Fire Protection Analysis

Robert and Margrit
Mondavi Center
for the Performing Arts
UCDavis

FPE 596 Cumulative Experience Project
California Polytechnic State University – San Luis Obispo
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Keywords: Life Safety Code, RSET, ASET, Performance Based Design, Fire Dynamics Simulator (FDS)

Executive Summary

This document is the report of the culminating experience as part of the master's program in fire protection engineering at the California Polytechnic State University, San Luis Obispo. This report contains a life safety analysis of the fire protection systems of a chosen project building. The building examined is the Robert and Margrit Mondavi Center for the Performing Arts, located on the University of California Davis campus. The building was constructed in 2002 where the first performance occurred in October 2002.

A large portion of the report applies prescriptive code requirements to evaluate compliance with current codes and standards. The analysis involves the requirements for construction, structural fire protection, occupant egress, fire detection and alarm, and fire suppression.

The final section of the report is a performance based analysis of two fire scenarios including the lobby atrium and the main theater stage locations. The Available Safe Egress Time (ASET) versus Required Safe Egress Time (RSET) model was used to evaluate the performance of the fire protection systems in each space. A tenability analysis was used to produce the ASET for occupants to escape the building. To evaluate tenability conditions in each space during a fire, Fire Dynamics Simulator (FDS) was used. To estimate the RSET, Pathfinder was used to estimate occupant egress times from the space.

The performance based analysis provides recommendations to reduce the risk or consequences of a fire in each space. Recommendations for both spaces involve the removal of fuel sources from the space and should be considered a high risk if not removed without further analysis showing otherwise. The fuel source within the lobby was already planned before this report was created.

Even though the author believes this report to be valid, it should be noted that this report was an academic exercise and consultation with a licensed professional engineer should occur before changes are made to the building.

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Section 1.
Building Introduction

1.1 Building Overview

The Robert and Margrit Mondavi Center for the Performing Arts is a performing arts building located on the University of California Davis campus in Davis, California. The building contains two performance spaces, the 1,801 seat Jackson Hall and the 250 seat Vanderhoef Studio Theatre. Other spaces including the Yocha Dehe Grand Lobby and the Bartholomew Room can be used for special events and meetings.

1.2 Applicable Codes

The following relevant codes were used for the original building design:

1995 California Building Code
1995 California Fire Code
1993 NFPA 72, National Fire Alarm Code
1992 NFPA 13, Standard for the Installation of Sprinkler Systems

The following relevant codes were used to analyze the fire protection systems currently in the building:

2010 California Building Code
2010 California Fire Code
2013 NFPA 72, National Fire Alarm and Signaling Code
2013 NFPA 13, Standard for the Installation of Sprinkler Systems

All code references throughout the report are from the 2010 California Building Code unless otherwise specified.

Section 2.
Code Analysis

2.1 Building Occupancy Classification

The building is a mixed occupancy. The entire building except for the Studio Theatre is classified as an Assembly Group A-1 occupancy. The Studio Theatre space is classified as an Assembly Group A-3 occupancy.

The building contains Business and Storage accessory occupancies.

2.2 Construction Classification

Because the building is a mixed occupancy classification, the most stringent requirements must be used, which is based on the Assembly Occupancy, A-1. The building construction is Type IB because the building construction elements are of non-combustible materials and the applied structural fire protection is less than would be required for a Type IA building.

2.3 Building Height and Area

The building height and area were calculated in accordance with the California Building Code Table 503. The maximum allowable height is 160 feet and 5 stories plus 20 feet and 1 story for having an automatic sprinkler system. The building is 97.5 feet tall and 5 stories. The allowable floor area per story is unlimited.

2.4 Structural Fire Protection

Table 2.1 shows the required and applied fire protection of the building construction elements.

Table 2.1 – Building elements construction fire protection requirements

Building Element	Required Fire-Resistance Rating (hour)	Applied Fire-Resistance Rating (hour)
Primary structural frame	2	2
Bearing walls		
Exterior	2	4
Interior	2	2
Nonbearing walls/partitions		
Exterior	0	0,1
Interior	0	0,1
Floor construction	2	2
Roof construction	1	1

A fire-resistance rating for the exterior walls is not required for walls with a fire separation distance greater than 30 feet away from the centerline of a public way or street, the closest interior lot line, or to an imaginary line between two buildings on the property. Figure 2.1 shows the separation distances. Only the West side of the building does not meet the 30 feet requirement. The distance between the Mondavi Center and an imaginary line between the Mondavi Center and the next building is less than 30 feet but greater than 10 feet. This requires a fire-resistance rating of 1 hour for a Type IB building, unless it is a bearing wall, which is required to have a 2-hour fire-resistance rating.

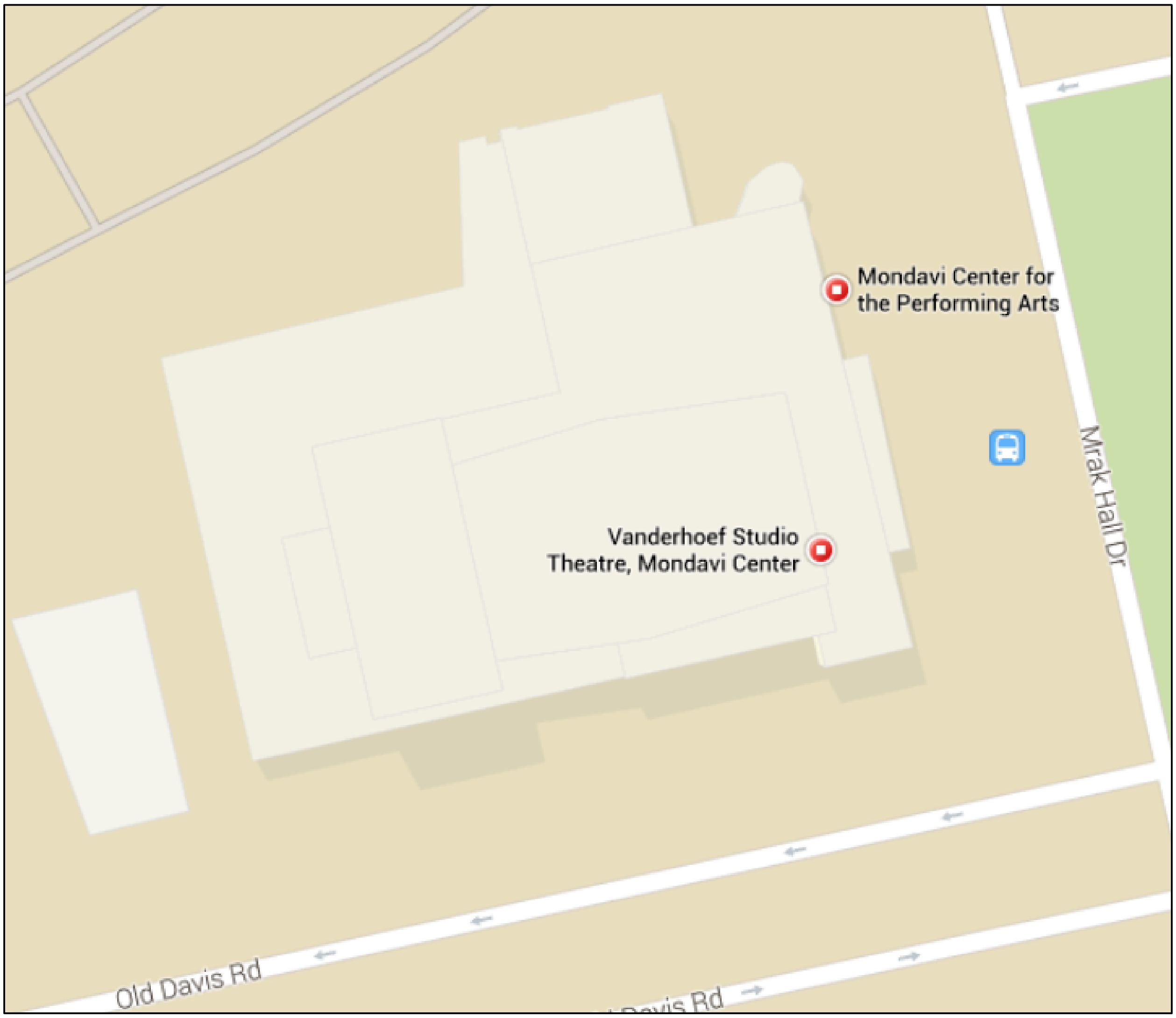


Figure 2.1 – Building exterior separation distances

Separation Requirements

The A-1 and A-3 occupancies are not required to be separated because they are both Assembly occupancies. Table 2.2 summarizes the separation requirements for incidental accessory occupancies. Table 2.3 summarizes the separation requirements for the building egress components. Table 2.4 summarizes the separation requirements for special situations unique to

certain building elements. Figure 2.2 shows the plan view of the 1st floor with existing separations.

Table 2.2 – Separation requirements for incidental accessory occupancies

Room/Area	Req. Separation	Applied Protection
Fire Pump Room	2-hr; or 1 hr w/ fully sprinklered	2-hr fire barrier and sprinklers
Storage rooms >100 ft^2	1-hr or auto fire-extinguishing system	Sprinklers
Furnace Room	1-hr or auto fire-extinguishing system	Sprinklers

Table 2.3 – Separation requirements for egress components

Space	Req. Separation	Applied Protection
Corridors	1-hr or 0-hr w/ Fully Sprinklered	1-hr fire partition
Horiz./Vert. Exit Enclosures	2-hr fire barrier	2-hr fire barrier

Table 2.4 – Separation requirements for special situations

Space	Req. Separation	Applied Protection
Atrium <-> Rest of building	1-hr fire barrier or Horiz. Exit	1-hr constr. 20 min. doors
Proscenium wall	2-hr construction	2-hr fire barrier*
Stage to adjacent spaces	2-hr fire barrier	2-hr fire barrier*
Adjacent <-> adjacent spaces	1-hr fire barrier	1-hr fire barrier

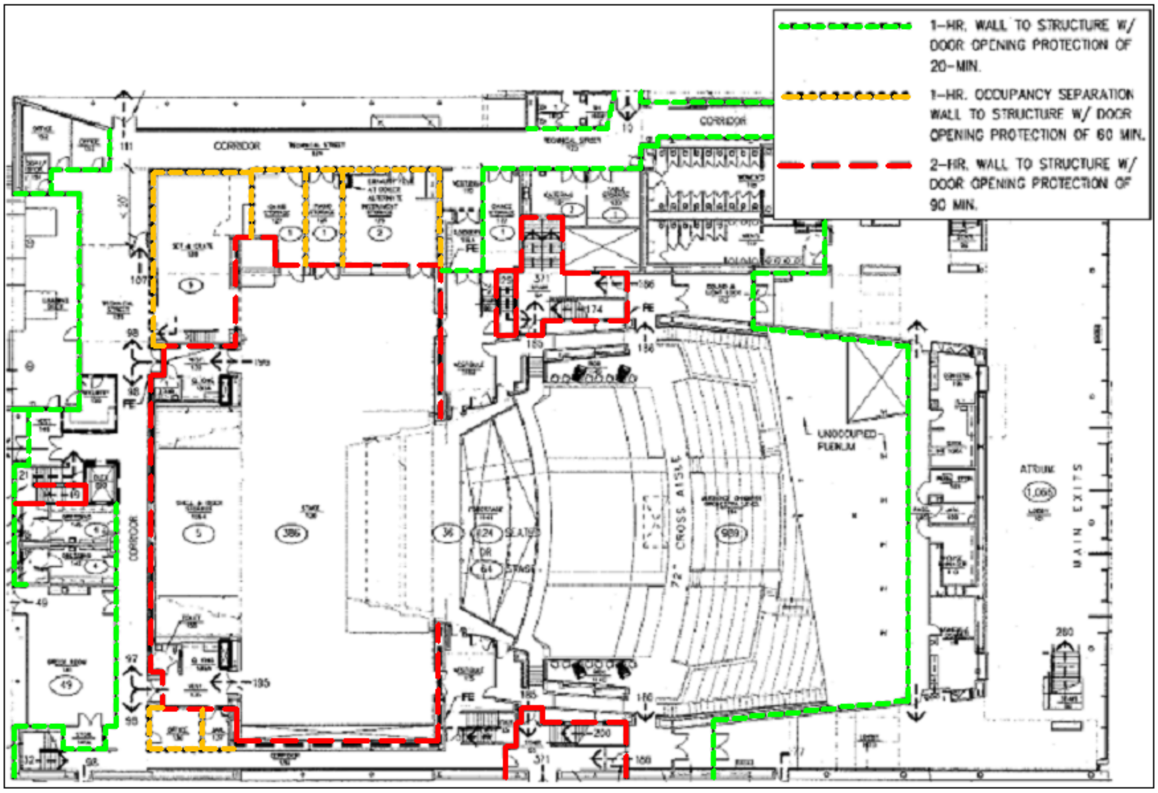


Figure 2.2 – 1st floor existing separations

Most separation requirements are met or exceeded. Because the lobby space is an atrium space, the space is required to be separated from the rest of the building by a 1-hour fire barrier or a horizontal assembly. The design plans specify 1-hour rated wall construction with 20-minute rated doors. To be a 1-hour fire barrier, the doors must be 45-minute rated doors. This does not comply with the current code.

The proscenium wall, which is the wall that separates the stage from the audience hall seats in Jackson Hall, has a 2-hour fire-resistance rating except for the opening. The opening is allowed to be protected by a fire curtain that complies with NFPA 80, Standard for Fire Doors and Other Opening Protectives. The fire curtain that is in place is a 20-minute rated fire curtain. At the time of design, the California Building Code required a proscenium curtain that is 20-minute rated. These opening and wall requirements are only required when the stage is greater than 50 feet in height.

All spaces adjacent to the stage are required to be separated from the stage by a 2-hour fire barrier as well. Then, those spaces must be separated from each other by a 1-hour fire barrier. There is a storage area at the back of the stage that is not separated from the stage. The space is used to store the shell structure, which is 57 feet wide, 42 feet tall, and 27 feet deep. Per code, the space should be separated from the stage by a 2-hour fire barrier, however, this is not feasible due to the size of the structure to be stored. It is likely that the Authority Having Jurisdiction approved the request to not separate this space. Figure 2.2 shows the shell storage space to the back of the stage. The performance section of this report will analyze this space.

Section 3.
Egress

3.1 Occupancy Classification and Use

The entire building is classified as an Assembly occupancy A-1 with the exception of the Studio Theatre having an Assembly occupancy of A-3. Occupancy separation of assembly occupancies is not required under the California Building Code.

Other spaces incidental to the main occupancies include business and storage spaces. Appendix B shows the layout of the building with each space marked for its specific use.

3.2 Occupant Load

The occupant load for individual spaces and each floor can be seen in Table 3.2. The occupancy load factors used were taken from the California Building Code Table 1004.1.1 and can be seen in Table 3.1. The two theaters used a combination of load factors. The fixed seating areas used the number of fixed seats as the occupant load. The disabled seating areas used the concentrated assembly factor and the non-fixed booth seating used the unconcentrated assembly factor.

The lobby occupant load was calculated using the most restrictive value of 5 square feet per person since it is used for events. The 1995 CBC requires a value of 7 square feet per person be used. The original design calculation either did not use the required 7 square feet per person value or did not use the correct area. With an area of 5,949 ft^2, an occupant load of 850 is obtained, which is significantly higher than the value of 760 shown in the obtained plans. Using the current code, the load factor of 5 creates a much higher occupant load of 1,190 occupants just on the third floor.

It should also be noted that the Jackson Hall and Lobby well never be simultaneously occupied. Therefore they should be considered independently for egress.

The Jackson Hall fixed seating areas have an occupant load equal to the number of seats. For the non-fixed seating areas within the theater, the concentrated assembly load factor was. The amount of Jackson Hall seating can also be reduced to allow for more stage space or basement level orchestra space. The occupant load of this area was factored into the calculation of each space as if it was fully occupied for each space.

A load factor for the fly gallery is not specified in the CBC, the value of 100 was taken from Table 7.3.1.2 of NFPA 101, Life Safety Code.

Table 3.1

Function of Space	Load Factor (ft^2 per person)
Assembly Fixed Seats Standing Concentrated Unconcentrated	 # of seats 5 net 7 net 15 net
Business Area	100 gross
Accessory storage, mechanical equipment rooms	300 gross
Stages	15 net
Fly Gallery	100 net

3.3 Exit Capacity

Section 1005.1 of the CBC gives the requirements for egress widths. The total means of egress width shall not be less than the total occupant load served multiplied by 0.3 in. per occupant for stairs and 0.2 inches per occupant for other egress components. Also, the loss of one means of egress must not reduce the capacity to less than 50 percent of the required capacity.

Table 3.2 shows the calculated occupant load and exit capacity of each space. Each individual exit capacity was calculated using its most limiting door or stair. Each space's capacity was calculated by combining its individual exit capacities. The loss of any one exit does not reduce the capacity to less than 50 percent for any floor, but only the first floor has enough exit capacity to handle the occupants it serves.

Table 3.2

Location	Floor Area (ft^2)	Load Factor (ft^2 per person)	Load	Limiting Door/Stair Exit Capacity
Atrium Lobby 1st Floor 2nd Floor 3rd Floor	 8,615 2,435 5,949	5	 1,725 **900** **1190**	 3,105 **560** **761**
Jackson Hall Seating Orchestra/Parterre First Balcony Second Balcony	 580 580 300	# seats, 7, 100	 1,179 393 364	 1309 400 400
Studio Theatre	3,334	# seats, 7, 15	335	390
Stage	9,500	15, 300, 100	498	675
Back of House 1st Floor 2nd Floor	 6,000 1,500	7, 15, 100, 300	 718 96	 756 329
Basement	2,700	7, 15, 100, 300	107	467

Section 1004.5 requires that means of egress that converge from above and below must have exits that can accommodate both floors. All four exits where this occurs easily meet the capacity requirement. The West exit doors accommodate occupants of the Basement and Back of House Second Floor. The load is easily met with a door discharge capacity of 300 occupants. Both North and South stair enclosures easily accommodate egress from the Basement and First Balcony.

3.4 Arrangement of Means of Egress

Exit Access

Section 1015.2 gives the requirements for exit positioning. The exits must be placed so that their availability is made obvious and unobstructed at all times. The Mondavi Center has great visibility throughout the building, finding an exit would not be difficult should the need arise.

Section 1015.2.1 requires that where two exits or exit access doorways are required, they must be placed an appropriate distance apart. Because the building is fully sprinklered, the distance may be reduced to one third of the diagonal distance of the entire building. Because the building corridors are protected by at least 1-hour fire resistance ratings, the distance between exits may be measured along the corridors. Each level meets this requirement.

Section 1022.2 requires that the two exit enclosures terminate at an exit discharge or a public way. The North exit enclosure is actually in the middle of the building, but the enclosure travels to the basement level and opens outside to a stair leading to a public way. The South enclosure discharges directly to a public way.

Section 1014.2.2.1 requires that basement space must have at least one exit access that leads directly to an exterior exit door opening directly to an exit discharge. Stair enclosure S6 meets this requirement by being enclosed with a 2 hour fire resistance rating and leading to the exit enclosure that leads directly to an exit discharge to a public way.

In Appendix B, the floor plans are shown labeled with the floor exits, exit discharges, and exit enclosures on the floor plans.

Travel Distance

The exit access travel distance requirements are given in Section 1016. Table 1016.1 gives an exit access travel distance of 250 feet for assembly occupancies with a sprinkler system. This is measured from the most remote position of a story along a path of egress to the nearest exit.

The Orchestra Terrace seating section exits to the atrium and requires special consideration to meet requirements. The egress path goes through the Lobby atrium from the second level to the main exit. The egress path can only travel 200 feet through an atrium and 250 feet total. This arrangement is still acceptable.

The balcony lobby at the third floor of the atrium must also meet the 200 feet requirement down two flights of stairs to the main lobby exit discharge.

Because the stairways serving the West end of the building are not enclosed, the travel distance must be measured down the stairs and through the floor of exit discharge. The distance is still measured to be less than the required 250 feet.

All other spaces meet the travel distance requirement of 250 feet.

Common Paths of Travel

Section 1028.8 requires that common paths of egress travel do not exceed 30 feet from any seat to where an occupant has two options of egress paths. This requirement is satisfied in the theater seating.

Throughout the rest of the building, Section 1014.3 requires that common paths of egress travel cannot exceed 75 feet.

Dead Ends

Section 1018.4 gives the requirements for dead ends. Dead ends in corridors cannot exceed 20 feet. There are no dead ends that come close to 20 feet within the building. Section 1028.9.5 requires that dead end aisles cannot exceed 20 feet as well. None of the aisles exceed this requirement.

Area of Refuge

Areas of refuge are required for persons with disabilities by Section 1007 in order to egress from the upper levels of the Jackson Hall theater seating. The elevator lobbies in the atrium space act as the areas of refuge. Because the elevator lobbies are in an atrium, section 1007.6 allows the elevator lobbies to be unenclosed, assuming the atrium space is formed by a smoke barrier.

3.5 Fire Resistance Ratings of Egress Components

Section 404.6 requires atriums to be separated from adjacent spaces by a 1-hour fire barrier. The Mondavi Center satisfies this requirement through all floors of the atrium lobby.

There are two enclosed exit stairs in the building that connect the three floors of the Jackson Hall Theater seating and adjacent atrium space. Section 1.1.5.2 requires that exit enclosures connecting less than four stories have at least a 1 hour fire resistance rating. Both enclosures have a 2 hour fire resistance rating with 90-minute rated doors.

The egress stairways on the West side of the building do not need to be enclosed because they only connect two floors together. The basement access stair in the West end of the building is enclosed from the First Floor, allowing the stair leading to the Second floor be open.

All exit access corridors are protected with at least a 1 hour fire resistance rating.

3.6 Interior Finish

Section 1028.11 requires that sloped assembly aisle surfaces not exceeding one unit vertical in eight units horizontal consist of a ramp having a slip resistant walking surface. The Jackson Hall Theater orchestra seating contains this on the lower level. The aisles exceeding this slope are required to have risers and treads that extend across the full width of aisles.

3.7 Exit Signage

Marking of Egress

Section 1011.1 requires that assembly occupancies have approved exit signs marking every exit and exit access door in the building. If the path of egress to an exit is not readily visible, the direction of egress must be shown with an exit sign. At no point in an exit access corridor or exit passageway can there be more than 100 feet to the nearest visible exit sign.

The main exterior exit doors are not required to have exit signs because it is obviously and clearly identifiable as exits.

Floor-level exit signs and path marking is not required in this building because it is protected throughout by an approved supervised sprinkler system. Regardless, this building was still fitted with floor-level exit signs.

Illumination of Egress

Section 1006 gives the requirements for illumination of egress components. The means of egress must be illuminated at all times when the building is occupied. The illumination level must be at least 1 foot-candle at the walking surface. For theaters, the illumination at the walking surface may be reduced to not less than 0.2 foot-candle during performances, as long as the fire alarm system restores illumination automatically. During loss of primary power, emergency power shall be provided in aisles and egress stairways in the theaters, in the corridors, exit enclosures, and exit passageways, exterior egress components and landings, and interior exit discharge elements.

Section 4.
Fire Detection, Alarm, and Communication

4.1 Code Requirements

The California Building Code Section requires that the Mondavi Center must have a manual fire alarm system that activates the occupant notification system. There is an exception for buildings that are fully sprinklered and have waterflow initiation but it does not apply in this case because the building is used for educational purposes. Because there is an atrium connecting more than two stories, the CBC requires that a fire alarm system with smoke detection throughout the atrium must be installed.

Regardless of the CBC requirements, the UC Davis Standards and Design Guide overrides these requirements and requires a full fire detection and alarm system per Section 28 31 00 Fire Detection and Alarm.

The CBC also requires that system alarm activation must activate an emergency voice/alarm communication system because the occupant load is greater than 1,000 people and because there is an atrium connecting more than two stories.

The building does contain detection and alarm through with an emergency voice/alarm communication system.

4.2 System Operating Characteristics

This project building uses a proprietary system. The fire alarm control panel (FACP) transmits a signal to the UC Davis Police Department Communications Center. The Communications Center will then notify the UC Davis Fire Department to respond. The system was initially installed with an auxiliary alarm system. The FACP was originally connected to a Gamewell street box (shunt type) that would be tripped during an alarm condition. However, UC Davis has removed these boxes throughout the campus, including this one.

The FACP can receive signals from multiple types of addressable devices initiating an alarm, trouble, or supervisory signal. Through the build in DACT, it will then send out a signal through two telephone lines through the telecom room to notify the fire department. Notification devices, including emergency voice/alarm communication systems and visible notification systems, will also be activated to notify occupants.

If a fire is detected in the main lobby or studio lobby (Fire alarm or sprinkler Zone 6), smoke control operations will activate. Smoke dampers will shut off system air supply to the upper lobby and open the main lobby doors. Two exhaust fans in the ceiling will turn on, venting smoke out of the atrium.

Fire Alarm Control Panel

The IntelliKnight 5820XL Addressable Fire Alarm Control Panel (campus wide standard), manufactured by Silent Knight, is located in the Security Room 150, near rear building entrance. The UC Davis Standards and Design Guide Section 28 31 00, Fire Detection and Alarm, requires that all fire alarm system products must be manufactured by Silent Knight. The Fire Alarm Control Panel is accompanied by the following devices:

1 Multi-circuit Voice Evacuation Panel

- Wheelock, Model SC-SAPE-AA4SR
- Located adjacent FACP

4 Fire Alarm Annunciators

- Silent Knight, Model 5860
- Located throughout building near entrances

1 Firefighter Control Panel

- H.R. Kirkland
- Located adjacent FACP

2 Fire Alarm Power Supply

- Silent Knight, Model 5895XL
- Located in room 109 and room 303

1 Smoke Control Panel

- Notifier AFP-1010
- Located in room 109

4.3 Signal Disposition

Alarm Signal

The system goes into alarm when any smoke or heat detectors are triggered, a manual pull box is pulled, or a waterflow switch detects movement. Elevator lobby detectors also recall elevators. Heat detectors in the elevator equipment room will, after recalling the elevators, shunt power to them. Duct dampers will close according to their respective smoke detector.

When an alarm signal is triggered, automatic visual and voice signals will be activated throughout the building. All magnetic door holders will also release. If detection is triggered in the main lobby or Studio Theatre lobby, lobby smoke removal sequence will be initiated.

An alarm signal is annunciated on each Annunciator panel and then transmitted to the UCD Police Department Communications Center via two dedicated telephone lines through the communications room.

Supervisory Signal

Supervisory signal shall occur if a tamper switches on the Fire Alarm Control Panel door, Emergency Voice/Alarm Communications system door, or Fire Alarm Power Supply door are triggered. Waterflow tamper switches on the sprinkler system will set off a supervisory signal as well.

A supervisory signal is annunciated on each Annunciator panel and then transmitted to the UCD Police Department Communications Center via two dedicated telephone lines through the communications room.

Trouble Signal

Fire pump phase reversal, fire pump loss of AC power, and system equipment malfunction will cause a trouble signal.

A trouble signal is annunciated on each Annunciator panel and then transmitted to the UCD Police Department Communications Center via two dedicated telephone through the communications room.

4.4 Initiation

Manual Fire Alarm Boxes

Manual fire alarm boxes are required to be within 5 feet of each exit. Additional boxes must be installed so that there is no point within the building further than 200 ft away from a box. The handle must be between 42 and 48 inches above the finished floor. The box must be colored red.

Smoke Detectors

The campus standards require that detector location and spacing be determined by use of NFPA 72 Appendix A for irregular areas where smooth ceiling spacing does not exceed 30 feet per Section 28 31 00 [3.1 B.]. The corridor smoke detectors are designed in accordance with NFPA 72 Appendix A. Corridors that are 8 feet wide or less have detectors spaced at 40 feet, which is in accordance with NFPA 72 Appendix A for 30 foot spacing detectors.

There are four rooms that do not contain spot type smoke detection: three dressing rooms and a mechanical room. The reason for this is unknown. In place of spot type detection, open air, photoelectric, duct smoke detectors may have been used. These are the only rooms that have these open air duct detectors in the return air ducts. The applicable standard, UL 268A, explicitly states that duct detectors are not intended for open area protection. It would not have been any issue to extend spot type detection into this space. It may be a good idea to extend detection into this space because dressing rooms can have significant fuel loads due to performance equipment and wardrobes. Figure 4.1 shows the locations of the three dressing rooms adjacent to the Studio Theatre and their open air duct detectors.

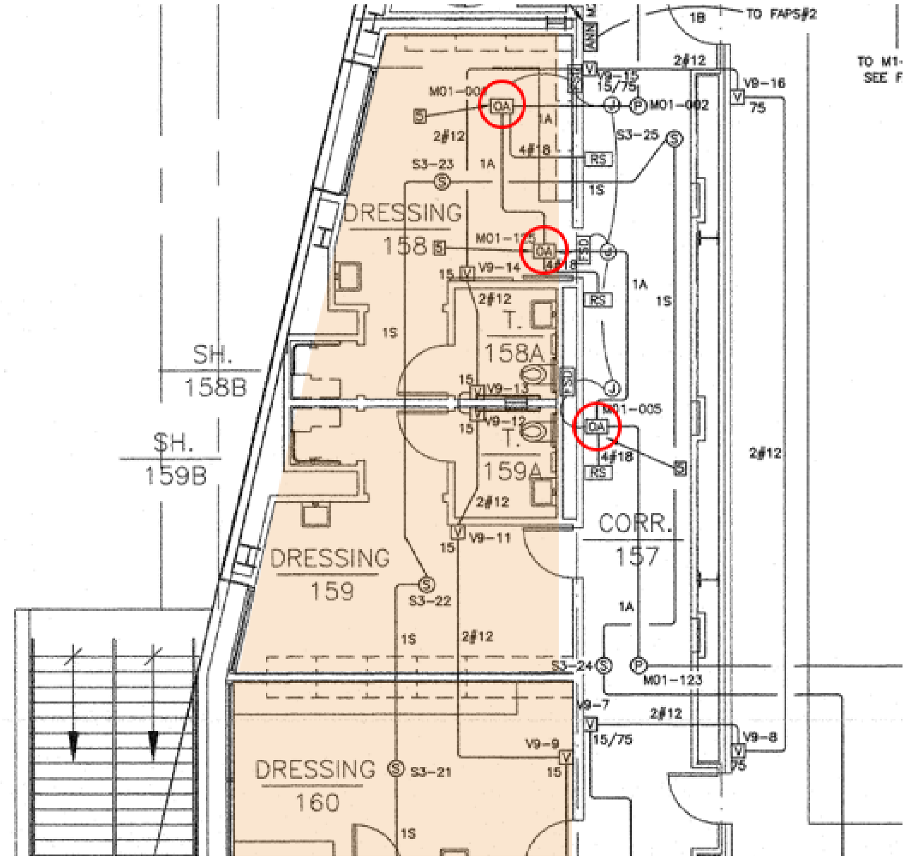


Figure 4.1 – Lobby atrium 2nd floor beam detector at 14 feet above the floor

Heat Detectors

Heat detectors are only used in elevator equipment rooms, used to shunt power to the elevator, and the boiler room. The heat detectors in the elevator equipment rooms are positioned in accordance with NFPA 72. Section 21.4.1 establishes the requirements that the heat detector used to shut down power before the sprinkler system activates must have a lower temperature rating and a higher sensitivity than the sprinkler. The detector used has a temperature rating of 135°F and a spacing of 70 feet where the sprinkler has a temperature rating of 155°F.

Beam Detector

A beam detector was installed in the lobby atrium 2nd floor bannister, as shown in Figure 4.2, to improve smoke detection in the lobby atrium. However, due to numerous nuisance alarms, the device has been taken out of service. The detector has initiated an alarm condition several times in situations such as when a coat was placed over the banister blocking the beam and when a service worker placed a ladder in the beam path. The beam detector should not activate an alarm signal in these situations because the System Sensor data sheet for the device specifies that a measured obscuration value above 95% will produce a trouble signal. The beam detector is not necessary for stratification because the atrium air handling system does not allow heat buildup at the ceiling because it circulates air through the ceiling.

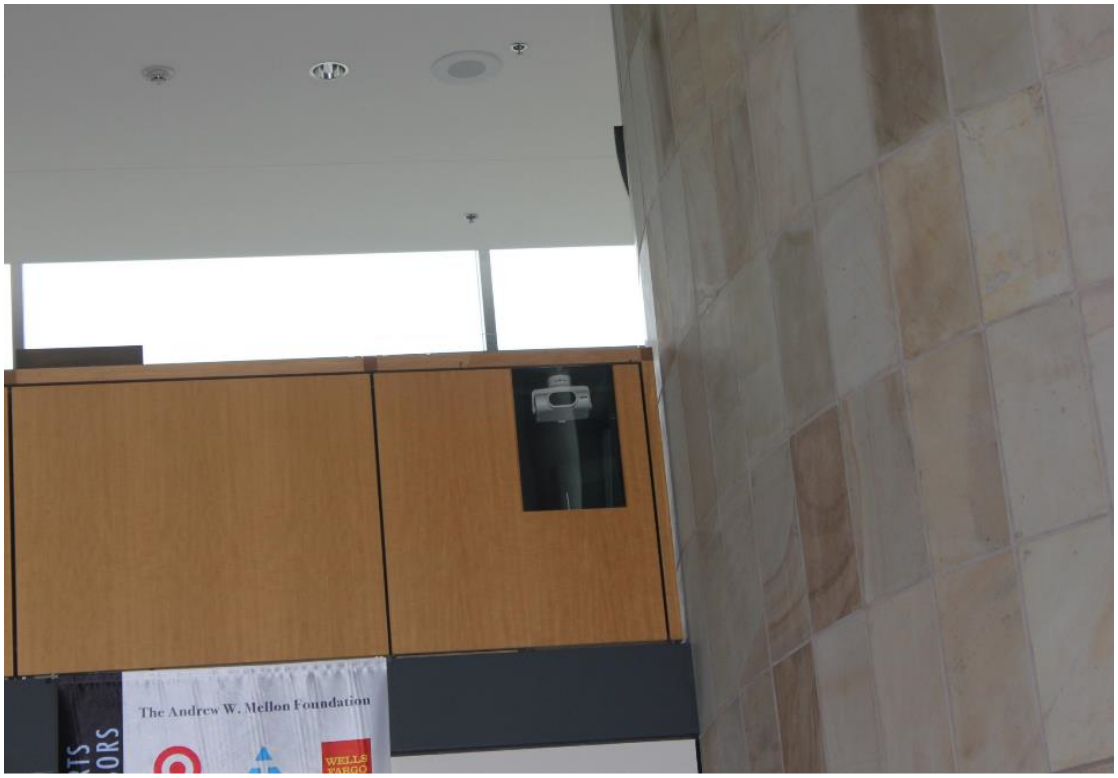


Figure 4.2 – Lobby atrium 2nd floor beam detector at 14 feet above the floor

Because the diameter of a smoke plume expands at a rate of approximately 0.4 times the height, the beam detector spacing at 14 feet should be no more than 6 feet. There is only one beam detector in this space that is over 30 feet wide. Therefore, there should be at least 5 beam detectors to adequately cover this space.

Fire Dynamics Simulator (FDS) was used to simulate smoke detection in this space by beam detection and spot type detection. When the fire was approximately 9 feet away from the edge of the beam, the beam detector never saw an obscuration value above 10%. According to the device data sheet, a value of 30% ($\pm$ 5%) is required to activate. Therefore, the beam detector does not activate.

When the beam was placed directly over the fire, the beam detector saw 30% obscuration and activated at approximately 37 seconds. However, the spot type detector at the ceiling at 40 feet detected the fire in 26 seconds.

These observations make it clear that the beam detector is not efficient or necessary for this space.

Initiating Device List

28 Manual Fire Alarm boxes

- Simplex 2099-9754 Manual Pull Station
- Module: Silent Knight SD500-MIM
- Mounted 48” Above finished floor to center of device
- Location:
  - Next to all exit doors

- In basement, next to exit stairs leading to first floor

161 Photoelectric Smoke Detectors w/ Low Profile Detector Base

- Silent Knight SD505-APS Photoelectric Smoke Detector
- Silent Knight SD505-6AB Low Profile Detector Base
- Ceiling Mounted
- Location:
    - All rooms including bathrooms, storage rooms, elevator mechanical room
    - Corridors spaced at a 40 ft maximum
    - Not in mechanical, fire pump, telecom or boiler rooms
    - Not in Jackson Hall audience chamber or Studio Theatre
    - Not in dressing rooms 160, 159 and 158
    - Not in certain rooms that already have a Photoelectric smoke detector with detector relay that cover the room sufficiently

37 Photoelectric Smoke Detectors w/ Relay Detector Base

- Silent Knight SD505-APS Photoelectric Smoke Detector
- Silent Knight SD505-6RB Relay Detector Base
- Ceiling/Wall mounted above doorway or elevator doorway
- Ceiling mounted in Boiler room
- Location
    - Outside elevator
    - Elevator recall activation
    - Elevator fire curtain activation
    - Outside all Fire Doors
    - Door holder/release
    - Set & Crate Room
    - roll up door release
    - Boiler Room

4 Heat Detectors w/ Low Profile Detector Base

- Silent Knight SD505-AHS Fixed Temperature Heat Detector
- Silent Knight SD505-6AB Low Profile Detector Base
- Shunt Trip Elevator Power
- Ceiling mounted
- Location
    - Boiler Room
    - Elevator Equipment Rooms
    - Elevator Shunt Power
    - Near fire sprinkler head

1 Beam Detector

- System Sensor 6424 Projected Beam Smoke Detector
- Wall mounted
- Location:
    - Atrium Second Level banister

19 Duct Detectors

- Silent Knight SD505-AIS Ionization Smoke Detector
- Silent Knight Duct Detector Housing
- Mounted on side of air duct

4 Open Air Smoke Detectors

- System Sensor 2151 Duct Smoke Detector
- Photoelectric Smoke Detector
- System Sensor B114LP Detector Base
- Pendent mounted inside return air duct
- Location:
    - Return air ducts for Dressing Rooms 160, 159 and 158
    - Basement return air duct for Basement Level Boiler Room

8 Waterflow Switch Monitors

- Waterflow Switch FBO
- Module: Silent Knight SD500-AIM
- Location:
    - Basement main sprinkler line
    - Orchestra level sprinkler risers

8 Tamper Switch Monitors

- Tamper Switch FBO
- Module: Silent Knight SD500-AIM
- Location:
    - All control valves
    - Double check valve assembly
    - Orchestra level sprinkler risers

22 Duct Detector Remote Test Switches

- Silent Knight SD505-DTS Duct Detector Remote Test Switch
- Mounted 72” above finished floor to center of device
- Location:
    - At each duct smoke detector

4 Open Air Detector Remote Test Switches

- System Sensor RTS-451 Remote Test Station
- Mounted 72” above finished floor to center of device
- Location:
    - At each open air duct detector smoke detector

6 Fire Curtain Fusible Link

- FBO
- Fixed Temperature, 165° F
- Location:
    - Spaced along curtain cable

2 Fire Line Release Pull Ring

- FBO
- Manual operation
- Location:
    - Upstage of the proscenium wall on either side of the opening

4.5 Notification

Visible Notification

The visible characteristics of this system comply with NFPA 72 Section 18.5. Wall mounted strobe devices are mounted 80 to 96 inches above the finished floor in accordance with 18.5.4.1. Rooms containing strobes are designed in accordance with 18.5.4.3.

Strobe devices in corridors are installed with at least a 15 candela rating. However, several corridor ends do not have strobe devices located within 15 feet of the end. This is a code violation of NFPA 72 Section 18.5.4.4.5. These situations also are not in compliance with 18.5.4.3. Each situation could easily be fixed by having placed one strobe device closer to the corridor end in question.

In one specific location, shown in Figure 4.3, a strobe notification device is blocked by a roll down security door. In the figure, the security door is shown in the normal up position, but even rolled up, the egress door on the right still blocks the strobe from reaching the office space to the left. There are no other strobes that reach this area.

Figure 4.3 – Wall mounted strobe blocked by security gate

Audible Notification

The Emergency Voice/Alarm Communications system was designed in accordance with the UCD Standards and Design Guide. Speakers shall be installed so that speakers use ½ watt setting unless otherwise specified on the drawings [2.10 F. 2.]. The drawings show no other watt

settings to be used. The standards and design guide also states that bathroom speakers shall be set to the lower setting of ¼ watt because alarm threshold may be high [2.10 E. 6.]. Therefore, ¼ watt speakers should be indicated on the drawings. Either the speakers are set to ½ watt or the bathroom requirement was not established or enforced when the alarm system was designed in 1992. Either way, it will be easy to check and fix by looking at the individual speaker. Decreasing the watt setting will only decrease the load on the amplifiers.

Considering all speakers are powered at ½ watt, the decibel rating for the speakers and speaker/strobes is 84.4 dBA at 10 feet. The furthest distance between any two speakers is in audience chamber in Jackson Hall at 80 feet. Using NFPA 72 Table A.18.4.3 we can find the average ambient sound of places of assembly to be 55 dBA. Using the 6 foot rule of thumb we can estimate the dBA output of the speakers in the center of the hall to be 72.1 dBA. Per 18.4.3.5.1, the sound level must be 15 dB above ambient. Therefore, the sound system must achieve a sound level of 70 dBA or higher. The building meets this requirement throughout.

Another consideration in the audience chamber is a loud performance may be in progress when an alarm condition occurs. The maximum sound level will likely be much higher than 55 dBA. To accommodate for this, the FACP has the capability to shut down all performance system speakers and change lighting conditions to assist alerting occupants. Strobe lighting will also be effective in notifying occupants.

Notification Appliance List

8 Speaker/Strobes

- Wheelock ET70-24MCW Speaker/Strobe
- Wall Mounted 80" above finished floor to bottom of device
- Location:
  - Basement: Electrical room, telecom room, boiler room, mechanical room, corridor outside mechanical room, trap room

149 Strobes

- Wheelock RSS-24MCW and RSS-241575 Strobes
- Wall Mounted 80" above finished floor to bottom of device
- Location:
  - All corridors, dressing rooms, green room, certain storage rooms, concessions rooms, bathrooms, main stage, Jackson Hall and Studio Theatre

201 Ceiling Mounted Speakers

- Wheelock ET90-R
- Ceiling Mounted
- Location:
  - All corridors, Jackson Hall, Studio Theatre, bathrooms, green room, dressing rooms, select other rooms

12 Wall Mounted Speakers

- Wheelock ET70-R
- Wall Mounted 80" above finished floor to bottom of device

- Location:
    - Orchestra pit, main stage, shell and riser storage

1 Sprinkler Alarm Exterior Bell

- FBO
- Wall Mounted 10' above finished grade
- Location:
    - Outside on the west/rear side of the building facing fire department connection

4.6 Power Requirements

Requirements

The requirements for secondary power are established by the UC Davis Standards and Design Guide and NFPA 72 Section 10.5.6. UC Davis requires that backup battery systems shall be provided with the capability of a 24 hour standby period followed by 5 minutes of alarm [2.4 F.1.h.]. However, NFPA 72 requires that a system utilizing a emergency voice system will be capable of 24 hours of standby followed by 15 minutes of alarm [10.5.6.3.1(2)].

Assumptions

Signaling line circuit M02 has been assumed to be one circuit attached to Room 303 Fire Alarm Power Supply #2. Looking at the riser diagram or the plan drawings, it is impossible to see what lines are connected to which Fire Alarm Power Supply. The worst case scenario has been chosen to connect the circuit to only one of the two devices. FAPS#2 was chosen because it has a SLC Expander module attached to it. It is also assumed that FAPS#2 was intended to carry at least part of the M02 circuit.

Battery Calculations

The battery calculation spread sheets can be found in Appendix F and the voltage drop calculations can be found in Appendix G.

Calculations were performed on the current fire alarm and backup system. Three separate rooms on different floors contain a control panel with backup batteries. Battery capacity requirements were calculated for each room. The room with the main FACP also contains the voice evacuation panel. Fire Alarm Power Supply #1 is located next to the Smoke Control Panel. The secondary power of these two devices is from the same set of batteries, so their individual requirements are consolidated. FAPS #2 is located remotely.

Calculations show that the FACP and EVAC system will only use 64% of the battery's rated capacity. However, the UC Davis Standards and Design guide requires that the batteries must not exceed 80% of its rated capacity and also must contain 25% reserve capacity for future expansion. The current batteries do not provide quite enough capacity to support these requirements. 26.08 Amp-Hours of capacity are required where 26 Amp-Hours are provided.

Battery information for the equipment in room 109 and 303 was not acquired. To find the minimum battery capacity to meet the requirements, the minimum required capacities are multiplied by 1.25 again. This is to account for the requirement where the current draw cannot exceed 80% of the battery rated capacity. Looking again at Table 4.1, a minimum capacity battery for the FAPS#1 and the SCP shall provide at least 5.66 Amp-Hours. For FAPS#2 batteries with a minimum capacity 10.88 Amp-Hours shall be provided. Two 12V 6AH and two 12V 12AH batteries will be sufficient.

Table 4.1 Battery Calculation Summary

	Required Standby Capacity (Amp-Hours)	Required Alarm Capacity (Amp-Hours)	Total Required Capacity (Amp-Hour)	Adjusted Required Capacity (Amp-Hour)	Actual Battery Rated Capacity (Amp-Hour)
Security Room 150 FACP and EVACS	13.46	3.23	16.69	26.08	26.00
Janitor Room 109 FAPS#1 and SCP	2.16	1.46	3.62	5.66	Unknown
Storage Room 303 FAPS#2	4.67	2.29	6.96	10.88	Unknown

Section 5.
Fire Suppression

5.1 System Design

The Mondavi Center is protected throughout by a fully supervised wet-pipe system automatic sprinkler system as required by the California Building Code Section 903.2.1.1. Because the building is larger than 52,000 ft^2, it must be separated into zones protected by separate risers. The building is separated into six zones, each with a separate riser. Table 5.1 shows the separate zones and their locations. Figure 5.1 shows the floor plan with each zone's location.

Table 5.1

Zone	Location
1	Basement
2	Back of House
3	Stage
4	Jackson Hall Audience Chamber
5	Studio Theatre
6	Atrium/Lobby

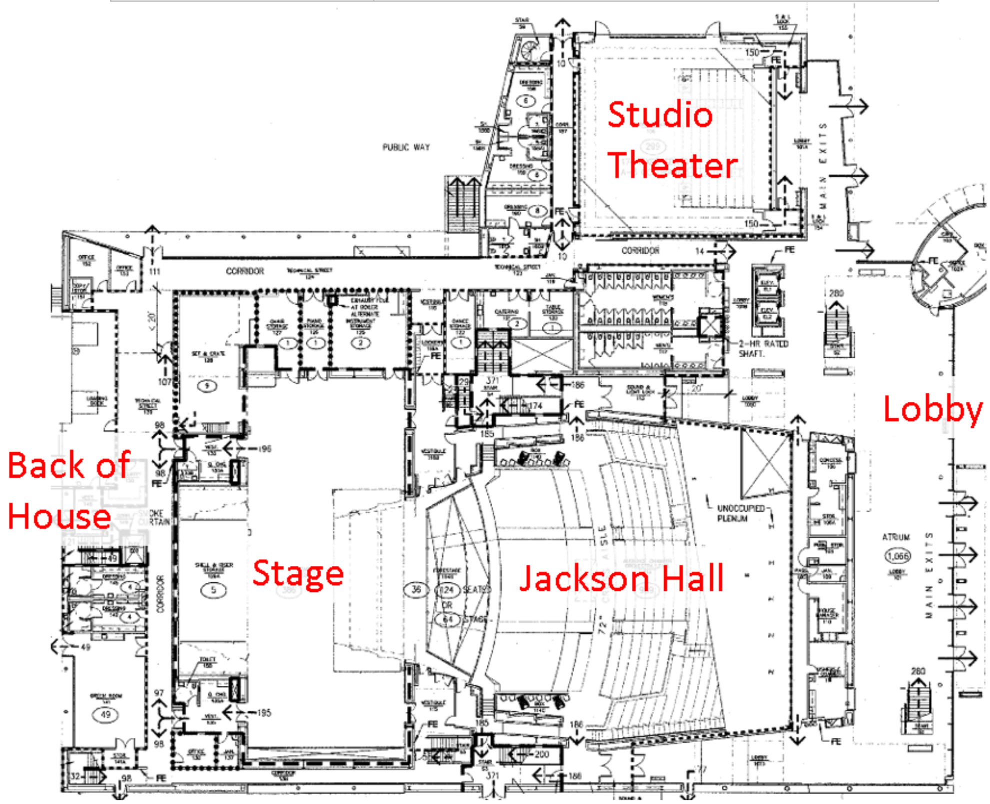


Figure 5.1 – Sprinkler zones

Design Basis

The building contains three different occupancy classifications. The basement, Zone #1, has an occupancy classification of ordinary hazard (Group 1), the stage, Zone #3, has an occupancy classification of ordinary hazard (Group 2), and the rest of the building is light hazard. The loading dock is ordinary hazard (Group 2) and because of this, 15 feet inside Zone #2 must be designed for the same ordinary hazard (Group 2).

Ordinary hazard zones #1 and #3 are separated from the light hazard areas by two hour fire resistance rating construction with 90 minute fire doors, which allows the adjacent zones to be considered separate in the hydraulic calculations.

The total building hose stream allowance required for hydraulic calculations is 250 gpm. The building is fully supervised by the UCD Dispatch Center, therefore the required water supply duration is the lower 60 minutes.

The density area method was used to calculate the hydraulic sprinkler demands. Table 5.2 shows the design criteria for each zone.

Table 5.2

Zone	Occupancy Classification	Design Density (gpm/ft^2)	Area (ft^2)
1	OH (GRP 1)	0.15	1500
3	OH (GRP 2)	0.20	1500
2,4,5,6	Light Hazard	0.10	1500

5.2 Water Supply

Existing Water Supply

The water is supplied by a 12 inch UC Davis campus controlled water line. An 8 inch water line connects the 12 inch water line to the fire pump in the basement pump room. This 8 inch line supplies the sprinkler system and the standpipe system. The following campus water supply data was given by the UCD Fire Department for this building:

Static Pressure:	65 psi
Residual Pressure:	20 psi
Flow:	16,825 gpm

Fire Pump and Jockey Pump

The installed fire pump is a 6x6x9.5 Vertical In-Line Pump, type 1580, manufactured by A-C Fire Pump Systems. The following data was found from the information plate on the pump:

Flow:	65 psi
Head:	20 psi
Speed:	16,825 gpm
Impellor Diameter:	7.75 in.
Net Pressure at 150% Capacity:	61 psi
Max. Net Pressure Developed:	97 psi
Maximum B.H.P.:	54.5

The installed jockey pump is a Grundfos type CR2-60. It maintains the system pressure against minor system pressure losses. The following data was found from the information plate on the pump:

Flow:	11 gpm
Head:	220 ft
Speed:	3,450 rpm

Combined Water Supply

The UC Davis water supply and fire pump data were combined for the sprinkler system design analysis. Figure 5.2 shows the combined supply curve at the base of the risers. Pressure losses were considered due to the distance and elevation difference from the pump location in the basement to the risers on the first floor. The losses were calculated with an assumed 750 gpm flow.

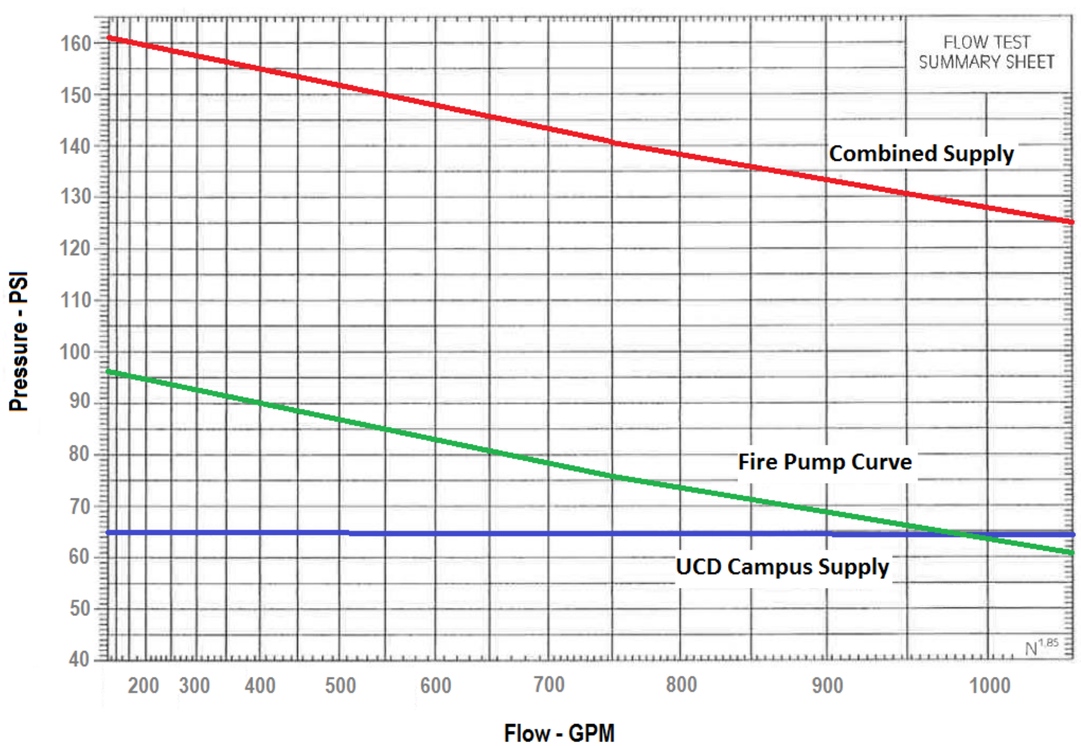


Figure 5.2 – Water supply curve

5.3 System Components

The 8” ductile iron supply line connected to the UC Davis water main has a double check valve assembly with two supervised OS&Y gate valves. The 8” supply pipe enters the building through the basement on the north side of the building and into the pump room.

Existing Water Supply

The pump room is located in the basement of the building. The following tables show the components installed in the pump room.

Table 5.3: Pump Section

Device	Manufacturer	Model	Nom. Fitting Size
OS&Y Gate Valve	AVK	45-200-11	8”
Eccentric Reducer	Victaulic	51-C	8” to 6”
Fire Pump	A-C Fire Pump Systems	6x6x9.5F type 1580	6”
Eccentric Reducer	Victaulic	51-C	6” to 8”
Pressure Relief Valve			
Check Valve	Victaulic		8”
Supervised Butterfly Valve			8”

Table 5.4: Venturi Loop

Device	Manufacturer	Model	Nom. Fitting Size
Throttle Valve			8”
Venturi Meter	Gerand		8”

Table 5.5: By-pass Loop

Device	Manufacturer	Model	Nom. Fitting Size
Supervised Butterfly Valve	Victaulic		8”
Check Valve	Victaulic		8”
Supervised Butterfly Valve	Victaulic		8"

Table 5.6: Jockey Pump Loop

Device	Manufacturer	Model	Nom. Fitting Size
Supervised OS&Y Gate Valve			2”
Check Valve			2”
Jockey Pump	Grundfos	CR2-60	2”
Pressure Relief Valve			2”
Supervised OS&Y Gate Valve			2”

Table 5.7: Jockey Pump Loop

Device	Manufacturer	Model	Nom. Fitting Size
Butterfly Valve with Tamper Switch	Victaulic		3”
Waterflow Switch	System Sensor	WFD30-2	3”
Pressure Gauge			3”
Test and Drain Valve			2”

Sprinklers

Table 5.8 shows all of the sprinklers and their specifications installed in the building.

Table 5.8: Sprinklers

Manufacturer	Model	Thread Size	Orifice Size	K-Factor (gpm/psi$^{1/2}$)	Temp. Rating (° F)	Type	Amount
Viking	Horizon-Mirage	1/2"	1/2”	5.5	155	Conc. SSP	18
Viking	Horizon-Mirage	1/2"	1/2"	5.5	165	Conc. SSP	109
Gem	A	17/32”	3/4"	8.1	165	E.C. HSW	14
Central	ELO LH	3/4"	0.64”	11.4	155	E.C. SSP	30
Viking	Micromatic “M”	1/2"	1/2"	5.5	155	HSW	11
Viking	Microfast “M”	1/2"	1/2"	5.5	200	QRHSW	5
Viking	Microfast “M”	1/2"	1/2"	5.5	155	QRHSW	4
Viking	Microfast “M”	1/2"	1/2"	5.5	155	Rec. QRSSP	208
Viking	Microfast “M”	1/2"	1/2"	5.5	155	Rec. SSP	318
Viking	Micromatic “M”	1/2"	1/2"	5.5	155	Rec. SSP	14
Viking	Micromatic “M”	1/2"	1/2"	5.5	155	SSP	64
Viking	Micromatic “M”	1/2"	1/2"	5.5	155	SSP	50
Viking	Micromatic “M”	1/2"	1/2"	5.5	155	SSU	226

Riser Assembly

The riser assembly is located on the ground level, in the north corridor in the back of house zone. There are 6 riser assemblies that each contain the components shown in Table 5.9. All risers are equipped with a combination inspectors test and drain that drains into an exterior storm water drain.

Table 5.9: Riser Assembly

Device	Manufacturer	Model	Nom. Fitting Size
Butterfly Valve with Tamper Switch	Victaulic		3”
Waterflow Switch	System Sensor	WFD30-2	3”
Pressure Gauge			3”
Test and Drain Valve			2”

Fire Department Connections

The building has three separate fire department connections. One is on the East side at the front of the building, one is on the South side by the street, and the last one is at the rear West side parking lot. The East side and South side connections have four 2½” connections each

where the rear one has two 2½” connections. Originally the West side connection was not installed for the Mondavi Center. The decision was made to connect it to the Mondavi Center due to its proximity to the building. The pipe to the connections are 6” in diameter and connects to the system between the supply control valves and system control valves.

5.4 Hydraulic Calculations

Computer based hydraulic calculations were performed to determine the maximum system demand. The complexity of this building’s system made it impractical to perform by hand. AutoSPRINK VR10 was used to perform the calculations.

Method Used

The Audience Chamber, Zone #4, ended up being the most hydraulically demanding. It was not the obvious choice. The design area for the stage, Zone #3, is at a higher elevation, a higher occupancy hazard, and contains more sprinklers in the design area, but still did not come close to the Zone #4 demand.

The design area sprinklers are the Central ELO LH extended coverage standard suppression pendent sprinklers. The maximum spacing that is allowed by its listing is 20 ft by 20 ft. All the sprinkler coverage areas are 400 ft^2 because the furthest sprinkler is spaced that way. NFPA 13, 11.2.3.2.2.3 requires that the minimum design area must be the area protected by 5 sprinklers or the design area corresponding to the hazard, whichever is greater. 5 sprinklers protect an area of 2000 ft^2, which is greater than the 1500 ft^2 design area for light hazard.

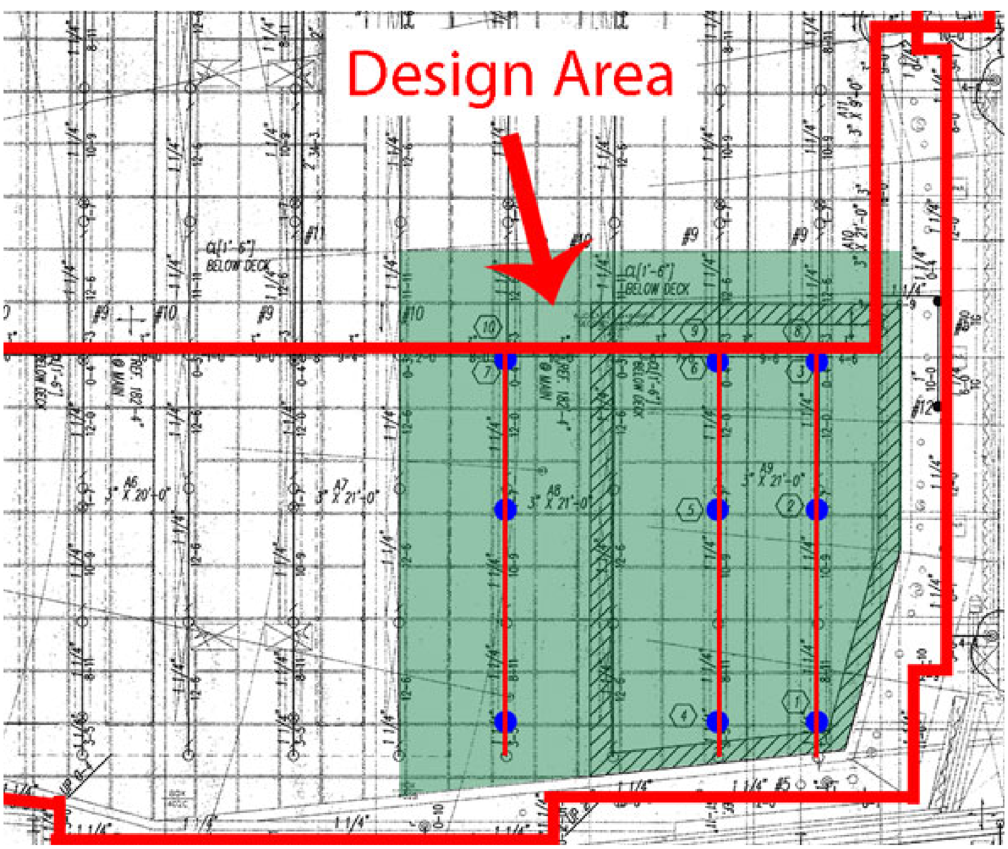


Figure 5.3 – Design area

Not all of the sprinklers are evenly spaced at 20 ft apart. None of the sprinklers in the design area utilize their entire 400 ft^2 capacity. This causes 5 sprinklers to only provide 1230 ft^2. In order to reach the required 2000 ft^2, a total of 9 extended coverage sprinklers had to be included in the design area. The minimum total flow required for 9 extended coverage sprinklers totals to 360 gpm. The green area in Figure 5.3 shows the final design area compared with the original design area. The entire sprinkler system run back to the risers is shown in Appendix H.

Results

Using the AutoSPRINK VR computer software, the total water demand becomes 406 gpm at 132.2 psi at the base of the riser. Including the hose stream brings the total water demand to 656 gpm at 132.2 psi at the base of the riser.

The UC Davis Standards and Design guide requires that a 10% safety factor must be added to either the pressure or the flow rate. Increasing the pressure by the safety factor increases the supply dangerously close to the maximum supply. Increasing the water flow by the 10% safety factor still keeps the required water supply safely under the supply curve. The total demand curve and water supply curve are shown in Figure 5.4. The original design curve is also shown in green.

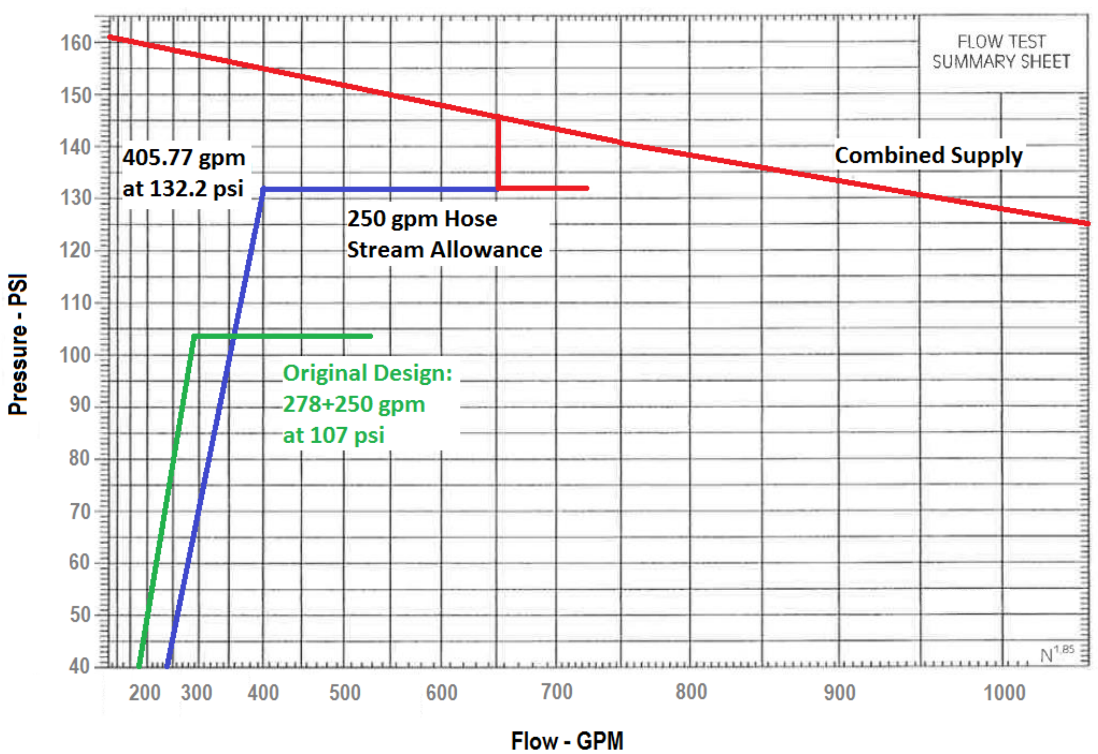


Figure 5.4 – Water supply and demand curve

Analysis

This design does comply with NFPA 13. However, the design could be improved considerably.

This design area had a significantly higher demand than the rest of the system. The system could have been easily modified to improve the demand. Using smaller design area sprinklers

and spacing them more evenly could decrease the demand significantly by reducing the design area and flow requirements per individual sprinkler.

The original design calculated a much lower demand at 528 gpm at 107 psi at the base of the riser. However, the plans show only 6 sprinklers in a design area of 1500 ft2. The difference in design method may be due to the original design using the 1994 edition of NFPA 13.

If the original design is correct, the pump is oversized for this application. At 528 gpm, the available pressure is approximately 150 psi. This gives a buffer of 40%. The high pressures may cause problems with the small K value of 5.5 most of the sprinklers have. High pressures can distort the discharge pattern of low K value sprinklers. NFPA 13 Section 8.3.4 requires sprinklers have at least a K value of 5.6 unless otherwise permitted. However, this requirement is not in the 1997 edition of NFPA, therefore it is doubtful that it is in the 1994 edition.

Section 6.
Performance Based Analysis

6.1 Method

The performance based analysis of this project uses the Available Safe Egress Time (ASET) versus Required Safe Egress Time (RSET) method. The ASET is the estimated available time when the egress paths are considered safe for egress. A tenability analysis was performed to estimate the time until safe egress is not possible. The tenability of the space is estimated using the computational fluid dynamics model, Fire Dynamics Simulator (FDS) version 6.1, developed by the National Institute for Standards and Technology. The tenability factors include the carbon monoxide concentration, air temperature, visibility distance, and heat flux from the fire.

The RSET is the estimated time it takes for occupants to exit the space. The RSET comprises the detection, alarm, pre-movement, and movement times. The detection time is estimated using FDS to estimate the time it takes for a smoke detector to activate. The alarm and pre-movement time were estimated based on suggested values from a British Standard on occupant movement, PD-7974-6:2004. The movement time was estimated using the computer model PATHFINDER version 2014, developed by Thunderhead Engineering.

Two fire scenarios were used. One involves a fire in the lobby atrium space on the east side of the space. The other involves a fire in the storage space at the back of the Jackson Hall stage.

6.2 Tenability Criteria

Visibility

The visibility criterion was selected based on research performed by Sherfig and Hadjisophocleous. A value of 10 meters is suggested.

Toxic Gas Exposure

According to Purser, carbon monoxide is the most important toxic product from a fire to cause incapacitation. To calculate the concentration for incapacitation, the Stewart equation is suggested:

$$F_{I_{CO}} = 3.317 \times 10^{-5}[CO]^{1.036}(V)(t)/D$$

Where
[CO] = Carbon monoxide concentration (ppm v/v 20°C)
V = Volume of air breathed each minute (L)
t = Exposure time (minutes)
D = Exposure dose (percent COHb) for incapacitation

A suggested default case assuming the occupants are in a state of "light work" gives input values for V = 25 and D = 30. Using a fractional dose of 1.0 to reach incapacitation, a carbon monoxide concentration of 950 ppm is calculated over a 30 minute exposure time.

Exposure to Heat

Exposure to heat from fire can cause incapacitation and death from heat stroke, body surface burns, and respiratory tract burns. Purser suggests that conditions are maintained below a temperature of 60°C.

Radiant Heat

The radiant heat flux maximum limit was taken to be 2.5 kW/m^2 as is suggested by Babrauskus in the SFPE Handbook.

6.3 Lobby Fire Scenario

6.3.1 Scenario Overview

The first design fire scenario is located within the lobby atrium space. The space has a fully automatic sprinkler system and full smoke detection. Immediately after detection of smoke, the emergency voice alarm/communication system activates throughout the building, commencing egress. The atrium has a mechanical smoke management system that also activates with smoke detection or sprinkler water flow. In this case, because the building has full smoke detection, smoke detection activates the smoke control system.

Figure 6.1 – Lobby Atrium

The smoke control system comprises two 77,000 cfm exhaust fans, seven make-up air doors, and mechanical make-up air vents. The exhaust fans are located above the 4th floor doors leading to the Jackson Hall seating. The make-up air doors are the main lobby and Studio Theatre entrance doors. The mechanical make-up air floor vents are located around the perimeter of the 1st floor of the main lobby, as shown in green in Figure 6.1. There is also one mechanical make-up air floor vent on the 2nd floor balcony area directly adjacent to the Bartholomew Room in the oval shaped building. The West side of the elevator structure has a mechanical make-up air vent on the 1st floor and 3rd floor. When the smoke control system activates, the following operations sequence occurs:

1. Lobby and bathroom air handling units shut down.
2. Make-up air doors open.
3. Fire smoke dampers close to the 2nd floor supply air vents, except for the balcony vent adjacent to the Bartholomew Room.
4. Lobby return air handling unit dampers switch to outside air configuration.
5. Return air handling unit and smoke exhaust fans turn on.

6.3.2 Design Fire

The space does not contain many combustible objects most of the time. During performances however, they do have a small coat check area with two coat racks. They also sometimes allow for the storage of backpacks for students, since they are not allowed to be brought into the theater. This creates an unpredictable fire hazard because the contents of every backpack would be unknown. The design fire is based on a fire that is initiated within the coat check area, spreading to both coat racks.

Figure 6.2 shows the floor plan of the Northern half of the 1st Floor of the lobby. The fire is shown against the glass wall on the North end of the lobby, adjacent to the oval shaped building. The blue line shows the edge of the floor above. The fire is mostly under this balcony and has a sprinkler and a smoke detector directly above the fire. Smoke detection is used to initiate the smoke control sequence, which was estimated to be 21 seconds by the FDS model.

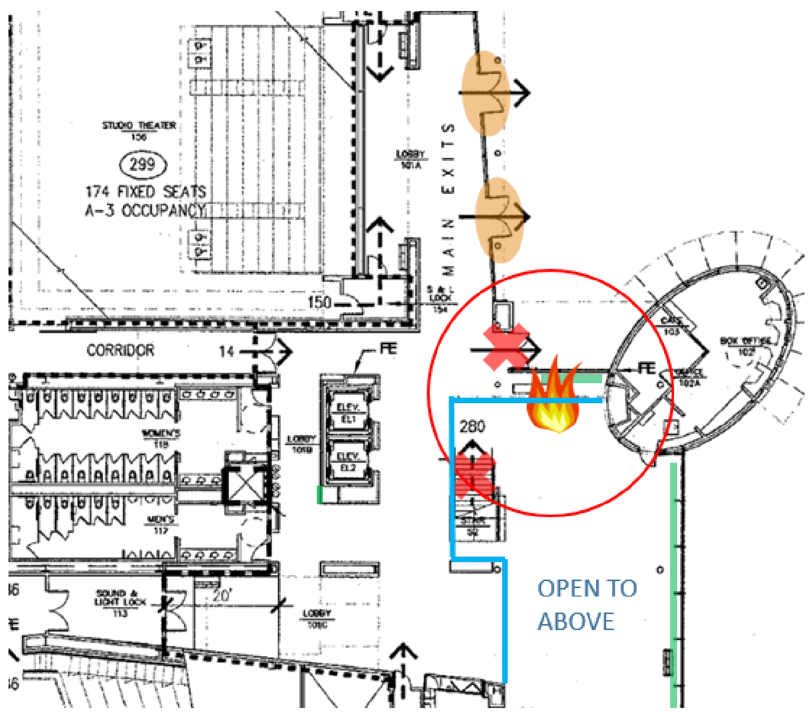


Figure 6.2 – Northern half of the lobby atrium

The red ring is the area where heat flux from the fire is greater than the 2.5 kW criteria for untenable conditions. This figure shows that the exit door and stairway within the ring are within an untenable area and was not used for the egress time estimation. The following calculation, Equation 6.1, shows how the untenable radius of 18 feet around the fire was

calculated using the point source radiation model. A safety factor of 2 was used as suggested in the SFPE Handbook.

$$R = \sqrt{\frac{Q_r}{4\pi q''_{r,t}}} = \sqrt{\frac{(800\ kW)(0.3)}{4\pi(2.5\ kW/m^2)}}$$

$$R = 2.8\ m = 9\ ft$$

Equation 6.1

$$R_{SF} = 9\ ft \times 2 = 18\ ft$$

The fuel load of dozens of backpacks and two coat racks is difficult to predict. However, because the coat check area is directly under a sprinkler, it is assumed that the sprinkler controls the fire. The heat release rate is ramped up, using a fast growth rate t^2 profile, until sprinkler activation. The heat release rate at sprinkler activation was estimated using two methods, the DETACT model, based on Alpert correlations, and Fire Dynamics Simulator (FDS) model developed by the National Institute of Standards and Technology (NIST).

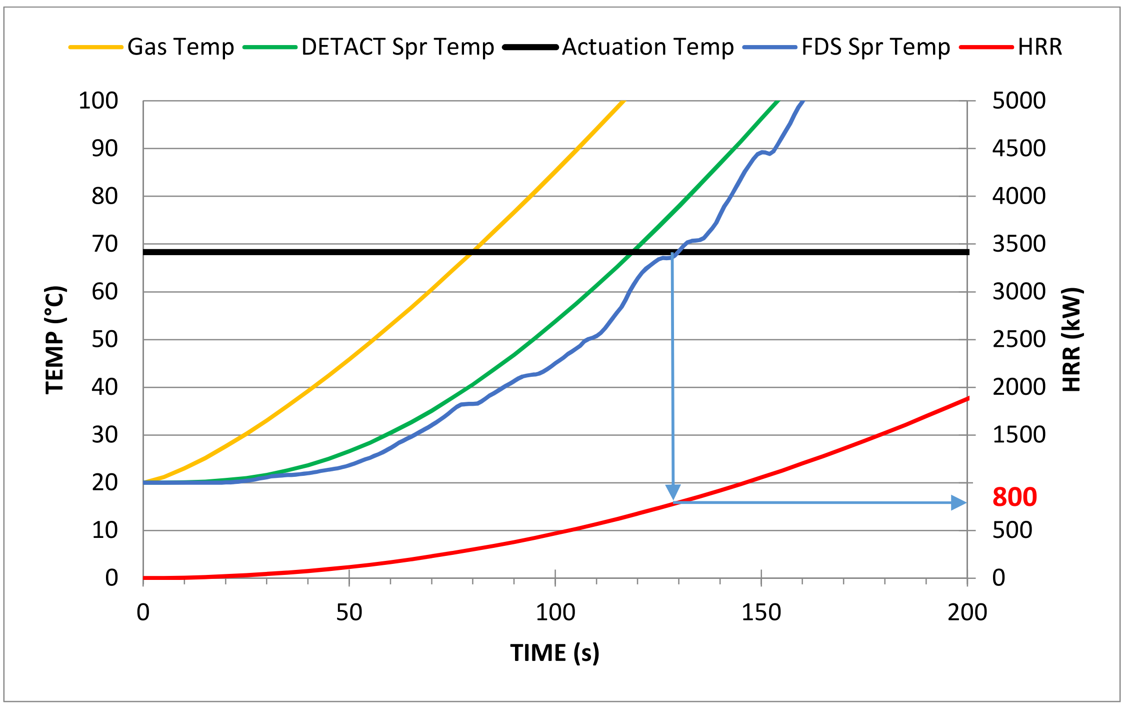


Figure 6.3 – DETACT and FDS sprinkler temperature estimation

Figure 6.3 shows the heat release rate versus time with estimated sprinkler temperatures, as was estimated by the DETACT and FDS models. The DETACT model estimated sprinkler activation at about 120 seconds. FDS showed a longer activation time of 130 seconds. This is likely due to FDS taking into account the effects of air flow due to the smoke control system activating at only 21 seconds into the simulation. The more conservative value of 130 seconds was used to limit the fire size to 800 kW.

6.3.3 Concerns

The main concern is that the smoke management system needs to be capable of exhausting enough smoke in order to maintain tenable conditions for the duration of egress.

The other concern involves the balcony directly above the fire, which is the only egress path for one space. The lobby has the potential to hold a large number of occupants. Queuing will likely occur in the space. One particular spot contains an allowed load of 49 occupants with only one door, which then egresses through the atrium space, directly above the fire on the 2nd floor. This is an assembly space called the Bartholomew Room. Because it is the only escape route, it is very important to maintain tenable conditions on this balcony. Figure 6.4 shows the plan view of the second floor lobby and Bartholomew Room and the fire design fire location.

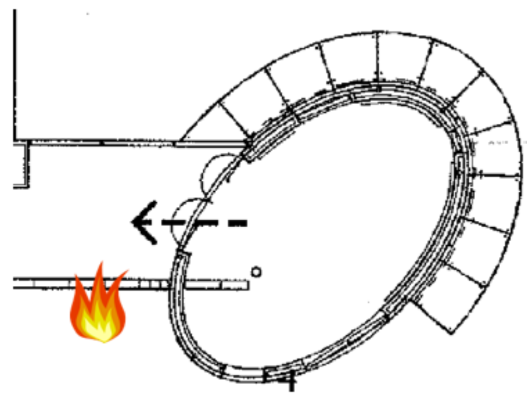


Figure 6.4 – Plan view of lobby 2nd floor

The beam detector in the lobby is also a concern because it has been taken out of service due to nuisance alarms. It should be verified that adequate smoke detection can still be achieved without it. The beam detector is discussed in the Fire Detection, Alarm, and Communication section 5.3 of this report.

6.4 Lobby Fire Results

6.4.1 Available Safe Egress Time (ASET)

As shown in Figure 6.5 below, Carbon Monoxide concentrations stay well under the 1,000 PPM criteria during the entire FDS simulation and was maintained constant by the smoke exhaust system.

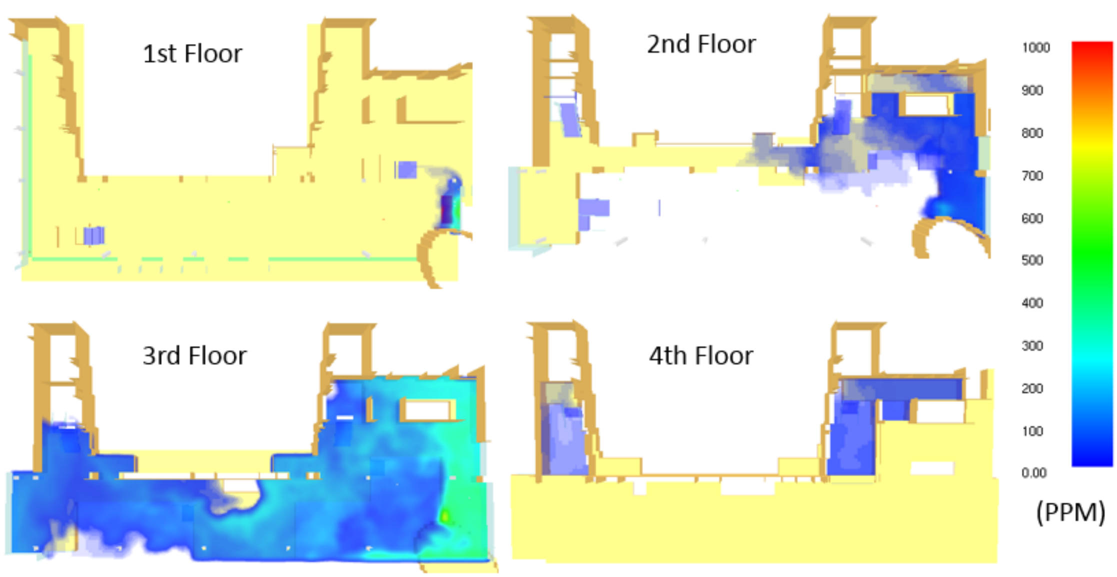


Figure 6.5 – Fire Dynamics Simulator Estimated Carbon Monoxide Concentration at 600 Seconds

As shown in Figure 6.6 below, temperature levels do approach the tenability criteria of 60° C, however, they are still within the limit.

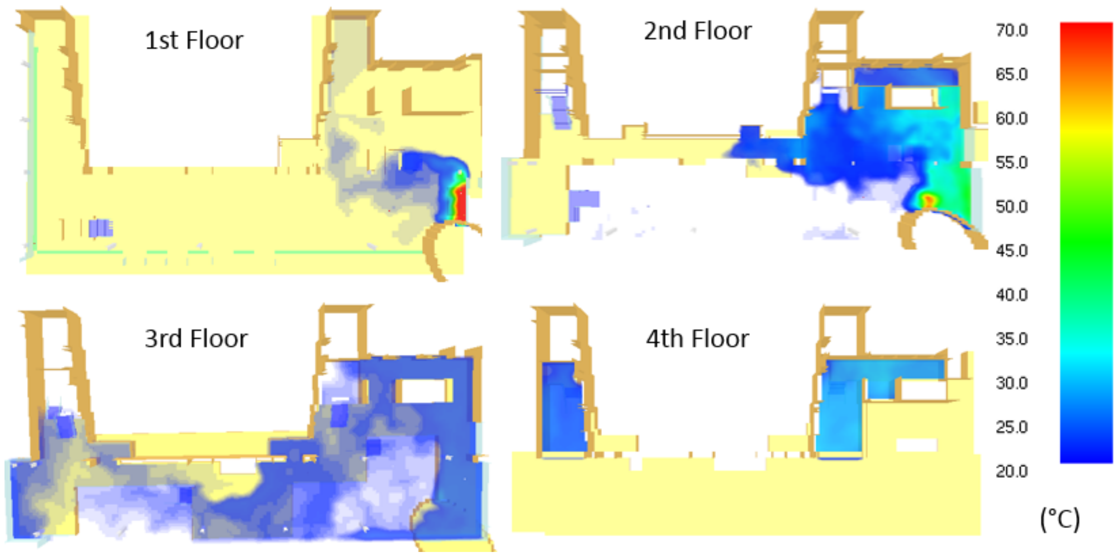


Figure 6.6 – Fire Dynamics Simulator Estimated Temperature at 600 Seconds

As shown in Figure 6.7 below, visibility levels on the 1st and 4th floors stay within the tenable limits. However, the 2nd and 3rd floors lose tenability at the balconies just above the fire.

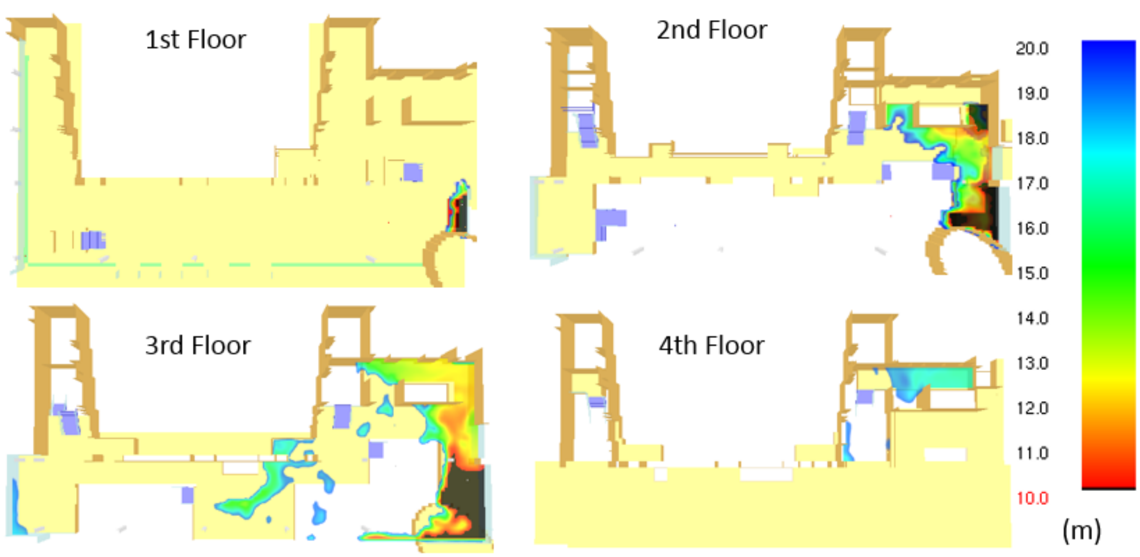


Figure 6.7 – Fire Dynamics Simulator Estimated Visibility Distance at 600 Seconds

As shown in Figure 6.8 below, the 10 meter visibility distance is lost at about 225 seconds on both levels, resulting in an available egress time of 225 seconds for those spaces. This is the

balcony that serves as the egress path for the Bartholomew Room occupants.

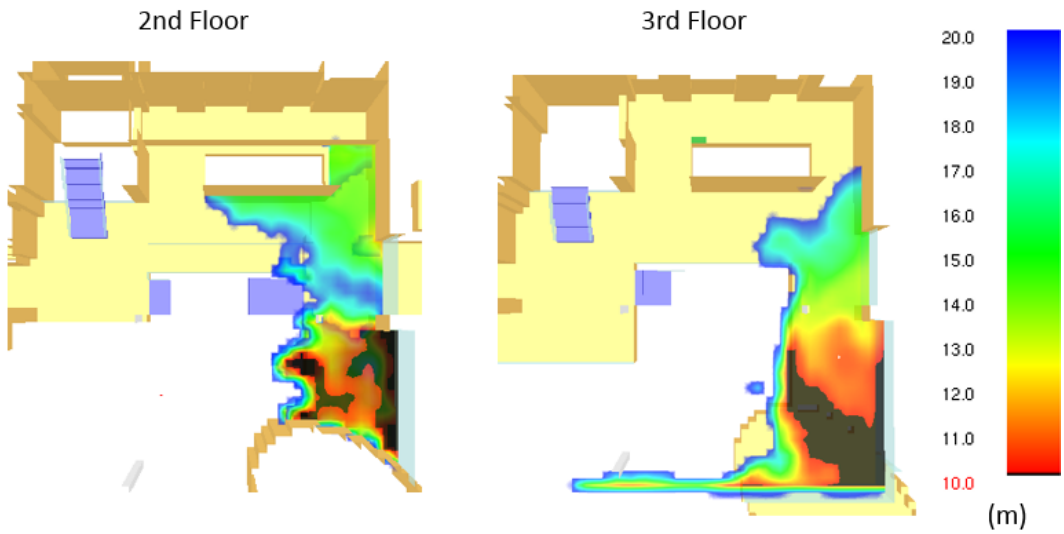


Figure 6.8 – Fire Dynamics Simulator Estimated Visibility Distance at 225 Seconds

6.4.2 Required Safe Egress Time (RSET)

The detection time was estimated by simulating a smoke detector in Fire Dynamics Simulator. Because the smoke detector is directly above the fire at about 9 feet above the floor, the detector responds very quickly at approximately 21 seconds.

The alarm time was estimated using the British Standard, PD-7974-6:2004. The document suggests using a time that is the time it takes for the emergency voice message to be spoken twice. This was estimated to be 20 seconds.

Pre-movement time was estimated in accordance with the British Standard, PD-7974-6:2004. The building has a full Emergency Voice/Alarm Communications system with a pre-recorded message, which activates immediately after detection. The occupants will be awake but were not considered familiar with their surroundings. During any event, the assembly occupied staff contains staff, trained to evacuate the building. Because of these assumptions, the 1st percentile pre-movement with a Management Level M2 classification was used. The 1 minute pre-movement time used is sufficiently conservative considering these circumstances.

The movement time was estimated using PATHFINDER. The lobby was not loaded using the calculated occupant load calculated in the Egress Analysis section of this report. The value calculated there is not a reasonable value to use for a performance based design. Judging by conversations with building management, the highest load the lobby sees is during performances in Jackson Hall. The space is used for events, but all planned events are capped at 200 to 250 occupants, significantly less than the code required calculated load of almost 4,000. During performances, however, even though it is very unlikely, the lobby could see the all of the theater’s 1,801 occupants in the lobby. Therefore, 1,801 occupants was used because that is the actual limited capacity of the theater. The occupants were evenly spaced throughout the lobby.

In reality, all of the theater occupants do not stay in the lobby at once. After a performance, many occupants leave the building soon after the show. During intermissions, many guests stay in the theater instead of move into the lobby where other exits are used during emergencies. Considering this, using the 1,801 occupant load is sufficiently conservative.

PATHFINDER estimated the time for occupants to move past the untenable space, shown in Figure 6.8, to be 39 seconds. Figure 6.9 shows the PATHFINDER results at 39 seconds.

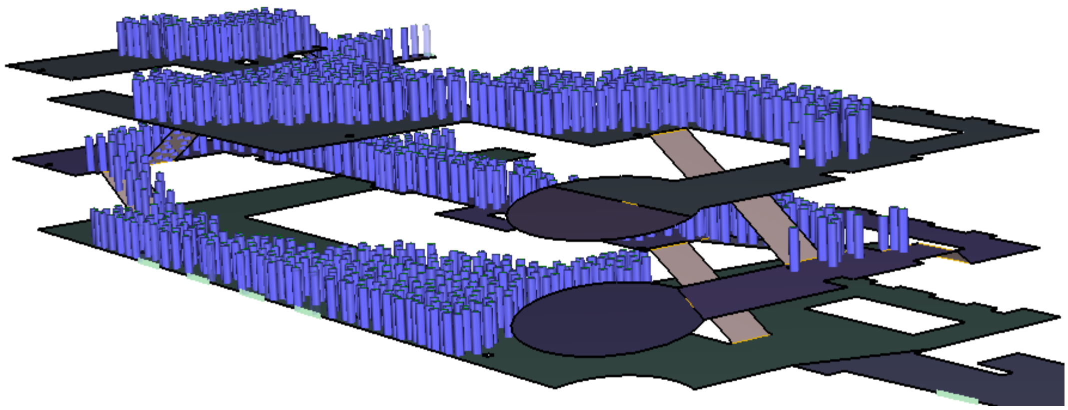


Figure 6.9 – PATHFINDER simulation results at 39 seconds

A safety factor of 1.5 was used in accordance with California Building Code section 909.4.6, which states that smoke control systems be operational for 20 minutes or 1.5 times the calculated egress time, whichever is less.

Table 6.1 – Lobby atrium required safe egress time (RSET)

Scenario	Detection Time (s)	Alarm Time (s)	Pre-movement Time (s)	Movement Time (s)	CBC Factor	Total RSET (s)
Lobby Atrium Fire						
2nd Floor Egg	21	20	60	39	1.5	392
3rd Floor Egg	21	20	60	39	1.5	257
Elev. Lobbies	21	20	60	∞	1.5	∞
Entire Lobby	21	20	60	440	1.5	812

6.4.3 ASET vs. RSET

Table 6.2 shows the summarized comparison of the calculated ASET and RSET values. It can be seen that all of the Lobby Atrium locations maintain tenable conditions. The 2nd floor and 3rd floor balconies, however, only meet the requirements by 15 seconds.

Table 6.2 – Lobby atrium ASET vs. RSET Summary

Scenario	Detection Time (s)	Alarm Time (s)	Pre-movement Time (s)	Movement Time (s)	CBC Factor	Total RSET (s)	Total ASET (s)
Lobby Atrium Fire							
2nd Floor Balc	21	20	60	39	1.5	210	225
3rd Floor Balc				39		210	225
Elev. Lobbies				∞		∞	∞
Entire Lobby				440		812	∞

6.4.4 Recommendations

The lobby meets the tenability criteria, but only just barely. It is recommended that the coat check area be moved out from under the balcony. Another FDS simulation was run to estimate conditions when the fuel is moved to the center of the lobby. Surprisingly, even though the fire was allowed to increase to 2 MW as could be seen by two full coat racks, tenable conditions were shown throughout the atrium. Therefore, an easy way to reduce risk would be to move the coat check area there.

However, a better way would be to have a permanent coat check area within its own enclosed room. During the development of this cumulative experience project, it was discovered that plans are already in motion to add a dedicated coat check room within the Egg structure. This would likely significantly improve the conditions during a fire due to significantly limiting the amount of oxygen available for the fuel. Also, if the door used has an automatic door release, as does the rest of the building's doors, the likelihood of untenable conditions in the lobby, resulting from a fire in the closed room, is even more unlikely.

6.5 Stage Fire Scenario

6.5.1 Scenario Overview

The second design fire scenario is located within the Jackson Hall stage storage area, which is shown on the right side of Figure 6.10. At the opposite end of the seating there is a 60 foot wide by 30 foot deep and 45 foot tall storage space called the shell riser storage space. The storage area is completely open to the stage area. Even though all storage areas appurtenant to the stage are required to be separated from the stage by a 2 hour fire barrier, this space cannot be separated because of the shell structure that is stored in this space.

Figure 6.10 – Jackson Hall Stage and Shell Riser Storage

The stage can be used in several different configurations, as shown in Figure 6.11. The configuration shown to the top right of Figure 6.11 shows the shell structure enclosing the proscenium opening improve accoustic sound coming from the stage. When the shell structure is not in use, the back side of the shell is removed and folded together, while the sides and top stay in one piece. The entire structure is then raised by air canisters and physically pushed to into the shell riser storage space. Because the shell riser structure is solid, it completely shields all sprinklers above the storage space from applying water to anything stored underneith. Therefore, it is assumed that the fire will not be sprinkler controlled as it was in the lobby fire scenario.

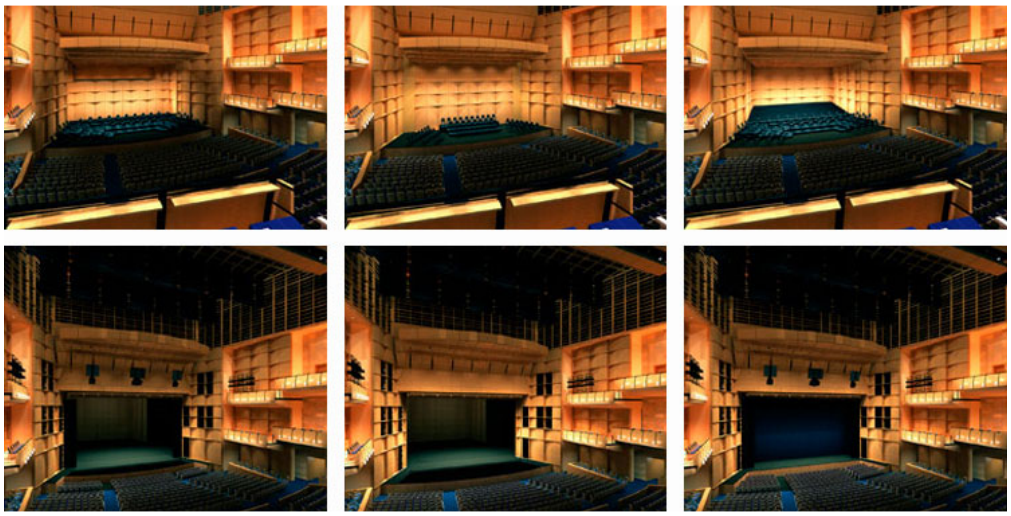


Figure 6.11 – Jackson Hall stage configurations

The stage only has smoke detection above doors that automatically close on detection. When these detectors activate, they also activate the emergency voice alarm/communication system. The highest smoke detector in the space is approximately 25 feet above the stage floor above a roll down door. FDS estimated smoke detection occurring at 160 seconds. The stage ceiling contains six heat activated vents. The proscenium opening to the theater seating is protected by a 20 minute rated fire curtain, which is lowered to cover the opening by manual activation and heat activated fusible links. It is assumed that the curtain is not manually activated. None of the sprinklers, heat vents, or fire curtain fusible links activated during the FDS simulation.

6.5.2 Design Fire

The storage space contains miscellaneous storage in addition to the shell structure, which can change depending on the performances. Looking at a picture of the storage space, Figure 6.12, a rack of insulated theater electrical audio and power cables can be seen circled in red. This presents a very high fuel load because the cables are hanging from the rack with plenty of air between them. This could cause a very well ventilated fire situation to occur. The design fire used assumes that this rack of cables ignites and fire spreads to the entire rack. The calculated maximum heat release rate is then maintained at a constant value because the fire could easily spread to adjacent fuels.

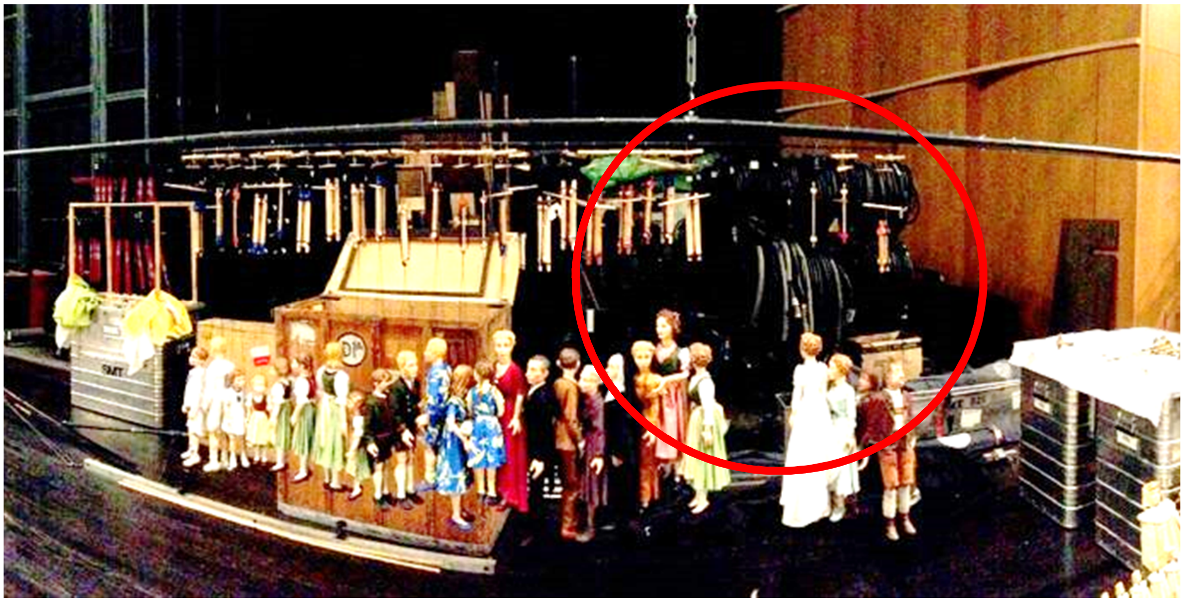


Figure 6.12 – Jackson Hall stage configurations

The heat release rate ramps up at a conservative t^2 rate until the maximum calculated heat release rate. The maximum heat release rate was calculated using a correlation provided by Lee. The correlation is based on cable tray fire data obtained by Tewarson et al. and Sumitra. The following calculation using this correlation shows the maximum heat release rate is 4 MW.

$$\dot{q}_{fs} = 0.45\dot{q}''_{bs}A$$

$$\dot{q}_{fs} = 0.45\left(589\frac{kW}{m^2}\right)(15\ m^2) \qquad \text{Equation 6.2}$$

$$HRR = 4000\ kW$$

Figure 6.13 shows the location on the storage space and the design fire fuel. The red ring is the area where heat flux from the fire is greater than the 2.5 kW criteria for untenable conditions. This figure shows that the exit door on the north side of the stage is within the untenable region. Therefore, this door will not be used in the egress time calculation. The following calculation shows how the untenable radius of 40 feet around the fire was calculated using the point source radiation model. A safety factor of 2 was used as suggested in the SFPE Handbook.

$$R = \sqrt{\frac{Q_r}{4\pi q''_{r,t}}} = \sqrt{\frac{(4000\ kW)(0.3)}{4\pi(2.5\ kW/m^2)}} \qquad \text{Equation 6.3}$$

$$R = 6.2\ m = 20\ ft$$

$$R_{SF} = 20\ ft \times 2 = 40\ ft$$

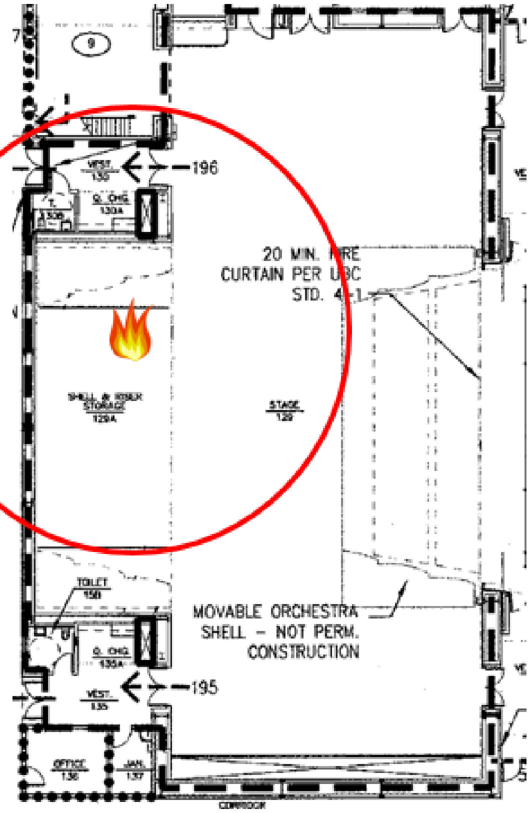


Figure 6.13 – Plan view of the Jackson Hall stage and storage area

6.5.3 Concerns

The main concern of a fire in this space is that a very high heat release rate, long duration, fire could occur in a high value space with a high occupant load. There is effectively no suppression systems available to the space. The shell structure completely shields any fire from water.

Smoke detection could also be delayed for a long time. During a performance, the stage may be kept dark. Because the storage space could be even darker, hidden behind curtain, human detection cannot be relied upon. Because there are no smoke detectors in that space or at the stage ceiling, it could take a long time before the stage ceiling space fills enough to activate the highest detector. By this time, the heat release rate of the fire can be very high.

The delayed detection time not only delays occupant egress, but it also delays fire fighter response. By the time fire fighters arrive, the fire could already be too large and visibility levels may be too low for manual suppression.

6.6 Stage Fire Results

6.6.1 Available Safe Egress Time (ASET)

As shown in Figure 6.14 below, Carbon Monoxide concentrations stay well under the 1,000 PPM criteria for at least the 600 second duration that the simulation was run.

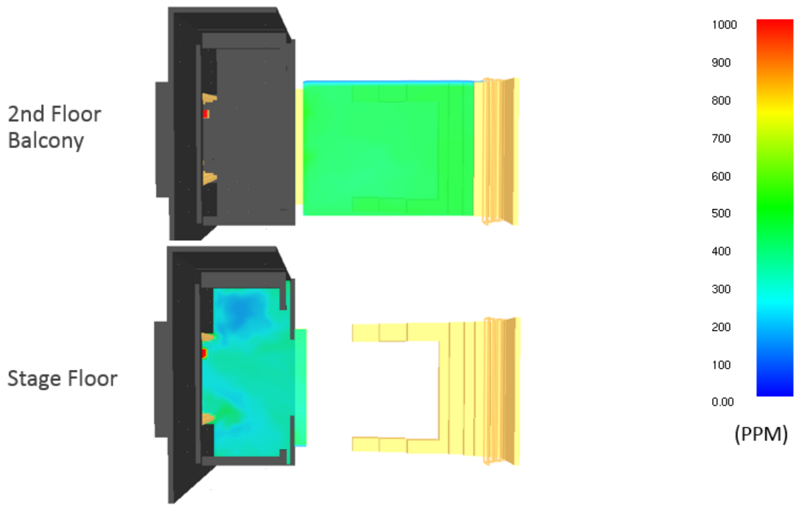


Figure 6.14 – Fire Dynamics Simulator Estimated Carbon Monoxide Concentration at 600 Seconds

As shown in Figure 6.15 below, temperature levels do approach the tenability criteria of 60° C, however, they are still within the limit.

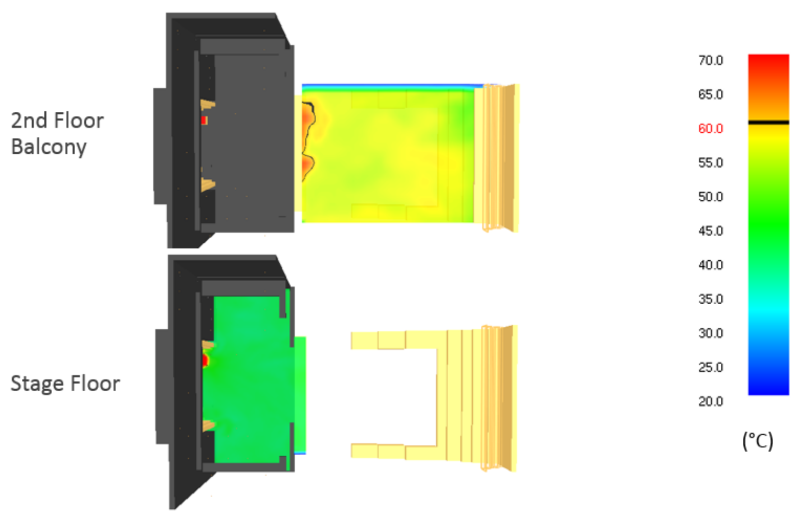


Figure 6.15 – Fire Dynamics Simulator Estimated Temperature at 600 Seconds

As shown in Figure 6.16 below, visibility levels at both the stage and the seating lose visibility tenability. The theater seating begins to lose tenability at around 415 seconds and completely

loses it at about 445 seconds. The stage begins to lose tenability at 750 seconds and then at 800 seconds it is completely lost.

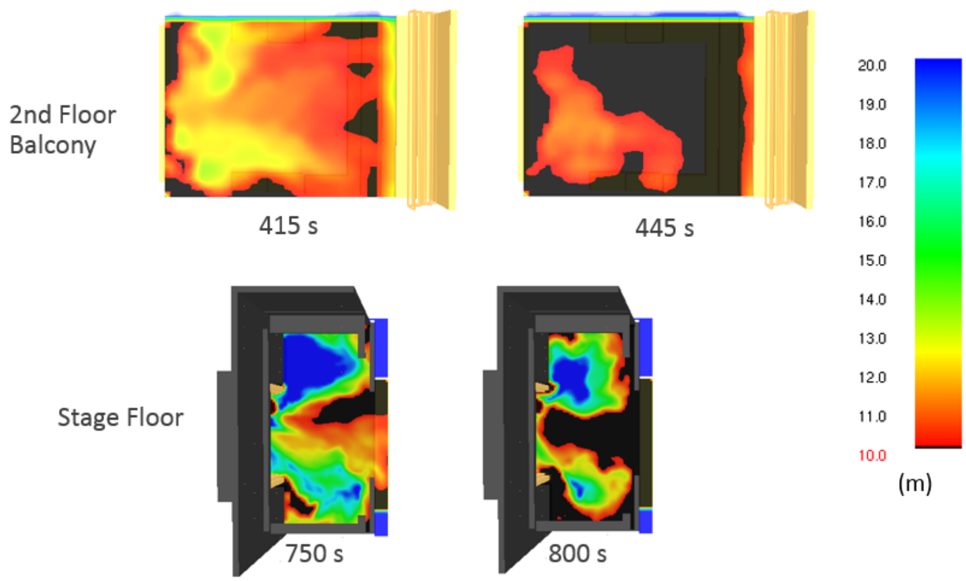


Figure 6.16 – Fire Dynamics Simulator Estimated Visibility Distance at 600 Seconds

6.6.2 Required Safe Egress Time (RSET)

The detection time was estimated by simulating a smoke detector using Fire Dynamics Simulator. There was a significant delay to the detection of smoke because the only smoke detector is about 25 feet above the stage floor when the stage ceiling is at 87 feet high. The stage ceiling space must fill before it can reach the detector. Because the proscenium wall height is also higher than the smoke detector at about 40 feet, the smoke layer descends slower once it spills into the theater, further delaying smoke detection. FDS estimated this detection time to be about 160 seconds.

Human detection cannot be relied upon in most situations. A fire in this space, even though there are over 2,000 occupants in the space, human detection is even more unreliable because of how dark a theater can get. Especially at the back of the stage where all the walls are painted black and the space is only used for storage, the space can be very dark.

The alarm time was estimated using the British Standard, PD-7974-6:2004. The document suggests using a time that is the time it takes for the emergency voice message to be spoken twice. This was estimated to be 20 seconds.

Pre-movement time was estimated in accordance with the British Standard, PD-7974-6:2004. Because the scenario is an assembly occupancy, it is expected that the occupants will be awake with a focal point at the stage. The building also has a full Emergency Voice/Alarm Communications system with a pre-recorded message where the system removes power from the performance audio systems, turns on the lights, and activates the alarm signal immediately after detection. For this design fire, automatic detection occurs when the fire has already produces a large amount of smoke. The FDS simulation also shows smoke spilling into the seating hall at the detection time. During any event, the assembly occupied staff contains staff,

trained to evacuate the building. Because of these assumptions, the 1st percentile pre-movement with a Management Level M2 classification was used. The 1 minute pre-movement time should be considered significantly conservative considering the circumstances.

The movement time was estimated with PATHFINDER, shown in Figure 6.17. The red spaces are the 2 hour rated exits. The movement time was taken as the time it took for all occupants in the theater to move into the exit enclosure. Tenable conditions were required to be shown at the worst case location, which is the 2nd Floor Balcony. This method was chosen because, even though PATHFINDER shows the occupants on the 2nd Floor Balcony enter the stairs before the Orchestra seating occupants, the opposite could occur because many occupants from all levels use the same single exit door. Queuing at the bottom of the exit enclosure stairs occurs when occupants from different floors merge. It cannot be proved that the occupants on the above floors will be allowed to move to the discharge door first. Therefore PATHFINDER was used to estimate the time when the last occupant enters the exit enclosure. This time was estimated to be 404 seconds.

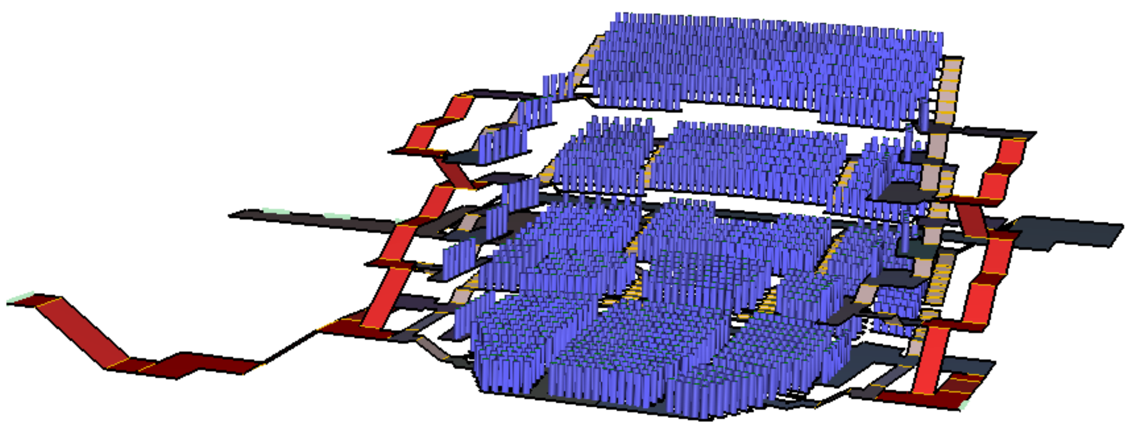


Figure 6.17 – PATHFINDER model of the Jackson Hall seating

A safety factor of 1.5 was used in accordance with California Building Code section 909.4.6, which states that smoke control systems be operational for 20 minutes or 1.5 times the calculated egress time, whichever is less.

Table 6.3

Scenario	Detection Time (s)	Alarm Time (s)	Pre-movement Time (s)	Movement Time (s)	CBC Factor	Total RSET (s)
Stage Storage Fire 2nd Balcony Stage	160	20	60	404 234	1.5	966 711

6.6.3 ASET vs. RSET

Table 6.4 shows the summarized comparison of the calculated ASET and RSET values. In the stage storage fire scenario, the required safe egress time is barely under the available. The

theater seating doesn't even come close to passing. The required safe egress time is over twice the available.

Table 6.4

Scenario	Detection Time (s)	Alarm Time (s)	Pre-movement Time (s)	Movement Time (s)	CBC Factor	Total RSET (s)	Total ASET (s)
Stage Storage Fire Stage Theater Seats	160	20	60	234 404	1.5	711 **966**	750 **415**

6.6.4 Recommendations

Clearly the stage fire is a large concern with a risk of very high consequences. Not only is the loss of life a large concern, but the monetary cost of such a fire could be extremely large. The damage to the campus image could also be very big.

Three recommendations are made for this case. The first is to add more smoke detection to the stage ceiling. Because the storage area ceiling is blocked by the shell structure, smoke detection at that area is not as effective. Adding smoke detectors at the ceiling of the stage showed a reduction in smoke detection by about 50%, from 160 seconds to 77 seconds.

The next recommendation is to optimize the egress of occupants from the theater seating. Because the staff is trained to evacuate occupants already, PATHFINDER can be used to predict the best evacuation routes out of the seating areas. A travel time reduction of 25% was achieved with this method. Also allowing occupants to egress through the Lobby decreased the evacuation time an additional 30%. This is allowed per code because the only limitation is the 250 foot travel distance to an exit with 200 feet allowed through the atrium space. A total travel time reduction of about 48%, from 404 seconds to 210 seconds, was achieved.

Combining the smoke detection and egress optimization methods, the RSET was reduced by about 43%, from 966 seconds to 550 seconds. This is quite a dramatic improvement. However, due to the fire size, it is still not enough

Therefore, the final recommendation is to move the combustible material out of the storage space.

Appendix A – Jackson Hall Seating

Figure A.1 – Orchestra/Orchestra Terrace Seating

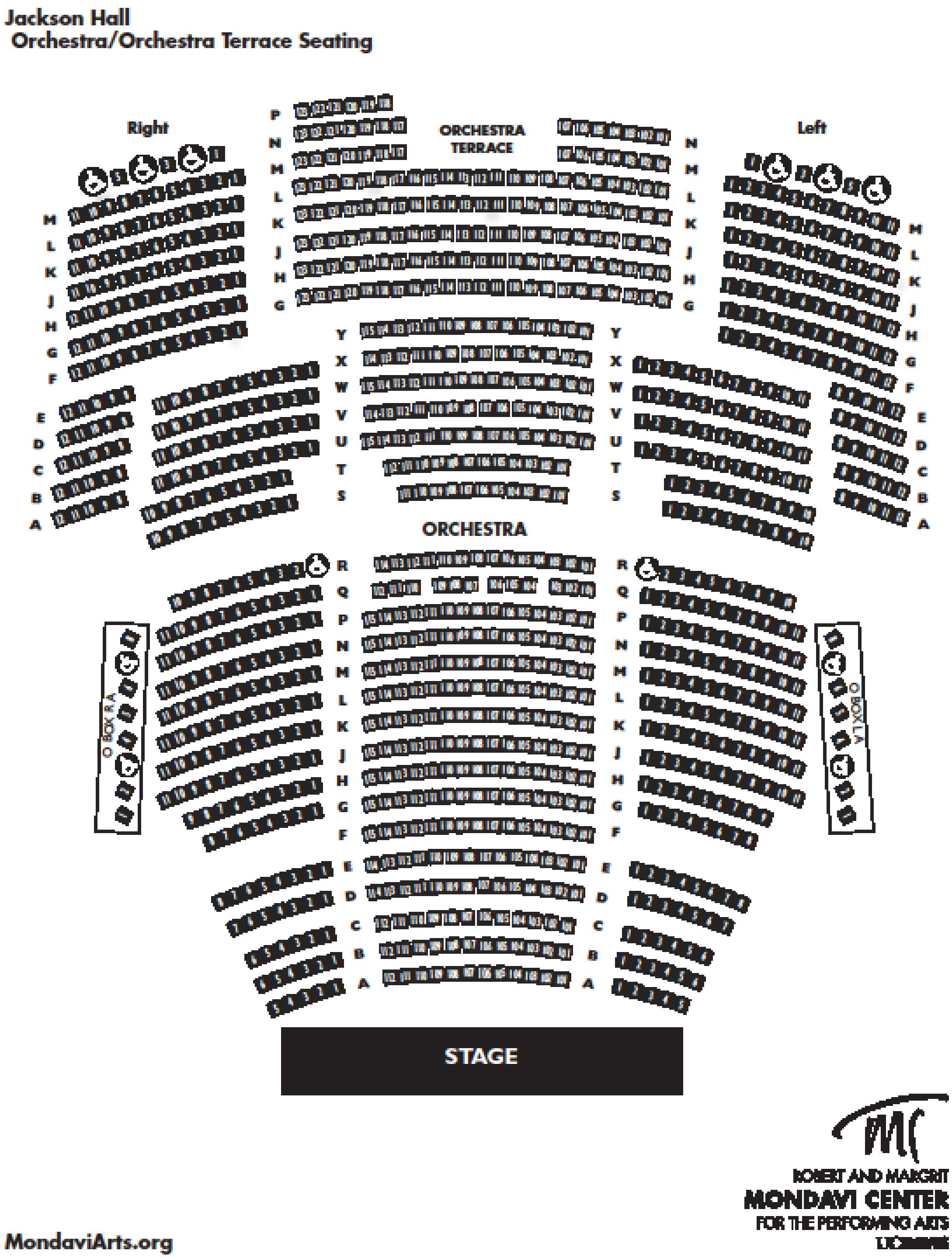


Figure A.2 – Grand Tier/ First Balcony

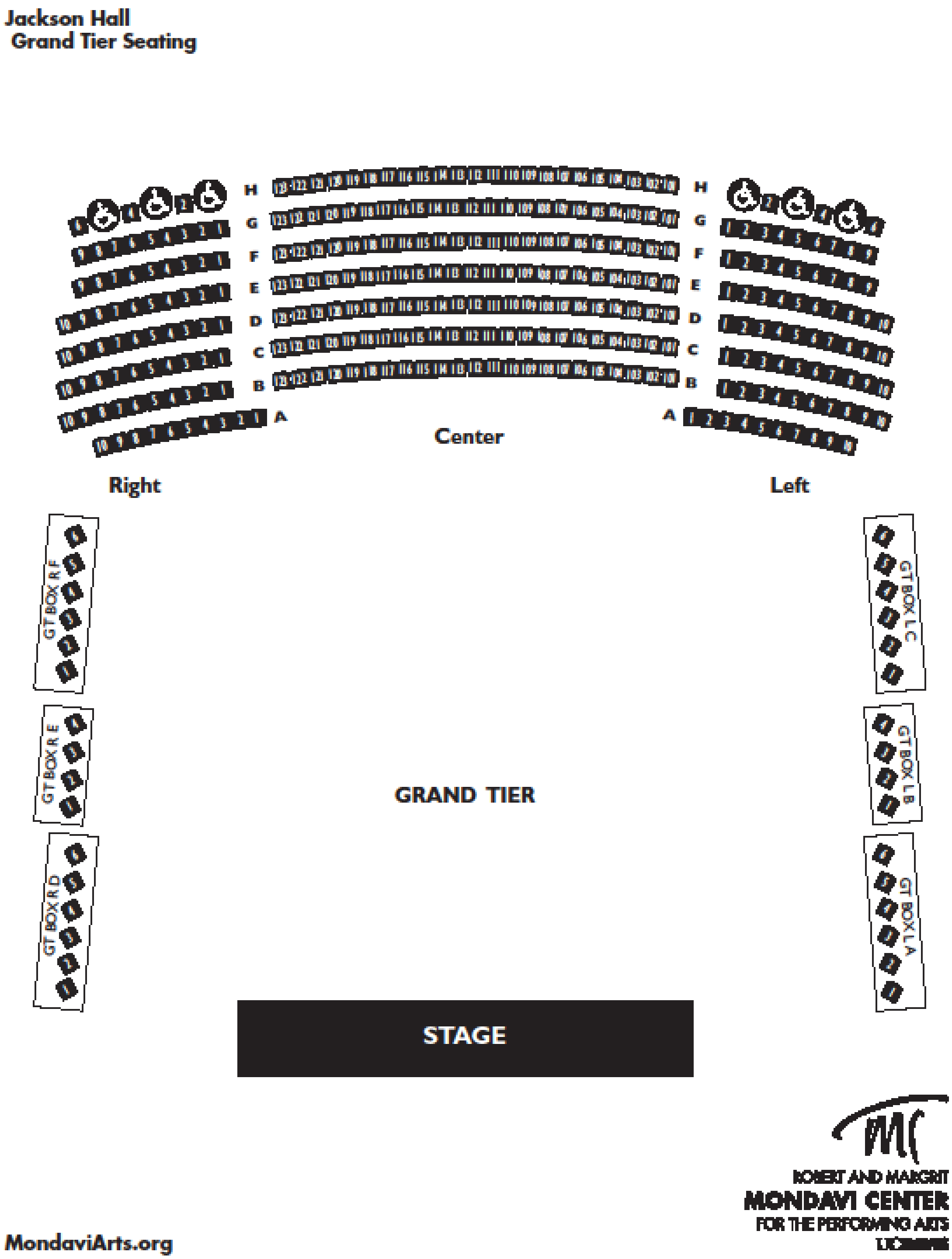
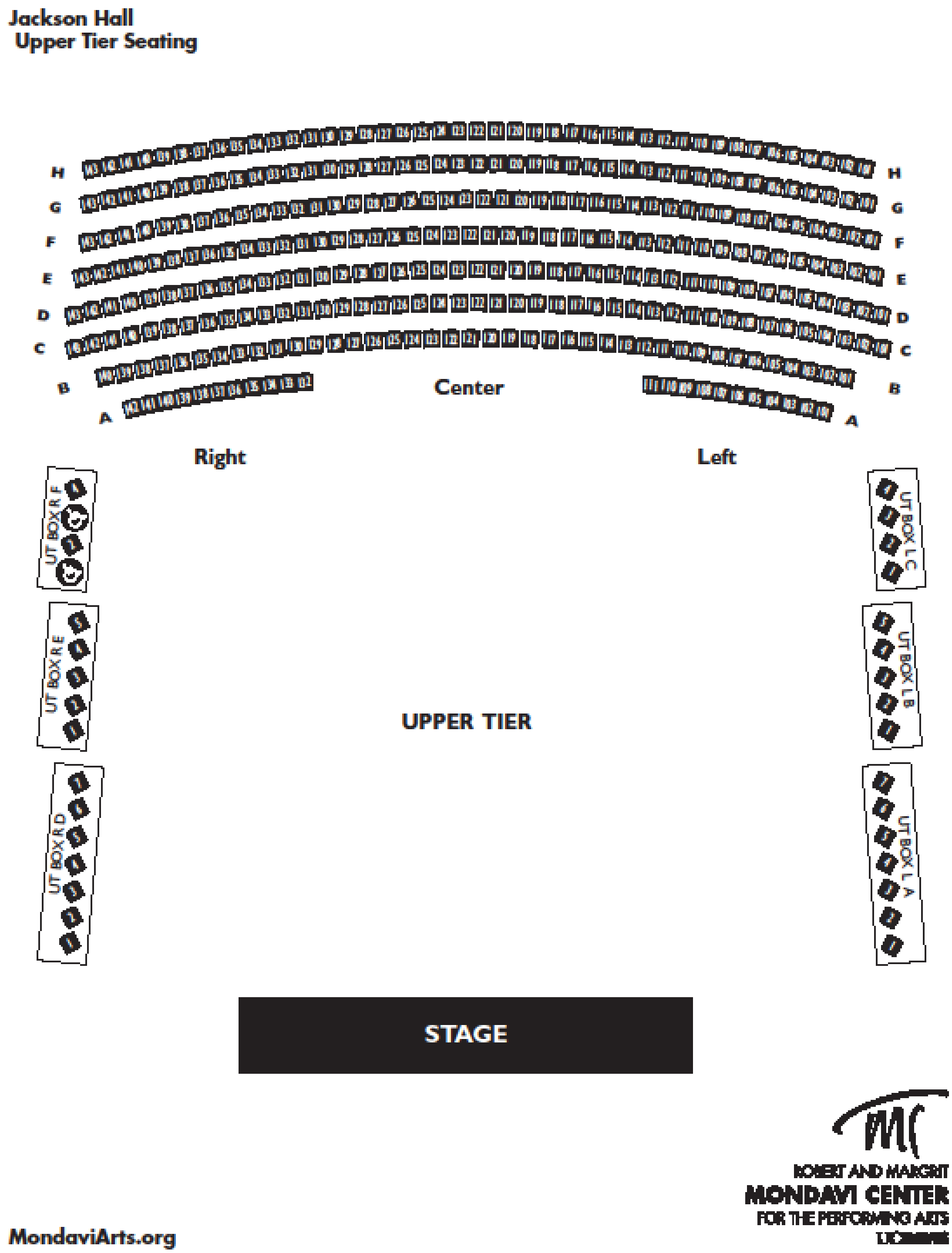


Figure A.3 – Upper Tier/Second Balcony Seating



Appendix B – Floor Plans of Space Use and Exit Locations

Figure B.1 – Basement

A – Fixed	Access Corridor
A – Concentrated	Exit Enclosure
A – Unconc.	Exit
Stage	Exit Access
Business	Exit Discharge
Storage	

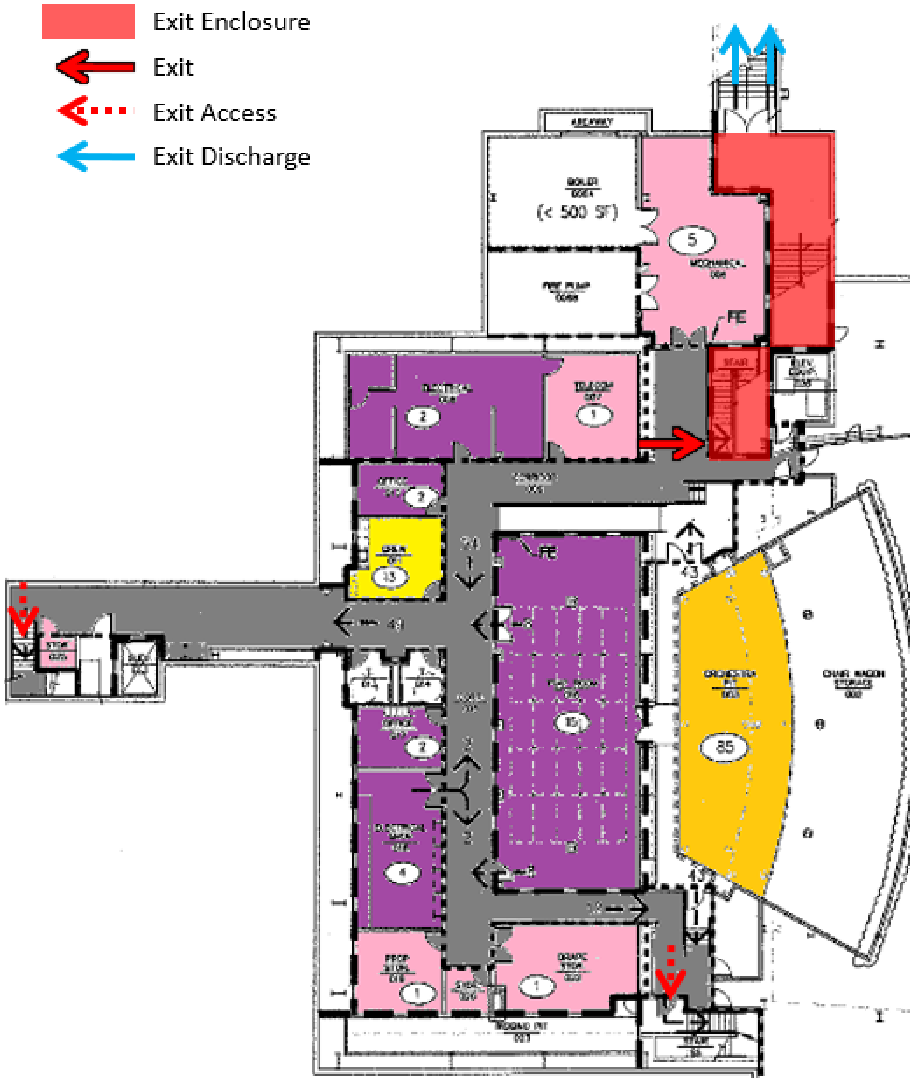


Figure B.2 – Orchestra – First floor

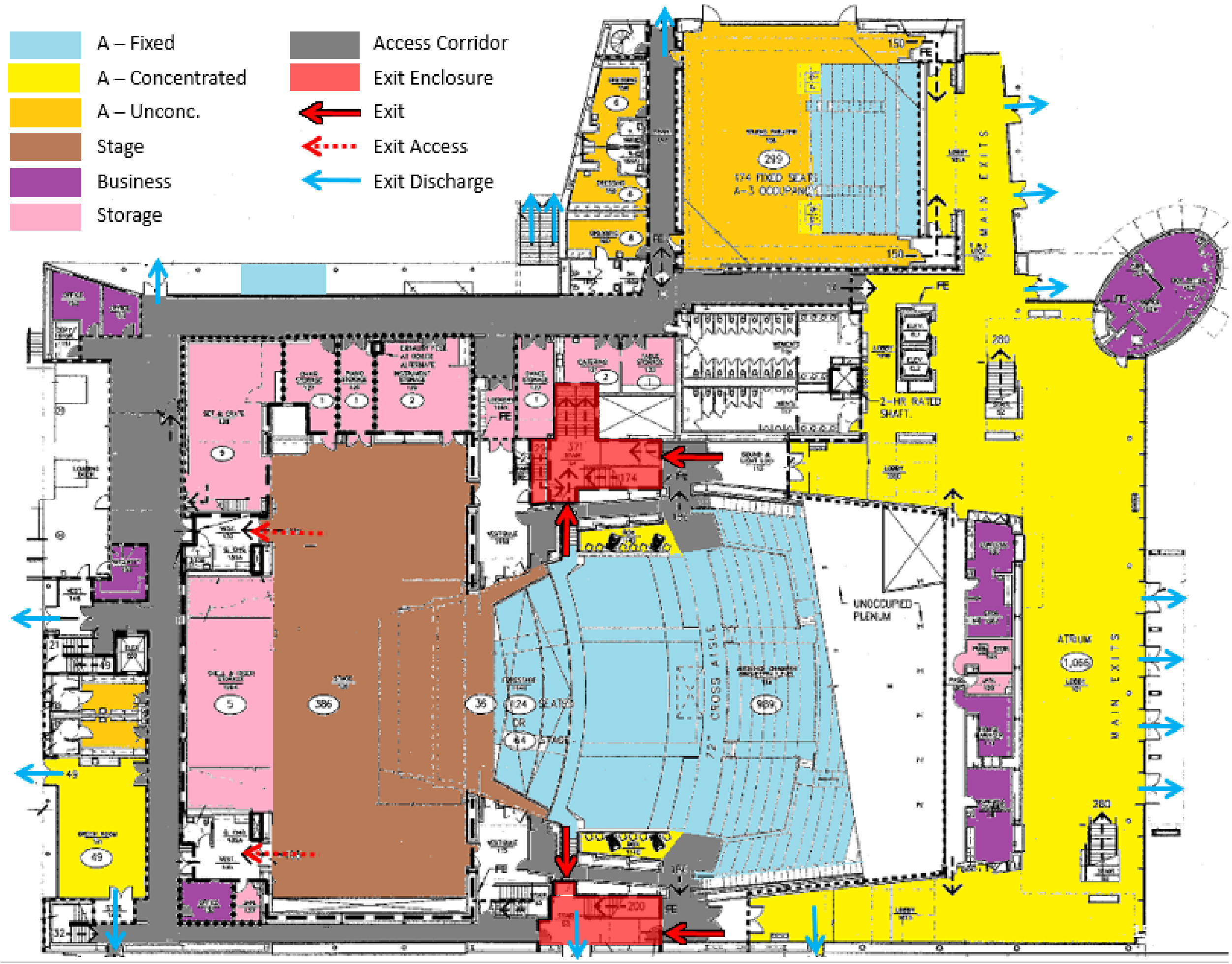


Figure B.3 – Upper Orchestra Seating/2nd Floor Lobby

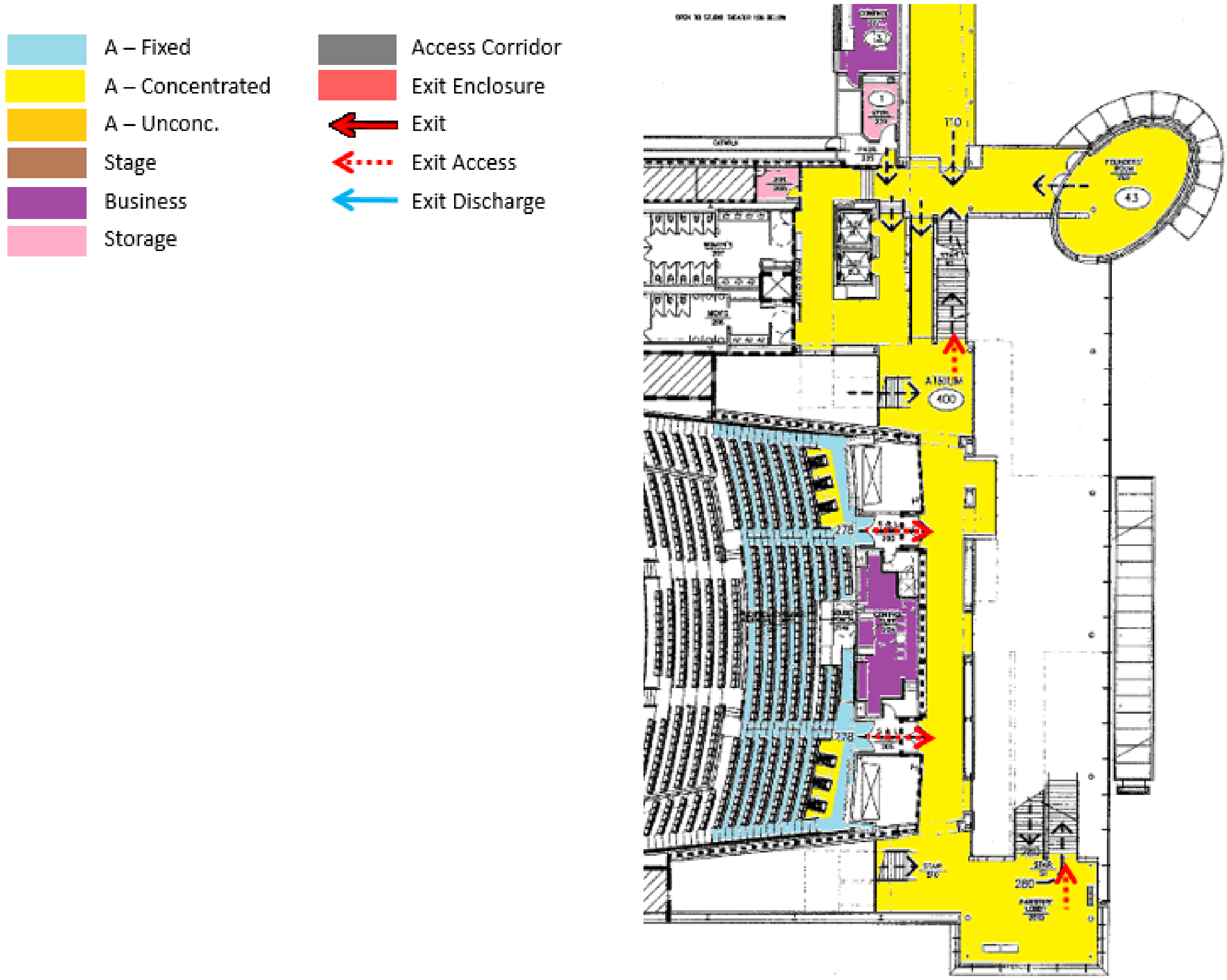


Figure B.4 – 1st Balcony/3rd Floor Lobby/2nd Floor Back of House

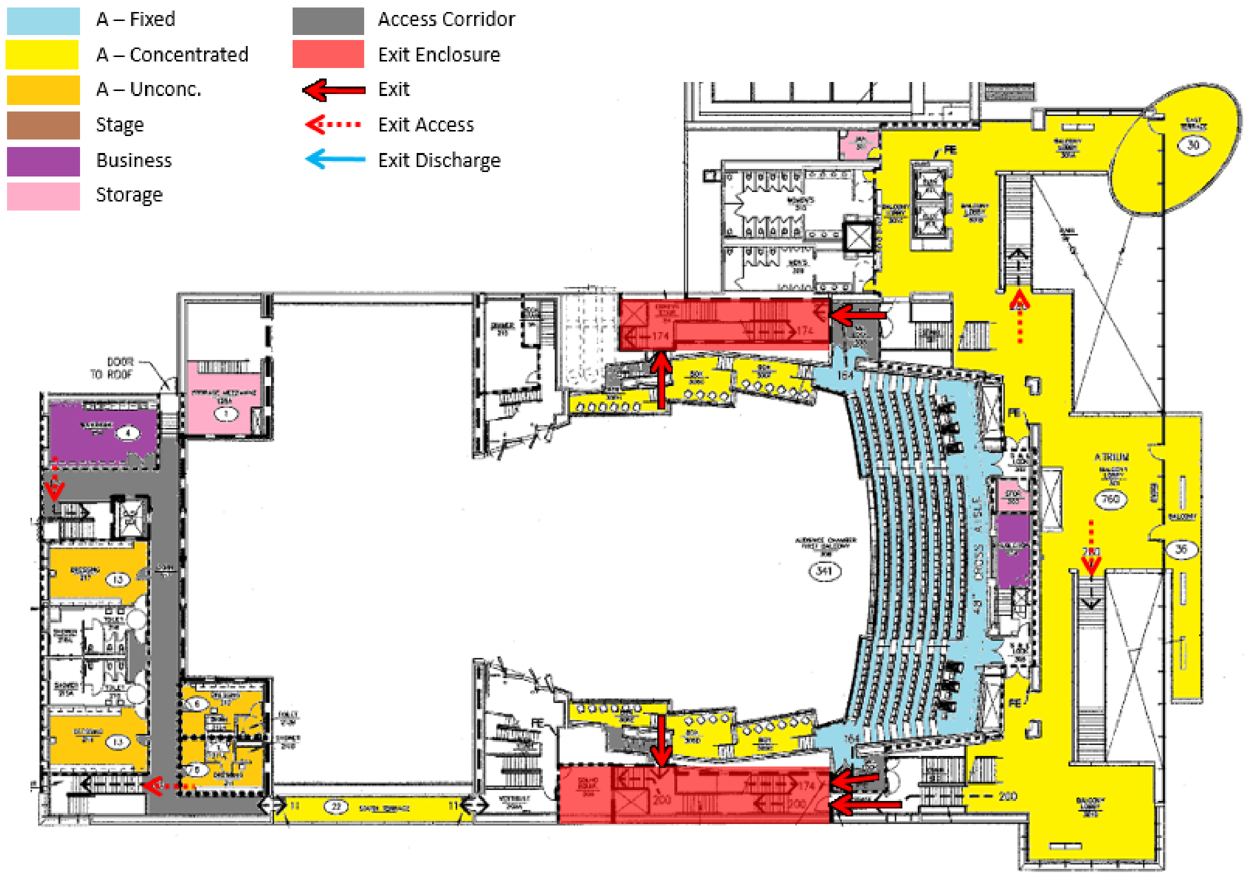
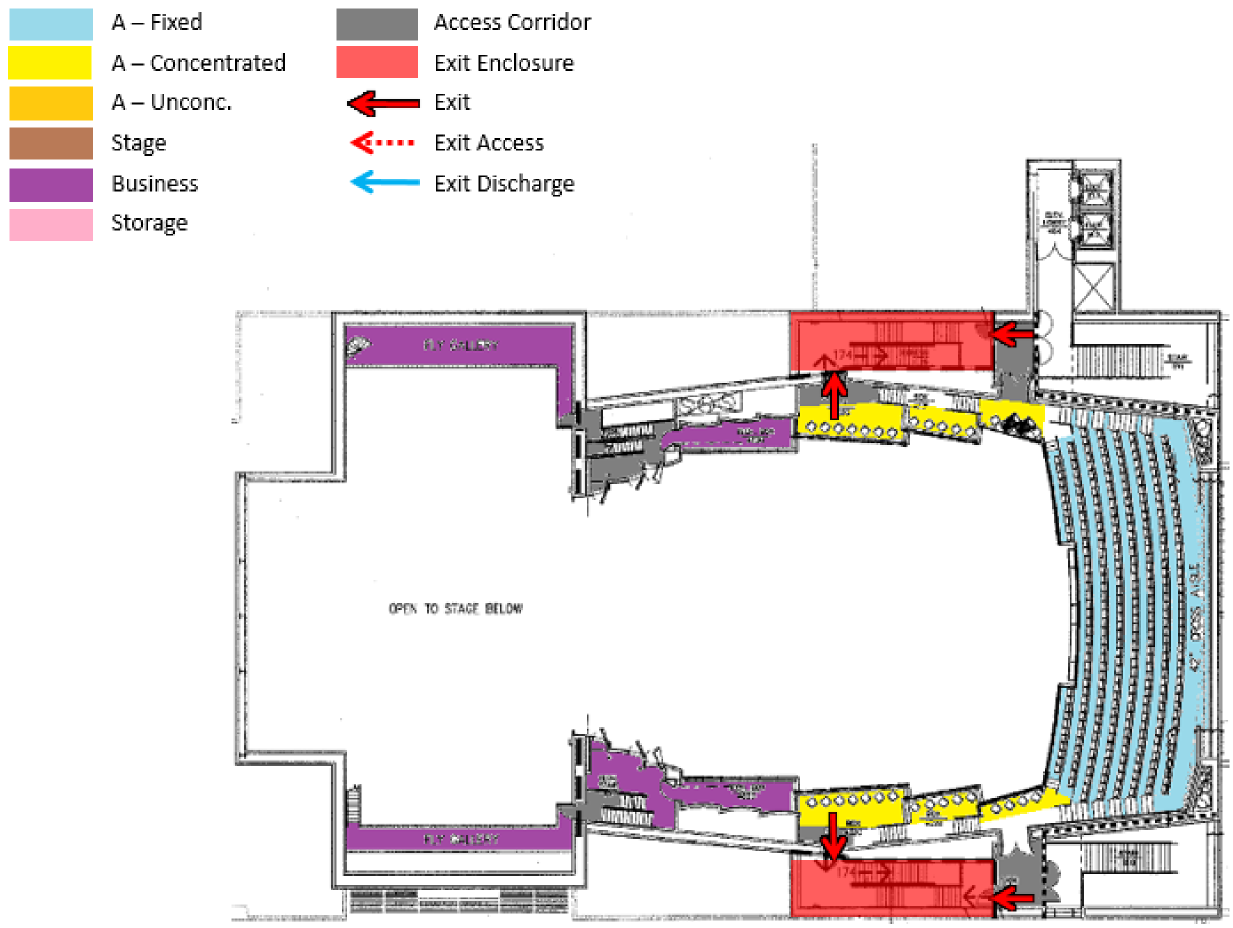


Figure B.5 – 2nd Balcony/4th Floor Lobby



Appendix C – Exit Capacity Calculations

Table C.1 – Exit Capacity Calculation Spreadsheet

Basement Floor	Clear Width (in)	Count	Factor	Capacity
S. Stair S5	44	1	0.3	147
W. Stair S8	52	1	0.3	173
N. Stair S6	44	1	0.3	147
Total Floor Exit Capacity				467
1st Floor				
Main exit doors	89	7	0.2	3105
Atrium side exit	31	1	0.2	155
S. Exit Stair (S3) Doors	37	3	0.2	562
OR S. Exit Stair (S4)	60	1	0.3	200
N. Exit Stair (S4) Doors	37	2	0.2	375
OR N. Exit Stair (S4)	60	1	0.3	200
W. Green Room Exit	60	1	0.2	300
SW Corridor Exit	31	1	0.2	157
W. Corridor Exit	60	1	0.2	300
NW. Corridor Exit	60	1	0.2	300
N. Studio Theater Exit	60	1	0.2	300
Total Floor Exit Capacity				5016
Parterre Level				
N. Terrace Stair	60	1	0.3	200
Atrium Stair (S1, S2)	84	2	0.3	560
Total Floor Exit Capacity				760
First balcony/Second Floor				
Atrium Balcony Stair (S1, S2)	84	2	0.3	560
SW. Atrium Balcony Stair (S10)	60	1	0.3	200
S. Exit Stair (S3) Door	35	2	0.2	353
S. Exit Stair (S3) Door	41	1	0.2	203
OR S. Exit Stair (S3)	60	1	0.3	200
N. Exit Stair (S4) Door	35	2	0.2	353
OR N. Exit Stair (S4)	60	1	0.3	200
SW. Stair (S7)	55	1	0.3	183
W. Stair (S8)	52	1	0.3	173
Total Floor Exit Capacity				1517

Second Balcony

S. Exit Stair (S3) Door	35	2	0.2	353
OR. S. Exit Stair (S3)	60	1	0.3	200
N. Exit Stair (S3) Door	35	2	0.2	353
OR. N. Exit Stair (S3)	60	1	0.3	200
Total Floor Exit Capacity				400

Vertical Exit Discharge

South Exit Stair (S3) Discharge	79	1	0.2	395
N. Exit Stair (S4) Discharge	113	1	0.3	377

Orchestra Level - Jackson Hall

S. Exit Door	37.45	2	0.2	375
S. Discharge Door	79	1	0.2	395
N. Exit Door	37.45	2	0.2	375
N. Exit Stairs	113	1	0.3	377
East Door	60	2	0.2	600
Total Exit Capacity				1349

First Balcony - Jackson Hall

N. and S. Exit Door	35.3	4	0.2	706
N. and S. Exit Stair	60	2	0.3	400
Total Exit Capacity				400

Second Balcony - Jackson Hall

N. and S. Exit Door	35.3	4	0.2	706
N. and S. Exit Stair	60	2	0.3	400
Total Exit Capacity				400

Stage - Jackson Hall

W. Exit Door	67.5	2	0.2	675
Total Exit Capacity				675

Studio Theater

Exit Door	39	2	0.2	390
Total Exit Capacity				390

Appendix D – Pathfinder

Figure D.1 – Model Overview

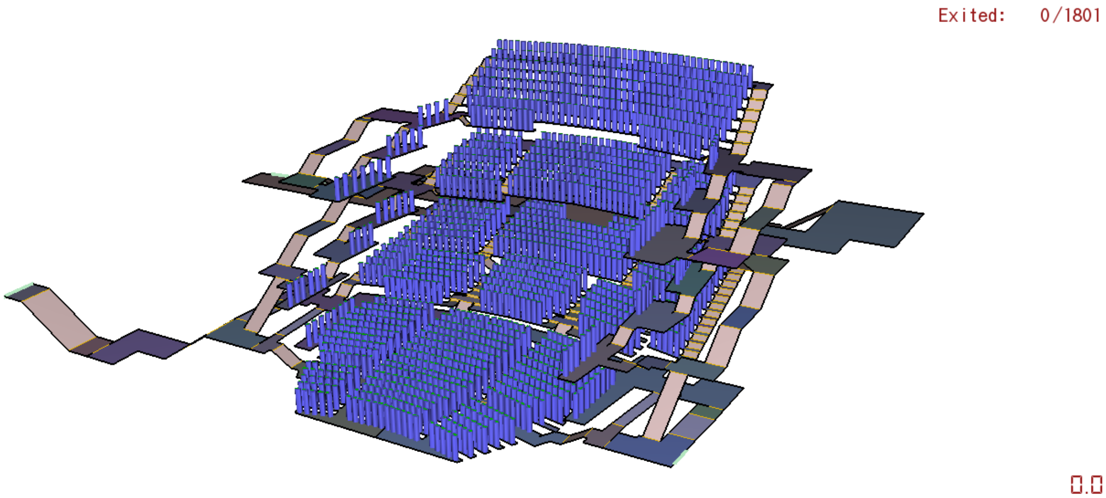


Figure D.2 – Orchestra Level

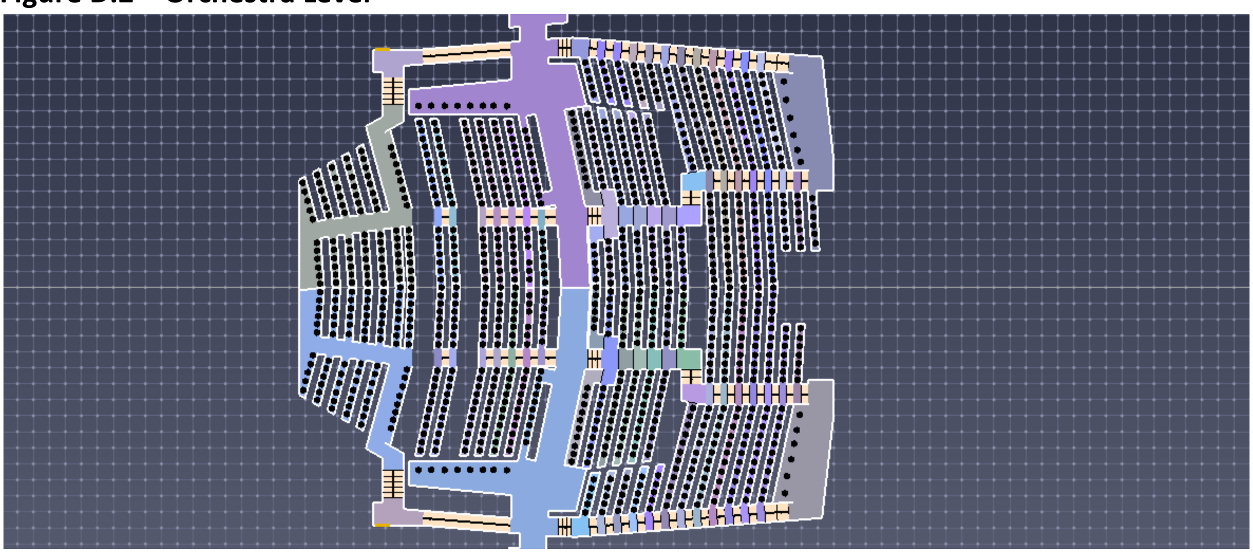


Figure D.3 – First Balcony Level

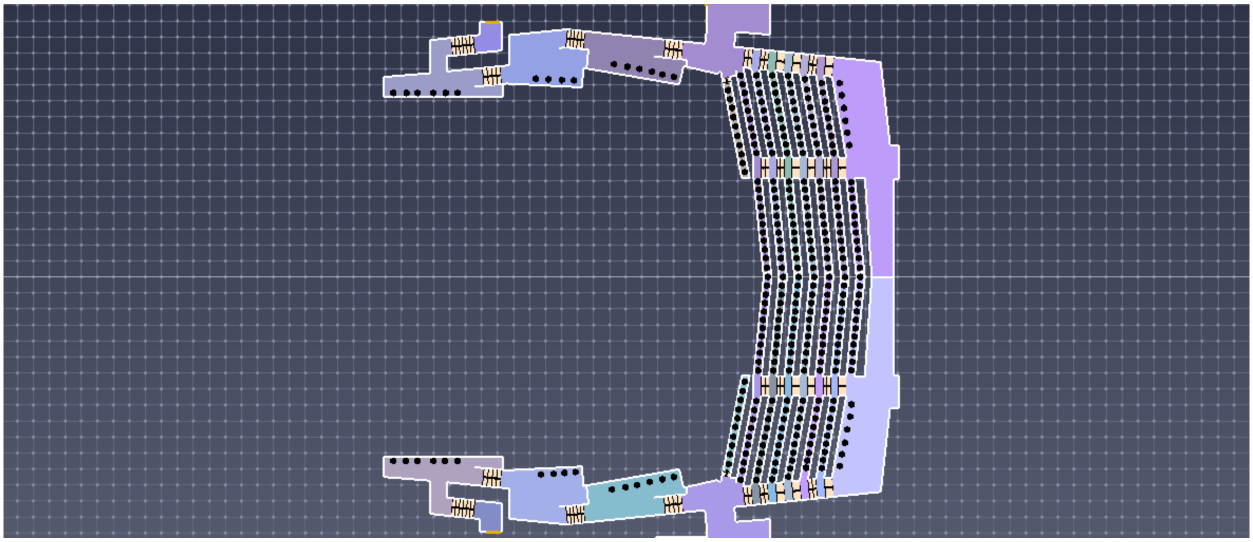
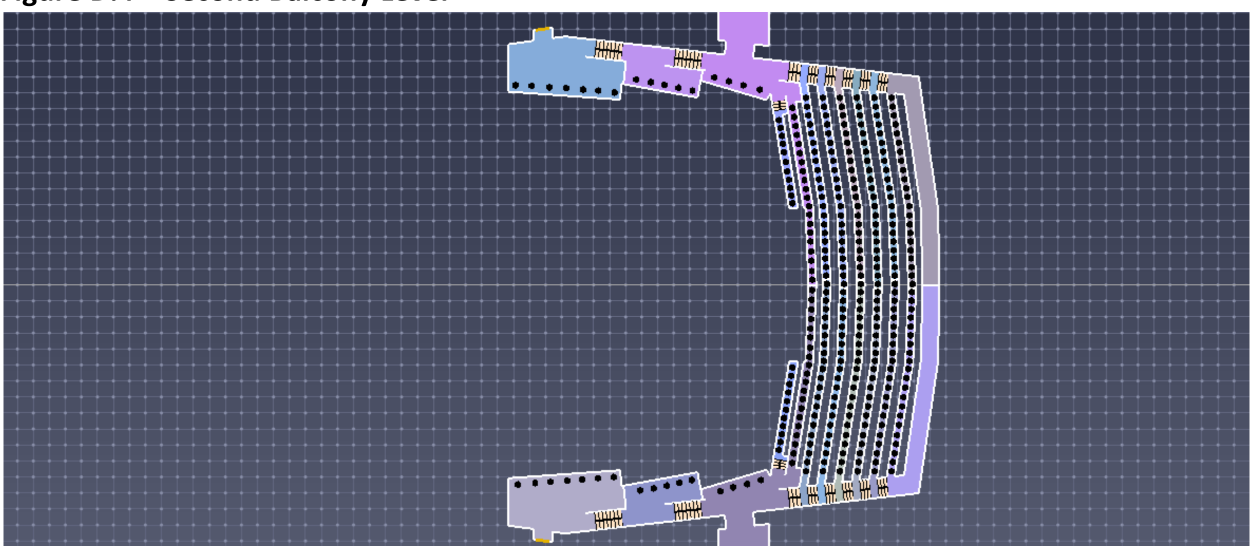


Figure D.4 – Second Balcony Level



N. Exit Enclosure

lower orchestra exit – 139 Occupants

Assume already queued at t = 0

25’ Aisle

Fs = Fsm = 24
Fc = (24)(3.5)
Fc = 84 persons/min

Figure 3-13.81[1] => D = 0.13
S = 275 – 2.86(275)(0.13) = 173 ft/min

t = 25/173 = 0.1445 min

Stair

6.5 ft long, 7,11

Fs(stair) = 84/3.333
Fs(stair) = 25.2 > Fsm = 18.5

Figure 3-13.8 => D = 0.11
S = 212 – 2.86(212)(0.11) = 145.3

t = 6.5/145.7 = 0.0447 min

Fc = (18.5)(3.333)
Fc = 61.667

Assume 8ft Wide Corridor till exit – 23 ft long

Fs(corr) = 61.667/(8-1.5) = 9.487 < Fsm

Figure 3-13.8 => D = 0.025
S = 255.7 > Sm = 235

t = 23/235 = 0.0979 min

Time to reach convergence point
t = 0.1445 + 0.0447 + 0.0979
t = 0.2871 min

[1] Chapter 3-13: “Employing the Hydraulic Model in Assessing Emergency Movement”, SFPE Handbook, 4th Edition

N. Exit Enclosure
Upper Orchestra Exit – 138 Occupants
Assume already queued at t = 0

56' long 6' cross aisle

Fs = Fsm We(cross) = 6 – 1 = 5
Fsm = 24

Fc = (24)(3.5) = 84 people/min

84 = Fs(cross) (5)
Fs(cross) = 16.8

Figure 3-13.8 => D = 0.075
S = 216 ft/min

t = 56/216 = 0.2593 min

Exit Door

Fs(door) = 84/2.12 = 39.62 > Fsm = 24

Fc = (24)(2.12) = 50.88 people/min

Corridor

Fs(corr) = 50.88/(6.1605 – 1.5) = 10.9 < Fsm

Figure 3-13.8 => D = 0.045
S = 239.67 > Sm = 235

t = 25/235 = 0.1064 min

Total time to converging stair
t = 0.3657 min

Second Balcony
Assume queue at t = 0

4ft wide stair -> 5.85 ft wide corridor 32.2 ft long

Fs = Fsm = 21.2
Fc = (21.2)(4-0.5) = 74.2 people/min

Fs(corr) = 74.2/(5.85-1.5)
Fs(corr) = 17.06 < Fsm

Figure 3-13.8 => D = 0.075
S = 275 – 2.86(275)(0.075) = 216

t = 32.2/216 = 0.1491 min

Exit Door

Fs(door) = 74.2/1.94 = 38.25 > Fsm = <u>24</u>
Fc = (24)(1.94) = 46.56 people/min

Corridor
29ft x 5ft

Fs(corr) = 46.56/(5-1.5)
Fs(corr) = <u>13.30</u> < Fsm

Figure 3-13.8 => D = 0.05
S = 275 – 286(275)(0.05) = 235.7 > <u>235</u>

t = 29/235 = <u>0.1234</u> min

Stair
33.25 ft x 5 ft 7,11

Fs(stair) = 46.56/(5-1) = <u>11.64</u> < Fsm

Figure 3-13.8 => D = 0.06
S = 212 + 2.86(212)(0.06) = 175.6 ft/min

t = 33.3/175.6 = <u>0.1896</u> min

First Balcony Landing

Fs(corr) = 46.56/(5-1.5) = 13.30

D = 0.05
S = 235

t = 8/235 = <u>0.03404</u> min

Second Balcony Occupant Time to First Balcony Convergence
t = <u>0.4961</u> min

<u>First Balcony – 171 Occupants</u>
Same as Second Balcony to stair of convergence

Fc = 74.2 people/min
Fs(corr) = 17.06

t = <u>0.1491</u> min

Exit Door

Fsm = 24
Fc = (24)(1.94) = 4656 people/min

Amount of First Balcony Occupants in stair when Second Balcony Occupants converge

= (46.56)(0.4961 – 0.1491)
= (46.56)(0.347)
= 16 people => leaves <u>155 Occupants to queue</u>

Fc = 46.56 + 46.56 = 93.12

Stairs
36 ft x 5 ft 7,11

Fs = 93.12/(5-1) = 23.287 > Fsm = <u>18.5</u>

Figure 3-13.8 => D = 0.175
S = 212 – 2.86(212)(0.175) = 105.9

t = 36/105.9 = <u>0.3399</u> min

Corridor
33 ft x 5 ft

Fc = (18.5)(5-1) = 74

Fs(corr) = 74/(5-1.5) = 21.14

Figure 3-13.8 => D = 0.08
S = 275 – 2.86(275)(0.08) = 212

t = 33/212 = 0.1557

Time convergence point is reached by all levels

t = 0.4961 + 0.3399 + 0.1557
t = <u>0.9917</u> min

When does queuing happen?
Stair limiting factor

Fc = 50.88 + 61.667 + 46.56 = 159.107
Fs = 159.107/(10-1) = <u>17.7</u> < Fsm = 18.5 queuing does not happen yet

Fc = 159.107 + 46.56 = 205.7
Fs = 205.7/(10-1) = 22.86 > Fsm = 18.5

Queuing occurs when occupants of 1st/2nd Balconies Reach 10' stair convergence point at time 0.9917 min.

Occupants Ahead of Convergence point at t = 0.9917 min

Lower Orchestra Exit

0.3657 – 0.2871 = 0.0786 Time occupants pass through 10' stair before convergence

Fs(stair) = 61.667/(10-1) = 6.85 < Fsm

=> Fc = 61.667

\# of occupants = (61667)(0.0786) = 4.847 leaving 134.153 left

All Orchestra

0.9917 – 0.3657 = 0.626 min

Fc = 50.88 + 61.667 = 112.547

\# of occupants = (112.547)(0.626) = 70.45 occupants leaving 201.703 occupants from Orchestra

At 0.9917 min, all floor occupants converge at the top of the 10 stair and queuing occurs.

Stair
10 ft x 20 ft

Fc = 50.88 + 61.667 + 45.56 + 45.56
Fc = 203.667

Fs = 203.667/(10-1) = 22.63 > Fsm = <u>18.5</u>

Fc = (18.5)(10-1) = 166.5

Figure 3-13.8 => D = 0.175
S = 212 – 2.86(212)(0.175) = 105.9 ft/min

t = 20/105.9 = <u>0.1889</u> min

Corridor
30 ft x 10 ft

Fs = 166.5/(10-1.5) = 19.6 < Fsm

Figure 3-13.8 => D = 0.1
S = 275 – 2.86(275)(0.1) = 196.4

t = 30/196.4 = <u>0.1527</u> min

Doorway
74.2 inches

Fs = 166.5/(6.183-1) = 32.1 > Fsm = <u>24</u>
Fc = (24)(6.183-1) = 124.4

Door Landing
7 ft x 10 ft

Fs = 124.4/(10-1.5) = 14.64 < Fsm

Figure 3-13.8 => D = 0.065
S = 275 – 2.86(275)(0.065) = 223.9 ft/min

t = 7/223.9 = <u>0.0313</u> min

Outside Stair
20 ft x 10 ft 7,11

Fs = 124.4/(10-1) = 13.78 < Fsm

Figure 3-13.8 => D = 0.075
S = 212 – 2.86(212)(0.075) = 166.5 ft/min

t = 20/166.5 = <u>0.1201</u> min

<u>Total Jackson Hall Evacuation Time</u>

= 0.9917 + 0.1889 + 0.1527 + 0.0313 + 0.1201
+ (348 + 134.153 + 201.703)/(124.4 people/min)
= 1.4847 + 5.4972
= **<u>7 minutes</u>**

Appendix F – Battery Calculation Excel Sheets

Table F.1 – Main Fire Alarm Control Panel Current Calculations

Device	Model #	Standby Current Per Unit (Amps)	QTY	Total Standby Current Per Unit (Amps)	Alarm Current Per Unit (Amps)	QTY	Total Alarm Current Per Unit (Amps)
FACP - RM 150	5820XL	0.215	1	0.215	0.385	1	0.385
Annunciator	5860	0.02	2	0.04	0.025	2	0.05
FAPS #1 - RM 109	5895XL	0.01	1	0.01	0.01	1	0.01
SLC Expander	5815	0.055	2	0.11	0.055	2	0.11
Photoelectric Det.	SD505-APS	0.00055	120	0.066	0.00055	120	0.066
Fire Door Relay	SD505-6RB	0.000082	32	0.002624	0.000082	32	0.002624
Heat Detector	SD505-AHS	0.00055	3	0.00165	0.055	3	0.165
Manual Pull	2099-9754	0	17	0	0	17	0
Mini Module	SD500-mim	0.00055	17	0.00935	0.00055	17	0.00935
Duct Detect	SD505-AIS	0.00055	11	0.00605	0.00055	11	0.00605
Duct Detect Housing	SD505-ADH	0.00055	11	0.00605	0.00055	11	0.00605
OA detector	2151	0.00012	4	0.00048	0.00012	4	0.00048
OA detect base	b114lp	0.00012	4	0.00048	0.13	4	0.52
RTS duct	SD505-DTS	0.006	11	0.066	0.006	11	0.066
RTS OA	RTS-451	0	4	0	0.105	4	0.42
remote relay	SD500-ARM	0.00055	18	0.0099	0.00055	18	0.0099
waterflow monitor	SD500-AIM	0.00055	9	0.00495	0.00055	9	0.00495
tamper monitor	SD500-AIM	0.00055	19	0.01045	0.00055	19	0.01045
Water Pump Monitor	SD500-AIM	0.00055	3	0.00165	0.00055	3	0.00165
Strobe 15/75	RSS-241575	0	20	0	0.09	20	1.8
Strobe 15	RSS-24MCW	0	21	0	0.06	21	1.26
Strobe 30	RSS-24MCW	0	7	0	0.092	7	0.644
Strobe 75	RSS-24MCW	0	4	0	0.165	4	0.66
Strobe 110	RSS-24MCW	0	4	0	0.22	4	0.88
		Total Standby Current:		0.561A	Total Alarm Current:		7.088A
		15 Minute Alarm (Amp-Hour):			1.77		
		24 Hour Standby (Amp-Hour):			13.46		
	Total Required Capacity (Amp-Hour):				15.23		

Table F.2 – Fire Alarm Power Supply #1 Current Calculations

Device	Model #	Standby Current Per Unit (Amps)	QTY	Total Standby Current Per Unit (Amps)	Alarm Current Per Unit (Amps)	QTY	Total Alarm Current Per Unit (Amps)
FAPS #1 - RM 109	5895XL	0.04	1	0.04	0.16	1	0.16
Annunciator	5860	0.02	2	0.04	0.025	2	0.05
FAPS #2 - RM 303	5895XL	0.01	1	0.01	0.01	1	0.01
Strobe 15/75	RSS-241575	0	12	0	0.09	12	1.08
Strobe 15	RSS-24MCW	0	27	0	0.06	27	1.62
Strobe 30	RSS-24MCW	0	5	0	0.092	5	0.46
Strobe 75	RSS-24MCW	0	3	0	0.165	3	0.495
Strobe 110	RSS-24MCW	0	9	0	0.22	9	1.98
		Total Standby Current:		0.090A	Total Alarm Current:		5.855A
		15 Minute Alarm (Amp-Hour):			1.46		
		24 Hour Standby (Amp-Hour):			2.16		
	Total Required Capacity (Amp-Hour):				3.62		

Table F.3 – Smoke Control Panel Current Calculation

Device	Model #	Standby Current Per Unit (Amps)	QTY	Total Standby Current Per Unit (Amps)	Alarm Current Per Unit (Amps)	QTY	Total Alarm Current Per Unit (Amps)
Smoke Control Panel	AFP-1010	0.222	1	0.222	0.226	1	0.226
Monitor Module	FMM-101	0.00035	22	0.0077	0.0051	22	0.1122
Control Relay Module	FRM-1	0.00035	20	0.007	0.00035	20	0.007
		Total Standby Current:		0.237A	Total Alarm Current:		0.345A
		15 Minute Alarm (Amp-Hour):			0.09		
		24 Hour Standby (Amp-Hour):			5.68		
	Total Required Capacity (Amp-Hour):				5.77		

Table F.4 – Fire Alarm Power Supply #2 Current Calculations

Device	Model #	Standby Current Per Unit (Amps)	QTY	Total Standby Current Per Unit (Amps)	Alarm Current Per Unit (Amps)	QTY	Total Alarm Current Per Unit (Amps)
FAPS #2 - RM 303	5820XL	0.04	1	0.04	0.16	1	0.16
Annunciator	5860	0.02	0	0	0.025	0	0
SLC Expander	5815	0.055	1	0.055	0.055	1	0.055
Photoelectric Det.	SD505-APS	0.00055	81	0.04455	0.00055	81	0.04455
Fire Door Relay	SD505-6RB	0.000082	11	0.000902	0.000082	11	0.000902
Heat Detector	SD505-AHS	0.00055	0	0	0.055	0	0
Manual Pull	2099-9754	0	14	0	0	14	0
Mini Module	SD500-mim	0.00055	14	0.0077	0.00055	14	0.0077
Duct Detect	SD505-AIS	0.00055	6	0.0033	0.00055	6	0.0033
Duct Detect Housing	SD505-ADH	0.00055	6	0.0033	0.00055	6	0.0033
OA detector	2151	0.00012	0	0	0.00012	0	0
OA detect base	b114lp	0.00012	0	0	0.13	0	0
RTS duct	SD505-DTS	0.006	6	0.036	0.006	6	0.036
RTS OA	RTS-451	0	0	0	0.105	0	0
remote relay	SD500-ARM	0.00055	7	0.00385	0.00055	7	0.00385
waterflow monitor	SD500-AIM	0.00055	0	0	0.00055	0	0
tamper monitor	SD500-AIM	0.00055	0	0	0.00055	0	0
Water Pump Monitor	SD500-AIM	0.00055	0	0	0.00055	0	0
Strobe 15/75	RSS-241575	0	19	0	0.09	19	1.71
Strobe 15	RSS-24MCW	0	55	0	0.06	55	3.3
Strobe 30	RSS-24MCW	0	10	0	0.092	10	0.92
Strobe 75	RSS-24MCW	0	3	0	0.165	3	0.495
Strobe 110	RSS-24MCW	0	11	0	0.22	11	2.42
		Total Standby Current:		0.195A	Total Alarm Current:		9.160A
		15 Minute Alarm (Amp-Hour):			2.29		
		24 Hour Standby (Amp-Hour):			4.67		
	Total Required Capacity (Amp-Hour):				6.96		

Table F.5 – Number of different candela settings on each circuit

Panel	MFACP						FAPS #1						FAPS #2				
Circuit #	V1	V2	V3	V4	V12	Total	V5	V6	V7	V8	V9	Total	V10	V11	V13	V14	Total
15/75	5	4	3	4	4	20	2	4	1	2	3	12	4	2	0	1	19
15	3	2	4	6	6	21	2	3	3	11	8	27	9	9	4	6	55
30	0	3	1	0	3	7	0	0	4	1	0	5	0	3	2	0	10
75	1	1	0	1	1	4	0	0	0	0	3	3	0	0	0	0	3
110	0	0	3	1	0	4	2	3	0	3	1	9	0	0	1	1	11

Table F.6 – Emergency Voice/Alarm Communications Panel Current Calculation

	Circuit #	QTY	Watt Setting	Total Watts	Total Watts per Amplifier	Current Per Amplifier (Amps)
Amplifier #1 80W	S1	22	1/2	11	37	1.924
	S2	39	1/2	19.5		
	s4	13	1/2	6.5		
Amplifier #2 80W	S3	20	1/2	10	36.5	1.898
	S9	53	1/2	26.5		
Amplifier #3 80W	S5	17	1/2	8.5	39	2.028
	S6	37	1/2	18.5		
	S7	11	1/2	5.5		
	S8	13	1/2	6.5		
					Total Alarm current:	5.85A
					15 Minute Alarm (Amp-Hour):	1.46

Table F.7 – Required Standby and Alarm Capacity Calculations

	Required Standby Time (Hours)	Total Standby Current (Amps)	Required Standby Capacity (Amp-Hours)	Required Alarm Time (Hours)	Total Alarm Current (Amps)	Required Alarm Current (Amp-Hours)
Security Room 150 FACP and EVACS	24	0.56	13.46	0.25	12.94	3.23
Janitor Room 109 FAPS#1 and SCP	24	0.09	2.16	0.25	5.86	1.46
Storage Room 303 FAPS#2	24	0.19	4.67	0.25	9.16	2.29

Appendix G – Voltage Drop Calculation

Lumped Method is use for worst scenario with factor of safety added on to the length of the circuit due to estimated wire lengths.

NEC CH. 9 Table 8: 12 AWG Stranded Uncoated Copper Wire:

R = 1.98 ohm/kFT

Total Length of single circuit with factor of safety:

Factor of safety used because length is estimated.

2 * L = 2 * 594 = 1188 + 15% * 1188 = 1366.2 ft

Current Draw from Horn Strobe and Sync Module cut sheet:

15/75: 0.09 A * 2 = 0.18 A

15 cd: 0.06 A * 11 = 0.66 A

30 cd: 0.092 A * 1 = 0.092 A

75 cd: 0.165 A * 0 = 0

110 cd: 0.22 A * 3 = 0.66 A

Total: 1.592 A

Minimum Supplied Voltage:

Vterm = 24V – 24V * 15% = 20.4

Minimum Device Voltage:

Operating Voltage Range with MDL3 Module: 16V – 33V

Vload = 16V

Voltage Drop Calculation:

VD = 2 * L * R * I / 1000

VD = 1366.2 * 1.98 * 1.592 / 1000

<u>VD = 4.31</u>

%VD = (VD / 24) * 100

%VD = (4.31 / 24) * 100

<u>%VD = 18.0%</u>

Vterm – VD must be more than 16V.

20.4 – 4.31 = <u>16.09V</u>

VD is greater than 16V. Circuit complies with NFPA 72

Appendix H – Fire Sprinkler Remote Area

Figure H.1 – Orchestra Level

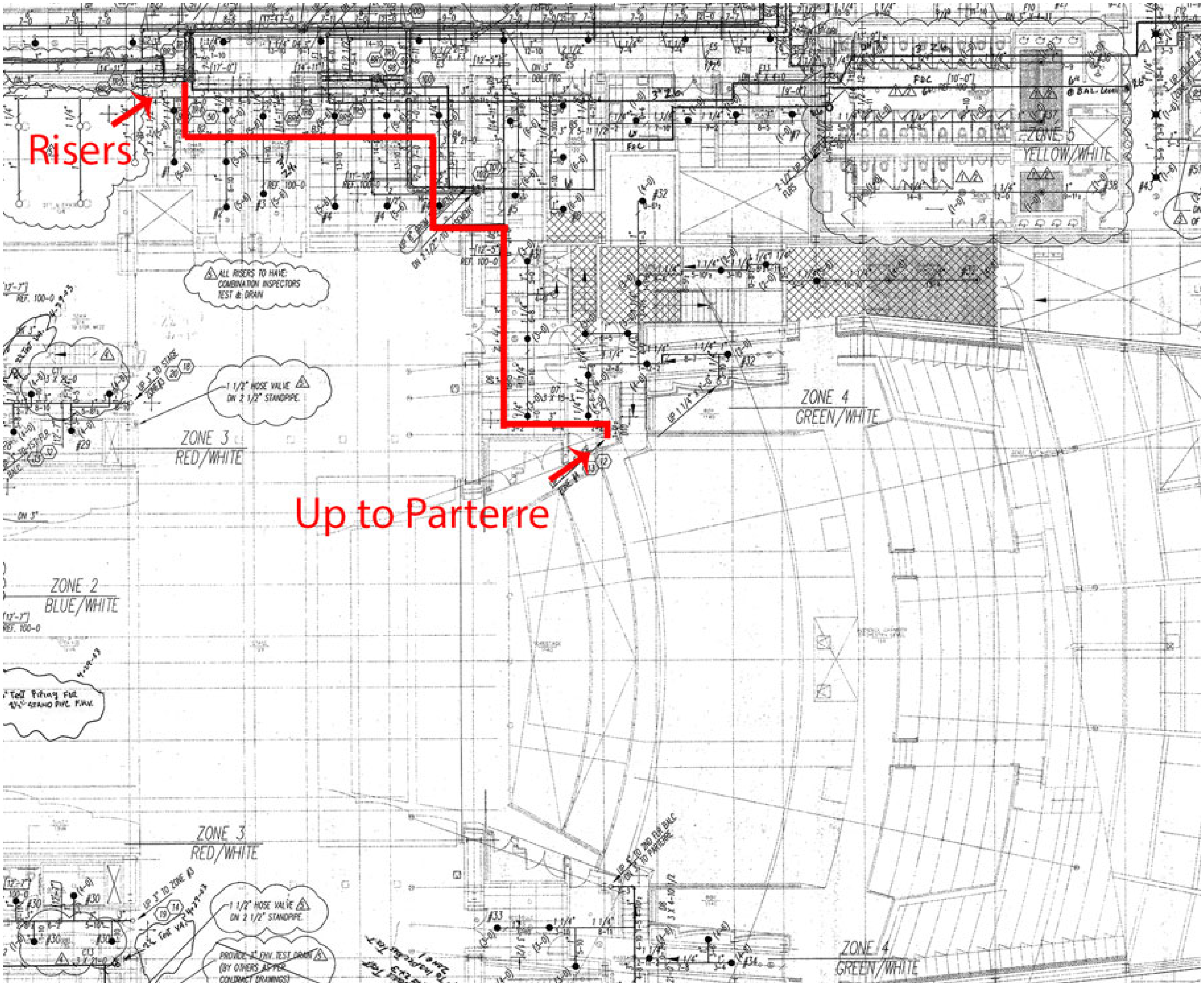


Figure H.2 – Parterre Level

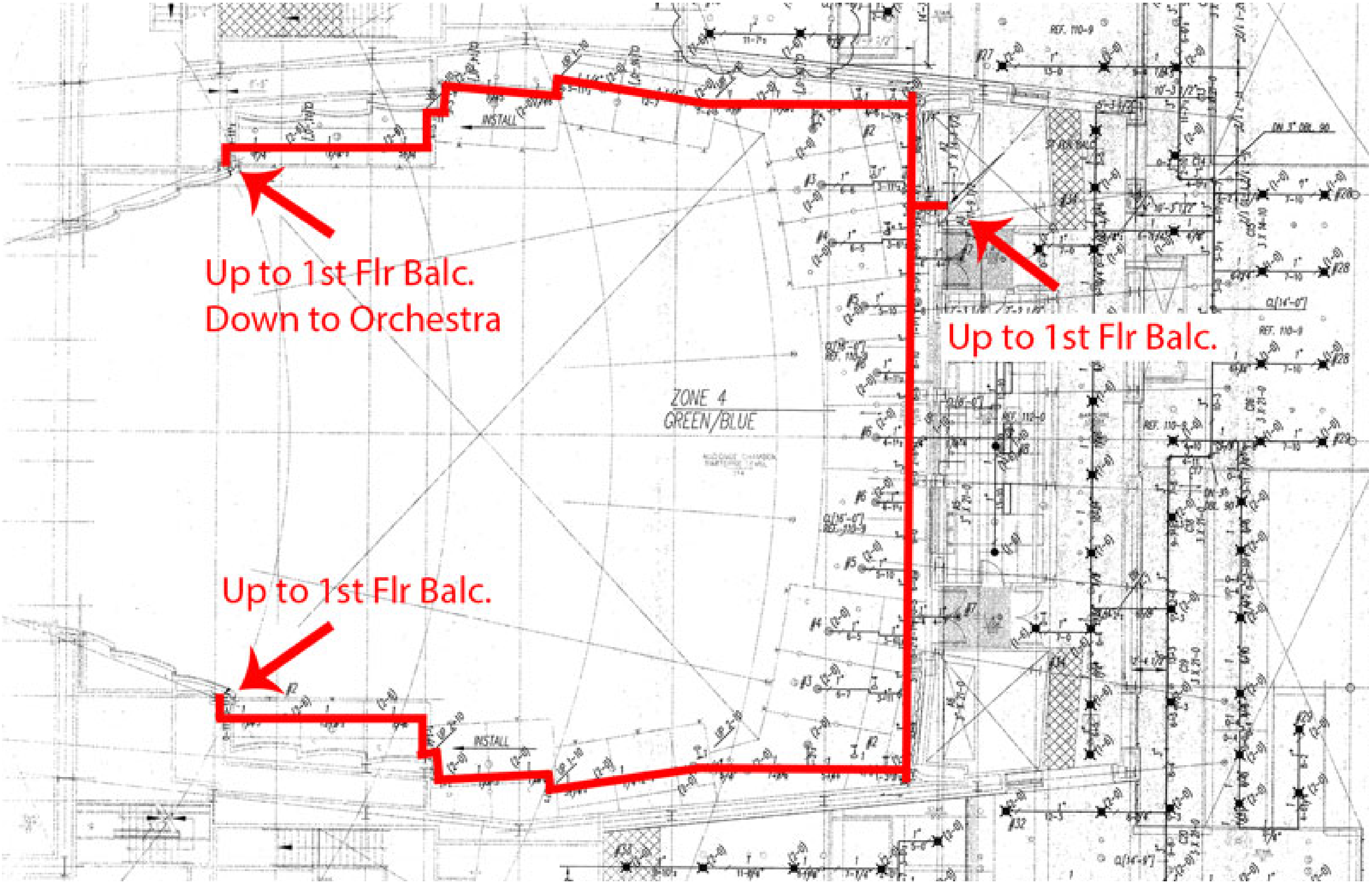


Figure H.3 – 1st Floor Balcony

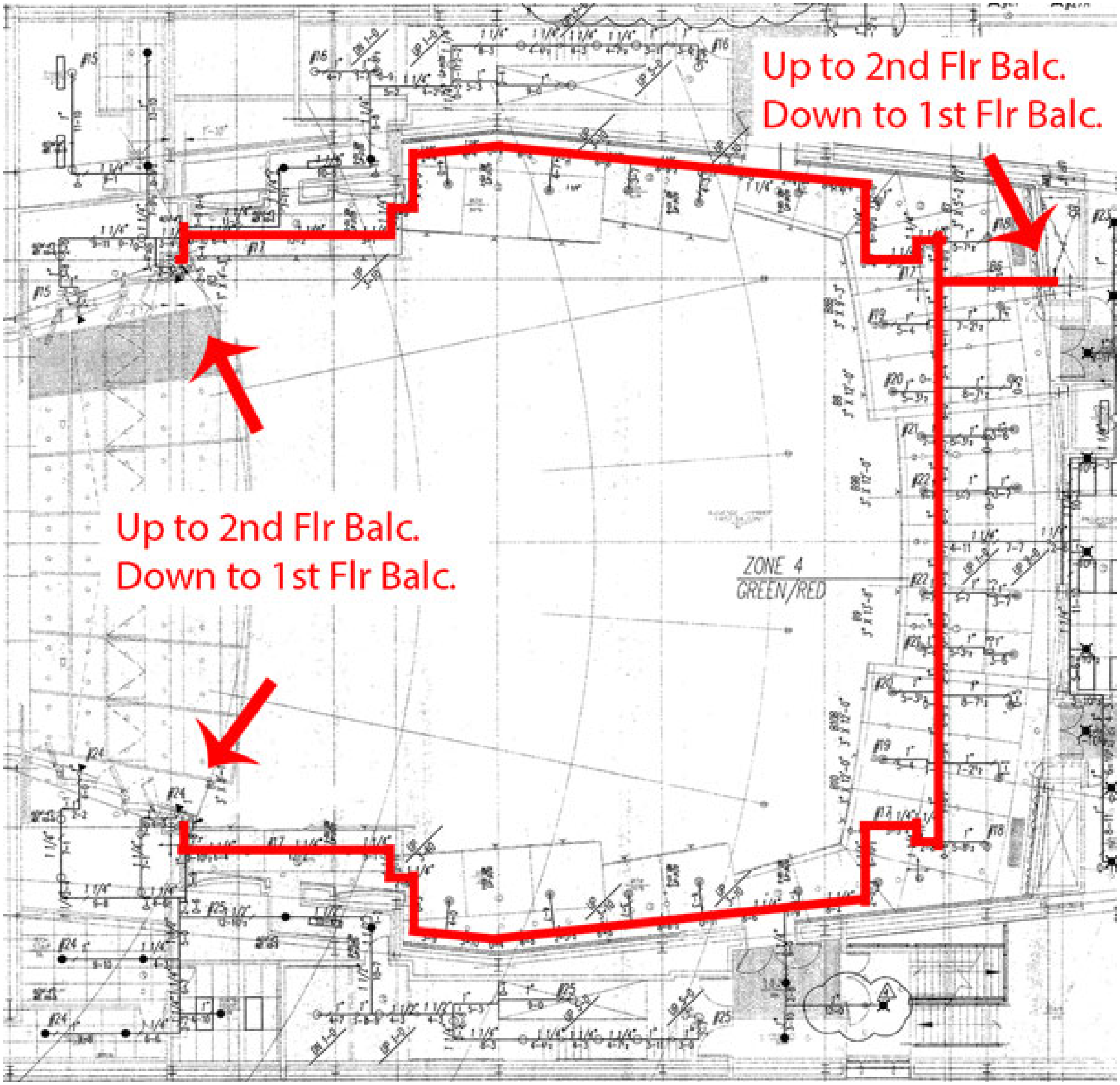


Figure H.4 – 2nd Floor Balcony