model does not integrate any fire dynamics. In SFPE mode, the occupants follow rules described in SFPE Engineering Guide – Human Behavior in Fire (SFPE, 2003): the speed of the occupants is a function of room density, however, occupants can occupy the same space, and flow rates through the doors are based on SFPE guidelines. In SFPE mode with collision avoidance, the occupants follow SFPE rules with the addition that they avoid colliding with other occupants. This hybrid approach doesn't greatly affect predicted exit times, but does make it easier to visually identify congestion and queues. In Steering mode the occupants are not externally constrained by door queues or room density. Instead, the occupants move toward their goals, while avoiding walls and other occupants, while maintaining a reasonable separation distance. This mode usually produces the most visually realistic results.

Does the model produce an output meeting the needs of the task at hand?

Yes

Appendix Q - Slide Show Presentation

FPE 596 CULMINATING PROJECT IN FIRE PROTECTION ENGINEERING

Project: Orangeburg Assembly Hall of Jehovah's Witnesses

Justin B. Biller, PE, MCP, CFPS
Winter 2014

CAL POLY

Culminating Project in FPE

Independent study resulting in a project based upon the culminating experience in fire protection engineering. The culminating project experience is to perform a comprehensive fire and life safety evaluation of a selected building, prepare a comprehensive report documenting the results of this evaluation and present this analysis and findings to a review committee.

MS Candidate: Justin Biller – Presented: March 21, 2014

Special Thanks to Advisors:

Dr. Frederick Mowrer & Dr. Christopher Pascual

FPE 596 – slide 2

CAL POLY

Presentation Outline

1 Design Team & Building Overview
2 Applicable Codes and Standards
3 Building & Life Safety Code Analysis
4 Egress Analysis
5 Fire Alarm Initiation and Notification Design
6 Fire Suppression Design
7 Performance-Based Fire Safety & Fire Protection Analysis
8 Recommendations & Conclusions

FPE 596 – slide 3

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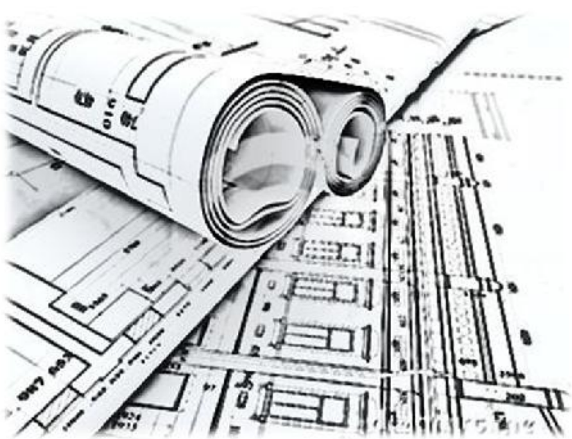

Part 1a
Design Team
Overview

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Design Team Overview

US Assembly Hall Design Group (USAHDG)

- Working Professionals – Part-time Volunteer Services
  - Architecture
  - Engineering – Civil, MEP, FPE
  - Construction Administrative Services
- Design And Construct Assembly Halls of Jehovah's Witnesses Throughout the Continental United States
- The Objectives of the Group
  - Provide Functional Facilities
  - Moderate in Design & Cost

Architect: J. Kenneth Ross, AIA
KenROSS Architects

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Design Team Overview

US Assembly Hall Design Group (USAHDG)

- Asked to Join Group in 2011 for Fire Protection Engineering Discipline
- Code Consultant
  - Code Analysis & Design Review
- Fire Protection System Overview & Conformance Review

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Part 1b Building Description & Overview

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Building Construction Overview

- Project Completed in 2013: Estimated > 5,000 Volunteers (Skilled & Unskilled Labor)
- Approximately 2 Years to Complete
- 66,000-square-foot
- $10 million in Construction Costs
- 3,000 Seat Auditorium
- Estimated Total Attendance:190,000 Visitors/Year

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Building Site Overview

- Orangeburg site - chosen from about 300 possible sites in SC
- Located near Charleston, SC - Vicinity of Interstate 26 & Interstate 95 Intersection
- Parking Lot – 1,000 Spaces
- Full Open Perimeter 58 acre site

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Part 2
Applicable Codes & Standards

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Codes & Standards Criteria

- South Carolina Building Code, 2006
- International Building Code (IBC) 2009
- International Fire Code (IFC) 2009
- NFPA 10, Standard for Portable Fire Extinguishers, 2007
- NFPA 13, Installation of Sprinkler Systems, 2007
- NFPA 72, National Fire Alarm and Signaling Code, 2007
- NFPA 80, Fire Doors and other Opening Protectives, 2007
- NFPA 90A, Standard for the Installation of Air-Conditioning & Ventilating Systems, 2009
- NFPA 92B, Smoke Management Systems in Malls, Atria and Large Spaces, 2005
- NFPA 101, Life Safety Code, 2009
- NFPA 220, Standard on Types of Building Construction, 2009

Performance-Based Fire Safe Design Criteria

- International Performance Code for Buildings and Facilities (ICCPC), 2009
- NFPA 101, Life Safety Code, 2009; Chapters 4 & 5
- NFPA *Fire Protection Handbook*, 20th Edition (NFPA FPHB)
- SFPE Engineering Guide, *Human Behavior in Fire*, 2003
- SFPE Handbook of Fire Protection Engineering, 4th Edition (SFPE HBFPE)
- SFPE Engineering Guide, *Performance-Based Fire Protection*, 2nd Edition

Part 3 Building & Life Safety Code Analysis

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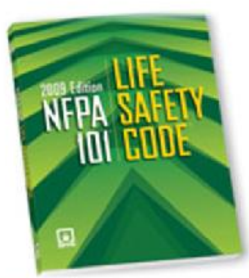
Building & Life Safety Code Analysis

Occupancy Classification:
South Carolina Building Code
- IBC Chapters 3 and 5
- A-3, Assembly – Religious Worship;
- Mixed Business (B) Occupancy;
- Accessory Uses (S) & (F-1)



Occupancy Classification:
Life Safety Code
- New Assembly – NFPA 101
- Chapters 6 and 12

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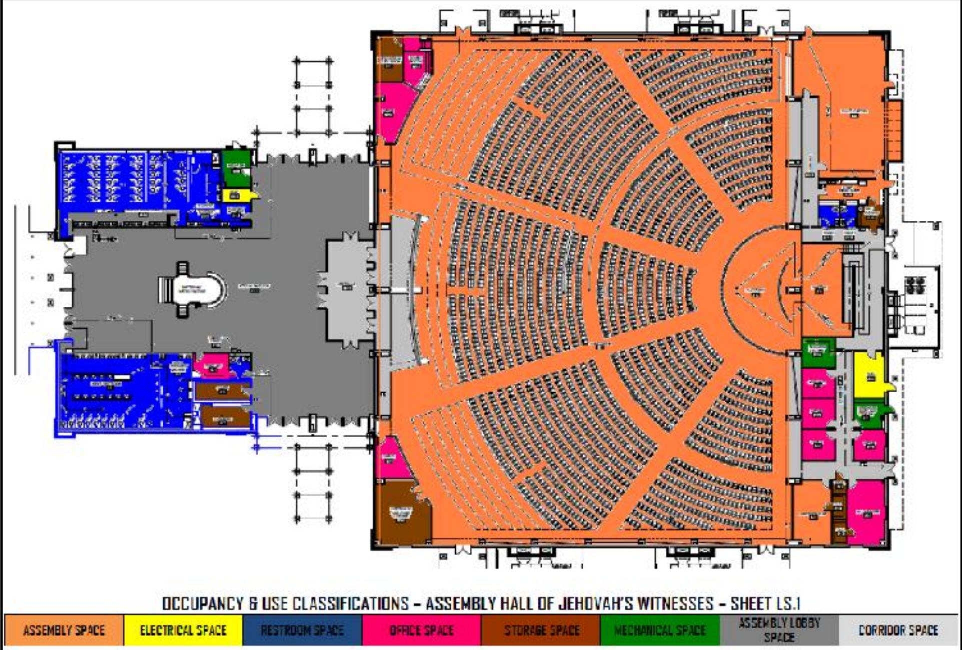

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Building Code Analysis

Mixed use and occupancy (IBC 508)

- **Accessory occupancies (IBC 508.2)**
- Storage spaces (S-1) & Mechanical, Equipment spaces (F-1) <10% aggregate building area

- **Incidental Use Areas (IBC 508.2.5)**
- Mechanical Room: 1 Hour or Automatic Sprinkler System
- Refrigerant Machinery Room: 1 Hour or Automatic Sprinkler System

- **Non-separated occupancies (IBC 508.3)**
- The office spaces - mixed-use non-separated B/A-3 occupancy
- A-3 Use - Building allowable areas are most restrictive A-3,

Use	Area (ft^2)	Allowable Area IBC Table 503 (ft^2)	Total Bldg. Area (ft^2)	Building Area Percent (%)
STORAGE ROOMS (S-1)	1,203	17,500	51,583	2
MECHANCIAL ROOMS (F-1)	474	15,500	51,583	1
ELECTRICAL ROOMS (F-1)	281	15,500	51,583	0.6

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Life Safety Code Analysis

- **Classification of Occupancy (NFPA 101, 6.1.2)**
- New Assembly for Worship Purposes > 50 Occupants

- **Multiple Occupancies (NFPA 101, 6.1.14)**
- Accessory spaces including office space, mechanical & electrical rooms would include NFPA 101 classifications of New Business & New Special Purpose Industrial

- Exit access of assembly spaces and adjacent accessory occupancy areas traverse same egress paths. Exit requirements are based on the most stringent requirements –Assembly Occupancy, per 6.1.14.2 & 6.1.14.1.3

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Building Code Analysis Height and Area Limitations

TABLE 503
ALLOWABLE BUILDING HEIGHTS AND AREAS[a]
Building height limitations shown in feet above grade plane. Story limitations shown as stories above grade plane. Building area limitations shown in square feet, as determined by the definition of "Area, building," per story

NFPA 220 Construction Types Added

GROUP		TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
	HEIGHT(feet)	UL	160	65	55	65	55	65	50	40
		Type 1(332)	Type II(222)	Type II(111)	Type II(000)	Type III(211)	Type III(200)	Type IV(2HH)	Type V(111)	Type V(000)
A-1	S A	UL UL	5 UL	3 15,500	2 8,500	3 14,000	2 8,500	3 15,000	2 11,500	1 5,500
A-2	S A	UL UL	11 UL	3 15,500	2 9,500	3 14,000	2 9,500	3 15,000	2 11,500	1 6,000
A-3	S A	UL UL	11 UL	3 15,500	2 9,500	3 14,000	2 9,500	3 15,000	2 11,500	1 6,000
A-4	S A	UL UL	11 UL	3 15,500	2 9,500	3 14,000	2 9,500	3 15,000	2 11,500	1 6,000
A-5	S A	UL UL	UL UL	UL UL	UL UL	UL UL	UL UL	UL UL	UL UL	UL UL
B	S A	UL UL	11 UL	5 37,500	3 23,000	5 28,500	3 19,000	5 36,000	3 18,000	2 9,000
E	S A	UL UL	5 UL	3 26,500	2 14,500	3 23,500	2 14,500	3 25,500	1 18,500	1 9,500
F-1	S A	UL UL	11 UL	4 25,000	2 15,500	3 19,000	2 12,000	4 33,500	2 14,000	1 8,500
S-1	S A	UL UL	11 48,000	4 26,000	2 17,500	3 26,000	2 17,500	4 25,500	3 14,000	1 9,000

Most Stringent

A = building area per story, S = stories above grade plane, UL = Unlimited, NP = Not permitted.
a. See the following sections for general exceptions to Table 503:
1. Section 504.2, Allowable building height and story increase due to automatic sprinkler system installation.
2. Section 506.2, Allowable building area increase due to street frontage.
3. Section 506.3, Allowable building area increase due to automatic sprinkler system installation.
4. Section 507, Unlimited area buildings.

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Building Code Analysis
Height and Area Limitations

Building Area Modifications - (IBC section 506) – Areas increases are allowed for fully automatic sprinkler protection and open frontage area around building perimeter:

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

A_a = Allowable building area per story (ft^2).

A_t = Tabular building area per story in accordance with Table 503 (ft^2)

I_f = Area increase factor due to frontage as calculated, per IBC section 506.2

$I_f = (F/P – 0.25)*(W/30)$

$I_f = (550 \text{ ft.}/550 \text{ ft.} – 0.25)* (30/30) = 0.75$

I_s = Area increase factor due to sprinkler protection per NFPA 13 as calculated in accordance with section 506.3. ($I_s = 3$)

Modified Building Allowable Areas

Type IA: Unlimited > 51,583 ft^2	**Type IB: Unlimited > 51,583 ft^2**
Type IIA: 58,125 ft^2 > 51,583 ft^2	Type IIB: 45,125 ft^2 < 51,583 ft^2
Type IIIA: 52,500 ft^2 > 51,583 ft^2	Type IIIB: 45,125 ft^2< 51,583 ft^2
Type IV: 61,750 ft^2 > 51,583 ft^2	
Type VA: 54,625 ft^2 > 51,583 ft^2	Type VB: 28,500 ft^2 < 51,583 ft^2

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Building Code Analysis
Type of Construction Requirements - IBC

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g]	3	2	1	0	2	2	2	1	0
Bearing walls Interior	3[a]	2[a]	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	$1^1/_2$[b]	1[b, c]	1[b, c]	0[c]	1[b, c]	0	HT	1[b, c]	0

For SI: 1 foot = 304.8 mm

Building Construction Type II B per IBC 507.6

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Building Code Analysis
Type of Construction Requirements – NFPA 220

Building Const. Type II (000) per NFPA 101 & NFPA 220

	Type I		Type II			Type III		Type IV	Type V	
	442	332	222	111	000	211	200	2HH	111	000
Exterior Bearing Walls[a]										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0^b	2	2	2	1	0^b
Supporting one floor only	4	3	2	1	0^b	2	2	2	1	0^b
Supporting a roof only	4	3	1	1	0^b	2	2	2	1	0^b
Interior Bearing Walls										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	1	0	2	1	0
Supporting one floor only	3	2	2	1	0	1	0	1	1	0
Supporting roofs only	3	2	1	1	0	1	0	1	1	0
Columns										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	1	0	H	1	0
Supporting one floor only	3	2	2	1	0	1	0	H	1	0
Supporting roofs only	3	2	1	1	0	1	0	H	1	0
Beams, Girders, Trusses, and Arches										
Supporting more than one floor, columns, or other bearing walls	4	3	2	1	0	1	0	H	1	0
Supporting one floor only	2	2	2	1	0	1	0	H	1	0
Supporting roofs only	2	2	1	1	0	1	0	H	1	0
Floor-Ceiling Assemblies	2	2	2	1	0	1	0	H	1	0
Roof-Ceiling Assemblies	2	1½	1	1	0	1	0	H	1	0
Interior Nonbearing Walls	0	0	0	0	0	0	0	0	0	0
Exterior Nonbearing Walls[c]	0^b	0^b	0^b	0^b	0^b	0^b	0^b	0^b	0^b	0^b

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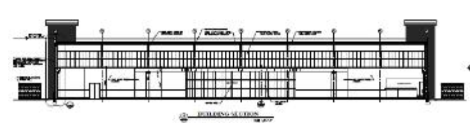
Structural Fire Protection - Prescriptive

Element	Rating
Primary Structural Frame	0
Exterior Bearing Walls	0
Interior Bearing Walls	0
Exterior Nonbearing Walls and Partitions	IBC Table 602
Interior Nonbearing Walls and Partitions	0
Floor Construction and Secondary Members	0
Roof Construction and Secondary Members	0



Platform
(IBC 410, NFPA 101 3.3.246 & 12.4.5)
The main podium used for educational & worship purposes can be a platform as defined by both the IBC and NFPA Non-combustible construction per IBC 410.4 & NFPA 101 12.4.5.1.

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Structural Fire Protection - Prescriptive

TABLE 602
FIRE-RESISTANCE RATING REQUIREMENTS FOR EXTERIOR WALLS BASED ON FIRE SEPARATION DISTANCE[a, e]

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

For SI: 1 foot = 304.8 mm.
a. Load-bearing exterior walls shall also comply with the fire-resistance rating requirements of Table 601.
b. For special requirements for Group U occupancies, see Section 406.1.2.
c. See Section 706.1.1 for party walls.
d. Open parking garages complying with Section 406 shall not be required to have a fire resistance rating.
e. The fire-resistance rating of an exterior wall is determined based upon the fire separation distance of the exterior wall and the story in which the wall is located.
f. For special requirements for Group H occupancies, see Section 415.3.
g. For special requirements for Group S aircraft hangars, see Section 412.4.1.

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Part 4
Means of Egress
Prescriptive
Requirements

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Egress Analysis

IBC Chapter 10

NFPA 101 - Life Safety Code Chapters 7 & 12

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Occupant Loads

USE	AREA (FT^2)	OCCUPANT LOAD FACTOR (FT^2 PER PERSON)	OCCUPANT LOAD
ASSEMBLY SPACE	29,000	Fixed Seating – N/A (Actual # of Seats)	2,966
ASSEMBLY LOBBY SPACE	7,181	15 gross*	479
PLATFORM	1,800	15 net	120
MULTI-PURPOSE ASSEMBLY SPACE (Room 119)	1,800	15 net	120
CONFERENCE ROOM	344	15 net	23
OFFICE SPACE	2,987	100 gross	30
ELECTRICAL SPACE	281	300 gross	1
MECHANICAL SPACE	474	300 gross	2
STORAGE SPACE	1,203	300 gross	5
CORRIDOR SPACE	2,824	100 gross	29
RESTROOM SPACE	3,689	100 gross	37
TOTAL	51,583	-	3,812

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Means of Egress Analysis

- Required - IBC 1021.1 and NFPA 101 section 7.4
- Occupant Loads >1,000 Occupants: 4 Primary Exits
- Provided - 8 Primary Exits Provided for Building
  - 7 Secondary Exits from Rooms
  - Auditorium Has 5 Primary Exits

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Egress Capacity

EGRESS COMPONENT	COMPONENT SIZE	EGRESS CLEAR WIDTH	CAPACITY FACTOR	MAXIMUM OCCUPANT LOAD CAPACITY	ACTUAL OCCUPANT LOAD CAPACITY
Door 100	6'-0"	66"	0.2	330	172
Door 100A	6'-0"	66"	0.2	330	172
Door 100B	6'-0"	66"	0.2	330	172
Door 100C	6'-0"	66"	0.2	330	172
Door 100D	6'-0"	66"	0.2	330	164
Door 100E	6'-0"	66"	0.2	330	164
Door 100F	6'-0"	66"	0.2	330	164
Door 100G	6'-0"	66"	0.2	330	164
Door 100H	6'-0"	66"	0.2	330	164
Door 100J	6'-0"	66"	0.2	330	164
Door 100K	6'-0"	66"	0.2	330	164
Door 111A [Ψ]	3'-0"	33"	0.2	165	2
Door 118	6'-0"	66"	0.2	330	371*
Door 118A	6'-0"	66"	0.2	330	371*
Door 118B	6'-0"	66"	0.2	330	371*
Door 118C	6'-0"	66"	0.2	330	371*
Door 119B	3'-0"	33"	0.2	165	60
Door 119C	3-0"	33"	0.2	165	60
Door 120	6'-0"	66"	0.2	330	179
Door 121B [Ψ]	3'-0"	33"	0.2	165	9
Door 128A [Ψ]	3'-0"	33"	0.2	165	2
Door 130A [Ψ]	3'-0"	33"	0.2	165	2
Door 134	6'-0"	66"	0.2	330	179
TOTAL	117'-0"	1287"	-	6,435	3,812

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Egress Capacity Components

- Aisles, Corridors, & Ramps – Min. 44 Inches Wide
- Doors – Min. 32 Inches Clear Width for Means of Egress Doors
- Assembly Space Main Exit - Main Entrance/Exit to be Sized For a Minimum of 1/2 the Total Occupant Load

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Arrangement of Means of Egress

- Remoteness of Exits to be a Minimum of 1/3 of The Maximum Overall Diagonal Dimension Of The Building Or Area
- A Minimum of 2 Exits or Exit Access Doors to be Remote
  - Additional Exits and/or Exit Access Doors to be Located as Remote as Practical

Occupancy	Common Path Limit (ft.)	Dead End Limit (ft.)	Travel Distance Limit (ft.)
Assembly	20 serving > 50 occupants 75 serving <50 occupants	20	250
Business	100	50	300
Special Purpose Industrial	100	50	400

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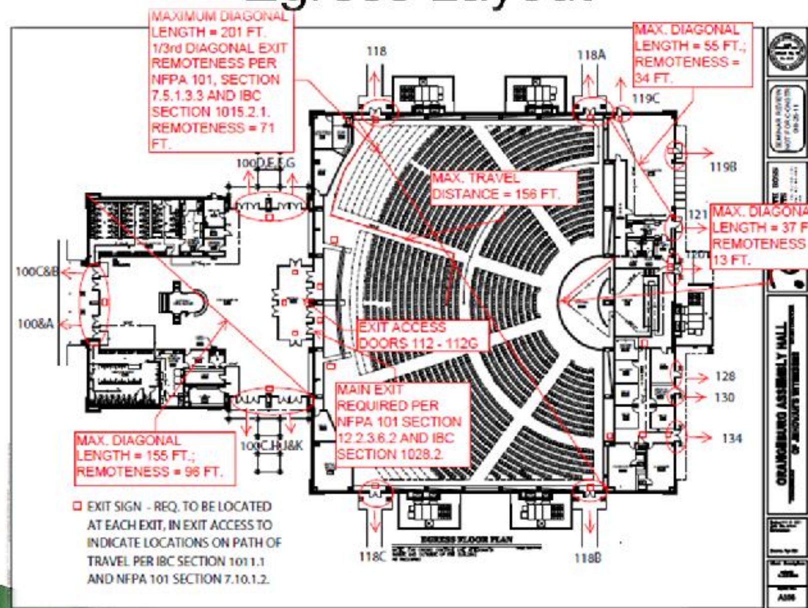
Egress Layout



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Assembly Use Egress Requirements

- Aisle Access ways At Both Ends - Increase the 12 In. Minimum Clear Width of Aisle Access way Increase By 0.3 in./Seat >14
- Aisle Access ways at One End Only – Increase the 12 In. Minimum Clear Width of Aisle Access way by 0.6 in./Seat > 7
- Aisle Access ways At One End - Maximum of 30 Feet Dead End
- Ramped Aisles - Aisles Serving Seats on Both Sides - 42 in.

Aisles & Aisle Accessway Width (IBC 1028.10, NFPA 12.2.5.5.5.1)

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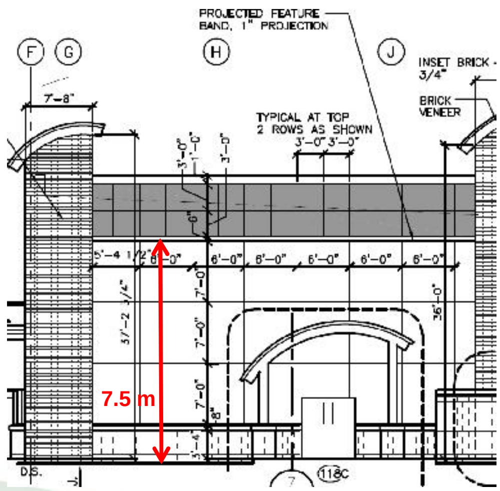
Assembly Use Egress Requirements

- "Seating served by a means of egress that is not subject to smoke accumulation within or under the structure."
- Smoke Protected Assembly Seating Reductions - reductions in egress capacity, and egress parameters including travel to exits and dead end aisle widths for seating rows are permitted
- SPAS is a performance measure smoke removal to a manageable height above occupants results in longer time to evacuate space

Smoke Protected Assembly Seating (SPAS) Provision (IBC 1028.6.2, NFPA 101 12.4.2)



Smoke Protected Assembly Seating

Number of Seats	Smoke Protected Assembly Seating								
	Inches of Clear Width per Seat Served				%		(ft)		
	Stairs & Aisle Steps with handrails within 30 inches	Stairs & Aisle Steps without handrails within 30 inches	Passageways, doorways and ramps not steeper than 1 in 10 slope	Ramps steeper than 1 in 10 in slope	Percent Reduction from Non-Smoke Protected Seating for Stairs & Aisles	Percent Reduction from Non-Smoke Protected Seating - doors, ramps, etc.	Travel Distance Limits*	Dead End Limits	Common Path of Travel
2,000	0.3	0.375	0.22	0.242	0	0	400	30	50
5,000	0.2	0.25	0.15	0.165	33.3	31.82	400	30	50
10,000	0.13	0.163	0.1	0.11	56.7	54.55	400	30	50
15,000	0.096	0.12	0.07	0.077	68	68.18	400	30	50
20,000	0.076	0.095	0.056	0.062	74.7	74.55	400	30	50
≥25,000	0.06	0.075	0.044	0.048	80	80	400	30	50

Table 6.4.1 Smoke Protected Assembly
***Assuming Fully Sprinklered Building**

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Smoke Management System

- NFPA 101, 12.4.2.1 establishes design parameters in which SPAS can be utilized:
- Protected with an approved, supervised automatic sprinkler system,
- Ventilation system shall be designed to maintain the level of smoke at not less than 6 ft. above the floor of the means of egress. The ventilation system shall be in accordance with NFPA 92B

Smoke Management Sys. for SPAS (IBC 1028.6.2, NFPA 101 12.4.2)

Axisymmetric Plume
Q = 3,000 kW
Qc = 1,750 kW
Z = 6 ft (1.83m)
Z_L = 11.5 ft (3.54 m)
Smoke Temperature (Ts) = 451°F (233 °C)
Exhaust Rate (V) = 21,125 cfm (9.97 m^3/s)

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Part 5 Fire Alarm & Detection System Prescriptive Requirements

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Fire Alarm System Design Criteria

- Fully Addressable Fire Alarm System
  - Manual and Partial Automatic
- Supervision of Fire Protection Systems
  - Automatic Fire Extinguishing Systems
  - Smoke Control System
  - Fire Detection Equipment
- Voice evacuation system is required for large occupant assembly occupancies > 1,000 occupants per IBC section 907.2.1.1 and NFPA 101 section 12.3.4.3.4.
- Voice evacuation system - emergency backup power supply per IBC section 907.5.2.2.4.

Fire Alarm System Design Criteria

Fire Alarm System Features

- Fire Alarm Control Panel
- Fire Alarm Annunciator Panel
- Supervision of Sprinkler System Alarm and Supervisory Devices
- Spot-type Photoelectric Smoke Detection Devices throughout Auditorium Space
- Duct Smoke Detection Devices
- Manual Fire Alarm Station Devices
- Audible Notification Appliances (Speakers)
- Visual Notification Appliances in Publicly Accessible Areas and Mechanical Rooms
- Class B Signaling Line Circuits for All Initiating Devices
- Class B Notification Appliance Circuits

Fire Alarm System Design Criteria

Minimum Code Requirements for Sound Pressures

Occupancy	Avg. Ambient dBA	Minimum dBA Required
Office Areas	55	70
Assembly Areas	55	70
Storage Areas	55	70
Mechanical Rooms	90	105

- Alarm Signals Transmit to a Central Station Service
- Alarm Notification via Speakers & Synchronized Strobes
- Full Evacuation via Temporal 3 Signal & Live Voice Capability to Override Pre-recorded Message

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Fire Alarm Sequence of Operation Matrix

		CONTROL PANEL						TRANSMIT ALARM			AUXILIARY FUNCTION				NOTIFY		
		ACTUATE COMMON ALARM SIGNAL INDICATOR	ACTUATE AUDIBLE ALARM SIGNAL	ACTUATE COMMON SUPERVISORY SIGNAL INDICATOR	ACTUATE AUDIBLE SUPERVISORY SIGNAL	ACTUATE COMMON TROUBLE SIGNAL INDICATOR	ACTUATE AUDIBLE COMMON TROUBLE SIGNAL	TRANSMIT FIRE ALARM SIGNAL TO SUPERVISORY STATION	TRANSMIT SUPERVISORY SIGNAL TO SUPERVISING STATION	TRANSMIT TROUBLE SIGNAL TO SUPERVISING STATION	SHUT-DOWN ASSOCIATED AIR HANDLER UNIT (HVAC)	ACTIVATE SMOKE CONTROL SYSTEM	RELEASE MAGNETICALLY HELD-OPEN DOORS	ACTUATE EVACUATION SIGNALS	FIRE ALARM SIGNAL TO CENTRAL STATION	SUPERVISORY SIGNAL TO CENTRAL STATION	TROUBLE SIGNAL TO CENTRAL STATION
SYSTEM INPUT		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	MANUAL PULL STATIONS	•	•					•					•	•	•		
2	AUDITORIUM SMOKE DETECTOR	•	•					•					•	•	•		
3	DUCT SMOKE DETECTOR	•	•					•			•	•	•	•	•		
4	WATER FLOW SWITCH - SPRINKLER SYSTEM	•	•					•					•	•	•		
5	TAMPER SWITCH - SPRINKLER SYSTEM			•	•				•							•	
6	TAMPER SWITCH - PIV/BACKFLOW SUPERV.			•	•				•							•	
7	INCOMING FIRE LINE SUPERVISORY CONN.			•	•				•							•	
8	FIRE ALARM AC POWER FAILURE			•	•				•								•
9	FIRE ALARM SYSTEM LOW BATTERY					•	•			•							•
10	OPEN CIRCUIT					•	•			•							•
11	GROUND CIRCUIT					•	•			•							•
12	CIRCUIT SHORT					•	•			•							•

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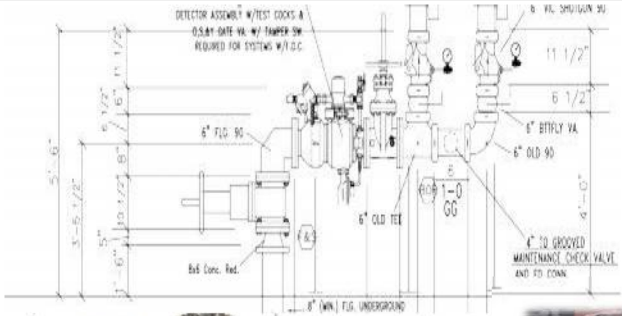

Part 6 Fire Suppression Prescriptive Requirements

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Automatic Fire Sprinkler Design Criteria

- Building Protected Throughout - Wet Pipe Sprinkler System
- Sprinkler System Designed & Installed - NFPA 13
- Quick Response Sprinklers Installed Throughout Compartments
- Design Primarily for Light Hazard Occupancy
- Calculation - Density/Area Method
- Sprinkler Piping - Schedule 40 Black Steel Pipe
- Double Check Backflow Preventer Connection to Municipal Supply
- Seismic Design Category of D - IBC Section 1613 Seismic Restraints per ASCE 7 & NFPA 13

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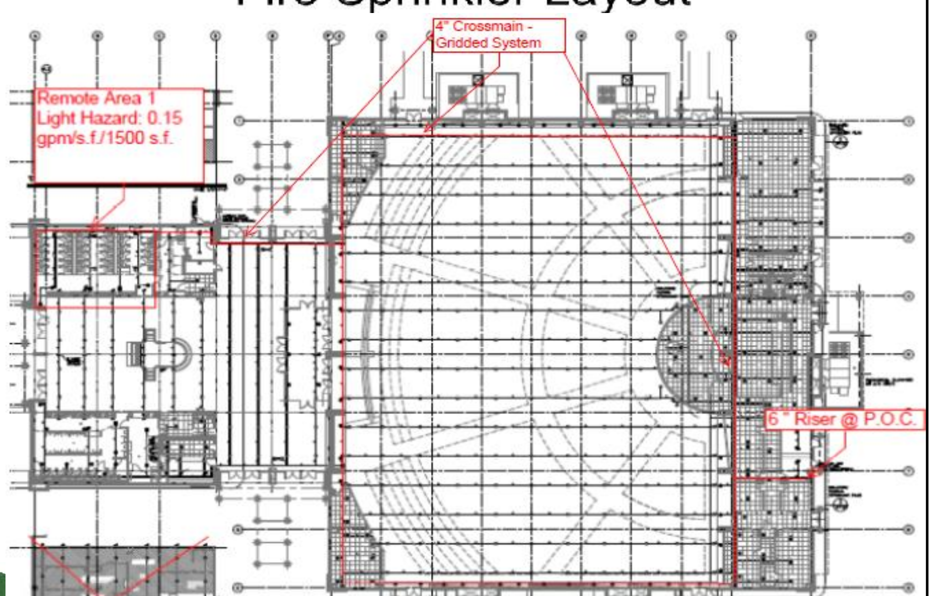
Automatic Fire Sprinkler Design Criteria

- Hydraulically Most Remote Locations
- Density, Area & Hose Req. from NFPA 13, Figure 11.2.3.1.1 & T.11.2.3.1.2

Throughout Facility Unless Otherwise Noted	
Hazard	Light
Design Density	0.10 gpm/SF
Design Area	1500 SF [1,2]
Hose Stream	100 gpm
Duration	30 minutes
Mechanical, Transformer, Electrical Rooms	
Hazard	Ordinary Hazard Group 1
Design Density	0.15 gpm/SF
Design Area	1500 SF [1]
Hose Stream	250 gpm
Duration	60 minutes
Storage, Trash, Mechanical Rooms with Fuel-Fire Equipment	
Hazard	Ordinary Hazard Group 2
Design Density	0.20 gpm/SF
Design Area	1500 SF [1]
Hose Stream	250 gpm
Duration	60 minutes

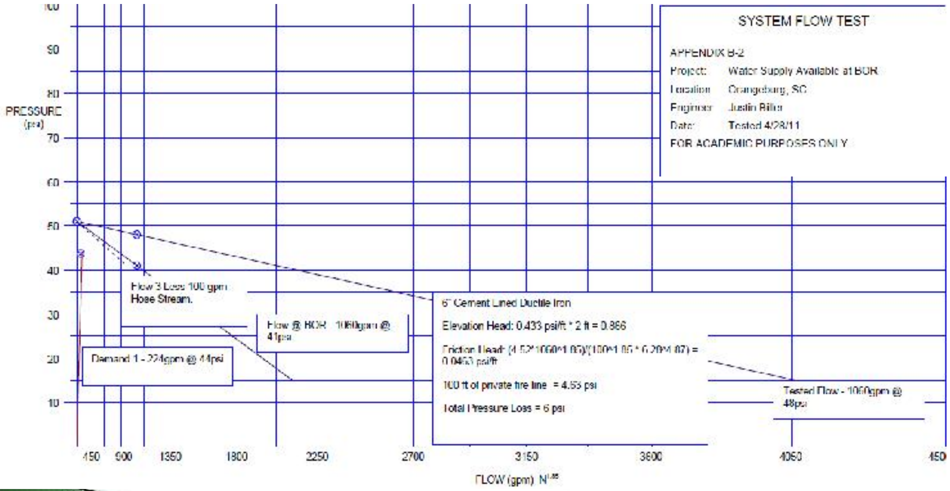
[1]Design area reductions in accordance with NFPA 13 (2007) chapter 11 will be applied as applicable.
[2] Design area slope increase is required in auditorium sprinkler remote area calculations in accordance with NFPA 13 (2007) chapter 11.

Fire Sprinkler Layout



Fire Protection Water Supply Analysis

Fire Suppression Available Water Supply
Static Pressure – 52 psig; Residual Pressure - 48 psig; Residual Flow –1,060 gpm



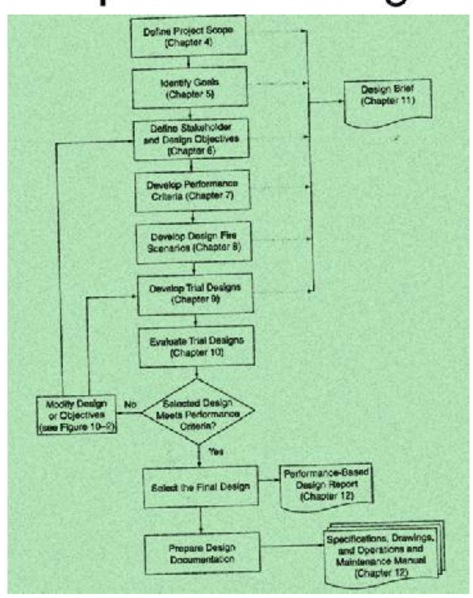
Portable Fire Extinguishers

- Portable fire extinguisher cabinets will be provided in closed-front, recess-mounted fire extinguisher cabinets of steel construction
- Cabinet sized to accommodate 2.5 gal pressurized water extinguishers, Class A
- Locations will comply with NFPA 10

Part 7 Performance-Based Fire Safety & Fire Protection

Performance Based Aspects of Design

- Performance Criteria
  - Goals & Objectives
- Fire Modeling Tools
- Available Safe Egress Time (ASET)
  - Fire Dynamics Simulator (FDS) Model
  - DETACT Model
- Fire Scenarios
- Egress Analysis
  - Pathfinder Model & SFPE Hand Calculations
  - Required Safe Egress Time (RSET)



Fire & Life Safety Goals

- Provide an Environment for the Occupants that is Reasonably Safe from Fire by the Following:

  (1) Protection of Occupants Not Intimate With the Initial Fire Development

  (2) Provide For Reasonably Safe Emergency Crowd Movement

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Fire Safety Objectives

- **Occupant Protection**

  Building Will Be Designed To Protect Occupants Not Intimate with the Initial Fire Development for the Time Needed to Evacuate Building

- **Systems Effectiveness**

  Fire Protection Systems Utilized to Achieve Stated Design Goals will be Designed to be Effective in Limiting or Mitigating the Hazard

  Systems will be Maintained Reliable

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Performance Criteria - ASET

- Available Safe Egress Time (ASET)
  Amount of Time that Elapses Between Fire Ignition & Development of Untenable Conditions

Tenability Limitation Criteria	Criteria Justification
Visibility Must Remain Above 10 m at 1.8 m (6 ft.) Walking Surface	*SFPE Fire Protection Engineering Handbook, Visibility and Human Behavior in Fire Smoke*
Temperature Must Remain Below 66° C at 1.8 m (6 ft.) Walking Surface	Figure 6.1 of the *Handbook of Smoke Control Engineering, Heat Tolerance for Humans at Rest, Naked with Low Air Movement*
Carbon Monoxide Concentration Must Remain Below 1,400 ppm at 1.8 m (6 ft.) Walking Surface	*Handbook of Smoke Control Engineering*

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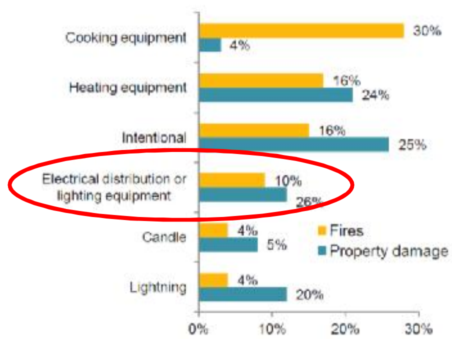
Design Fire Considerations

- IBC Section 909.9.1 Design Fire Size Analysis Must Consider the Following Factors to Determine the Appropriate Fire Size:
- **Fuel**
  (Potential Burning Rates)
- **Fuel Load** (How Much)
- **Effects of Fire**
  (Smoke Particulate Size)
- **Steady or Unsteady**
  (Burn Steadily or Simply Peak & Dissipate)
- **Likelihood of Sprinkler Activation**
  (Based on Height & Distance From the Fire)



NFPA Data: Leading Causes of Structure Fires in Religious and Funeral Properties, 2007-2011

- IBC Section 909.4.6 Establishes Criteria for Operation of Smoke Control for **20 Minutes or 1.5 Times the Calculated Egress Time (RSET)**, Whichever Is Less, As a Minimum Time for Evacuation or Relocation

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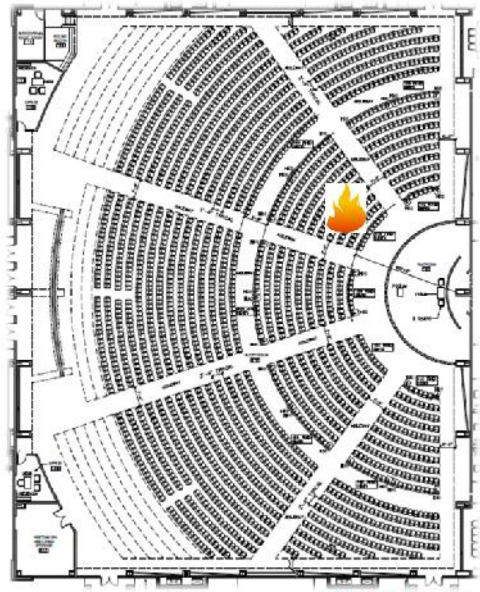
Fire Scenario 1



Polyurethane Foam Fixed Seating – Faulty Electrical Floor Receptacle Overheating Adjacent to Foam Padding Serving as Ignition Source

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Fire Scenario 1

Ultra-fast Growth Fire in the Auditorium Polyurethane Upholstered Seating (Steady State Fire) – Multiple Seats Ignited Until HRR Reached for Sprinkler Control

$$\dot{q}'' = \frac{X_r \dot{Q}}{4\pi R^2}$$

$\dot{Q}''$ = energy radiated per unit time per unit area (W/m^2 or kW/m^2)
X_r = fraction of energy radiated relative to the total energy released
$\dot{Q}$ = heat release rate (W or kW)
$4\pi r^2$ = surface area of sphere, where r is the radial distance to the target fuel

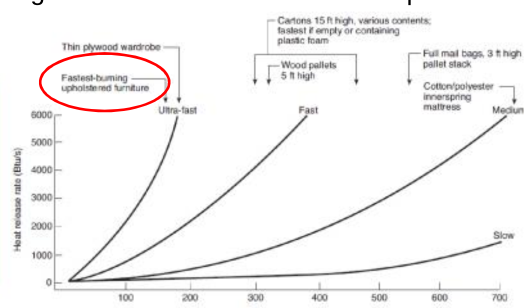

Table 17. *Heat release rates of chairs in recent NBS tests* [79, 102, 137, 170]

Specimen	Mass (kg)	Combustible (kg)	Style	Frame	Padding	Fabric	Interliner	Peak m (g/s)	Peak q (kW)
T50	16.5		waiting room chair	metal	cotton	PVC	—	NA	< 10
T53	15.5	1.9	waiting room chair	metal	PU	PVC	—	13.1	270
T54	[illegible]	[illegible]	metal frame loveseat	metal	PU	PVC	—	9.9	[illegible]
T75/F20	7.5 (x4)	2.6	stacking chairs (4)	metal	PU	PVC	—	7.2	[illegible]

[a] Estimated from mass loss records and assumed Δh_c.
[b] Estimated from doorway gas concentrations.

Source: Fire Behavior of Upholstered Furniture – (NBS) NIST, 1985

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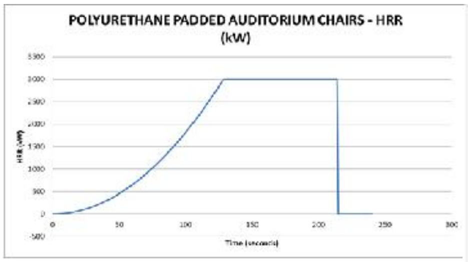
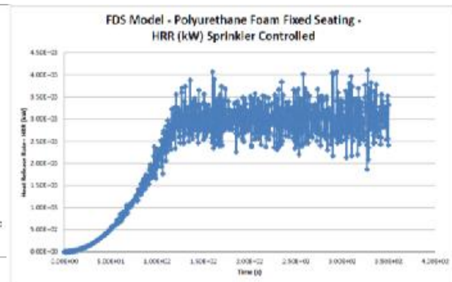
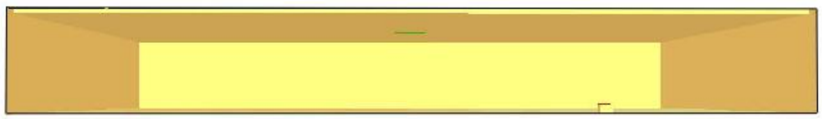
Fire Scenario 1 - Fire Dynamics Simulator Results





Design Fire – Ultrafast Growth Fire – Polyurethane Foam Upholstered Seating, Sprinkler Activation @ 3MW HRR Determined by DETACT



Compartment Model – FDS 6 Model, Smoke Exhaust @ 5.0 cu. m/s

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Fire Scenario 1 - Fire Dynamics Simulator Results

Compartment Fire Growth & Smoke Spread @ 120s

Compartment Fire Growth & Smoke Spread @ 250 s

Compartment Fire Growth & Smoke Spread @ 350 s

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Fire Scenario 1 - Fire Dynamics Simulator Results

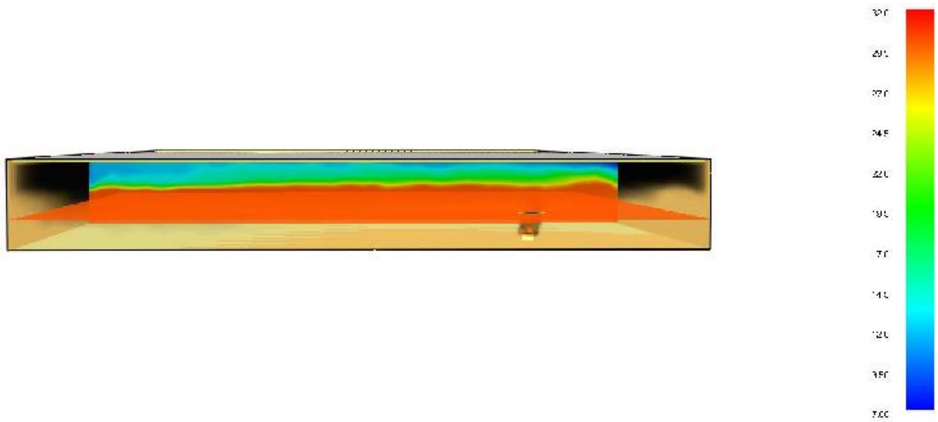

Figure 1, FDS Model – Soot Visibility @ 350 s

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Fire Scenario 1 - Fire Dynamics Simulator Results

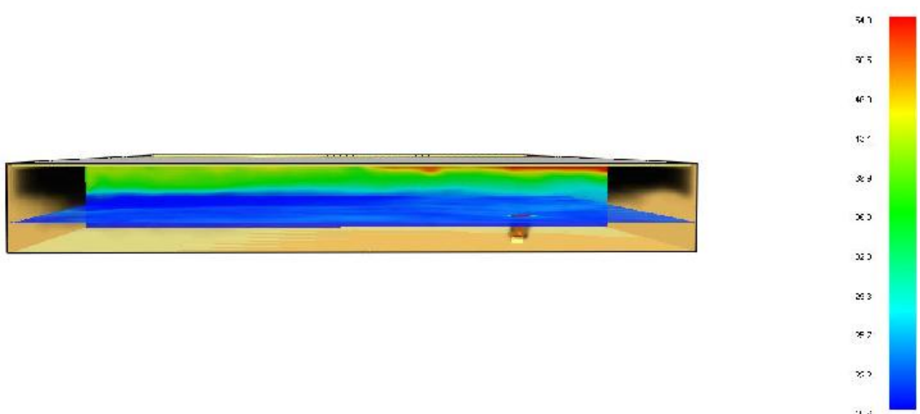

Figure 2, FDS Model – Compartment Temperatures @ 350s

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Fire Scenario 1 - Fire Dynamics Simulator Results

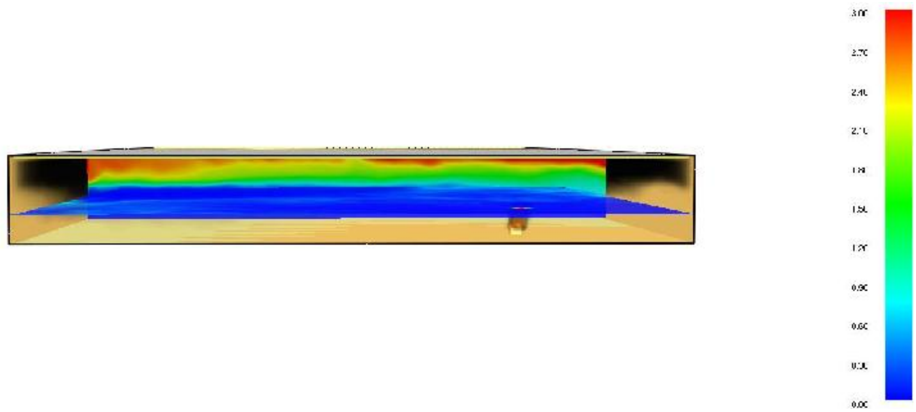

Figure 3, FDS Model – CO Mass Concentrations @ 350s

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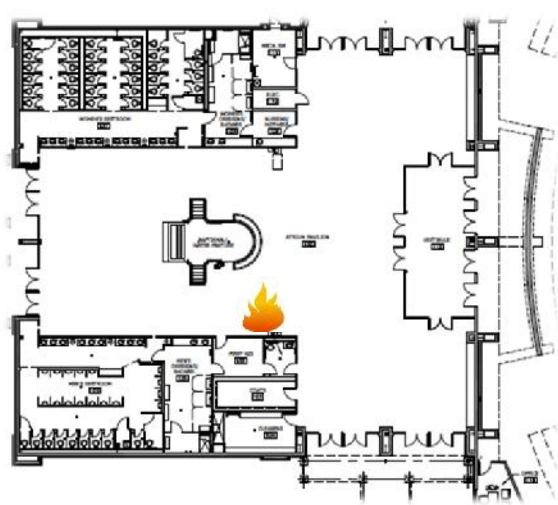
Fire Scenario 2



2 L Hand-sanitizer Station Spill - Ignition Resulted From Adjacent Electrical Receptacle Ignition Source

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Fire Scenario 2

Ultra-fast Growth Fire in Adjacent Lobby Area (Ethyl Alcohol Pool Fire)

- NFPA 101 Section 5.5.3.2 - Fire Scenario to Consider an Ultrafast Fire in the Primary Means of Egress
- The Most Common Alcohol-based Hand Rubs are Typically 60% Ethyl Alcohol or Isopropyl Alcohol by Volume – Source: Fire Protection Handbook

Representative Sample Data: Ignition Source - HRR (kW)	Sample Size (L)	Representative Sample Data Sources
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
200	2	ASHE Modeling Fire Data
80	2	ASHE Modeling Fire Data
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
200	2	ASHE Modeling Fire Data
80	2	ASHE Modeling Fire Data
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
100	1	ASHE Modeling Fire Data
40	1	ASHE Modeling Fire Data
200	2	ASHE Modeling Fire Data
80	2	ASHE Modeling Fire Data
Statistical Data Based on Sample Sources		
Mean	96	
Standard Deviation	59	
Max.	200	
Min.	40	

Source: Alcohol-Based Hand Rub Solution - Fire Modeling Analysis Report
August 22, 2003 - American Society for Healthcare Engineering

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Fire Scenario 2 – Published Data Results

- Fire Scenario 2 was Considered as Plausible & Relevant
- Further Modeling & Investigation Not Warranted
- Strict Adherence to Prescriptive Standards in NFPA 101 would Achieve Appropriate Level of Fire & Life Safety
- Trained Attendants with Portable Extinguishers Could Prevent Fire Growth to Adjacent Combustibles

Table 8 - Summary of Fire Model Results

	Fire Size kW	Temp. °F	Visibility feet	Carbon Monoxide ppm	Sprinkler Activation	Ignition of Targets
Scenario 1 1	100	158	47	13	N	N
	40	135	49	12	N	N
Scenario 1 2	200	247	27	25	Y 64 sec	N
	80	190	19	31	N	N
Scenario 1-3	100	195	30	21	N	N
	40	142	35	16	N	N
Scenario 1 4	200	397	12	56	Y 49 sec	N
	80	190	19	31	Y 195 sec	N
Scenario 1 5	100	150	49	12	N	N
	40	131	88	10	N	N
Scenario 1 6	40	134	18	20	N	N
Scenario 1 7	40	150	18	20	N	N
Scenario 2-1	100	102	90	6	N	N
	40	108	79	7	N	N
Scenario 2 2	200	138	61	10	Y 77 sec	N
	80	117	80	9	Y 251 sec	N

Source: Alcohol-Based Hand Rub Solution - Fire Modeling Analysis Report
August 22, 2003 - American Society for Healthcare Engineering

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Egress Analysis

T_{RSET} (Required Safe Egress Time) < T_{ASET} (Available Safe Egress Time)

Where,
$T_{RSET} = (t_d + t_a + t_p + t_e)$*1.5 (Safety Factor)
$T_{ASET} = t_u$
t_d = time of fire detection
t_P = occupant pre-movement time
t_r = occupant response time
t_e = travel time
t_u = time of untenable conditions

This would result in a T_{RSET} of **18 minutes**, where

t_d = 1 minutes (62 seconds - DETACT Model)
t_a = 1 minutes (60 second maximum, per NFPA 72)
t_P = 3 minutes (SFPE Recommends 3 -5 minutes based on level of assistance & way-finding ability)
t_r = 1 minute (SFPE Recommends this as part of pre-movement time of 3 -5 minutes)
t_e = 7 minutes (SFPE Hand Calculation)

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Egress Analysis – Hand Calc. SFPE Meth.

$$T_p = \frac{P}{(1-aD)kDW_e}$$

Where,
T_p = time for passage (min/sec)
P = population in persons
W_e = effective width (m)
F_c = Calculated flow where F_s (Specific flow - m/min, or m/s)

	ESTIMATED EVACUATION TIME								
Space to Evacuate	Population	Max. Flow F_s (persons/sec/m) NFPA FPH T. 4.2.8	Travel Speed Public Places Density is factor (m/sec) NFPA FPH T.4.2.3	Total We Effective Width (m)	Travel Distance to Exit (m)	Time to move to door (sec)	Time to move to door (min.)	Time to move thru door (sec)	Time to move to door (min.)
Auditorium	2966	1.09	0.28	10.96	48.00	171.43	2.86	248.28	4.14
Lobby	479	0.90	0.28	15.07	16.00	57.14	0.95	35.32	0.59
Total Evacuation Time (min.) - Auditorium Worst Case								7.00	

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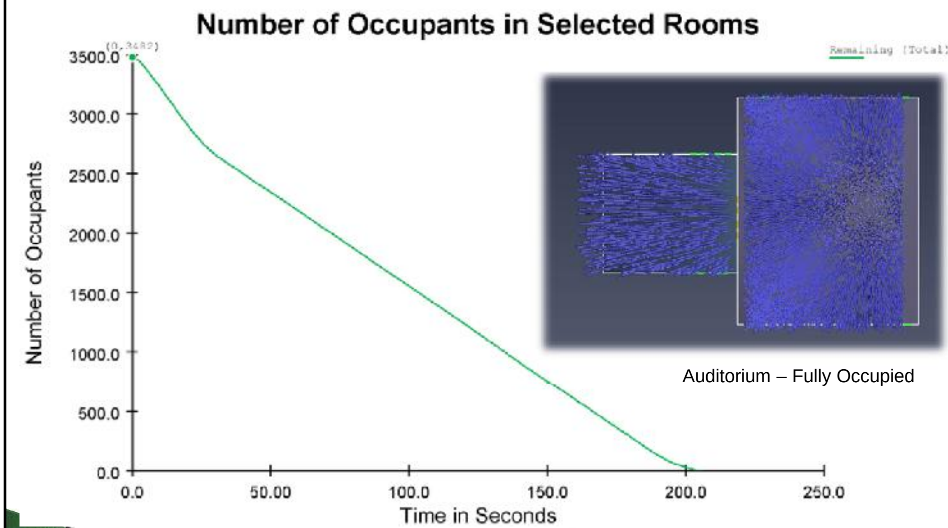
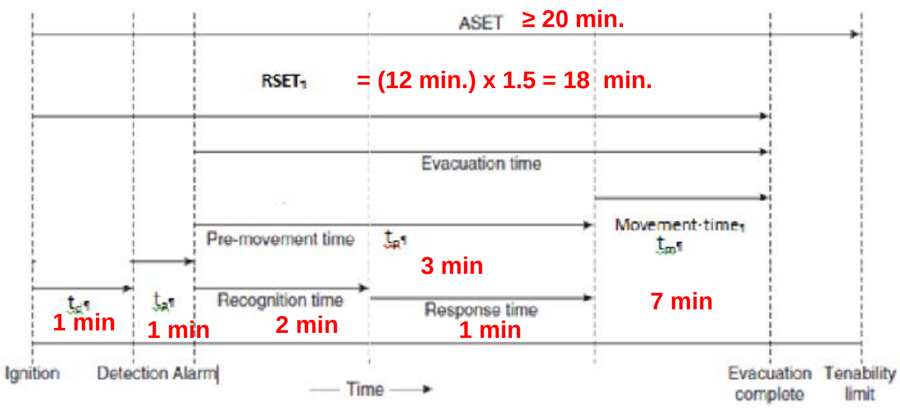
Egress Analysis – Pathfinder SFPE Meth.



Fire & Life Safety Objectives
Fire Scenario 1



DETACT Model Results (3 MW HRR Fire Simulated):
Smoke Detection Initiation @ 63 seconds
Sprinkler Activation @ 174 seconds

Part 8 Recommendations & Conclusions

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Conclusions

Fire Scenario 1: T_{ASET} = 20 min. > T_{RSET} = 12 min. x (1.5) = 18 min.

Tenability Limitation Criteria	FDS Modeling Results
Visibility must remain above 4 m at 1.83 m walking surface	Visibility maintained above 10 m at 1.83 m walking surface
Temperature must remain below 66° C at 1.83 m walking surface	Temperature maintained below 66° C at 1.83 m walking surface
Carbon monoxide concentration must remain below 1,400 ppm at 1.83 m walking surface	Carbon monoxide concentration is maintained below 1,400 ppm at 1.83 m walking surface

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Recommendations

- Fire Protection System Initial Integrated Testing & Commissioning
- Fire Protection System Regular Inspection, Testing & Maintenance (ITM)
- Ongoing Review of Evacuation Plan & Fire Management Plans
- Regularly Review & Update Life Safety Evaluation for Assembly Seating
- Regular Training for Auditorium Attendants on Fire Evacuation Plan

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Questions & Answers Session

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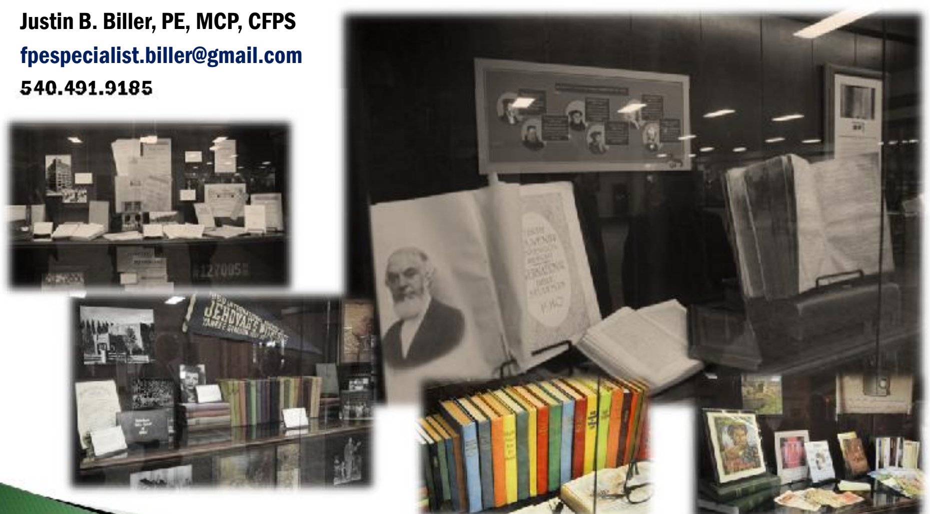

Historical Display Case

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