FIRE AND LIFE SAFETY ANALYSIS
PRESCRIPTIVE AND PERFORMANCE BASED APPROACH

CAL POLY RECREATION CENTER BUILDING # 43
SAN LUIS OBISPO, CALIFORNIA

CULMINATING PROJECT REPORT
CAL POLY FIRE PROTECTION ENGINEERING

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Keywords: Fire and Life Safety Analysis, RSET, ASET, Performance Based Design, Fire Dynamics Simulator (FDS)

EXECTUTIVE SUMMARY

The purpose of this fire and life safety analysis is to determine whether Cal Poly's Recreation Center meets fire safety goals. The primary fire safety goal is to provide building occupants with an environment that is tenable and allows for safe egress in the event of a fire, and reduce the likelihood of any catastrophic fire event. This goal can be achieved by protecting the occupants not intimate with the initial fire development and improving survivability of those occupants intimate with the initial fire development, NFPA 101, 2012.

A prescriptive-based design approach and a performance-based design approach are used to evaluate building safety. The prescriptive-based approach is used to evaluate the building's structural fire protection systems, fire detection and alarm systems, fire suppression systems and egress design, and is based on the 2007 California Codes in which the building was built.

The performance-based design approach is used to analyze how the building will perform in the event of a fire. The performance-based approach evaluates the building based on the required safe egress time (RSET) and available safe egress time (ASET) for occupants to evacuate the building safely in the event of a fire.

A tenability study was conducted to predict the effects of fire within the Old Gym space of the Recreation Center using natural ventilation to control smoke. The study is evaluated in this report using two computer software programs, Fire Dynamics Simulator (FDS) and Pathfinder, to determine if occupant safety is sufficient.

The results of this analysis showed inadequate time for people to egress safely from the gym with the fuel load of the bleachers. It was recommended that a mechanical exhaust smoke control system be installed to increase the ASET and allow everyone time to egress safely. This report remarks on the sprinkler system above the bleachers; questioning the reason for their design to be based off light hazard and not the class A plastic high pile storage.

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INTRODUCTION

This report covers the fire and life safety analysis of the new Cal Poly Recreation Center completed in January 2012. The new building was built onto part of an existing building. This report details the building, structural building details, occupancy, construction type, fire protection requirements, egress analysis, and code compliance of the Recreation Center. The renovation and expansion was designed in accordance with the prescriptive requirements in the 2007 California Building Code and the performance-based requirements in NFPA 101 2012. The Construction Life Safety Management Plan attached goes over what should have been provided during the construction phase of the new section of the Recreation Center and is attached as Appendix R.

APPLICABLE CODES

The most applicable codes examined are:

2007 California Building Code (CBC) Part 2, Title 24 C.C.R
2007 California Fire Code (CFC) Part 9, Title 24 C.C.R
NFPA 13, 2010 Standard for the Installation of Sprinkler Systems
NFPA 25, 2010 Standard for the Inspection, Testing, and Maintenance of Water Based Fire Protection Systems
NFPA 75, 2013 National Fire Alarm and Signaling Code
NFPA 101, 2012 Life Safety Code

Referenced sections are mentioned when used. When sections are referenced or “the Code” is referred to, the CBC is the reference code unless otherwise noted.

The SFPE Handbook 3rd edition and NFPA Hand Book 20th edition are also referenced within sections noted in text.

BUILDING DESCRIPTION

The expansion of the existing Recreation Center included remodeling approximately 26,300 ft^2 of the existing building and 100,275 ft^2 of new construction for a total of 165,717 ft^2. This new expansion contained a lobby, a 2-court gymnasium, administrative offices, six racquetball courts, a multi-activity center (MAC), weight fitness area, a wellness center, a cardio fitness area, exercise rooms, and a jogging track. The new additions are between two floors with all of the courts on the bottom floor and the other areas spread throughout. A floor plan is in Appendix A. The first floor has an approximate height of 18 ft. The second floor ceiling has varying heights throughout the gym. The cardio and weight lifting areas have a ceiling of 12 ft; but the track and basketball courts have the roof as their ceiling, which can reach 40 ft. The construction cost for the addition was $72 million and was funded by a $65 fee every quarter to every student since 2008. It opened its doors in 2012.

Prescriptive Based Fire Protection Analysis

USE AND OCCUPANCY

The Recreation Center building has multiple uses and occupancies. The courts, weight areas, and all other spaces not described as offices are occupancy A-3 as defined by CBC 303.1. The office space is categorized as occupancy B, section 304.1. Some rooms that hold low-hazard materials are listed as S-2 storage, section 311.3. After an occupancy classification has been given to each room where required, the corresponding load factor is applied to calculate the total occupancy for the space. The table below lists the occupancies and load factors for the Recreation Center. These load factors are used in Appendix B to find the occupancy of each room and floor of the building.

Table 1. Occupancy Type and Load Factor

Function of Space	Occupancy	Occupancy Load Factor (SF/person)
Business, office space	B	100
weight lifting space, exercise rooms with equipment	A-3	50
Racquetball Courts	A-3	8 per court
Assembly fixed seating	A-4	1 per 18 inches
Basketball Courts, multi-use assembly space, concentrated not fixed seating	A-3	7
Pre-function Space, standing non concentrated	A-3	15
Locker Room	A-3	50
Accessory Storage areas, mechanical equip room	S-2	300

HEIGHT AND AREA

The height and area limitations of a building vary based off the occupancy and type of construction. The main occupancy types are A-3 and B. The non-separated approach outlined in section 508.3.2 will be used. A-3 is the stricter of the two types and will be used in the following calculations to comply with, section 508.2. A-3 will be used when looking at Table 503 in section 503.1. The first floor has an area of 105,884 ft^2 and two stories above grade.

Table 2. Height and Area Allowances Based Off Construction Type

		TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
GROUP	HGT(feet) HGT(S)	UL	160	65	55	65	55	65	50	40
A-1	S	UL	5	3	2	3	2	3	2	1
	A	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500
A-2	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-3	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-4	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000

Several area modifications increase the allowable area in table 503, section 506.2.

$$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\}$$

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

A_t = Tabular are per story in accordance with Table 503.
I_f= Area increase factor due to frontage.
F = Building perimeter that fronts on a public way or open space having 20 feet (6096 mm) open minimum width (feet).
P = Perimeter of entire building (feet).
W = Width of public way or open space (feet) in accordance with Section 506.2

For the Recreation Center: F= 1,350ft, P=2000ft, W=30ft, $I_f = [1350ft/2000\,ft - 0.25]30/30$= .425
I_s is the sprinkler area increase and is 200% for buildings over two stories were the entire building is sprinklered, section 506.3.

$$A_a = \{15{,}500 + [15{,}500 * 0.425] + [15{,}500 * 2.0]\} = 53{,}087\ sqf$$

The area of the first floor at 105,884 ft^2 is well above 53,087sqf of type IIA. The first acceptable building type is then IB with an unlimited building area per floor and a maximum of 11 stories.

CONSTRUCTION TYPE AND FIRE RESISTANCE

Type IB construction has building elements listed in the table below which are noncombustible materials, except as permitted in section 603 of the Code. Per 602 there is no required fire resistance rating needed for exterior walls based on the building separation being over 30 feet.

Table 3. Fire Resistance Rating of Building Elements from Table 601

Building Element	Fire Resistance Ratings
Structural Frame	2
Exterior bearing wall	2
Interior bearing wall	2
Exterior Nonbearing walls and partitions	0
Interior Nonbearing walls and partitions	0
Floor construction	2
Roof construction	1

The structural frame consists of columns, girders, beams, trusses and spandrels having direct connections to the columns and bracing members designed to carry gravity loads. Floor and roof construction elements include their supporting beams and joists.

BUILDING ELEMENTS AND THEIR FIRE PROTECTION

The foundation uses reinforced concrete with footings for columns to attach. The steel columns are encased in 1.5 ft of concrete from the top of the pile cap to the top of the slab.

COLUMNS

The building uses different sizes of steel columns in its construction, outlined in Appendix C. A list of columns used is below. In order to protect these columns to a rating of 2 hours they are protected with Sprayed Fire Resistant Material (SFRM) These ratings were determined from UL X772 and are for contour sprayed columns.

Table 4. SFRM Thickness for 2 hour rating depending on Column Size

Column Size	Minimum SFRM Thickness for 2 hour rating in inches
W10x33	1-11/16
W10x39	1-3/8
W10x49	1-1/8
W10x60	1-1/8
W14x61	1-1/8
W14x74	1-1/8
W14X82	1-1/8

BEAMS AND JOISTS

The structural beams used in the building have a corresponding SFRM coating as well. These values comply with UL D739 using the nonspecific manufacturing company. This is also assuming that the concrete used is normal weight concrete for unrestrained assemblies.

Table 5 . SFRM Thickness for 2 hour rating depending on Column Size

Beam Size	Minimum SFRM Thickness for 2 hour rating in inches	
	Beam	Joist*
W12x19	7/8	1-1/2
W12x40	7/8	1-1/2
W12x53	7/8	1-1/2
W14x22	7/8	1-1/2
W16x31	7/8	1-1/2
W18x60	7/8	1-1/2
W24x62	7/8	1-1/2

The floor plans with beam sizes can be found in Appendix C.

SHAFT ENCLOSURES

Shaft enclosures are to be protected with a fire resistance rating of at least 1 hour, as the building is less than four stories, section 707.4. These enclosures include the elevators and any enclosed stairways. The openings in the floor of the second story looking into the lifting area and basketball courts do not have to be protected by a shaft enclosure as the opening only connects two stories, section 707.2 exceptions 7 and 10 for unenclosed stairs. Vertical exit stairs are unenclosed and do not need to be protected, section 1020.1 exception 9.

CORRIDORS

Section 1017.1 states that for a sprinklered building with business and assembly occupancy there is no rating requirement for corridors. No protection is needed around the second floor openings that abut corridors as the openings only span two floors and the corridors do not need to be rated. There are no corridor walls that are load bearing. The building is constructed with steel columns that hold all of the weight from the girders and beams that support the second floor and ceiling.

INTERIOR FINISH REGULATIONS

As has been demonstrated in several high casualty fires, interior finish can play a big role in spreading and starting a fire. Section 801.2 states that combustible materials can be used as finish for walls, ceilings, floors and other surfaces, but 801.2.2 states you cannot use foam plastics as an interior finish or trim except under section 2603.9 or 2604. These combustible materials for wall and ceiling finishes are governed in section 803. Under ASTM E 84 interior finished are classified into three groups with corresponding flame spread and smoke development values.

Class A: Flame spread 0-25; smoke-developed 0-450
Class B: Flame spread 26-75; smoke-developed 0-450
Class C: Flame spread 76-200; smoke-developed 0-450

Table 803.5 lists the class of interior finishes allowed in areas depending on the occupancy classification. As the building is mixed use with assembly, A-3, and business, B, the more strict regulations of A-3 will be used for interior finishes.

Exit enclosures and exit passageways:	Class C, exception b building only 2 stories
Corridors:	Class B
Rooms and enclosed spaces:	Class C

MEANS OF EGRESS

Egress requirements stem from the occupancy and the occupant load based off the area of the space. There are several egress requirements that the code provides that need to be taken into account, including: the required exit width for the number of occupants, section 1005.1; minimum number of exits due to occupant load, sections 1015.1 and 1019.1; exit arrangement, section 1015.2; and minimal travel distance from the most remote location within a story to an entrance of an exit, section 1016.1. There are also special requirements for assembly occupancies that must be followed in section 1025, and turnstiles that are the main entrance and exit are covered in section 1008.3.

REQUIRED EXIT WIDTH

Based off the occupancy load factors presented earlier, the total number of occupants is 5,878 for the first floor and 2,815 for the second floor. This can be seen in Appendix B. For egress requirements each floor is looked at individually, section 1004.4, as long as the exit capacity does not decrease in the direction of egress. Many exits in the Recreation Center are not for the public and serve as either small office space or storage space. The areas that need attention are the main exits that serve the vast majority of the occupants of the building. The required exit widths are calculated using table 1005.1 with the occupant loads that were calculated for each floor or area served. For stairways, the egress width must be 0.2 inches per occupant and for all other egress components; the required width is 0.15 inches per occupant. As the clear width for a standard door is 34 in, the occupant load per exit door is 226 people. However, section 1025.2 states that an assembly area with more than 300 occupants served must provide 0.2 inches per occupant. The total loads on each exit door are shown in Appendix B in front of each door.

Table 6. Egress Width Capacity

Location	Occupant Load.	Required Egress Width	Provided Width
Far West Exit	804	120.6	136
Middle of Building	452	67.8	68
Main East Entrance and Exit	1379	206.85	204
MAC	1230	246	340
North West Weight Area	452	67.8	68
Basket Ball Gym	1922	384.4	204
Old Existing Gym	1869	373.8	816
Pre-function Space	1221	183.15	408

The table above suggests an issue with the basketball gym. There are not enough exits for the space according to the code. This can be solved by adding more exits or agreements with the authority having jurisdiction. Besides the aforementioned exits, there is enough exit capacity for the Recreation Center.

EXIT ARRANGEMENT

Section 1015.2 covers the exit arrangement with respect to other exits. It states that when two exits are required the doors shall be placed a distance apart that is at least one-third the maximum overall diagonal of the used space, for a sprinklered building exception 2. This code is in place to keep more than one exit from becoming incapacitated from an incident due to the proximity of the exits. When there are three or more exits that are required for a space, at least two exit doors shall be arranged in this way. The Recreation Center and its rooms meet this requirement as seen in Appendix D.

TRAVEL DISTANCE

The maximum distance of travel from the furthest point away from an exit as listed from table 1016.1 is 250ft for assembly spaces and 300ft for business occupancy. The travel distances of the most remote locations of the building are shown in Appendix E.

SPECIAL REQUIRMENTS

Section 1025 of the code deals with egress requirements for assembly occupancies and is discussed here. Assemblies with occupancies above 300 are required to have a main exit. As many of rooms with over 300 occupants have a clearly defined exit the exception for 1025.2 states that the exits can be distributed around the perimeter provided that the total width of egress is at a minimum the required width. Additionally, one exit shall discharge directly to an exit, through a lobby to an exit, or a 1-hour rated corridor to an exit. All of the assembly spaces conform to this exception.

The basketball court located next to the main entrance has a posted occupant rating of 300 people, monitored by the management of the Recreation Center. If the basketball gym was classified by the code as an assembly space with 15 ft^2/person, then the occupant load would be 1922. This would require more exits; hence, it is capped at 300 people.

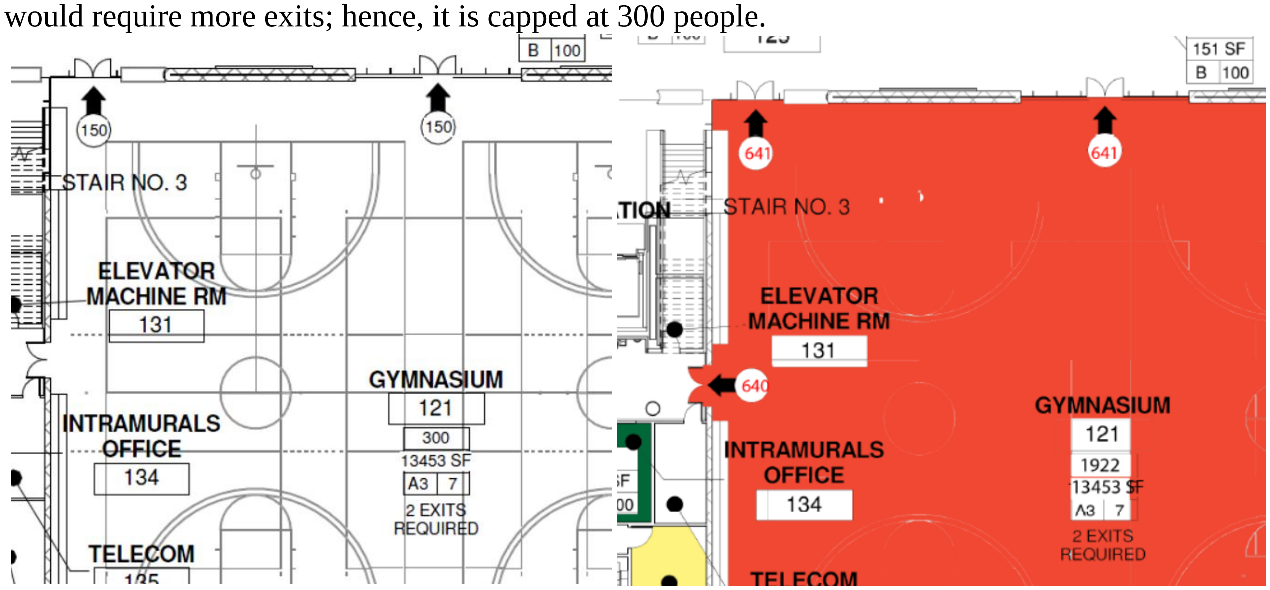


Figure 1. Gym as it stands on the left and gym as it could have been loaded.

Currently there are five turnstiles located at the main entrance to restrict unauthorized access to the building. Section 1008.3 states that turnstiles shall not be placed to obstruct any required means of egress. The only exception is if the turnstiles meet four additional criteria, but the exception only

allows for 50-person capacity per turnstile. With five turnstiles, that is 250 people, but the required egress is 260. This should be addressed, or discussed by facilities and risk management.

Figure 2. Turnstiles in place at the Recreation Center.

Fire fighter access and exterior exit locations can be found in Appendix F. Followed by the buildings exit signage layout and fire wall ratings in Appendix G.

SPRINKLER SYSTEMS

A standard wet pipe sprinkler system per NFPA 13, 2010 is employed to protect the Recreation Center.

CLASSIFICATION OF OCCUPANCY

The Recreation Center has two different classifications based on different hazards in particular areas. The majority of the building is Light Hazard, and includes administration, classrooms, and workout areas. The Janitor's closets, storage rooms, electrical rooms, telecom rooms, and mechanical rooms are classified as Ordinary Hazard.

WATER SUPPLY

FLOW TEST

A flow test was taken 3/8/2010 using two hydrants pictured in Appendix H and was the basis for the water supply. The flow test data sheet can be found in Appendix I.

Table 7. Flow Test from Hydrants next to Recreation Center on 3/8/2010

Flow Test	
Flow (gpm)	1186
Residual Pressure (psi)	132
Static Pressure (psi)	140

SYSTEM COMPONENTS

PIPING

The sprinkler system is fed by a city water supply in a 12 in PVC pipe that also feeds several hydrants that encircle the building, Appendix H. An 8 in PVC pipe tee's off the 12 in pipe that then attaches to a 6 in PVC pipe and then to the bottom of the riser where it connects to a 6 in schedule 40 steel pipe. The riser itself is 4 in, extends up 14 ft, and connects to a 3 in cross main system. The system branches out using pipes from 3 in down to 2.5 in pipe for the cross mains. The branch lines start at 2.5 in and move down to 1 in with sprinklers attached along as needed.

RISER

There are two risers comprised of a 4 in black steel pipe that connects to a control valve with its own monitored tamper switch. The risers continue up to a check valve to ensure water flows in the direction it is intended, which is up and out. There is a pressure gauge at the check valve measuring the supply water pressure and one after measuring the systems pressure. The fire department connection tee's into the riser after the check valve and continues to the exterior of the building, as seen in Appendix J with a close up of the systems pressure gauge. The Fire Department Connection (FDC) also has a check valve to ensure water does not flow out of the building. After the FDC tee connection, a water flow detector that is supervised and connected to the fire alarm system. The riser layout can be seen in Figure 3.

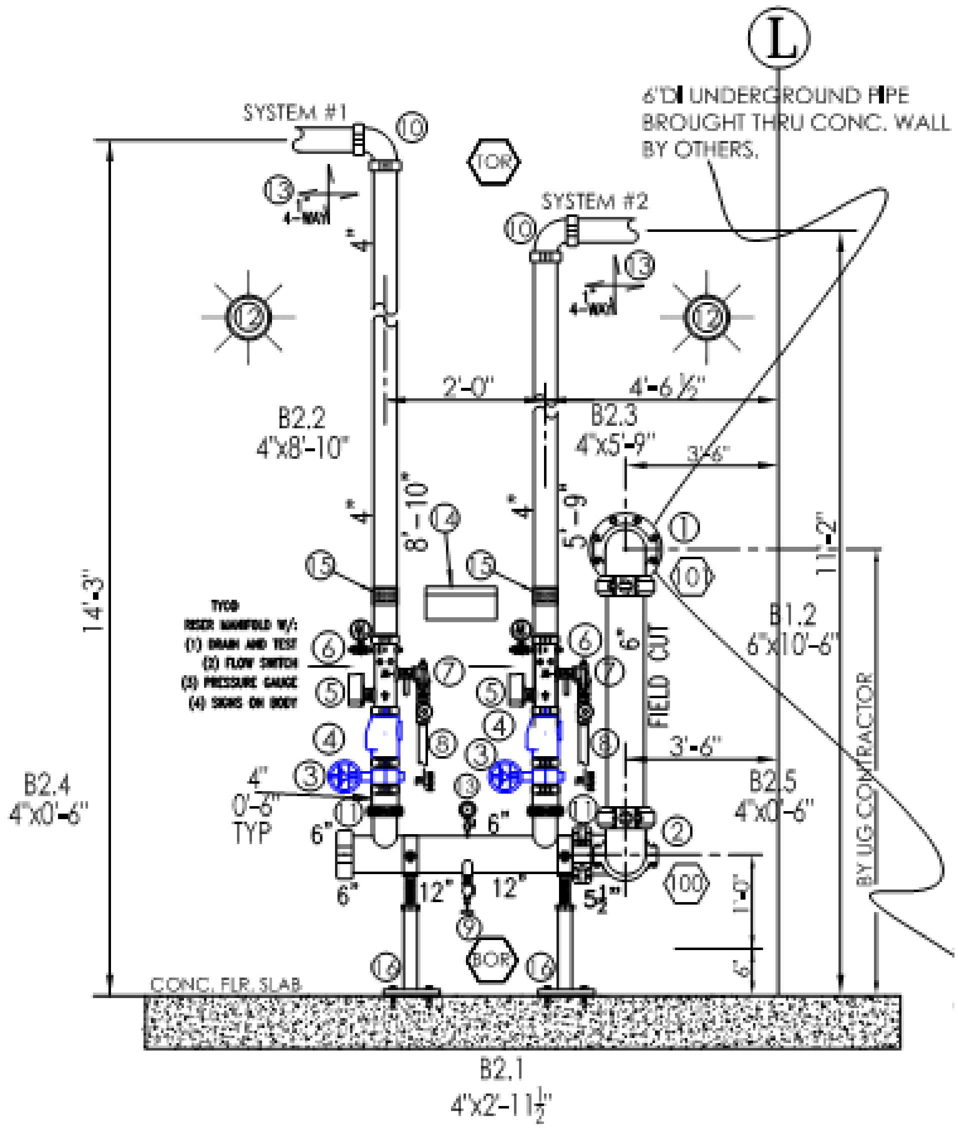


Figure 3. Riser for Recreation Center

SPRINKLERS

The sprinklers used throughout the building are by Viking and use uprights throughout most of the building, but include horizontal sidewall sprinklers. The sprinklers have an activation temperature of 155°F, K-factor of 5.6 with a ½" threaded connection. The sprinkler plans for the building are found in Appendix K.

MANUAL HYDRAULIC CALCULATIONS

DESIGN CRITERIA

According to Figure, 11.2.3.1.2, in NFPA 13, designing for light hazard gives you a discharge density of $0.10gpm/ft^2$ at $1{,}500ft^2$. Table 11.2.3.1.2 lists the hose stream allowances and system duration requirements. For light hazard, the combined inside and outside hose stream is 100gpm and a duration of 30 minutes. The table on the next page summarizes these criteria.

Table 8. Sprinkler Design Criteria

Design Criteria for Light Hazard	
Discharge Density (gpm/ft2)	0.1
Area of Operation (ft2)	1,500
Total Hose Stream (gpm)	100
System Duration (min)	30
Area per sprinkler	163
C-Factor	120

Table 9. Example remote area water demand calculation

Knowing the area per sprinkler and the area of operation, the number of sprinkler heads to design for can be calculated: $N_s = \frac{Area\ of\ Operation}{Area\ per\ Sprinkler} = \frac{1500}{163} = 9.2$ As you cannot have 9.2 sprinklers the number is rounded up to 10. Below is a sample calculation of a remote area in the Recreation Center. The full calculation can be found in Appendix L.

Step No.	Nozzle ID and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Notes	
	S1		q			1E	L	5	C=	120	Pt	4.6	k=	5.6
1	to				1.049		F	2			Pe	-0.9		Q=120*0.1=12
	1A	BL1	Q	12.0			T	7	pf	0.051	Pf	0.4	Pt=	4.6
	1A		q	0.0		1E	L	11	C=	120	Pt	4.1	k=	0
2	to				1.38	1T	F	9			Pe	3.9		q = k * (Pt)^1/2
	2A	BL1	Q	12.0			T	20	pf	0	Pf	0.3		
	2A		q	16.1			L	11.5	C=	120	Pt	8.2	k=	5.6
3	to				1.38		F	0			Pe	0.0		
	3A	BL1	Q	28.1			T	11.5	pf	0	Pf	0.7		
	3A		q	16.8			L	11	C=	120	Pt	9.0	k=	5.6
4	to				1.38		F				Pe	0.0		
	4A	BL1	Q	44.9			T	11	pf	0	Pf	1.7		
	4A		q	16.3			L	12	C=	120	Pt	10.7	k=	5.6
5	to				1.61		F				Pe	0.0		
	5A	BL1	Q	61.2			T	12	pf	0.128	Pf	1.5		
	5A		q	0.0		1T	L	13.5	C=	120	Pt	12.2	k=	0
6	to				1.61		F	8			Pe	3.5		
	6A	BL1	Q	61.2			T	21.5	pf	0.000	Pf	0.0		
	6A		q	0.0		1T	L	10	C=	120	Pt	15.7	k=	0
7	to				1.61		F				Pe	0.0		
	7A	BL1	Q	61.2			T	10	pf	0.000	Pf	0.0		
	Branch line 1												K=	15.457

The graph below shows the supply and demand of the sprinkler system with the water supply from the city line. The supply is so strong that there is no need for a fire pump.

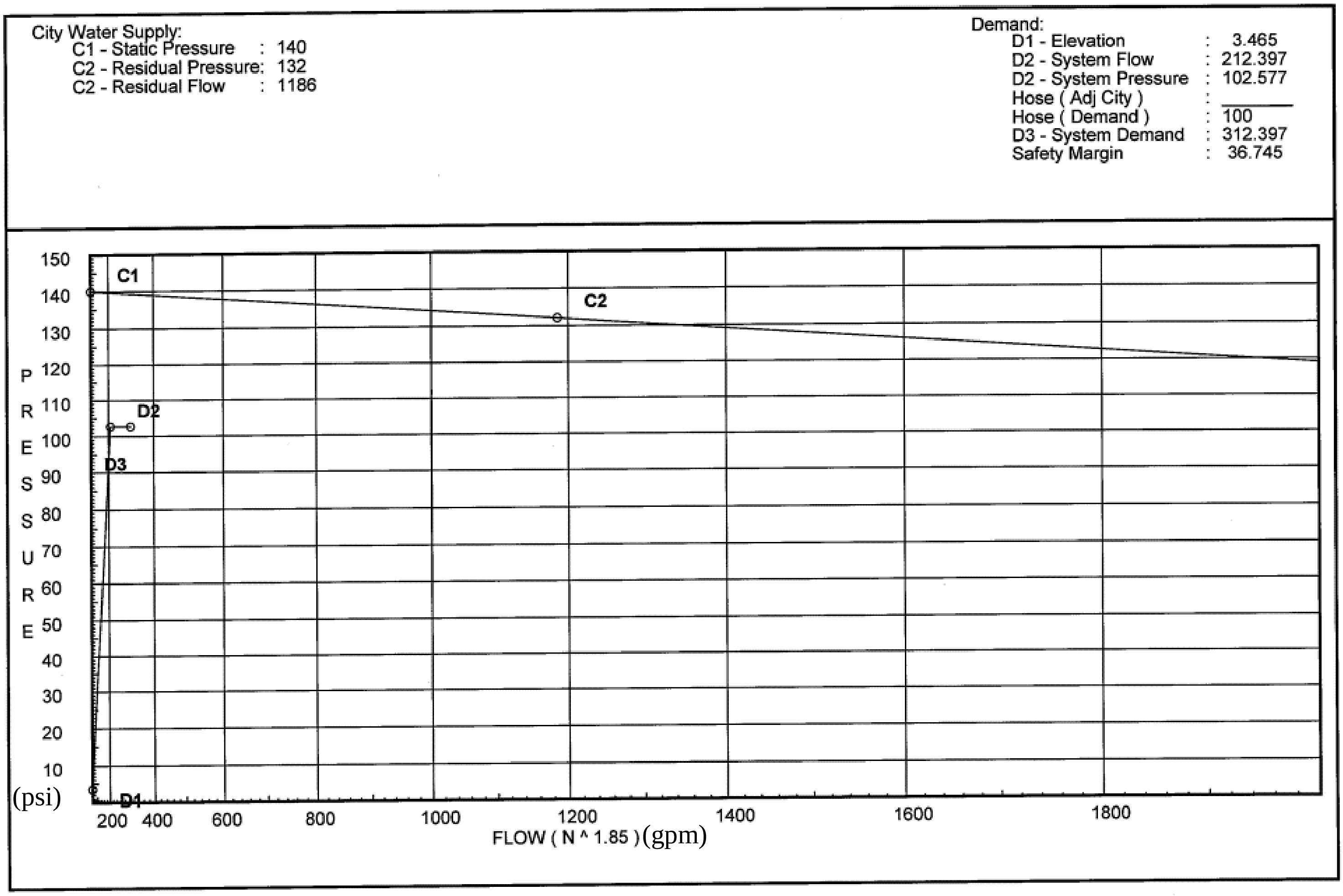


Figure 4. Water Supply and Demand Curve

INSPECTION, TESTING AND MAINTENANCE

Without proper care, sprinkler systems, and fire protection systems in general, can become useless. Many systems that have been in buildings for years are neglected and assumed to operate in the event of a fire. NFPA 25 is the standard for Inspection, Testing, and Maintenance of fire protection systems. The fires that make it to the news are not the ones that have a perfectly operating sprinkler system, but are the ones that either have no sprinkler system or have one that has not been inspected or tested in years. The following table is a guide that was tabulated from requirements in NFPA 25.

Table 10. Sprinkler system inspection testing and maintenance

Sprinkler System Component	Inspection	Frequency	Testing	Frequency	Maintenance
Water flow alarm devices	Shall be free from physical damage.	Quarterly	Open the inspectors test connection to check	Semiannually	According to the manufactures instructions
Control Valves	Verify that the valves are in the normally open or closed position, sealed, locked or supervised, accessible, PIV's provided with correct wrenches, free from external leaks.	Monthly	Operated through its full range and returned to its normal position.	Annually	According to the manufactures instructions
Gauges	Shall be in good condition and that normal water supply pressure is being maintained	Quarterly	Shall be replaced or tested by comparison with a calibrated gauge.	5 years	According to the manufactures instructions
Hanger/Seismic Bracing	Shall not be damaged, loose or unattached.	Annually	-	-	-
Pipe and Fittings	Shall be free from mechanical damage, leakage, and corrosion. Shall not be subject to other loads by material resting, or hung on pipe.	Annually	-	-	-
Sprinklers	Shall not show sign of leakage; be free from corrosion, foreign materials, paint, and physical damage. Any showing these signs shall be replaced. Sprinklers manufactured prior to 1920 shall be replaced	Annually	Sample sprinklers shall be submitted to a recognized testing laboratory acceptable to the AHJ for field service testing.	Depending on the type but at 50 years and every 10 years thereafter.	Spare sprinklers shall be kept on site for replacement if a sprinkler fails inspection.

SPRINKLER SYSTEM FINDINGS

The sprinkler system in the Recreation Center was designed to code and provides good coverage for all of the different areas and hazards. However, there are places where, in my opinion, the sprinklers could be potentially useless. The ceilings on the second floor in several locations- the existing gym, the new basketball courts and the track area- are all well over 40 ft tall, some almost 80 ft. Given this height and the massive amount of volume in the space, it would take a huge fire to activate the sprinklers in those areas. This is an instance where the code drives the requirement in order to have unlimited area, but there are definitely locations where the sprinklers would have almost no effect on a fire. NFPA 13 section A.8.1.1 states that, “based upon experience and testing, sprinklers have been found to be effective and necessary at heights in excess of 50ft. For a building to meet the intended level of protection afforded by NFPA, 13 sprinklers must not be omitted from such high ceiling spaces.” This may be true if the correct sprinkler type is used, but for light hazard design with quick response sprinklers? I do not think so. The sprinkler system in much of the space would be helpful and will remain that way as long as inspections and testing continue to make sure the system is still operational.

The biggest hazards in the gym are actually the retractable polyethylene bleachers. They stand 25ft tall. According to NFPA 13 table A.5.6.3, uncartoned plastic is a Class A plastic. This means the Chapter 15 Protection Criteria for Solid Pile of Plastic Commodities should be used to protect the gym space. The problem is that using the control mode density/area sprinkler method the maximum ceiling height allowed is 35 ft. Looking at table 15.4.1 in NFPA 13 for solid pile, exposed unexpanded plastic using Early Suppression Fast-Response Sprinklers the maximum ceiling height for a storage height of 25 ft is 40 ft. The ceilings span from 52ft to 72ft. With the current code, there is no proper way to protect a fuel load this great.

FIRE ALARM AND DETECTION SYSTEM

ALARM SYSTEM CODE REQUIREMENTS

For Group A assembly occupancy a manual fire alarm system shall be installed if the occupant load is above 300, as stated in section 907.2.1. In addition, section 907.2.1.1 states that an occupant load of over 1,000 shall initiate a signal using an emergency voice/alarm communications system in accordance with NFPA 72. California State Fire Marshal amendment, section 907.2.3.6.1, states that a listed automatic system shall be provided in all new public campuses and be both automatic and manual. All of the stated codes apply and must be adhered to.

SEQUENCE OF OPERATIONS

The following figure is the sequence of operations for the Recreation Center. It details what system inputs correspond to an output if the input requires a trouble, supervisory or alarm signal. A trouble signal is initiated by the fire alarm system or device and indicates a fault in a monitored circuit or component. A supervisory signal implies the need for action in connection with the supervision of the fire suppression system or the maintenance of related systems. An alarm signal is initiated by a fire alarm-initiating device such as a manual fire alarm box, automatic fire detector, water-flow switch, or other device in which activation is indicative of a fire being present.

Table 11. Sequence of Operation for the Recreation Center

General Alarm Voice Sequence of Operations

**AUDIBLE MESSAGE TO BE:
– (FEMALE VOICE, ENGLISH) "MAY I HAVE YOUR ATTENTION, PLEASE. "MAY I HAVE YOUR ATTENTION, PLEASE. THERE HAS BEEN A FIRE ALARM REPORTED IN THE BUILDING, THERE HAS BEEN A FIRE ALARM REPORTED IN THE BUILDING, PLEASE PROCEED TO THE NEAREST EXIT AND LEAVE THE BUILDING.

① SHUNT TRIP OF ELEVATOR MUST NOT BE ACTIVATED UNTIL PHASE 1 ELEVATOR RECALL HAS BEEN COMPLETED, OR WHILE PHASE 2 ELEVATOR SHUNT DISABLE KEYSWITCH IS ACTIVE

② FOR SPECIAL AMUSEMENT OCCUPANCY LOCATIONS

System Outputs

		Control Unit Annunciation						Notification									Required Fire Safety Control											Supplementary							
		Activate control panel trouble buzzer and LED	Activate control panel supervisory buzzer and LED	Activate control panel alarm buzzer and LED		Annunciate at remote fire alarm annunciator		Send signal to supervising station (24hr attended location)	Activate all audible**/visual devices throughout the building	Activate sprinkler alarm device	Send signal to elevator hat light	Notify fire department via supervising station	Activate associated residential sounders				Shutdown required air handling (HVAC) units throughout bldg	Close all combination smoke fire dampers throughout bldg	Open elevator shaft dampers		Recall associated elevator(s) (1st flr goes to alt.)	Shunt Elevator power ①	Activate elevator door smoke containment device throughout bldg	Disable elevator shunt trip ①		Close all won/roll down doors & shutters throughout bldg									
	System Inputs	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FF	GG	
1	Manual fire alarm box			●		●		●	●			●					●	●																	1
2	Area smoke detector/heat detector			●		●		●	●			●					●	●								●									2
3	Top of stair smoke detector			●		●		●	●			●					●	●								●									3
4	Air duct smoke detector		●			●		●									●	●								●									4
5	Return-air/in-duct smoke detector		●			●		●									●	●								●									5
6	120VAC duct smoke detector		●			●		●									●	●								●									6
7																																			7
8																																			8
9																																			9
10	Sprinkler water flow switch			●		●		●	●	●		●					●	●								●									10
11	Sprinkler valve tamper switch		●			●		●																											11
12	Sprinkler post indicator switch		●			●		●																											12
13	Elevator lobby smoke detector			●		●		●	●			●					●	●			●		●			●									13
14	Elevator mach room/shaft smoke detector			●		●		●	●		●	●					●	●	●		●	●				●									14
15	Elevator mach room/shaft heat detector			●		●		●	●		●	●						●	●							●									15
16	Elevator Ph2 shunt disable signal 1		●			●																		●											16
17	Elevator 120vac shunt trip circuit failure		●			●		●																											17
18																																			18
19																																			19
20																																			20
21																																			21
22																																			22
23	FACP 120vac power failure	●				●		●									●	●								●									23
24	System device wiring trouble/fault	●				●		●																											24
25	Open circuit	●				●		●																											25
26	Ground fault	●				●		●																											26
27																																			27
28																																			28
29																																			29
30																																			30
31																																			31
32																																			32
33																																			33
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FF	GG	

SEQUENCE OF OPERATION

ALARM SYSTEM COMPONENTS

The fire alarm system in place at the Recreation center is an alarm and notification system with manual and automatic detection. The system is based around a Notifier Fire Alarm Control Panel model NFS2-640 as seen below. This control panel has the capability of having one or two signaling line circuits, and can hold a total of 636 total devices, and 159 detectors/modules per signaling line. There are four built-in Notification Appliance Circuits (NACs) with 1.5 amps each. It also includes a digital voice command for voice evacuation, which is used for the In-Building Fire Emergency Voice/Alarm Communications system. This system distributes voice instructions as alert or evacuation signals pertaining to fire emergencies. The FACP has its own room in the northeast section of first floor as seen in figure 2; it must be located 66” above a finished floor from the top of the box.

Figure 5. Notifier NFS2-640 Fire Alarm Control panel

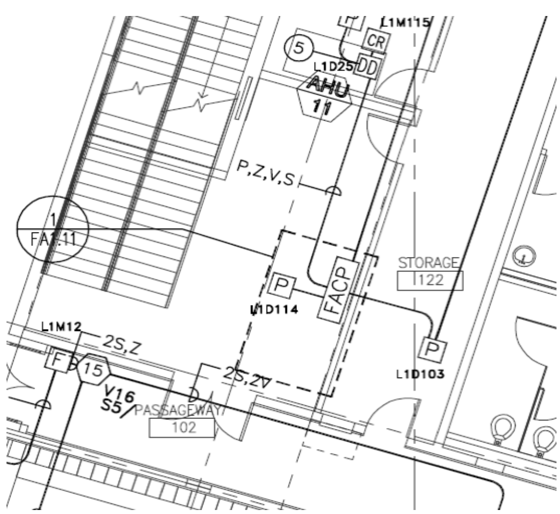


Figure 6. Location on Fire Alarm as builds of Fire Alarm Control Panel

The Recreation Center also has a remote annunciator (ANN) located next to the reception desk in the front of the gym next to the main entrance. Figure 4 shows its location, but it is not actually shown on the fire alarm as built drawings, Appendix M. It seems like the annunciator was simply left off the drawing altogether. The ANN should be mounted 66" from the finished floor to the top of the ANN.

Figure 7. Notifier remote annunciator model FDU-80

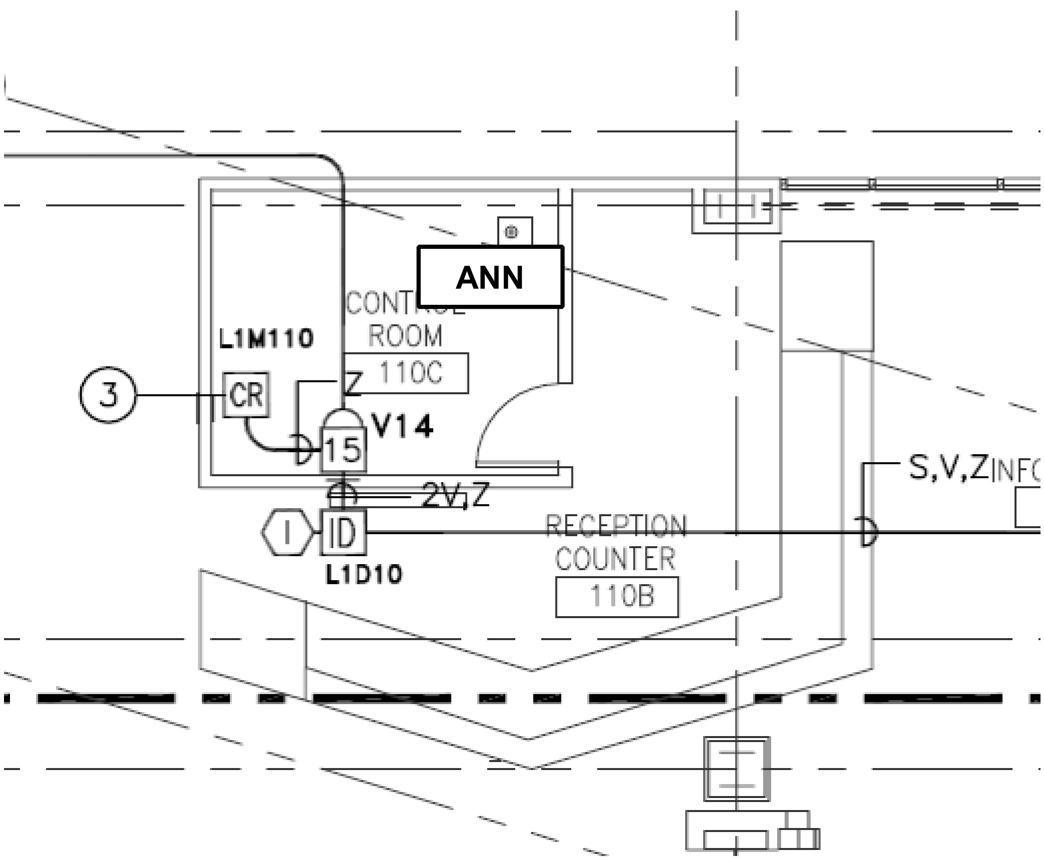


Figure 8. Drawing of where the remote annunciator is located in the Recreation Center

DETECTION DEVICES

All detection devices use two conductor 16AWG twisted and shielded wire from West Penn #D975. All conduits in the building are rigid steel ¾" unless otherwise stated. The Recreation Center uses smoke detectors, heat detectors, duct detectors, and water flow detectors as part of its automatic fire alarm system. Manual pull stations make up the manual fire alarm system.

SMOKE DETECTORS

The smoke detectors used are Notifier FSP-851 with a base model B710LP. They are photoelectric smoke detectors; 19 of them are spread throughout the building in mechanical and electrical spaces. There are some smoke detectors in the storage spaces of the old section of the Recreation center where they left the wire and conduits in place and simply updated the devices. These devices are to be ceiling mounted and spaced 30 feet apart or 0.7*30ft in the rooms that they occupy. This is not a problem as there is only one storage space in the building that contains more than one smoke detector.

Figure 9. Notifier FSP-851 photoelectric smoke detector or FST-851 heat detector

This is the same detector that is used as a duct detector to prevent the spread or recirculation of smoke, and is installed on the supply side of air-handling systems. These smoke detectors are placed in accordance with NFPA 72 section 17.7.5, Smoke Detectors for Control of Smoke Spread.

HEAT DETECTORS

The Recreation Center uses Notifier FST-851 heat detectors; they share the exact same body as the Notifier smoke detector and just have different electronics in them. There are only 3 of these heat detectors, which are located in the Elevator machine rooms. There are two located in the north elevator machine room, as shown below, and one in the south elevator machine room.

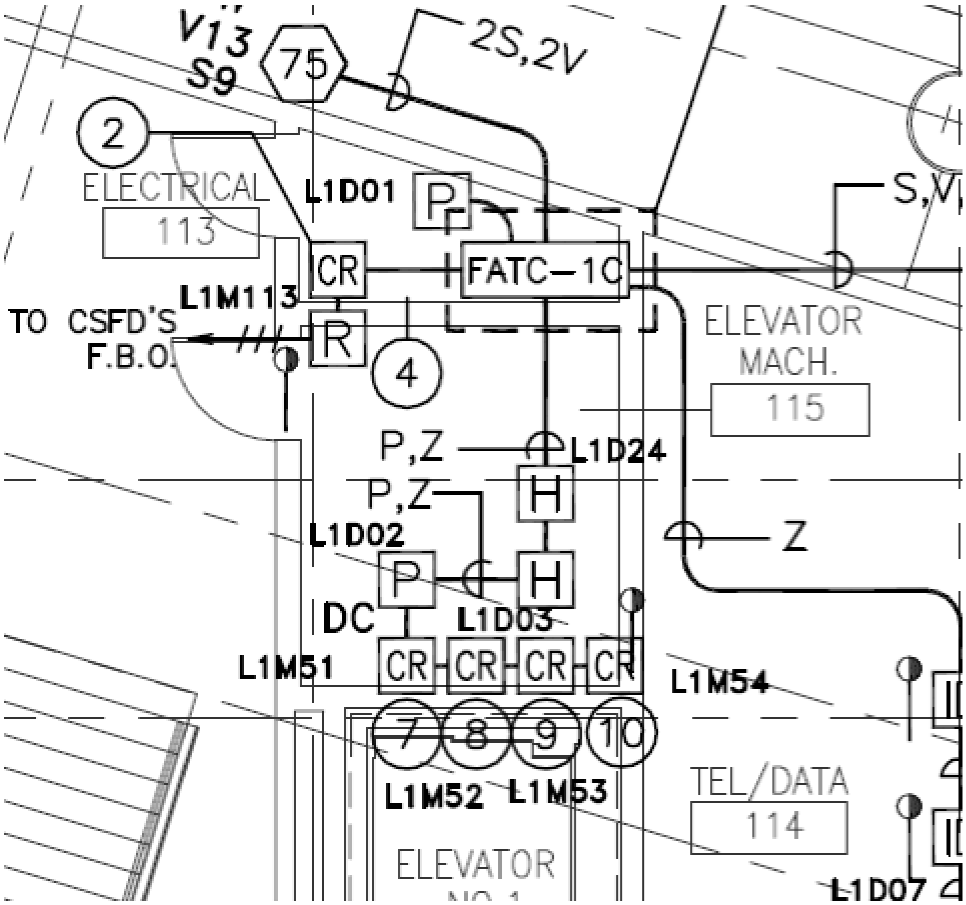


Figure 10. North Elevator machine room heat detector locations

The Recreation Center is also equipped throughout with an automatic sprinkler system, where each sprinkler head is essentially a heat detector. These sprinkler heads are quick release sprinklers that have an activation temperature of 155°F. Unfortunately throughout much of the Recreation Center the ceilings are anywhere from 40ft to 72ft tall; only a sizable fire can activate the sprinklers.

WATER FLOW DETECTOR

The Recreation Center uses a Potter VSR-S, Vane-Type Waterflow Switch as shown in figure 11. Once a sprinkler has been activated there is a maximum 90 second lag time as per Section 17.12.2 NFPA 72. This is to allow for surges in pressure to the water supply so there are not false alarms anytime the paddle moves a little in the pipe. Many of these systems are set up for quicker initiation than 90 seconds, and are usually between 30 and 45 seconds. Three risers supply the building's sprinkler system; two for the new section and one for the old. Each of them have their own flow detection. They are located directly behind the backflow preventer for each riser. The flow switch activates via a simple switch connected to the paddle inside the riser, as shown on the bottom of figure 7. When the water flows it toggles the switch and sends a signal back to the FACP.

Figure 11. Potter VSR-S, Vane-Type Waterflow Switch

MANUAL PULL STATIONS

At any exit to the exterior where the occupancy of the room is above 300 for assembly occupancy, the Recreation Center is supplied with a manual pull station. As most of the areas in the Recreation Center have assembly occupancies above 300, every major exit has a manual pull station. These pull stations are from Notifier model NBG-12LX, and are to be mounted at a height between 42in and 48in from the floor to the operable part of the pull station as per section 17.14.5, NFPA72. The manual pull station must also be located within 5ft of each exit doorway on each floor, and not exceed 200ft measured horizontally from the next nearest pull station by 17.14.8.4 and 17.14.8.5.

Figure 12. Manual Pull Station Notifier NBG-12LX

NOTIFICATION APPLIANCES

Once a detection device has activated the FACP gets a signal and activates the entire Recreation Center's alarm system. Even though the building is large enough to have a staged evacuation, it would be impractical. There is so much open and common space that if less than half the building went off the other part of the building would hear it, become confused, and incorrectly assume to exit. As such, the Recreation Center is set up to have enough exits for simultaneous evacuation of the entire building. The notification appliances described below are wired with 2 conductors containing 12AWG stranded wire. These are put into at least ¾" conduits unless specified in the fire alarm drawings in Appendix M.

SPEAKERS

There are two types of speakers used for the Recreation Center: System Sensor SPWK, and System Sensor SPCW. The SPWK speakers are a waterproof speaker that has been listed for outdoor use under UL S4048 for outdoor Fire Protective Signaling Systems. Both speakers have power taps from ¼ watt to 2 watts to make sure that the speakers can produce an alarm at 15db above the average ambient noise level as per 907.9.2 CBC 2007. The audible signal shall be the

standard fire alarm evacuation signal, ANSI S3.41 Audible Emergency Evacuation Signal, "three pulse temporal pattern," by section 907.9.2.1 CBC. The speakers also must be able to produce a prerecorded evacuation message with voice intelligibility within the acoustically distinguishable spaces under 18.4.10 NFPA 72. These spaces are to be set up by the system designer as per 18.4.10.1. The intelligibility shall not be required to be determined through quantitative measurements by section 18.4.10.4. Model SPWK is a wall mounted speaker that shall be at a height not less than 90 in, and model SPCW is a ceiling mounted speaker that has no specific spacing requirements.

Figure 13. System Sensor SPWK water proof speaker for outdoor use left, and SPCW ceiling mounted right

STROBES

On top of having an audible alarm system the Recreation Center has visible notification as well. In use is both a wall mounted strobe device, System Sensor SW, and ceiling mounted strobe device, System Sensor SCW or SCKR. The difference between the SCW and SCKR model is that the SCW is a white indoor use strobe and the SCKR is a red outdoor waterproof version. Strobes are required by CBC section 907.9.1.1, "visible alarm notification appliances in public use areas and common use areas, including but not limited to: Restrooms, shower rooms, corridors, gymnasiums, multipurpose rooms, lobbies, and meeting rooms." The code section lists more but these rooms take up a majority of the space in the Recreation Center. The strobes' intensity can all be adjusted depending on the size of the room and the minimum required light output. These strobes can be adjusted to 15, 30, 75, 95, or 115 candela. Table 1 and 2 give a guide for the size of the room and the minimum amount of light output needed depending on the strobes' mounting. Ceiling mounted strobes shall not be mounted above 30ft; if the ceiling is over 30ft then they should be suspended from the ceiling unless the 18.5.5.6 performance-based alternative determines a different mounting height under 18.5.5.4.6 NFPA 72. For wide-area signaling the AHJ shall approve the design. Wall mounted strobes shall be mounted such that the entire lens is between 80in and 96in above the finished floor. If the ceiling is lower than 80in the strobe is to be located 6in below the ceiling, and the room size covered by a single strobe is to be reduced by twice the difference between the minimum mounting height of 80in and the actual lower mounting height.

Figure 14. System Sensor Model SCW (left), and Model SCKR (right) strobes

Table 12. Room Spacing for Wall-Mounted Visible Appliances, Table 18.5.5.4.1(a)

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

NA: Not allowable.

Table 13. Room Spacing for Ceiling-Mounted Visible Appliances, NFPA 72 2013

Maximum Room Size ft	Maximum Room Size m	Maximum Lens Height* ft	Maximum Lens Height* m	Minimum Required Light Output (Effective Intensity); One Light (cd)
20 × 20	6.1 × 6.1	10	3.0	15
30 × 30	9.1 × 9.1	10	3.0	30
40 × 40	12.2 × 12.2	10	3.0	60
44 × 44	13.4 × 13.4	10	3.0	75
20 × 20	6.1 × 6.1	20	6.1	30
30 × 30	9.1 × 9.1	20	6.1	45
44 × 44	13.4 × 13.4	20	6.1	75
46 × 46	14.0 × 14.0	20	6.1	80
20 × 20	6.1 × 6.1	30	9.1	55
30 × 30	9.1 × 9.1	30	9.1	75
50 × 50	15.2 × 15.2	30	9.1	95
53 × 53	16.2 × 16.2	30	9.1	110
55 × 55	16.8 × 16.8	30	9.1	115
59 × 59	18.0 × 18.0	30	9.1	135
63 × 63	19.2 × 19.2	30	9.1	150
68 × 68	20.7 × 20.7	30	9.1	177
70 × 70	21.3 × 21.3	30	9.1	185

*This does not preclude mounting lens at lower heights.

COMBINATION SPEAKER AND STROBE

Most of the notification devices in the Recreation Center are a combination of speaker and strobe. System Sensor model SPSW is a wall mounted speaker strobe that is used throughout the gym. System Sensor Model SPSW and SPSWK are used for the big gyms where balls or other projectiles can hit them and outdoor use, respectively. The some of the SPSW speaker strobes have a wire guard and are only used with the 110 candela setting for vast area coverage such as big gym areas. Both the strobe and speaker requirements from the two previous sections apply for the speaker/strobe devices. Below are the different speaker/strobes used in the building. All fire alarm components data sheets can be found in appendix N.

Figure 15. System Sensor Speaker/Strobe Model SPSW left and middle, and SPSWK right

POWER SUPPLY REQUIREMENTS

Two independent and reliable power supplies are required, one primary and one secondary. They both must be adequate for the application as per section 10.6.3 NFPA 72. The primary supply for the Recreation Center is a branch line supply from commercial light and power. The secondary power supply shall automatically provide power within 60 seconds of the primary power failing to supply enough power to the system. The secondary power supply must be capable of operating the in-building fire emergency voice/alarm communications service under quiescent load for a minimum of 24 hours and 15 minutes under fire or other emergency conditions. The secondary power supply for the Recreation Center are battery packs with an example of a battery calculation shown on the next page. The rest of the battery calculations can be found in Appendix M.

Table 14. Battery calculation example for the FACP

Quantity	Device Type	Model	Standby Current	Total Standby Current	Alarm Current	Total Alarm Current
1	NFS2-640	CPU2—640 w/CPS—24	0.325	0.325	0.285	0.285
1	NFS2-640	KDM—R2	0.1	0.1	0.1	0.1
1	Voice	DVC&DVC—KD	0.5	0.5	0.5	0.5
32	Control Relay	FRM—1	0.00026	0.00832	0.0065	0.208
11	Duct Det	DNR w/ FSP—851	0.00036	0.00396	0.00686	0.07546
2	Heat Det	FST—851	0.0003	0.0006	0.0065	0.013
3	Monitor	DIMM	0.0006	0.0018	0.03	0.09
4	Monitor	FDM—1	0.00075	0.003	0.0064	0.0256
9	Monitor	FMM—1	0.00035	0.00315	0.005	0.045
4	Pull Station	FMM-101	0.00038	0.00152	0.00038	0.00152
19	Pull Station	NBG—12LX	0.00038	0.00722	0.00688	0.13072
46	Smoke Det	FSP—851	0.0003	0.0138	0.0068	0.3128
4	Pull Station	NBG12LOB	0	0	0	0
37	Speaker 25V	Speaker— 1/2 Watt Tap	0	0	0.02	0.74
1	Dialer	UDACT	0.04	0.04	0.1	0.1
7	Relay	PR—1	0	0	0.015	0.105
23	Remote LED	RA100Z	0	0	0.01	0.23
			Standby Load	1.008	Alarm Load	2.962

Standby Load	1.008	Amps	Alarm Load:	2.962	Amps
Stanby Time	24	Hours	Alarm Time:	15	Minutes
Total Standby Load	24.201	Amp-Hours	Total Alarm Load:	0.741	Amp-Hours

Batteries provided:	(2) BAT-12380		Available Battery	30.4	Amp-Hours
Battery Size:	38	Amp-Hours	Load (ALM+STBY)	24.941	Amp-Hours
De-Rated Size(80%)	30.4	Amp-Hours	Spare Capacity	5.459	Amp-Hours

INSPECTION, TESTING, AND MAINTENANCE

The initial inspection and testing of the fire alarm system is to ensure that the approved design documents match what is installed. The subsequent periodic tests and inspections are to assure that obvious damages or any changes to the system are noticed and addressed. This way the system is kept reliable and continuously operational. These tests and inspections fall under NFPA 72 chapter 14 for Inspection, Testing and Maintenance. Table 14.3.1 in NFPA 72 is a comprehensive list of the different visual inspections and intervals to conduct said inspections. The first general visual inspection that is listed is for all equipment to be inspected to ensure there are no changes that affect equipment performance. This includes building modifications, occupancy changes, changes in environmental conditions, device location, physical obstructions, device orientation, physical damage, and degree of cleanliness. This inspection is supposed to be conducted annually. Systems are to be tested in accordance to table 14.4.3.2. Maintenance inspection and testing records shall be retained until the next test and for one year thereafter.

PERFORMANCE BASED DESIGN

INTRODUCTION

The Life Safety Code, NFPA 12 2012, and SFPE Handbook 4th edition are used as a guide for constructing the performance based fire protection design approach. According to section 4.2.1, the structure shall be designed constructed and maintained to protect occupants who are intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place. As the Recreation Center does not have places of refuge, everyone will need to be evacuated before conditions become untenable.

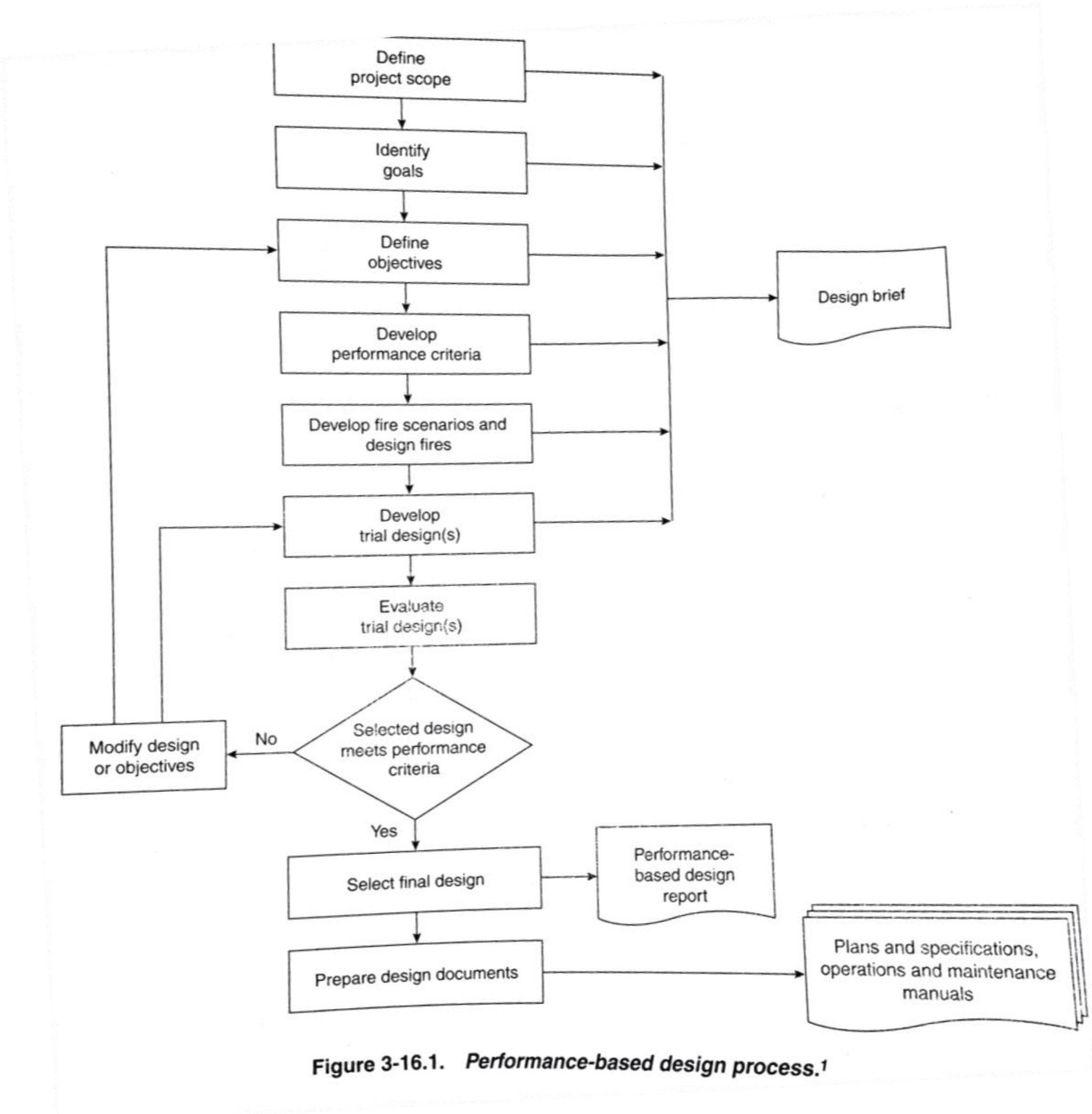


Figure 16. Performance-based design process from the SFPE Engineering Guide to Performance-Based Fire Protection, 2006.

The previous figure shows the outline for developing and implementing a performance based design, and will be used as a guide for the basis of this design.

PERFORMANCE CRITERIA

Performance criteria are how the design goals stated in the introduction are going to be quantitatively met. The design goal was to maintain a tenable environment long enough to protect occupants who are intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place. The table below lists the tenability criteria that will need to be met for safe egress.

Table 15. Tenability Criteria for Performance Based Design

Design Criteria	Tenability Limit	Source
Carbon Monoxide	6000 ppm	Incapacitation level Table 2-6.B1 SFPE Handbook
Temperature	140°F (60°C)	Assessment of Hazards to Occupants from Smoke, Toxic Gases, and Heat. By Purser in the SFPE Handbook 4th edition
Heat Flux	1.7kW/m^2	SFPE Engineering Guide, *Predicting 1st and 2nd degree skin burns from thermal radiation*
Visibility	42 ft (13m)	SFPE Handbook, Table 2-42 Assuming building occupants are unfamiliar with surroundings

CARBON MONOXIDE

Asphyxiant gases decrease the amount of oxygen that the person can absorb. CO is the main asphyxiant, from a fire that leads to the production of carboxyhemoglobin. Carboxyhemoglobin decreases the blood's oxygen-carrying ability, and results in the person fainting from not the lack of oxygen in the air but the ability to carry it in the blood. NFPA 101, 130, and 502 give limits to the tenability of CO. NFPA 130 and 502 state an 800 ppm with a 30-minute evacuation time. NFPA 101 states a steady concentration of 1,000ppm over a 30-minute period. The Fractional Effective Dose (FED) to incapacitation is greater than 0.3. This is determined by CO calculations assuming a 70 kg human performing light aerobic work and represents 50% of adults being affected.

TEMPERATURE

An immediate threat of a fire is usually the fire itself. If you are in the same room as the fire you will be exposed to possible hyperthermia, blisters, burns, and respiratory tract burns. According to Purser in the SFPE handbook, the cut off temperature between just experiencing hyperthermia and none of the acute affects is a smoke or air temperature of 120°C. Once you go beyond 120°C skin burns and respiratory tract burns are common. The temperature that would render untenable conditions however is 60°C for a smoke layer 1.8 m (6 ft) above walking surfaces to prevent. This temperature could cause respiratory tract burns in air that is fully saturated with water. This can happen if a sprinkler goes off.

HEAT FLUX

The radiant heat flux that is taken into consideration is the result of thermal radiation from a hot smoke layer down towards the evacuating occupants. The immediate heat flux as a result will not be taken into consideration as this performance-based design only protects those who are intimate with the beginning stages of the fire not throughout its duration. The radiant flux tenability limit is 1.7 kW/m^2 because an incident radiant flux greater than 1.7 kW/m^2 may cause pain on exposed skin after prolonged exposure, (SFPE Engineering Guide, Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation). This value is considered conservative compared to a radiant flux of 2.5 kW/m2 provided by the CIBSE Guide E – Fire Engineering. A smoke temperature maintained below 180°C will not exceed the radiant flux tenability limit. Thus, the criteria of providing a space that is under 60°C will cover the heat flux tenability criteria.

VISIBILITY

In order to keep people from stopping due to poor visibility a smoke layer must be maintained at 6 ft above the highest walking surface that occupants inhabit while egressing. Under 6 ft a visibility of 42 ft (13 m) is required for safe egress. This allows people to see where they are going in an environment that they are not familiar with. It has been found that if the visibility drops much past this and occupants are not familiar with their environment they are likely to stop moving altogether as they are not sure where to go.

DESIGN FIRE SCENARIOS

This performance-based analysis will look into three fire scenarios for the Recreation Center. One will be the reasonable worst-case fire scenario and the other two the next most practical challenging fire scenario. The first fire scenario described goes into the full performance based design, and not the other two, for academic purposes. As the first fire scenario is the worst case in terms of fuel load and occupant load, a lot of detail has gone into the analysis of this design fire scenario. The two other fire scenarios are listed as other possible fires that could occur in the building, but were not inspected with the detail that the first scenario is, due to academic purposes.

DESIGN FIRE SCENARIO 1

The old portion of the gym includes bleacher seating that when in use can hold approximately 4,000 people. This has happened recently during a concert that was hosted in the gym. The photo in figure below shows what the gym looks like when the bleachers are fully extracted.

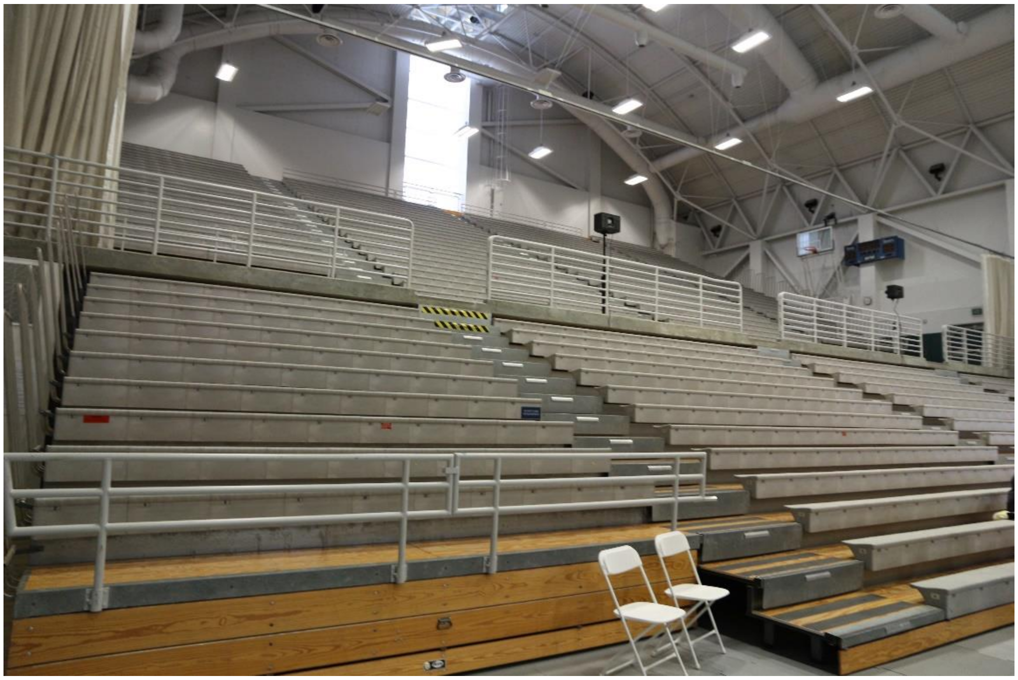


Figure 17. Bleachers fully extended on one side of the gym

These bleachers are made out of plywood for, standing and walking on, and polyethylene for the plastic seat section. This is shown in the next figure.

Figure 18. Bleacher components

The worst-case scenario is if the bleachers are fully loaded with 4,230 occupants, this is from the prescriptive code stating one occupant per 18 in. When the bleachers are fully extended they form a room underneath them that is protected from sprinklers should a fire start under them. A fuel load and little mindlessness could lead to a fire under the bleachers.

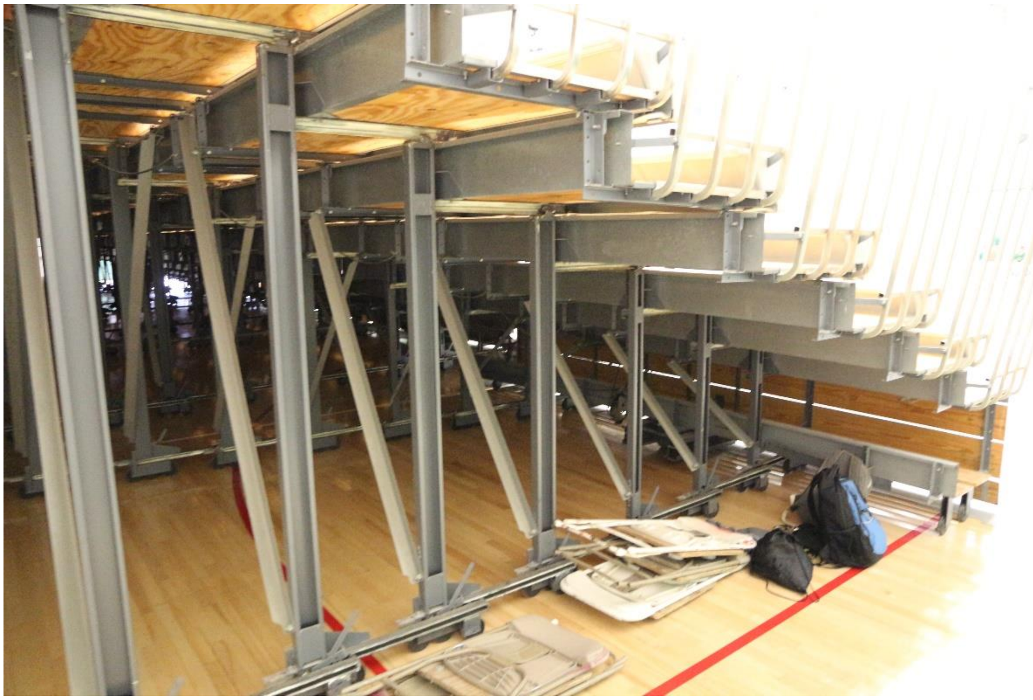


Figure 19. Backpacks stored under the bleachers basis for fire scenario

The figure above shows exactly the fuel load investigated. The bleachers are only extended when there are people in the building therefore, there is little reason to assume that no one will be around to spot the fire. One issue with this fire is the ability of the sprinkler system to suppress it, as it is under the bleachers. As the sprinkler system is located on the very tall curved ceilings that range from 54ft to 72ft high. This extreme height will allow the fire to grow to a sizable amount before the sprinklers are activated. The fire will be situated close enough to one of the exits, shown in the net figure, as to render that exit unusable.

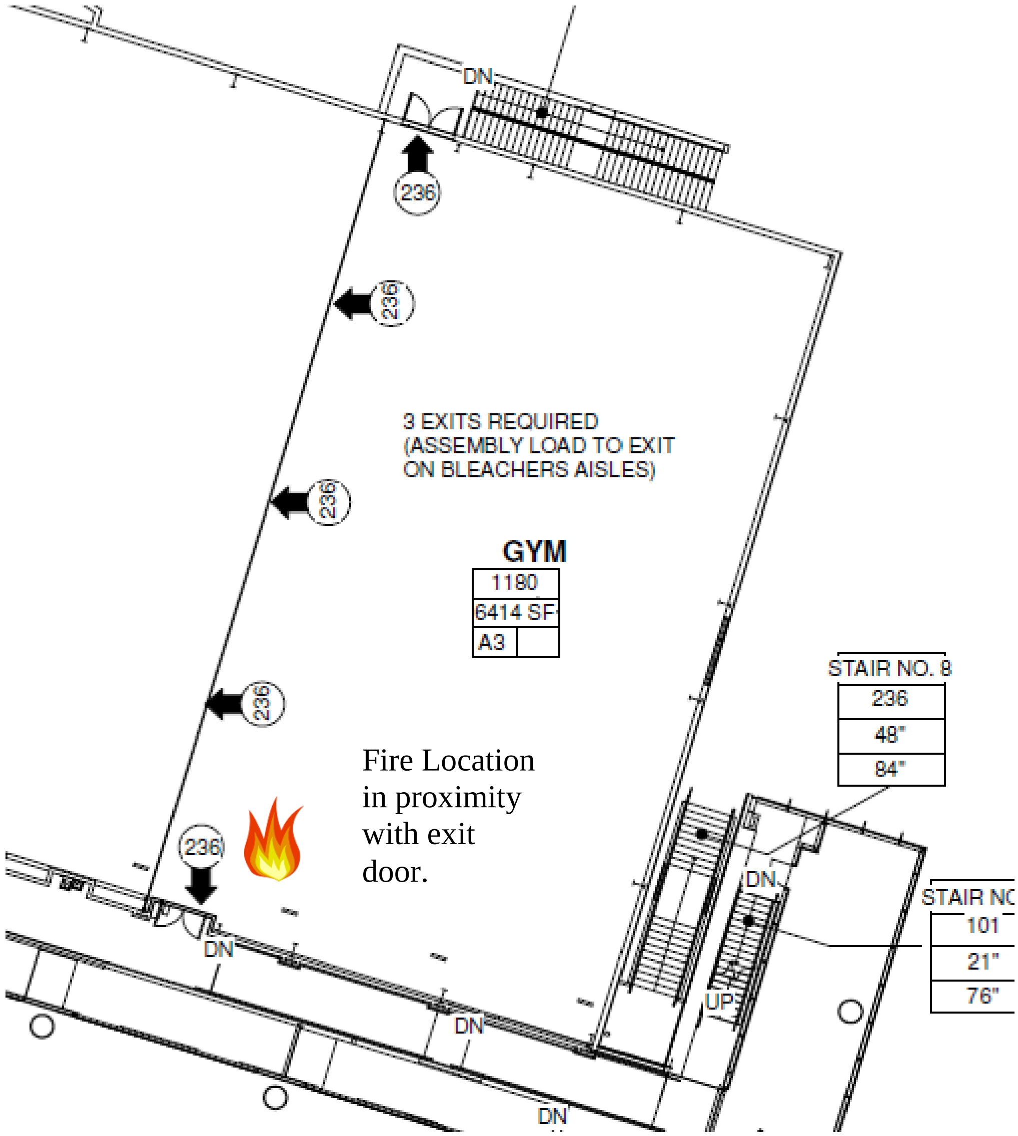


Figure 20. Fire location in relationship to the exit that it will be blocking on the second floor.

There are six vents on the ridge of the ceiling for ventilation of the space, each 4ft x 4ft. These vents have small fans attached to them but will not be modeled into this fire scenario. They are not meant for smoke control and purely provide minimal ventilation to the gym.

DESIGN FIRE DEVELOPMENT

The initial fire starts from two backpacks that were left under the bleachers. It is assumed one of these two backpacks contains a laptop and possibly a jacket. From the figures below, it was

postulated that such a fuel load would produce a heat release rate (HRR) of 300kW. This fire would then spread to the bleachers and cause a serious problem.

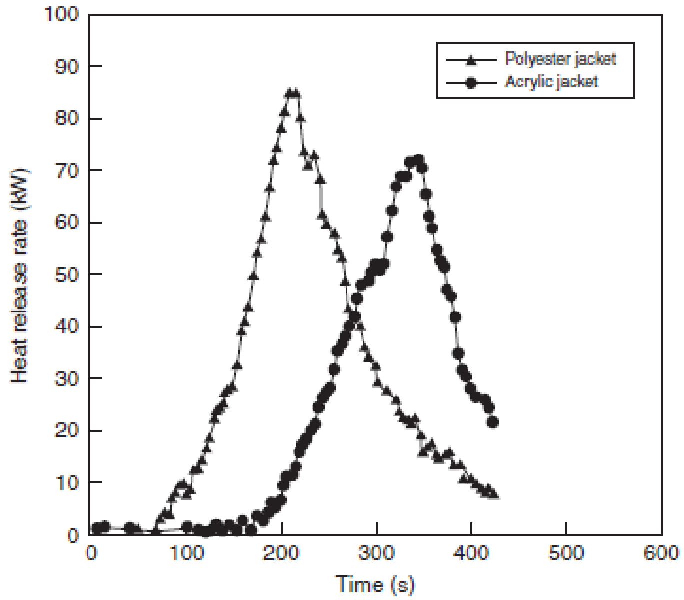


Figure 3-1.19. ***Two men's jackets.***

Figure 21. Two jackets HRR curves from SFPE Handbook

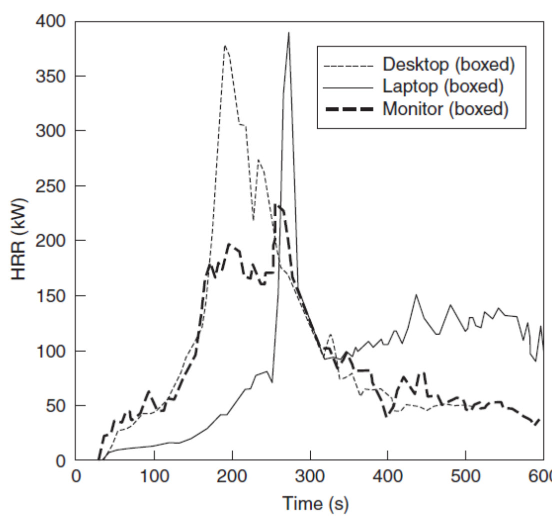


Figure 3-1.29. ***Single, packaged, and boxed computers and monitors.***

Figure 22. Solid line above show laptop HRR from SFPE handbook

FDS PARAMETERS AND INPUTS

FDS was used to model pyrolysis of the plywood and bleachers to simulate flame spread, and the fires natural growth. To accomplish this the plywood and polyethylene material has to be described in detail. These properties are gathered from table 3-4.13 and table 3-4.14 from the 4rd edition of the SFPE handbook as well as, "An Introduction to Fire Dynamics, by Drysdale.

Table 16. Properties used in FDS to model pyrolisis of the bleacher system

	Property	Quantity	Unit
Polyethylene	Soot Yield	0.102	kg/kg
	CO Yield	0.026	kg/kg
	Specific heat	2.3	kJ/kg°C
	Conductivity	0.5	W/m K
	Density	560	kg/m3
	Emissivity	0.92	-
	Heat of Combustion	43,400	KJ/kg
	Heat of Reaction	2,329	kJ/kg
	Reference Temperature	300	°C
Plywood	Specific heat	2.72	kJ/kg°C
	Conductivity	0.1	W/m K
	Density	420	kg/m3
	Heat of Combustion	19,600	KJ/kg
	Heat of Reaction	950	KJ/kg
	Reference Temperature	300	°C

The heat of reaction specifies the amount of energy consumed, per unit mass of reactant, which is converted into reaction products.

The pyrolysis method used was modeled after the Complex Pyrolysis model from the couch burn away example from NIST. This example couch file is attach in Apendix P for reference. The polyethylene and plywood were assumed to have the same reaction for the entire fire; this is an assumption to reduce the calculation time and complexity of the model. Another assumption is the Reference Temperature of both the plywood and polyethylene is 300°C. The Reference temperature is the temperature at which the mass fraction of the material decreases at its maximum rate. FDS calculates the parameters, A and E, using the reference temperature, T_p, in the equation below.

$$E = \frac{e\, r_p}{Y_0} \frac{R T_p^2}{\dot{T}} \quad ; \quad A = \frac{e\, r_p}{Y_0} e^{E/RT_p}$$

Equation 1. FDS uses the reference temperature, T_p, to solve for E and A.

$$r_{ij} = A_{ij} Y_{s,i}^{n_{s,ij}} \exp\left(-\frac{E_{ij}}{R T_s}\right) X_{O_2}^{n_{O_2,ij}} \quad ; \quad Y_{s,i} = \left(\frac{\rho_{s,i}}{\rho_s(0)}\right)$$

Equation 2. Reaction Rate of each material calculated with A and E from above equation.

In order to speed up the calculation process the backpack fire was modeled as an immediate 300 kW fire directly under the bleachers, as seen in the next figure.

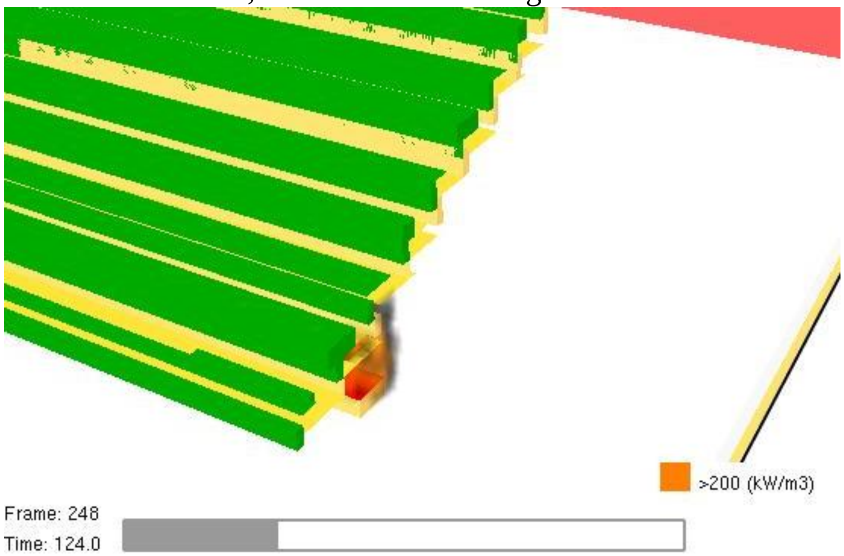


Figure 23. 300kW fire directly under the bleachers, just starting to grow at 124 seconds

The FDS model was broken up into six different meshes, and designated to six different cores on the computer, in an attempt to speed up computing time. The resolution around the fire and most of the right side of the model, shown below, was 0.1 m and 0.5 m for the rest of the gym. The 0.1 m level of detail was still enough to allow for pyrolysis reaction calculations while reducing the computing time from a finer resolution. As the rest of the gym was primary, calculating smoke movement a 0.5 m resolution was selected. Even with the decreased resolution, the model is still made up of 6.6 million cells. The model ran for 447.5 seconds and took 2 weeks of computation time to get that far.

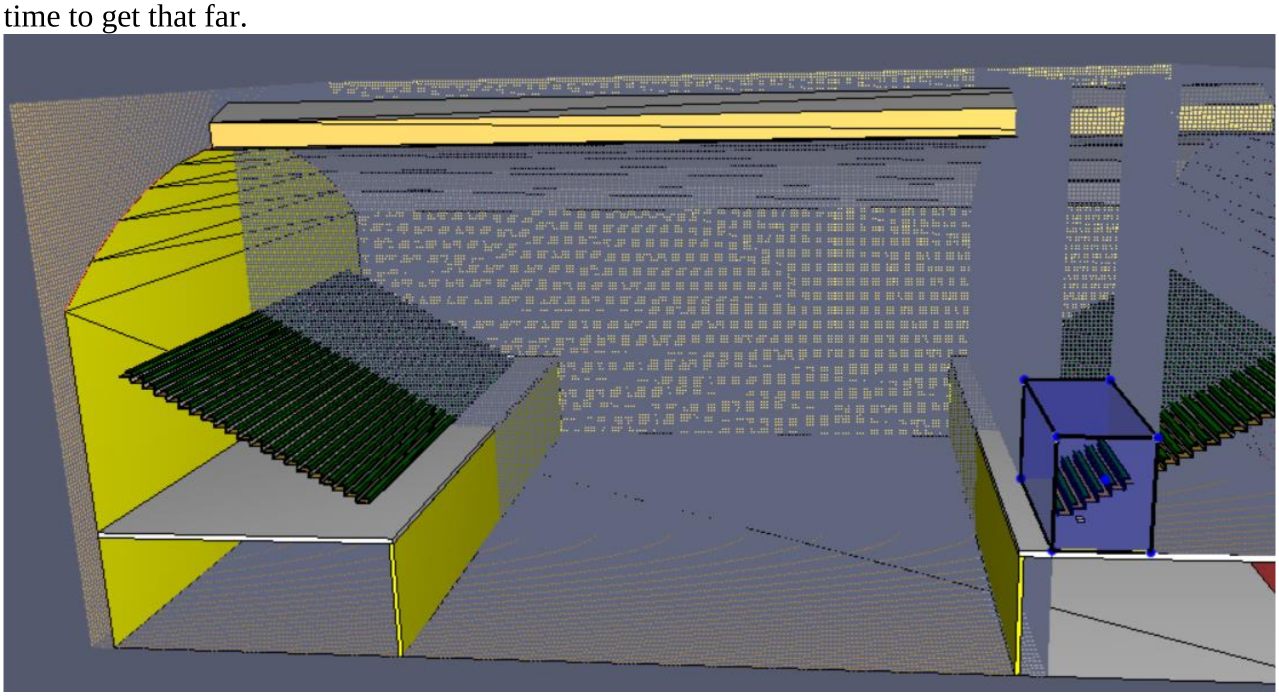


Figure 24. FDS Meshes

The reason for the long run times are the reaction chemistry that FDS does solving for the pyrolysis model. The figures below show the fire's growth over the time of the model. There was a lot of changing system and input parameters to get the model to work and actually burn away the surfaces. This was mostly due to the mesh resolution around the fire as well as specifying the correct density using the BULK_DENSITY parameter specified for each obstruction. Unfortunately, the time it took to work out the complications in the model and the model run time of 2 weeks led to only one run being completed. If there was more time at least one more model with alterations mentioned throughout this analysis would have been calculated.

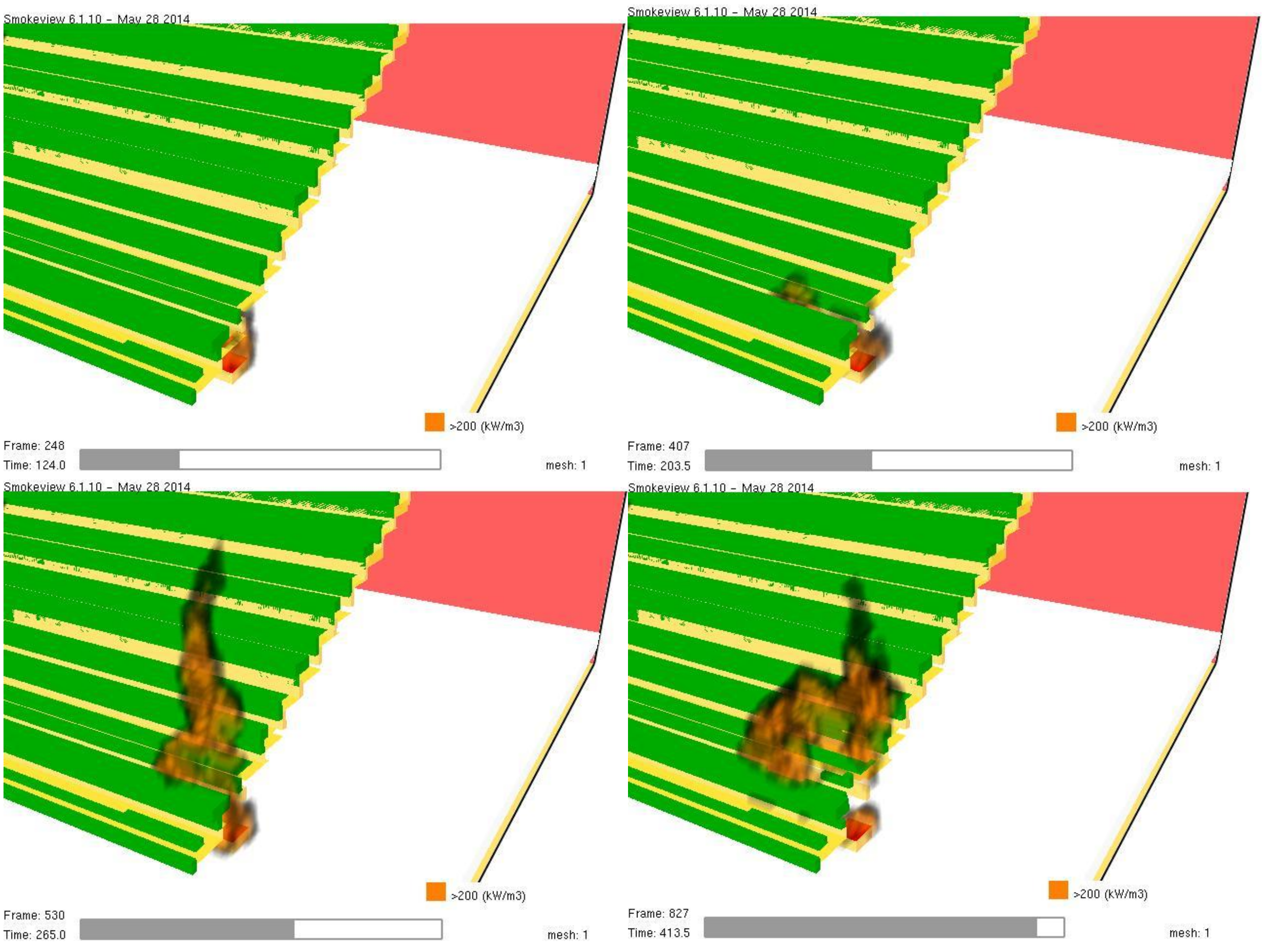


Figure 25. Flame spread at 204s, 283s, 345s, 493.5s throughout the model.

The sprinklers in the FDS model are designated with a given Response Time Index (RTI) of 55 $m^{1/2}s^{1/2}$, just above the limit for quick response sprinklers of an RTI of 50. This was used to make the model conservative. As the sprinklers for the space were not designed to handle such a large fuel load as the bleachers, which constitute a class A plastic high pile storage, they were purely used to see when they would activate. It would be a poor assumption that the sprinklers would be able to control the fire and maintain the HRR at the time of activation.

FDS RESULTS

The purpose of FDS is to determine how long occupants have to egress the building, or space, before they come across untenable conditions and become incapacitated, Available Safe Egress Time (ASET). FDS is a great tool at keeping track of the prescribed tenability requirements discussed previously. FDS also tracks the HRR as time goes on; this is shown in figure 25 below.

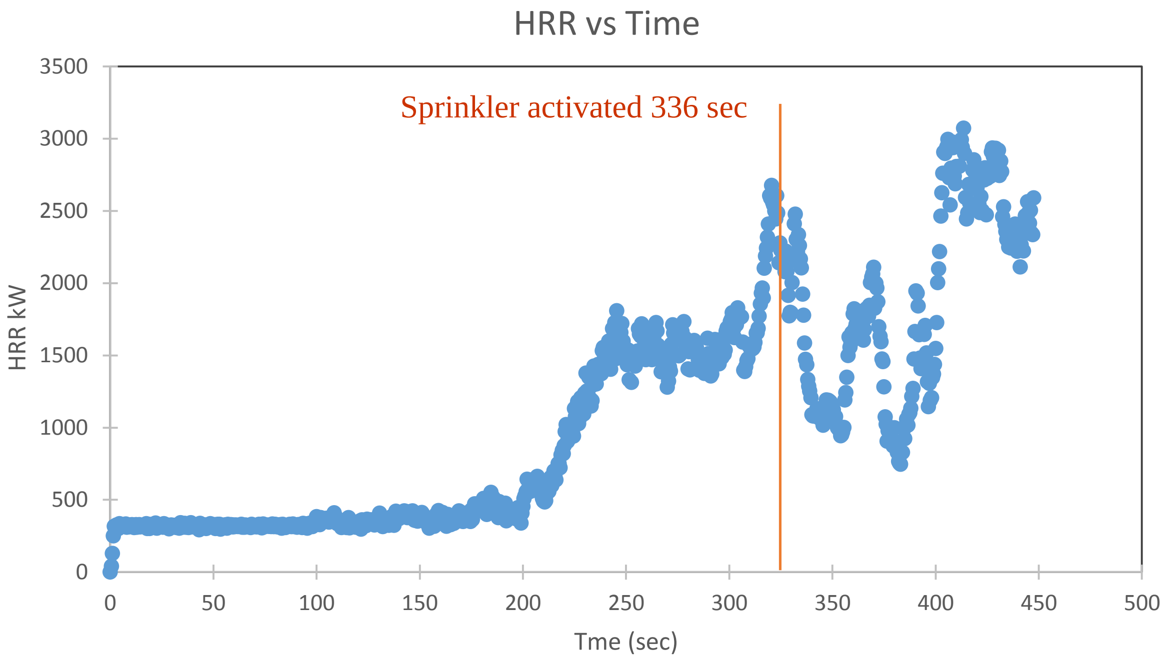


Figure 26. HRR of the bleacher fire over time

In order to decrease the FDS run time the backpack ignition fire was specified with an immediate 300 kW HRR and no ramp, and is why the HRR in the figure above starts at 300kW and not 0kW. In order to get a more accurate timetable for the fire, 80 seconds will be added to all of the FDS outputs. This is how long it takes for a fast fire grown curve to reach 300kW, meaning, a t^2 fire with a fire growth coefficient of 0.0469 kW/s^2. This was a conservative approach as the laptop and jacket fire test show a time to peak heat release of around 200 seconds, as seen in figures 21 and 22. A sprinkler did activate at 416 seconds into the fires growth or 336 in FDS time.

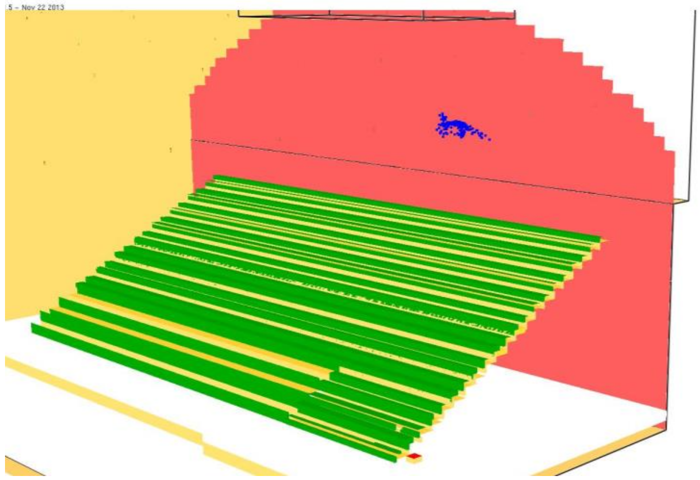


Figure 27. Sprinkler activation at 416 sec

Though we see that the sprinkler affects the HRR of the fire, figure 25, this is deceitful data as the inputs for the sprinkler were not set to replicate the design flow from the sprinkler system in place. Another FDS run should be conducted with correct sprinkler parameters before any results regarding the sprinklers impact on the fire can be stated. Even then FDS simply uses the water to take away energy from the pyrolysis rate to reduce the HRR, FDS User Guide. The sprinklers in this analysis will not be taken into account for affecting the HRR.

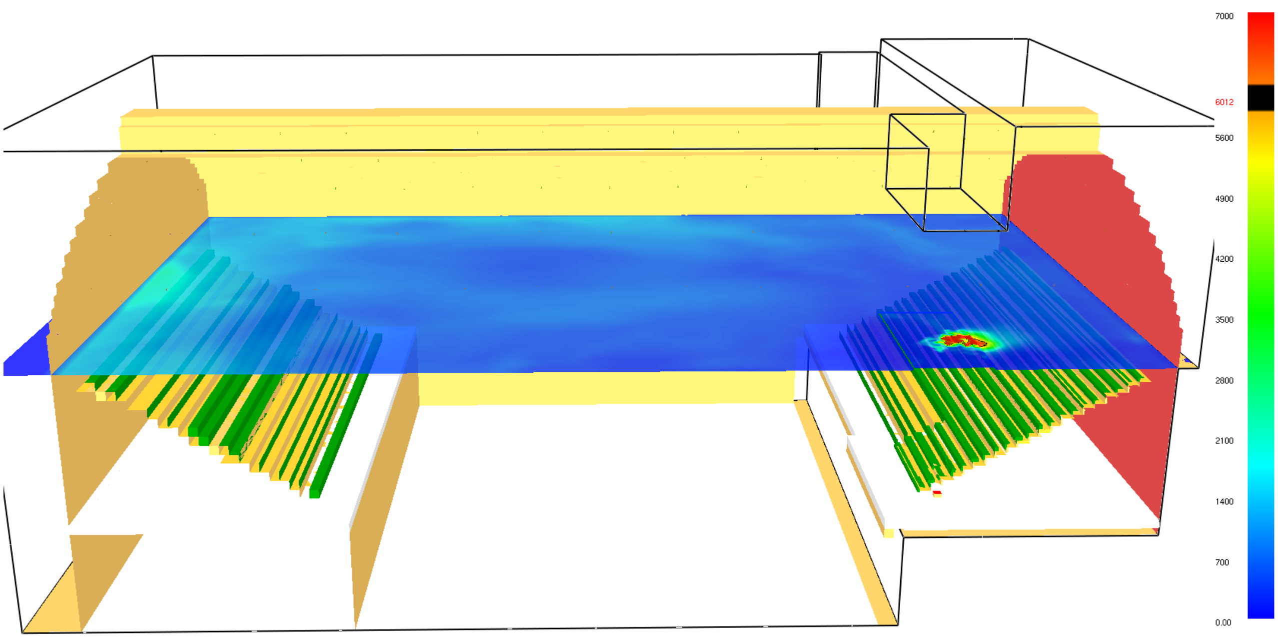


Figure 28. CO concentration slice file at 527.5 seconds, at head height of 1.83m above highest occupants.

As seen in the figure above, carbon monoxide is not a threat in such a large room and does not come anywhere near the 6000 ppm limit.

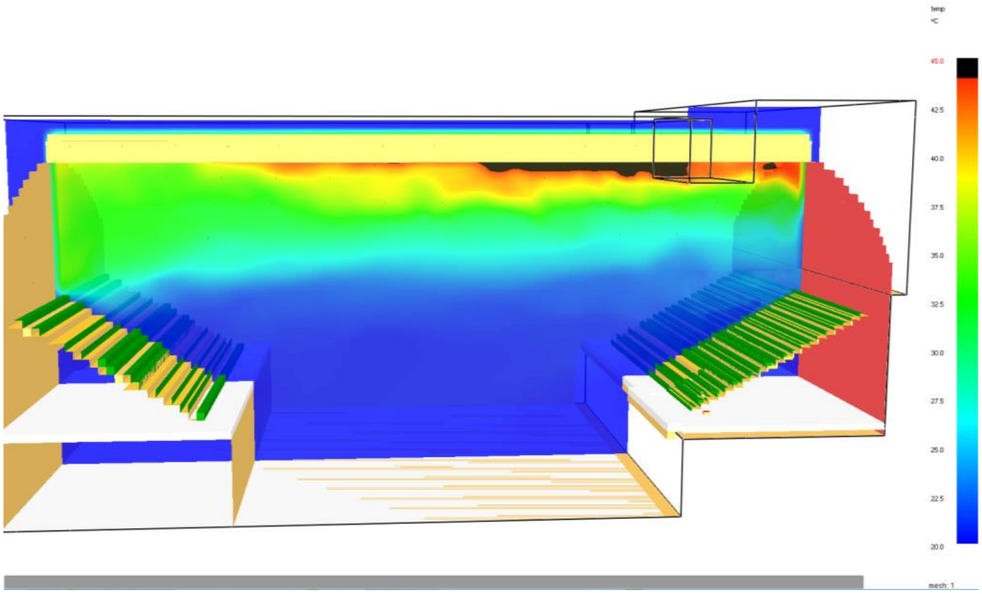


Figure 29. Temperature slice halfway through the model, 527.5 sec

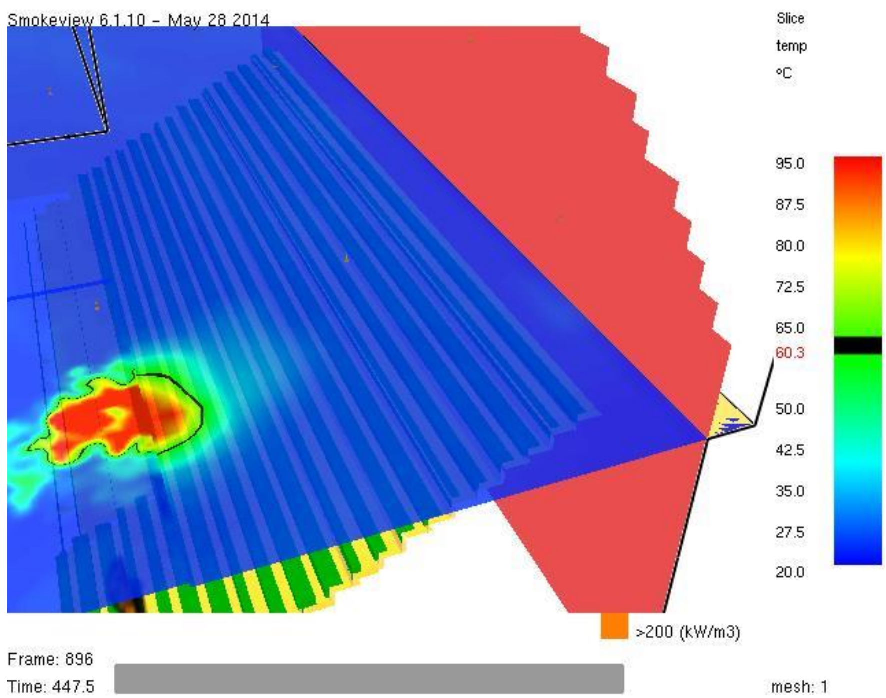


Figure 30. Temperature slice 1.83 m above the highest bleacher, 527.5 sec

The two previous figures show the temperature in the gym at 1.83 m above the highest bleacher and a slice down the middle of the gym, and that the temperature is nowhere near the 60°C limit.

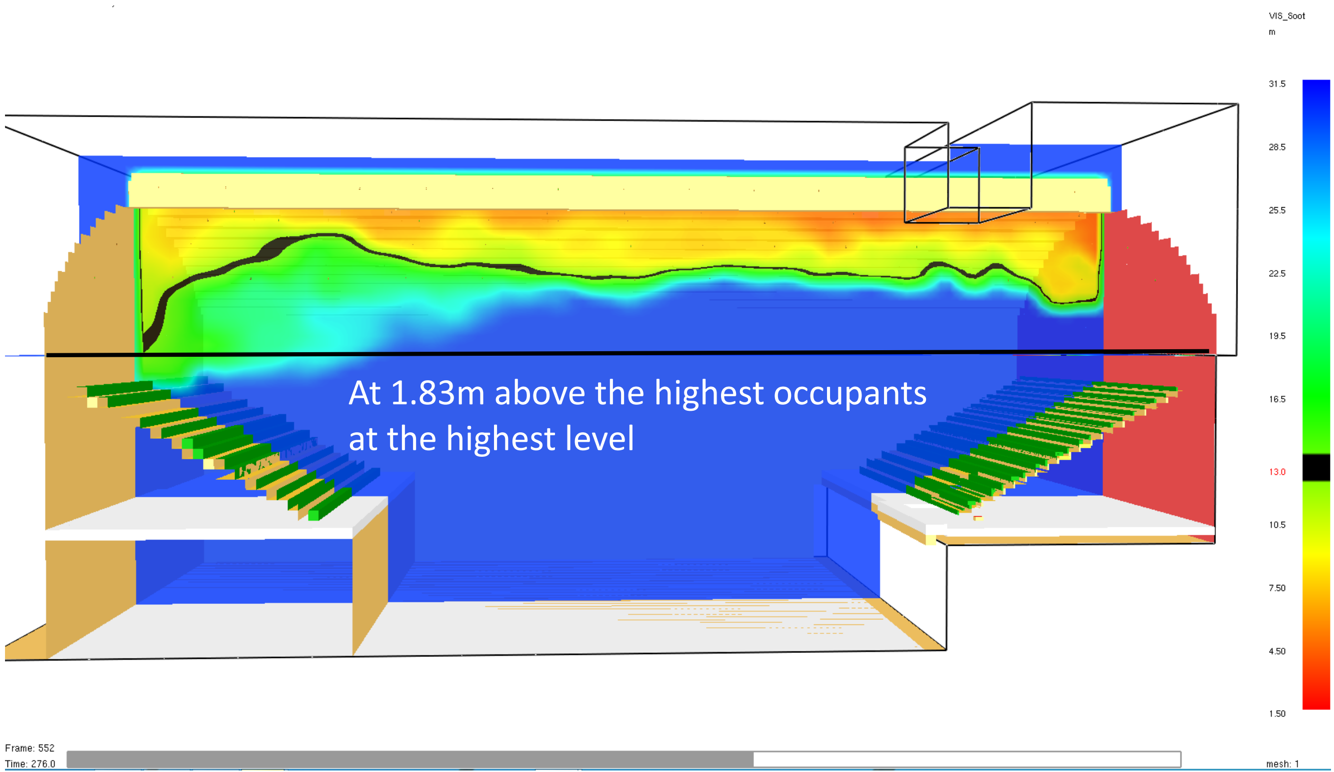


Figure 31. Visibility at 13 m reaching 1.83 m above the highest level of occupancy at 356 seconds

Visibility reaches its tenability limit of 13 m relatively quickly at 356 seconds into the fires life span. The smoke envelopes the left side bleachers and quickly spreads across the top bleacher as shown below.

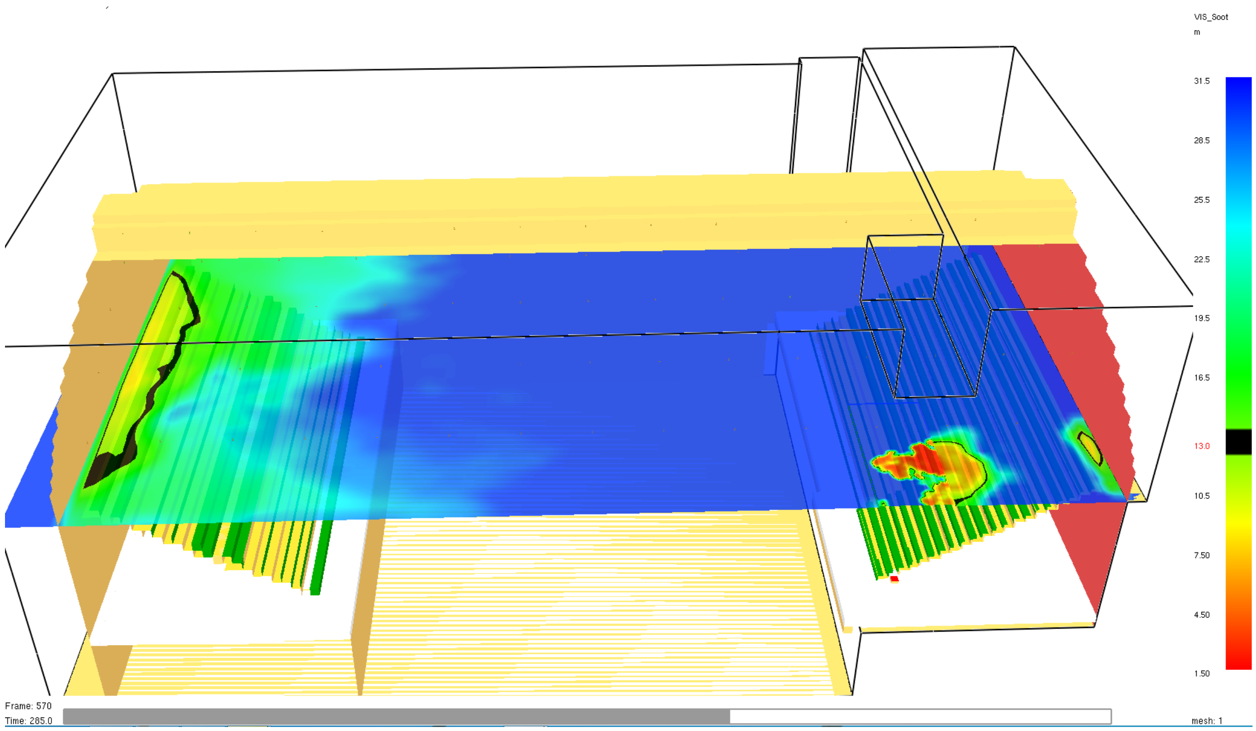


Figure 32. Visibility at 365 seconds 1.83 m above the highest bleacher

It is clear that smoke is the limiting factor that creates untenable conditions in the gym. This is not surprising as the bleachers produce a lot of smoke and there are only six small openings for natural ventilation. This sets the ASET at 365 seconds, 5 min 56 seconds. Looking at the end of the simulation shows that the smoke layer evens out and moves slowly down the bleachers.

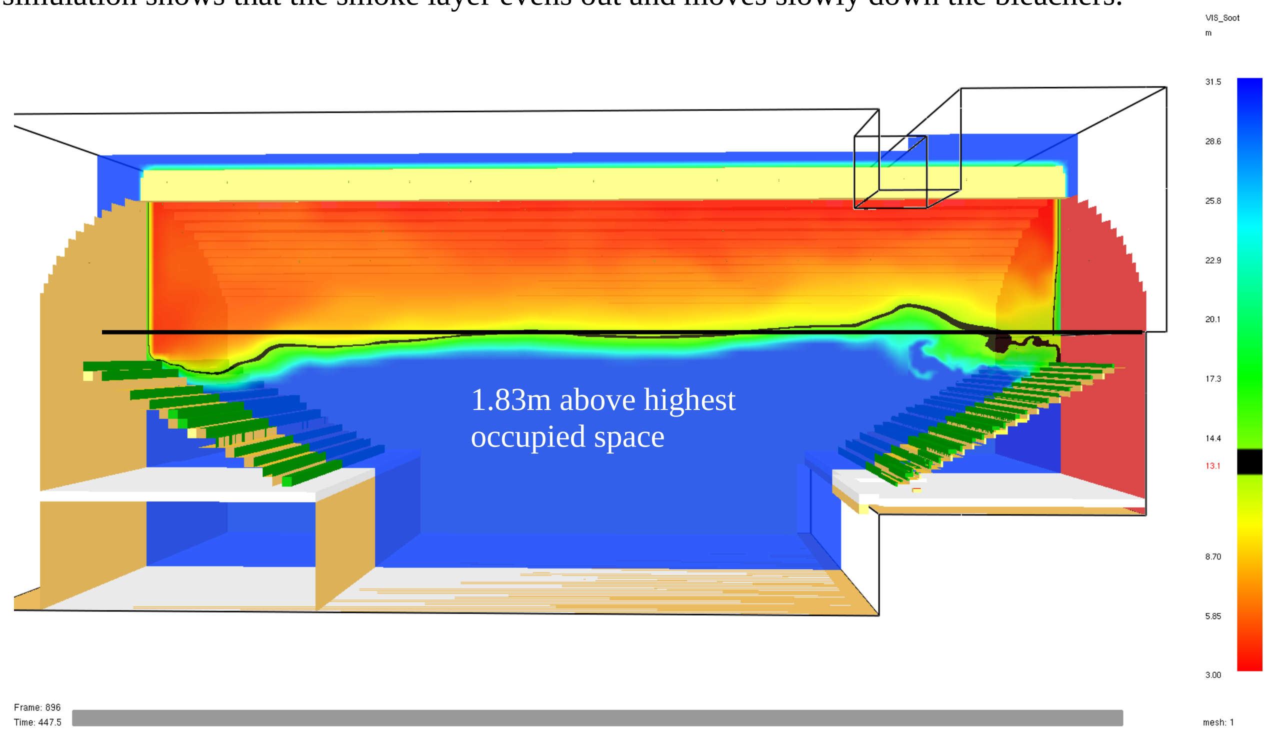


Figure 33. Smoke layer at 527.5 sec

The Required Safe Egress Time (RSET) will be determined when the last occupant starts to decend the bleachers. This will be determined in the Occupant Characteristics section.

FDS is a very powerful tool to determine the tenability of a space, in this case the gym. However, it can be very misleading if the correct inputs were not used or the mesh resolution was too large, giving inaccurate data. One of my professors has stated, and I agree, “Garbage in, garbage out.” This means that if improper inputs were entered, the model will give you inaccurate results that can lead to poor design. FDS can be manipulated to give the desired results rather than accurate ones. This model strives to use as accurate of data as possible, but the exact material properties of the real bleachers were not determined so data from handbooks were used in place of this. The pyrolysis model used relies on this data to spread the fire and model flame spread. Therefore, though this data and model seem very impressive, it should be noted that it is purely academic and in real life the fire could behave differently and produce different results. For instance to simplify the model only one reaction is specified, the burning of polyethylene. This implies it is using the chemistry for burning polyethylene even when it is burning the plywood. FDS is capable of running multiple reactions but it would be beyond the scope of this project. Taking all of this into consideration is why a 20% safety factor will be added to the RSET.

DESIGN FIRE 2

The second design fire is similar to the first in the sense that it looks at the bleachers in the old section of the gym. This time however, the bleachers are folded up in their normal storage orientation. They are like this 95% of the time. There is often loose material (i.e. trash cans,

backpacks, sports equipment) right next to the bleachers that could easily be the ignition source of the fire for this scenario. The next few figures show the bleachers and what the fire set up might be like. As the bleachers are not extended the occupant load in the space is greatly reduced and uses an occupant load factor of 15 persons/ft^2 giving 424 occupants on each wing of the second floor gym. This fire scenario has the potential of becoming a substantial fire as the bleachers can produce a significant heat release rate and smoke production. However, there are significantly fewer occupants when the bleachers are folded up then when they are down and full of people, 424 compared to1,040 per second floor wing. This means that the evacuation time is greatly reduced. The bleachers would still cause great harm to the building, especially if the fire occurred after hours at night and was only detected by a sprinkler activating. As seen from the first fire scenario the sprinklers would likely not activate until the fire is so large that the entire section of the gym would be gone.

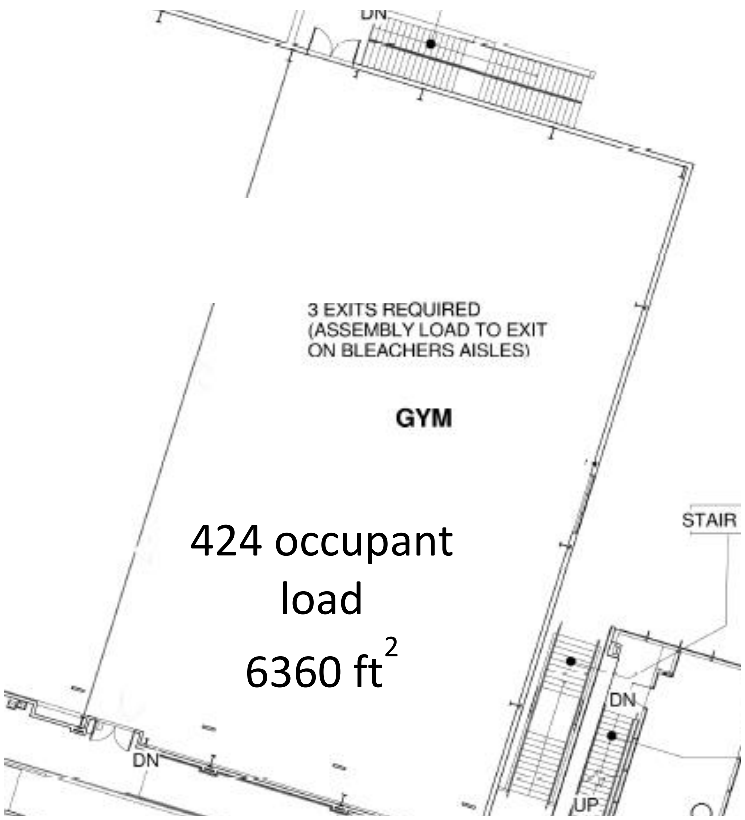


Figure 34. Second floor gym occupant load

Figure 35. Bleachers folded up in their storage orientation

Figure 36. Bleacher orientation side and back view

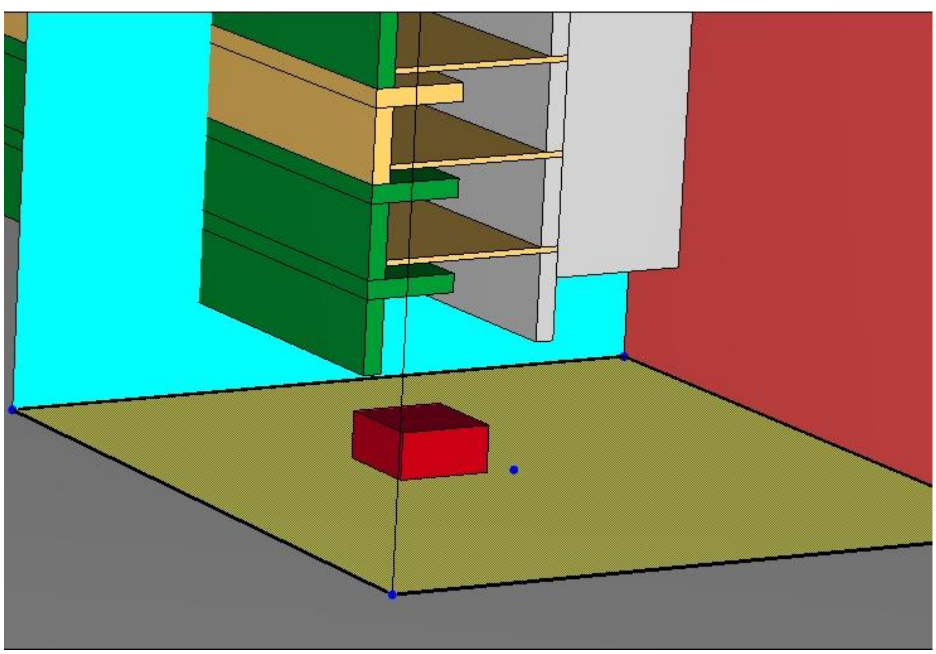


Figure 37. Fire scenario as would look in FDS modeling with the fire as the red cube

DESIGN FIRE 3

Based on the low fuel load of most of the gym the second fire scenario was chosen based on occupant load and fuel load. The Martial arts room in the Recreation Center is located on the first floor next to the old gym; it was unchanged from the old Recreation Center to the new one. The ceilings are 18 ft and the sprinklers are around 17.5 ft from the ground. The only way a significant fire could develop is if the sprinklers do not operate and the fire is allowed to grow until the fire department arrives. The exit layout is such that no matter where you are in the room an exit is at most 43 ft away. There are wrestling mats that span the entire floor of the room. These mats, measuring 4 in in depth, are made out of a PVC nitrile rubber foam that is covered by PVC vinyl for protection. It is assumed that the mats are the same as the ones used across the industry and had fire retardant applied to them in order to achieve a class I rating from ASTM E648 for a Fire Retardant Critical Radiant Flux. As these mats are never stored vertically, their flame spread is greatly reduced in their horizontal configuration.

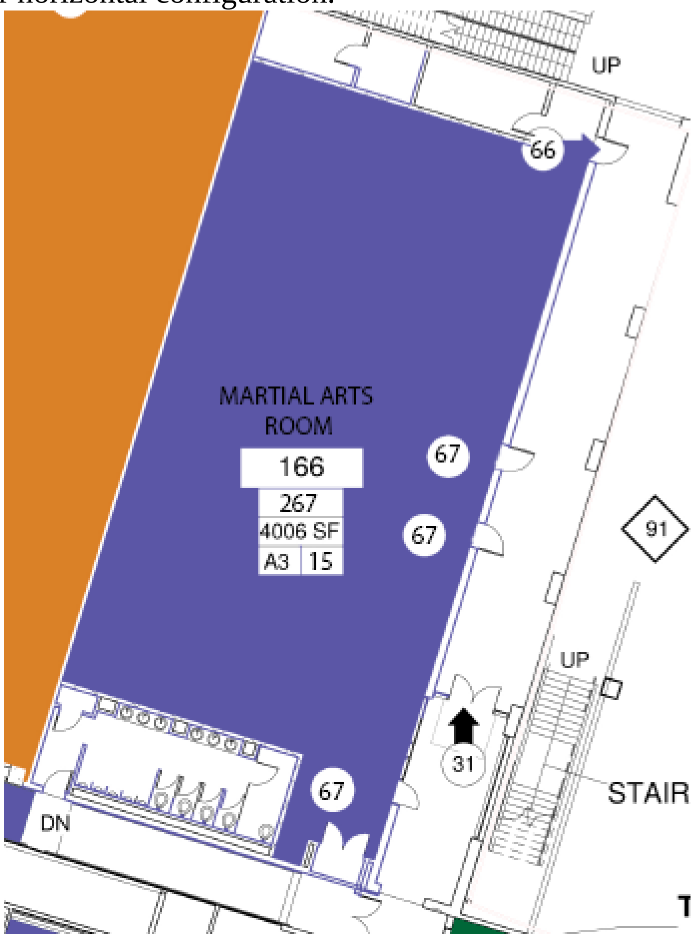


Figure 38. Martial Arts room and its occupant load

There is a big plastic garbage can in the room, as seen in the next figure; this is where the fire would originate. A NIST fire test, Appendix Q, was conducted on similar trashcans full of cellulose waste material. The results seen in the following figure demonstrate that it takes 800 seconds before the peak heat release rate is reached. It is assumed that the trash can produces a fast t^2 fire.

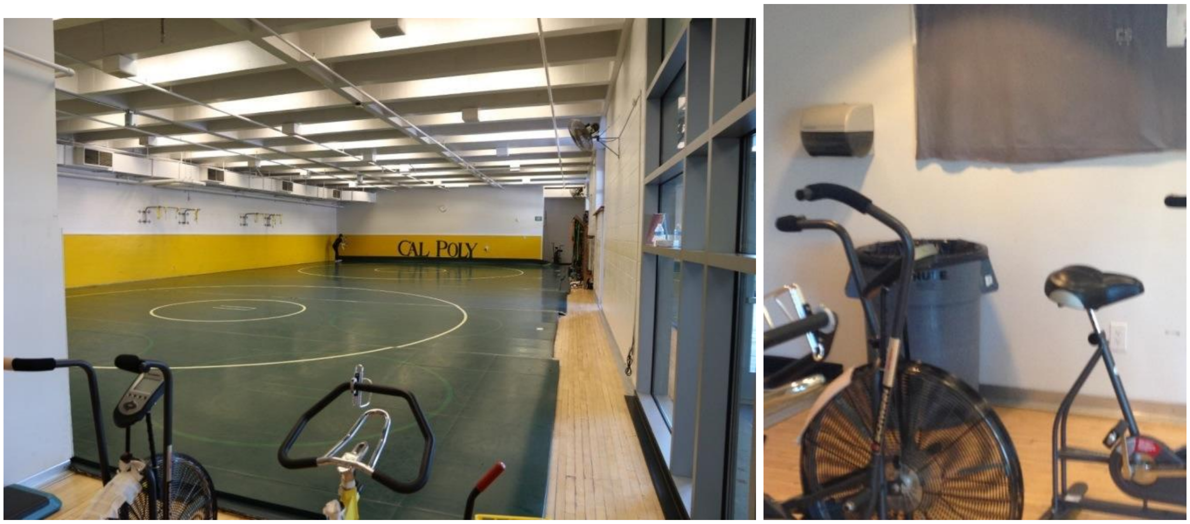


Figure 39. Martial Arts room with foam wrestling mats and trash can in room, right

The figure below shows the Pathfinder results for how long it takes 276 occupants to exit the room once they are alerted that there is a fire in the room. The fire is such a slow growing fire that all occupants will have evacuated before there is any threat of loss of life.

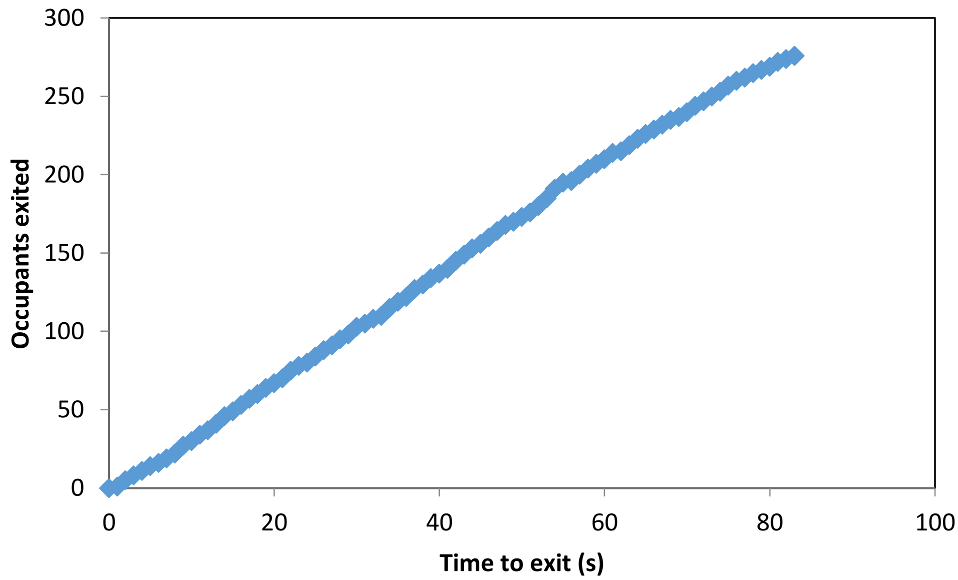


Figure 40. Time for occupants to egress from the Martial Arts Room

OCCUPANT CHARACTERISTICS

The occupants in the Recreation Center are generally students ranging from the age of 18 to 25. They are at the Recreation Center to work out, and are assumed to be awake and alert unless otherwise stated. Unless they are using the Recreation Center as a place for physical therapy to recover from some physical impairment, it is assumed the occupants are well bodied and can move

under their own power. We will assume that the occupants are scattered at random in the spaces they occupy, unless otherwise noted for a specific condition such as bleacher seating. The Recreation Center also employs staff who are trained for fire emergencies and decrease the pre-movement time by telling everyone to exit the building promptly.

OCCUPANT CHARACTERISTICS SPECIFIC FIRE SCENARIO 1

As the first fire scenario happens during a concert the occupants are not going to be at their most attentive as they would normally be when in the Recreation Center. Some of them will also undoubtedly be under the influence of one substance or another. This will increase the time to detection of the fire and their pre-movement time as people will take longer to process if there is in fact a threat and that they need to evacuate. However, these large events are required to have event staff and police officers present. These trained professionals will be able to inform the entire audience that they need to egress from the building.

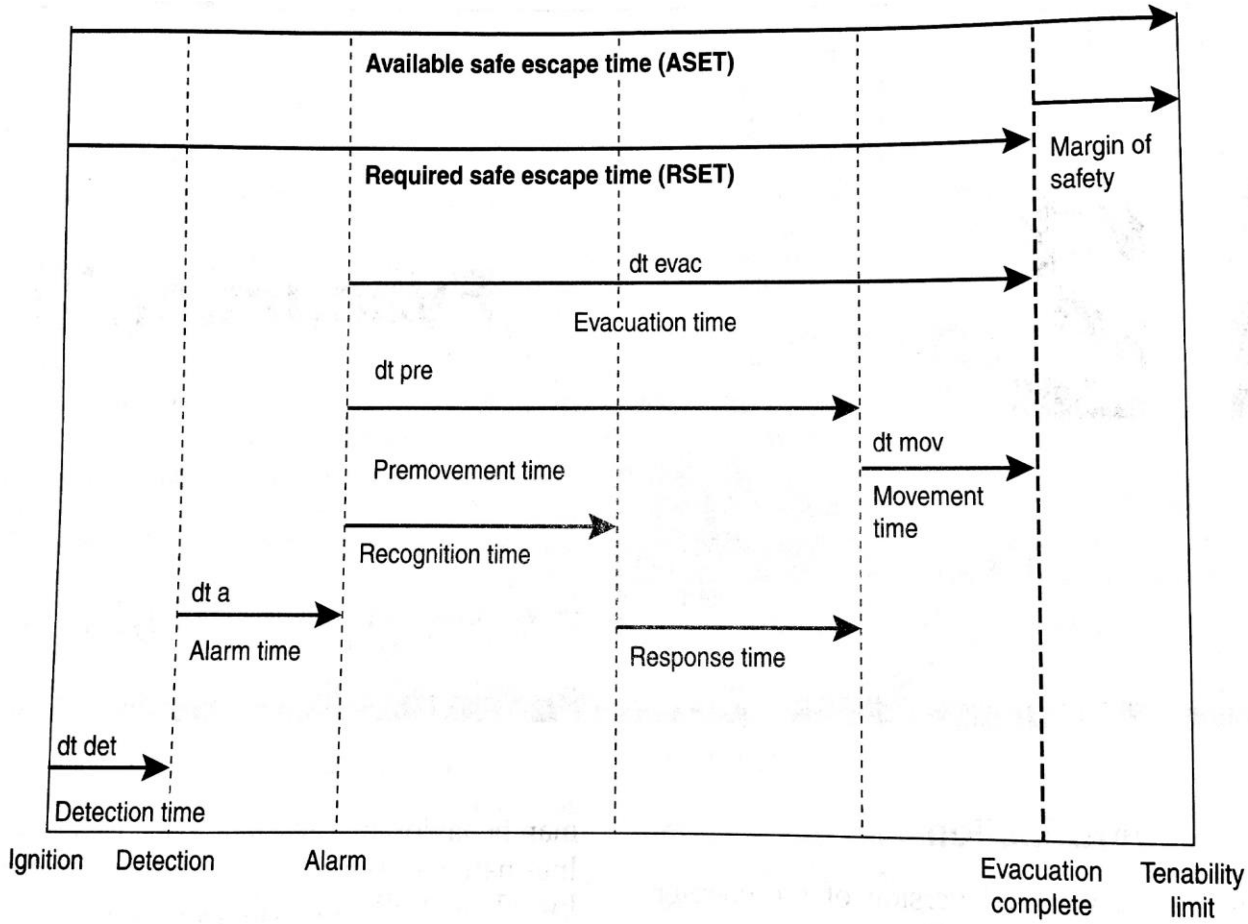
CALCULATING REQUIRED SAFE EGRESS TIME (RSET)

The Required Safe Egress Time is simply the time that it takes for everyone to completely exit the building, from the time that the fire starts to the time the last person exits. It is a combination of times that include the detection, notification, pre-movement, action, and travel time.

$$RSET = t_d + t_a + t_o + t_i + t_e$$

t_d = time from fire ignition to detection (detection time)
t_a = time from detection to notification of occupants of a fire emergency (notification time)
t_o= time from notification until occupants decide to take action (pre-movement time)
ti= time from decision to take action until evacuation commences (action time)
t_e = time from the start of evacuation until it is completed (travel time)

Guylene Proulx lays out the previous equation in Chapter 12 on Evacuation Time in the 4th edition of the SFPE Handbook. The figure below is also from the same chapter.



DETECTION TIME

The detection time is the time from the fire's ignition to first detection, be it by an automatic device or by an individual.

For design scenario one, it is likely that the fire will be detected by a person and not a device. This is due to no smoke detectors and high ceilings where the sprinklers are located. For this scenario, the detection time is assumed to be 45 seconds, where people in the near vicinity will smell smoke and one them will either investigate or notify event staff personnel.

For design scenario two, there will be no one in the room and the fire will be detected first by a sprinkler activating as there are no smoke detectors in the building.

ALARM TIME-NOTIFICATION TIME

The alarm or notification time is the time it takes from first detection to when a building wide alarm is sounded for evacuation to commence.

For design scenario one, someone will have to go to the nearest manual pull station and activate the fire alarm. This time has been modeled in pathfinder and can be seen in the next figure. It takes about 25 seconds to go from the fire to the nearest pull station.

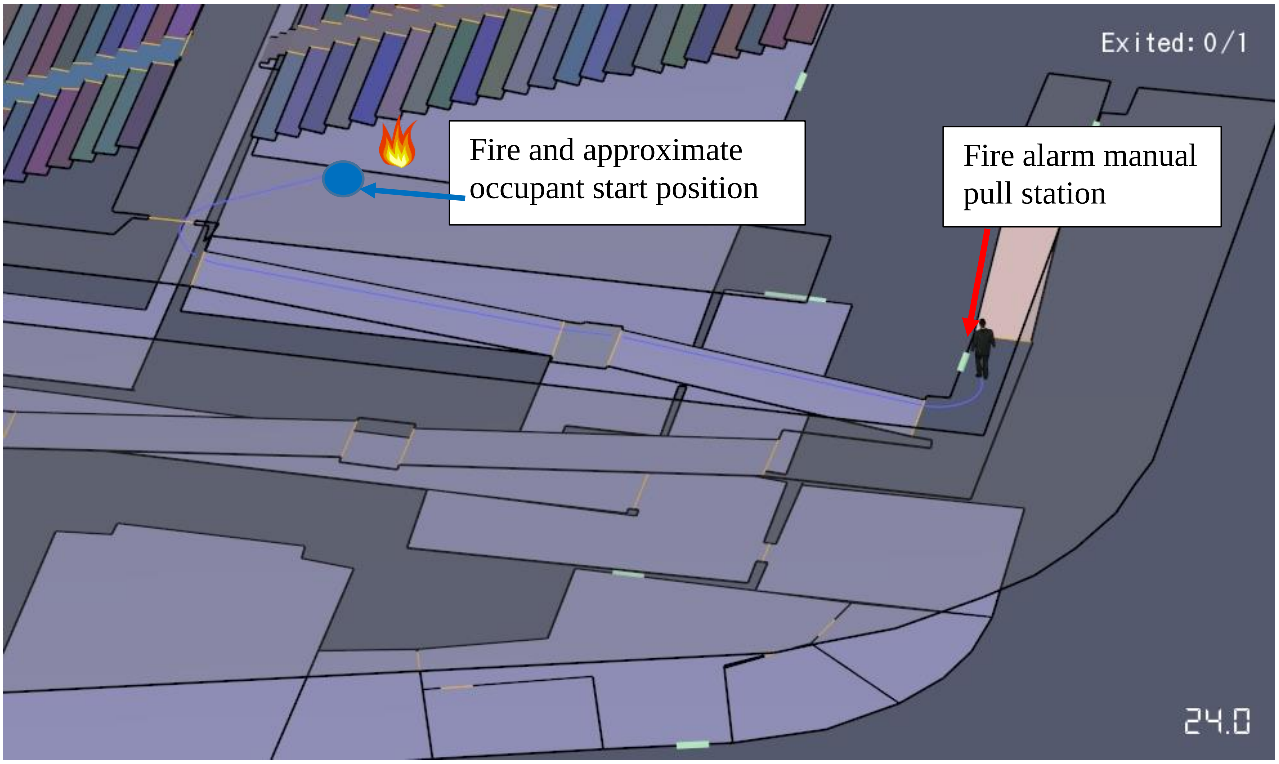


Figure 41. Alarm/notification time modeled in Pathfinder to show activation of pull station.

For design scenario two, once the sprinkler starts to flow water there is up to a 45-second delay on the water flow detector before it will activate the fire alarm system. This is required by code to ensure that sudden pressure swings in the sprinkler system do not cause the alarm to go off.

PREMOVEMENT TIME

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. Unannounced evacuation drills conducted in three IKEA stores by Franzch showed pre-movement time to be under 1 minute. Three Canadian government buildings had a mean time to movement of 50 seconds. The time to start for collected for over 1,000 occupants. A study of a large retail store conducted by Shields, Boyce and Silcock found that staff response had the most determinant effect on occupant start time to evacuation, with average time to start moving for customers after the sound of the alarm was 25 seconds. This from Section three chapter 12 of the 4th edition of the SFPE handbook, page 3-358.

For design scenario one, there are two factors that need to be taken into account to estimate an appropriate pre-movement time. The first is the state of the occupants and the setting. It was assumed that for a concert many people would not be at their most alert, or even under the influence. However, as stated before there will be professional staff assisting in the egress of the occupants from the space. The fire alarm system is also a mass notification alarm system that sends out an audible message telling people that, "there is a fire incident in the building and to evacuate immediately." These factors contribute to a quicker pre-movement time than if there was just a fire in an office building and you cannot see it. For this scenario, a pre-movement time will be assumed to be 30 seconds.

For design scenario two, everyone in the gym will be there to work out and not be under the influence of anything that would impair him or her from making decisions. Under these conditions, it is safe to say a conservative pre-movement time is 20 seconds.

TRAVEL TIME

Travel time is the time that it takes for people once they start egressing until the last person has left the building. For this complex building layout with as many occupants that can be in the gym at one time, 4,230, a computer aided egress model called Pathfinder was used. Pathfinder can use either a "steering" model or the SFPE model that uses queuing times and flow rates to find the egress time. Pathfinder allows modeling of the bleachers to the exact specifics of the room and accurately predict the movement time. The entire building was filled to capacity at 7,257 occupants; although this will probably not happen, it could theoretically. It takes 485 seconds for everyone to exit the Recreation Center assuming that everyone starts moving at the same time.

RSET

As shown in the FDS results section the RSET will be determined when everyone has left the top most bleacher. In order to line the Pathfinder model up the fire timeline the detection time of 45 sec, alarm time of 25 sec, and pre-movement time of 30 sec are added to the movement time. In total 100 seconds have gone by from the start of the fire to when people start moving towards the exits.

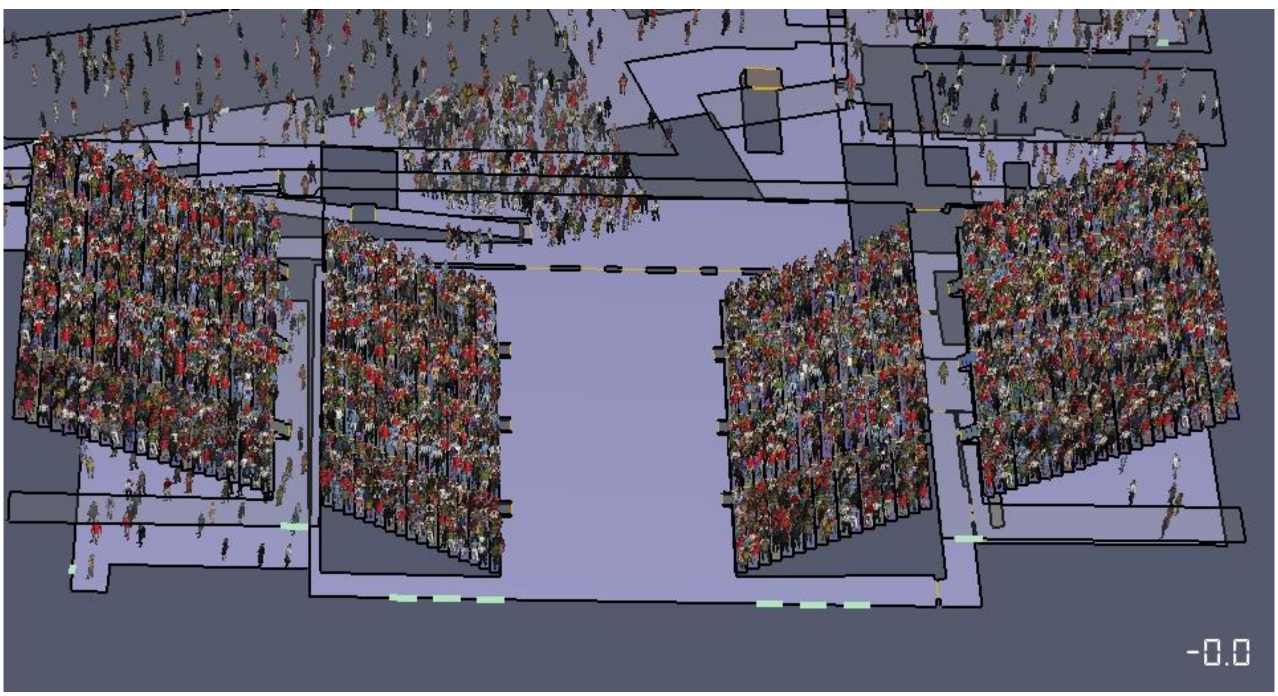


Figure 42. The Gym full of people before movement begins

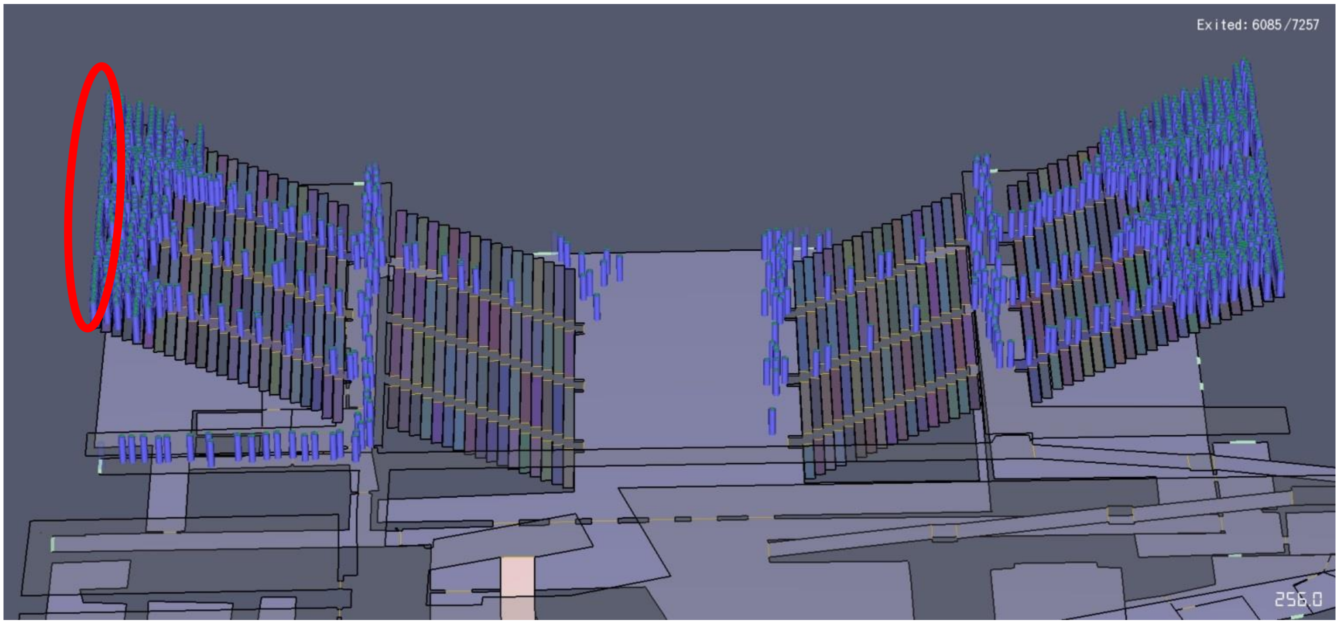


Figure 43. Time when conditions become untenable in red, at 356 seconds

Figure 43 shows when untenable conditions start to exist in the left top bleacher as determined by figure 31. There is clearly a problem already with lots of occupants still needing to egress from the bleachers before the top level can move down. This is of course assuming that occupants do not climb down the bleachers themselves but wait and use the stairs and aisles. The bleachers and gym should be designed assuming this fact, and this model will continue with that assumption.

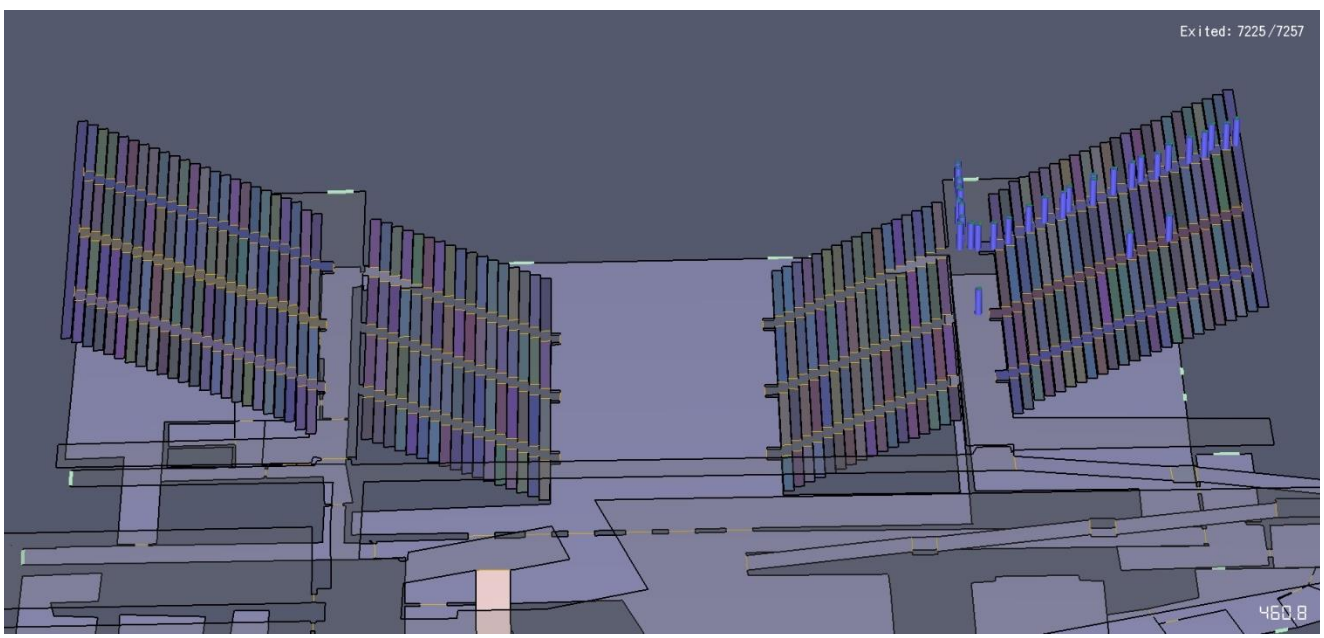


Figure 44. RSET reached at 560.8 seconds into the fire

At 460.8 seconds into the movement time the last occupant leaves the highest bleacher and descends to the exit. It only takes 25 more seconds before that occupant fully exits the gym. Adding the 100 seconds before the movement time gives a RSET of 560.8 seconds.

CONCLUSION

Looking at the ASET and RSET determines if the fire protection system that is in place is adequate for the fire scenario. With an ASET of 356 seconds and an RSET of 560.8 seconds, ASET<RSET; occupants will not be able to safely egress the gym before untenable conditions are reached and they succumb to smoke and reduced visibility. Up on the bleachers they will be more likely to injure themselves if they try to egress in the amount of smoke specified and will likely stop moving, not knowing where to go. There is a difference of 204.8 seconds, or 3 minutes and 24.8 seconds; this is a huge difference and will require additional protection systems be in place or upgraded to deal with the fuel load. I would first recommend that a mechanical exhaust smoke control system following CBC section 909 be installed to maintain a visibility above 13 m at the highest bleacher. This will allow everyone to egress in tenable conditions; the ASET would need to be 560.8 seconds + 560.8*0.2 = 672.8 seconds. Next would be to look into a sprinkler system that would be better suited to controlling this class A plastic high pile storage. The biggest problem is if a fire does break out under the bleachers sprinklers will not be able to reach it and control the fire. The sprinkler system in place is designed for light hazard gym space, and not a class A high pile exposed plastic such as these bleachers. The problem with the configuration of the gym and its high ceilings is that there is no sprinkler system that is designed to handle a fuel load this great with these ceiling heights. This needs to be taken into consideration and some additional protection must be added. Besides the bleachers and lack of protection in the old gym the rest of Recreation Center is of sound design for fire protection according to both the 2007 CBC and performance based design.

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