California Polytechnic State University, San Luis Obispo

Fire Protection Engineering Final Report: Baylor Scott & White Medical Center, College Town, TX

By Jonathan Lo

Statement of Disclaimer

This project report is a result of a class assignment; it has been graded and accepted as fulfillment of the course requirements. Acceptance of this report in fulfillment of the course requirements does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include, but may not be limited to, catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Keywords: Hospital Fire Protection Engineering, Hospital Life Safety Code, Hospital Performance-Based Design, Hospital Smoke Control, Hospital Fire Modeling (Fire Dynamics Simulator FDS, CONTAM, DETACT, Consolidated Fire and Smoke Transport CFAST, Pathfinder, PyroSim).

Table of Contents

Abstract

Summary

This report examines the Baylor, Scott & White Medical Center in College Station, TX. This hospital is a 324,070 square feet midrise building of Type I-A construction and Group I-2 occupancy, with a basement and five above-grade floors. Publicly-available, simplified floorplans were obtained from the internet, and a prescriptive- and performance-based analysis was formed around these plans. It should be noted that these online plans may not contain all information and details in that are found in architectural plans, and that assumptions were made in order to 'fill in the gaps' and proceed with this report. For example, on the basement floorplan, only one vertical exit is shown, and in this report it is assumed no other vertical exits are present, though in reality there may be. Such assumptions are noted at the time they are presented within this report.

This report includes a prescriptive-based analysis of the fire and life safety components of this building, which includes the egress, water-based fire suppression, detection and notification, structural, flammability assessment method, and smoke control systems. The prescriptive-based analysis is based on the IBC and associated NFPA standards, as adopted by the AHJ in the area. It is understood that as a health care facility, requirements and surveys by the Joint Commission (formerly Joint Commission on Accreditation of Healthcare Organizations, JCAHO, and Joint Commission on Accreditation of Hospitals JCAH) apply, in addition to those by AHJ's to other facilities and occupancies. However, the Joint Commission requirements are outside the scope of this report, and the report instead focuses on the focus on the IBC and NFPA standards.

This reports also includes a performance-based analysis of this building. The performance-based analysis considers two design fires based on data from the SFPE Handbook, 5th edition: an office workstation fire, and a patient bed fire. Pathfinder models with patient beds requiring assistance to move was used to estimate the required safe egress time (RSET) to evacuate from one smoke compartment to another via horizontal exits for each scenario. FDS models were then used to find the available safe egress time (ASET) based on tenability criteria.

Results

From the prescriptive-based analysis, and based on assumptions made in this report, the Baylor, Scott & White Medical Center generally meets code requirements. One example where this is not the case is in the number of exits provided from the basement level to the level of discharge on the ground floor. As noted in the summary though, another vertical exit may be present, but not shown on these simplified floorplans. Additionally, the assumptions made as to the occupancy classification and loads for spaces in the basement were deliberately chosen to be conservative, and in reality the occupant load may be below the threshold for two separate exits.

From the performance-based analysis, an ASET of over 500 seconds was calculated for the office fire scenario, which is greater than an RSET of 315.5 seconds for that scenario. However, an ASET of 260 seconds was calculated for the bedroom fire scenario, which is less than the RSET for that scenario. Additional examination of the model with stakeholders, including the AHJ and hospital, should be conducted to verify assumptions and data. In case RSET still exceeds ASET, additional engineered systems or administrative controls can be implemented to increase ASET until it exceeds RSET, including

increases in detection, notification, suppression, smoke control, flammability limits on fixtures, furnishings, and equipment, etc.

It should be noted that both the office and bedroom fire scenarios were based on a sprinkler-controlled fire, and several assumptions regarding the overall HRR curve, reaction chemistry, and other factors which may be further refined. The fact that the calculations assumed that the doors to the office and the bedroom were open during each fire scenario likely was a key component of these model calculations, and bares further examination.

Conclusions

This report serves as an academic analysis of the Baylor, Scott & White Medical Center in College Station, TX. While lack of detailed drawings and information necessarily make this report limited in use, it is hoped this paper serves as a basic review of the life safety systems of this hospital, and hospitals in general. It is also anticipated that this narrative may serve as a starting point for future detailed studies.

Introduction

This report examines the Baylor Scott & White Medical Center from under both a prescriptive code analysis and a performance-based analysis. The approach taken in this report is a simple one by choice, reflecting the author's lack of experience in this field. It is likely another engineer can identify improvements to the analysis conducted here. However, it is hoped that this paper demonstrates sound engineering judgement, as well as a basic understanding of the principals of fire protection engineering.

Note, details on the codes used as references—full names, code cycle year, etc.—are listed in the "References" section of this report. This report uses a shorthand when referring to them in the main body of this work. For example, when referring to Section 308.3.1.2 of the 2018 edition of the International Building Code, it is abbreviated in this report as 308.3.1.2 IBC.

Building Description

The Baylor Scott & White Medical Center is a hospital located at 700 Scott and White Drive, College Station, TX 77845. It was constructed six years ago in 2013 as part of Scott & White Healthcare for $90MM, and was originally called the Scott & White Medical Center. The same year construction on this hospital was completed, Scott & White Healthcare combined with the Baylor Health Care System to form Baylor Scott & White, which is the largest nonprofit healthcare system in Texas. The building was accordingly rebadged with the new, longer title of Baylor Scott & White in 2016.

This facility has a basement and five above-ground floors with an area of 324,070 square feet. This report assumes that each floor is self-contained, and there are no interior atriums or openings between floors. From the publicly-available plans, a natural lightwell is present between the 3rd and 5th floors, and there is an opening above the cafeteria, connecting Floor 1 with part of Floor 2. From satellite imagery of the building, it is assumed that the natural lightwell is open to the sky at the roof line. It is further assumed that both the natural light well and the cafeteria space are separated from floors 3 through 5 and Floor 2 respectively with appropriate barriers, such fire-rated glass walls. Note, sprinkler-protected glass walls are also possible, though if such a design is used for the building, the sprinkler design presented in this report may need to be modified to ensure an adequate level of sprinkler protection is provided for the glass. All of the assumptions regarding atriums should be confirmed with the Architect and Client. Under these assumptions, this report finds that there are no atriums or openings between floors under the definition of atriums under IBC Chapter 2, and that the provisions of atriums under IBC Section 404 do not apply to this building.

Assuming 12 feet per story and level surroundings, the highest occupied floor is located 48 feet above the lowest level of fire department access, and so it falls below the 75 feet requirement for a high-rise building classification as defined in the Chapter 2 of the IBC. Even considering the potential for a roof deck and conservative interpretation by the authority having jurisdiction, that would only increase the height of the highest occupied floor to 60 feet, and so it would still not be classified as a high-rise.

Building Function

Baylor Scott & White Medical Center is a 324,070 square feet hospital with 143 inpatient beds on a 98-acre campus. The hospital offers several services, including a laboratory, pharmacy, emergency room, surgery, labor and delivery, office, classrooms, and conference rooms. While the hospital falls under occupancy classification Institutional Group I-2 Condition 2 (308.3.1.2 IBC), there are several other uses in various spaces of this building. It may be best classified as primarily a hospital, with a mixed-use occupancy, and this report will examine this in greater detail during an occupancy analysis in the egress portion of the prescriptive analysis.

Pictures

Figures 1 through 6 show maps and pictures of the Baylor Scott & White Medical Center.

Figure # 1. Map of Texas, Showing Relative Location of Baylor Scott & White

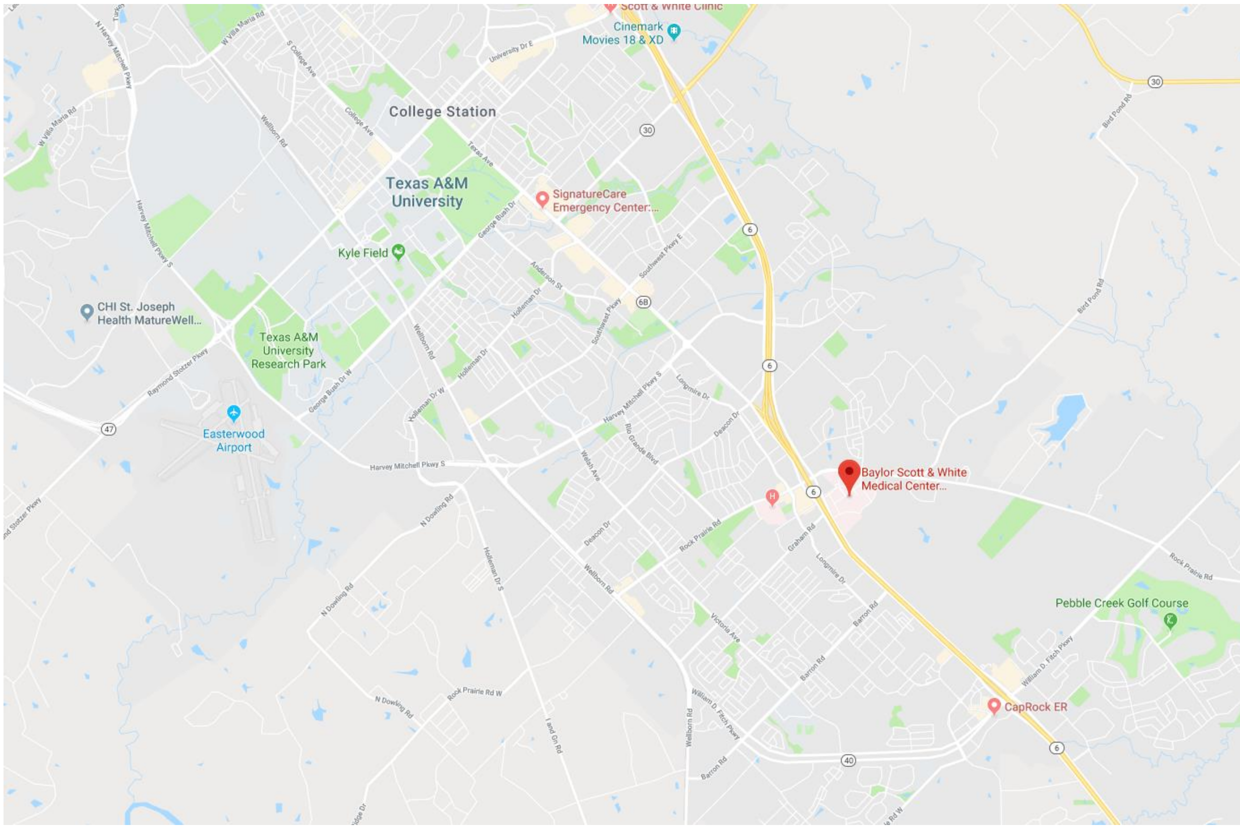


Figure # 2. Map of College Town, TX, Showing Relative Location of Baylor Scott & White

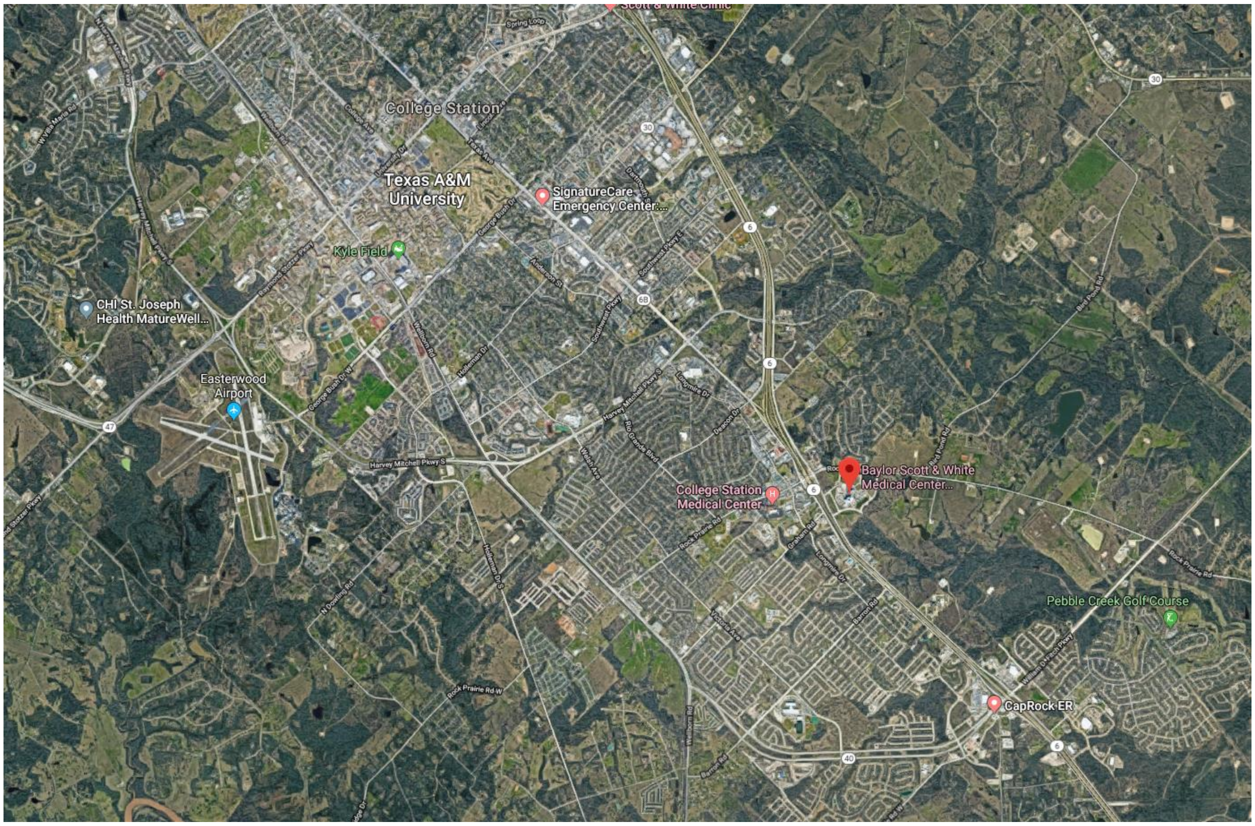


Figure # 3. Satellite View of College Town, TX, Showing Relative Location of Baylor Scott & White

Figure # 4. Satellite View of the Baylor Scott & White Medical Center and Campus

Figure # 5. Architectural Rendering of Baylor Scott & White

Figure # 6. Ground View of Baylor Scott & White

Floorplans

Below are floorplans for Baylor Scott & White. Note, these floorplans are publicly available on the internet. More information on these floorplans and their scaling can be found in Appendix A.

Figure # 7. Basement Floorplan

The Basement floorplan, Figure 7, shows that Environmental Services/Maintenance, a Laboratory, Pharmacy, and Crawl Space make up the bulk of the floor.

Figure # 8. Floor 1 Floorplan

The Floor One floorplan, Figure 8, show several features on the first floor, including dining rooms, lobby, registration, emergency room suite, x-ray rooms, electrocardiogram rooms, ultrasound rooms, nuclear medicine rooms, and magnetic resonance imaging rooms.

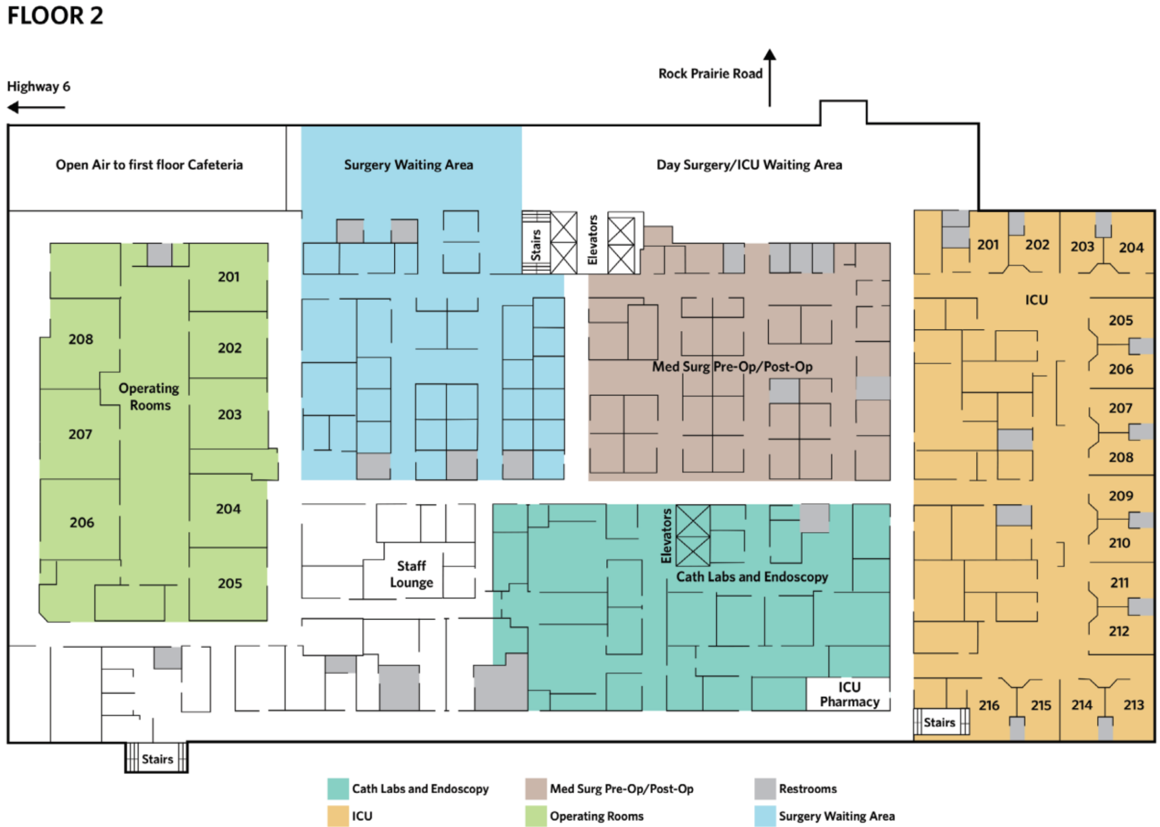


Figure # 9. Floor 2 Floorplan

The Floor Two floorplan, Figure 9, shows operating rooms, waiting areas, pre- and post-operation rooms, an intensive care unit, and a catheterization laboratory and endoscopy suite.

Figure # 10. Floor 3 Floorplan

The Floor Three floorplan, Figure 10, shows labor and delivery and recovery rooms, waiting areas, a newborn nursery, Caesarean section rooms, and neonatal intensive care unit.

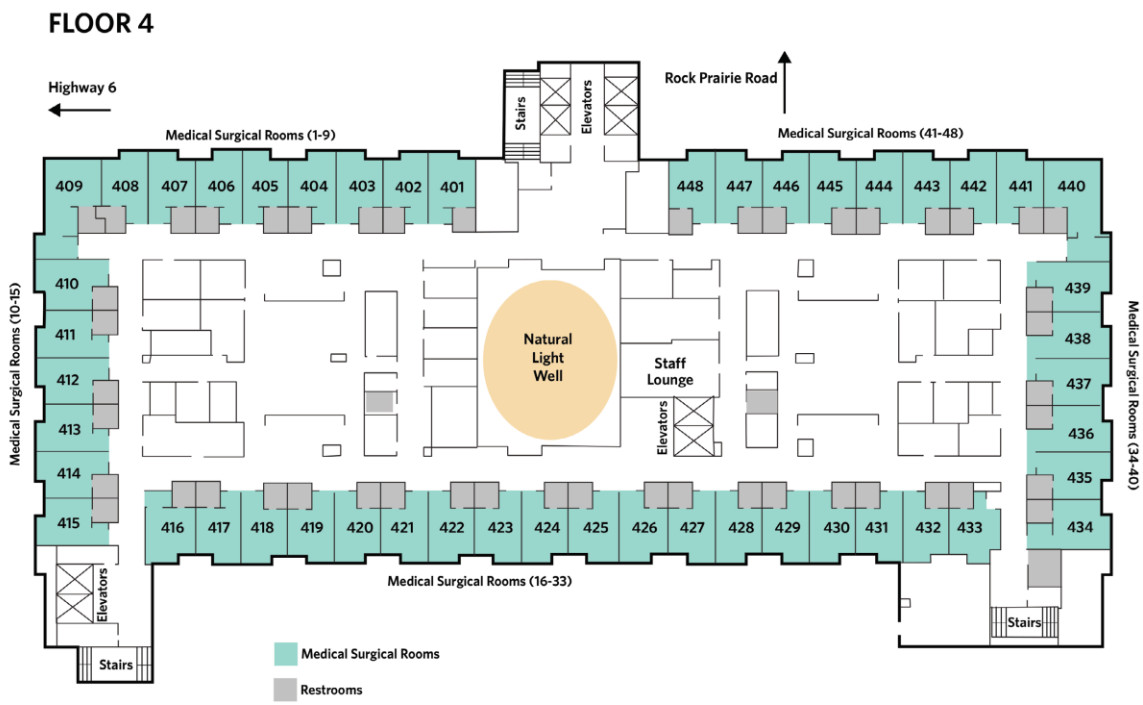


Figure # 11. Floor 4 Floorplan

The Floor Four floorplan, Figure 11, shows medical surgical rooms.

Figure # 12. Floor 5 Floorplan

The Floor Five floorplan, Figure 12, shows rooms that are shelled for expansion, classrooms, risk management rooms, and a medical records room.

Report

This report will show a prescriptive analysis and performance-based analysis of the Baylor Scott & White Medical Center. During these analysis, various aspects of fire protection engineering will be examined in either in one section (such as egress in prescriptive and design fire in performance-based) or both sections (such as flammability assessment and smoke control).

All information and the assumptions contained abstract and introduction hold true for the main body of the report. Following the prescriptive and performance-based analysis, the report will present conclusions and recommendations for any deficiencies found. Finally, the report contains both the reference and appendix sections.

Prescriptive Analysis

This report includes a prescriptive analysis of the building's fire and life safety features, to verify that implicit safety is achieved in the design of this hospital. The prescriptive analysis includes examining the egress, suppression, alarms, structural, flammability assessment, and smoke control components.

To find the applicable codes for this building, research was conducted to find what codes and standards the AHJ's for this facility have adopted. College Station is a city in Texas, and is located between Dallas, Austin, and Houston; it is 175 miles from Dallas, 107 miles from Austin, and 97 miles from Houston. Texas has adopted the International Code Council's standards (or I-codes), as well as the National Fire Protection Association's (NFPA) standards directly. The adoption of the I-codes and NFPA standards is in contrast to a state like California, which has built upon the model I-codes to create the California Building Code, California Fire Code, etc. College Station itself has adopted the ICC and NFPA standards, and are on a more current code cycle than the state is using. A list of the applicable references at the time of this report can be found in "References."

Performance-based Analysis

This report includes a performance-based analysis of the building's fire and life safety features to verify that explicit safety is achieved in the design of this hospital. The objective will be life safety, and the report uses tenability criteria to compare the available safe egress time (ASET) to the required safe egress time (RSET) for occupants. The calculation of ASET and RSET includes examining design fires, fire models, flammability assessment, and smoke control components.

Prescriptive Analysis

Egress

Introduction

The egress for this project is analyzed with respect to the 2018 edition of NFPA 101: Life Safety Code and the 2018 International Building Code. This report also references the 5th Edition of the SFPE Handbook, and material from the Cal Poly SLO FPE Program. The prescriptive analysis first presents all of the vertical and horizontal exits in the building.

Body

Exits

The vertical and horizontal exits are shown on the following figures (Figures # 13 – 18). Note, the horizontal exits are in the fire barriers that divide each floor into two smoke compartments, as required by code (407.5 IBC). The requirements for exits—such as total number of exits, separation distance, etc.—from IBC Chapter 10 are satisfied. Related details and calculations are shown below in this "Egress" subsection.

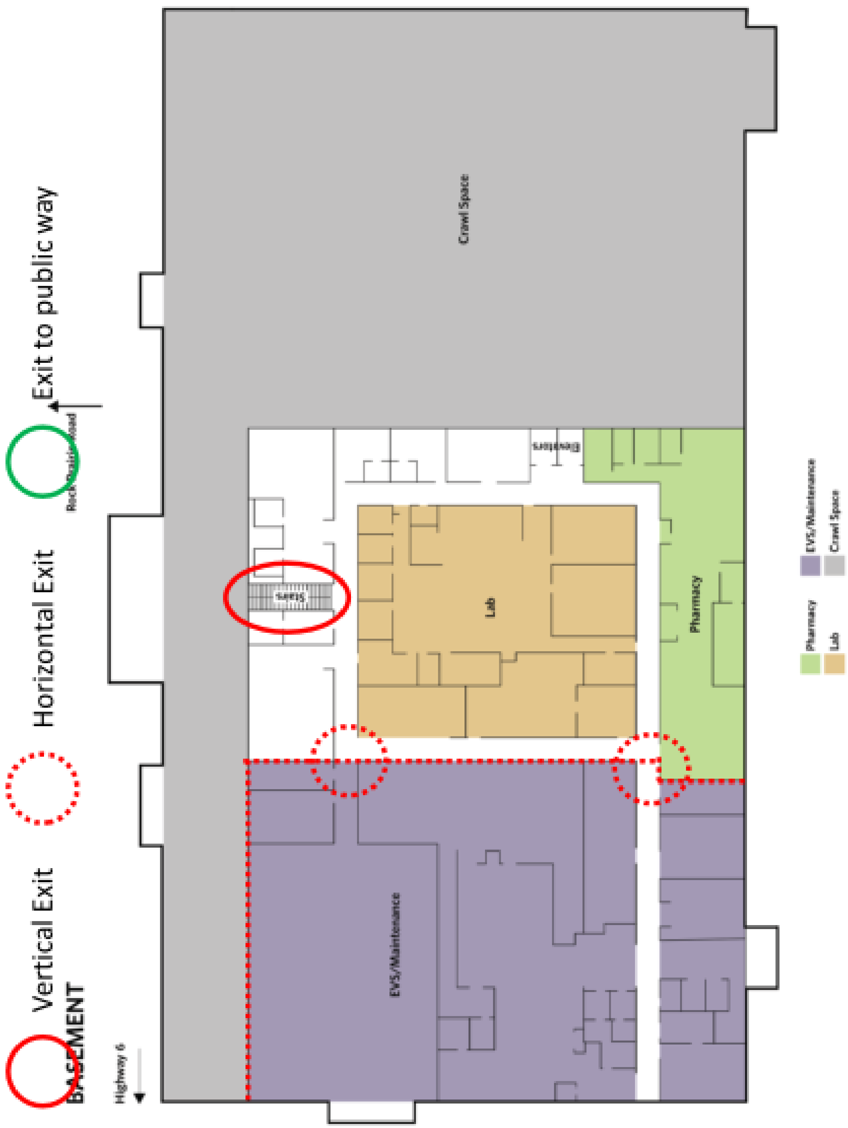


Figure # 13. Basement Exits

Figure # 14. Floor 1 Exits

Figure # 15. Floor 2 Exits

Figure # 16. Floor 3 Exits

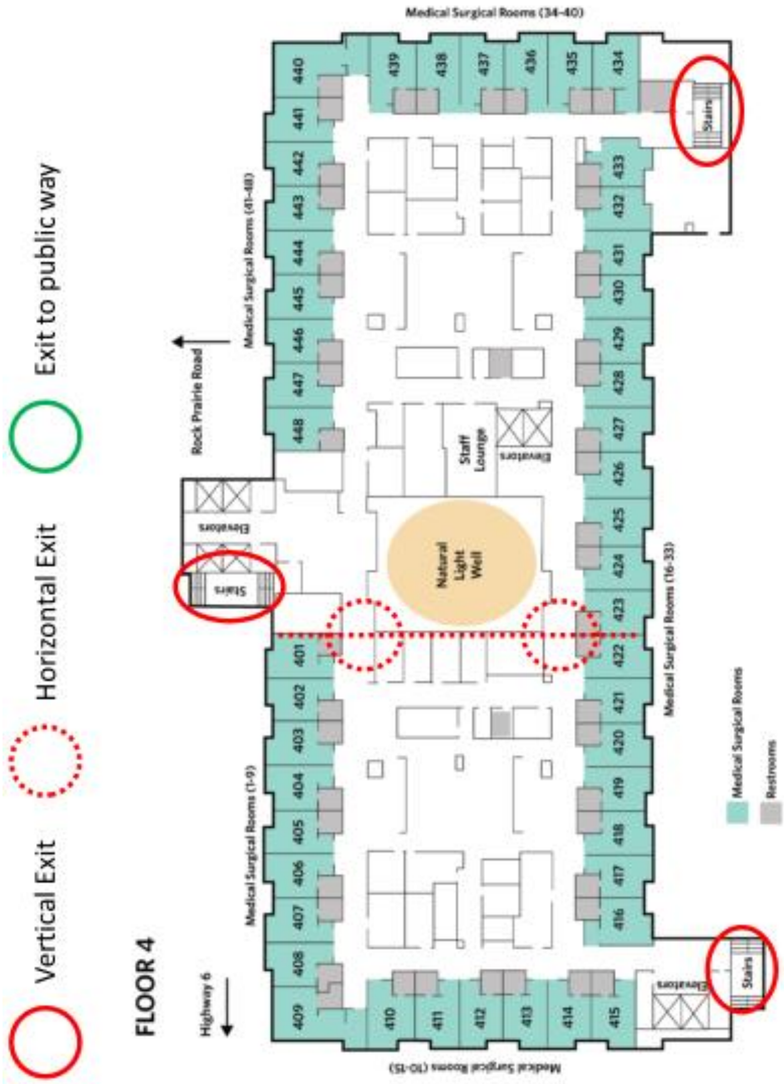


Figure # 17. Floor 4 Exits

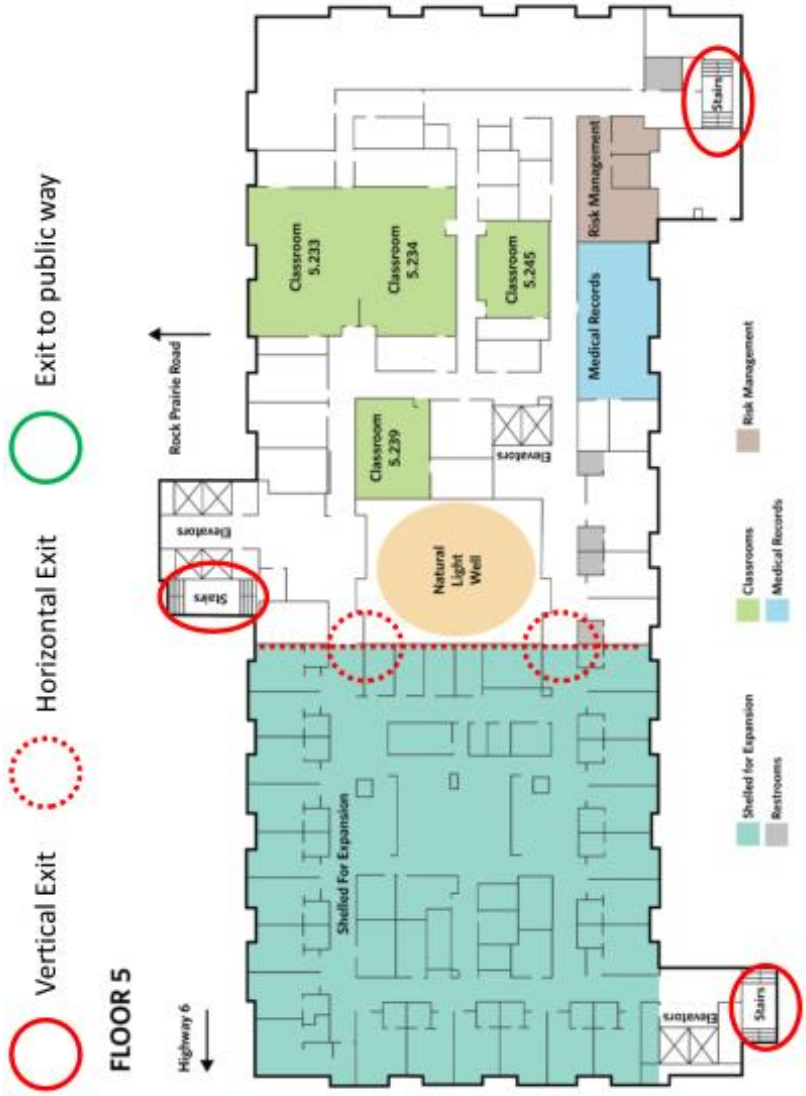


Figure # 18. Floor 5 Exits

Occupancy Classifications and Characteristics

A color-coded floor plan of the hospital is shown below in Figures # 19 – 24. It uses different colors to distinguish between each different occupancy classification. Of particular note is blue for exit access, green for vertical exits, and grey for service spaces (such as elevators, restrooms, electrical and telecommunication rooms, mechanical rooms, etc.).

In selecting the occupancy, some engineering judgement is required. The report used the material from Cal Poly SLO's FPE program and Chapter 6 of the 2018 LSC in determining the occupancy of each space. While some classifications were straightforward, in other cases some engineering judgement was required because of several valid possibilities. Where engineering judgement was required, the more conservative option was selected to account for a 'worst case' scenario. The choice of occupancy can and should be revisited once more detailed plans are available.

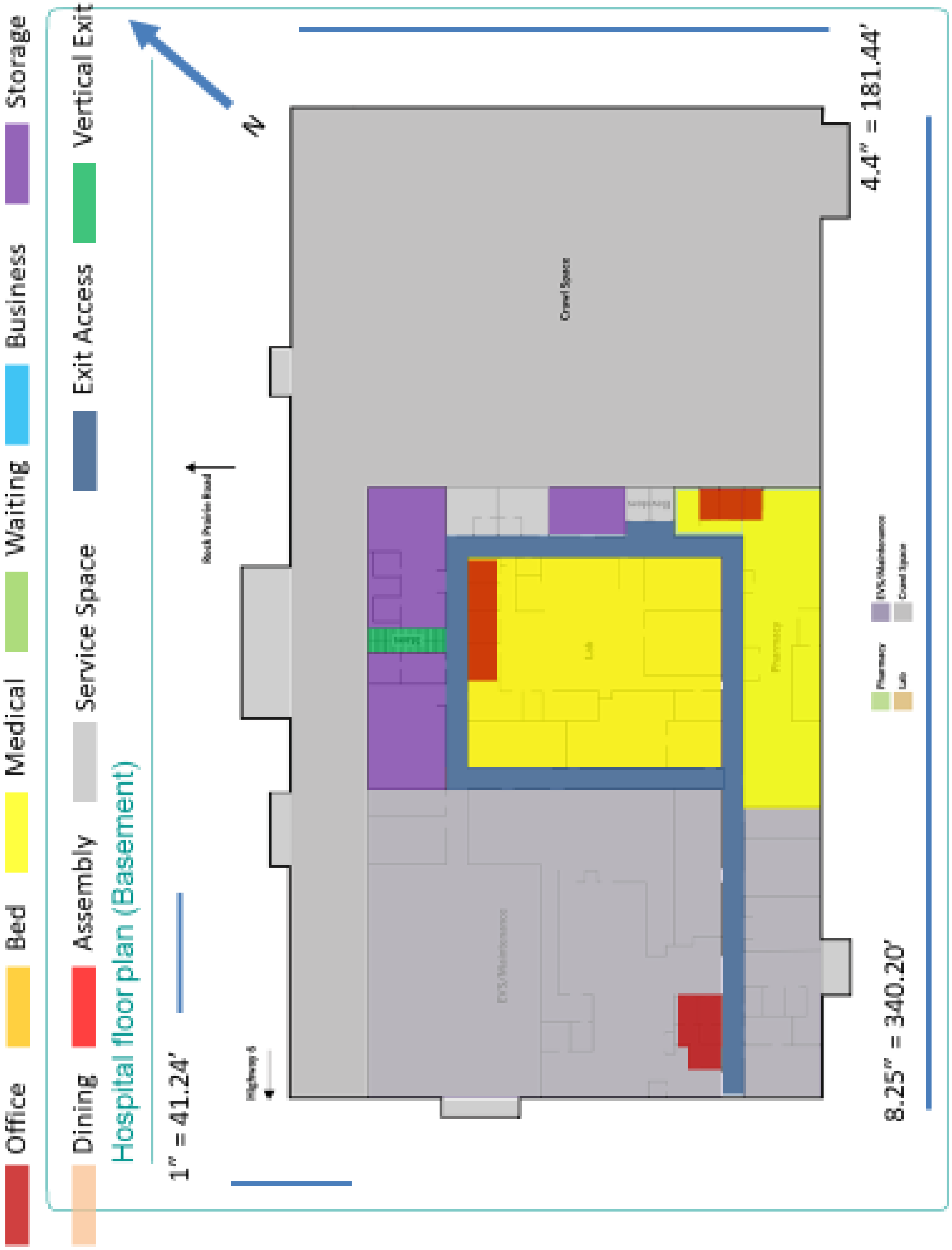


Figure # 19. Basement Occupancy Classifications

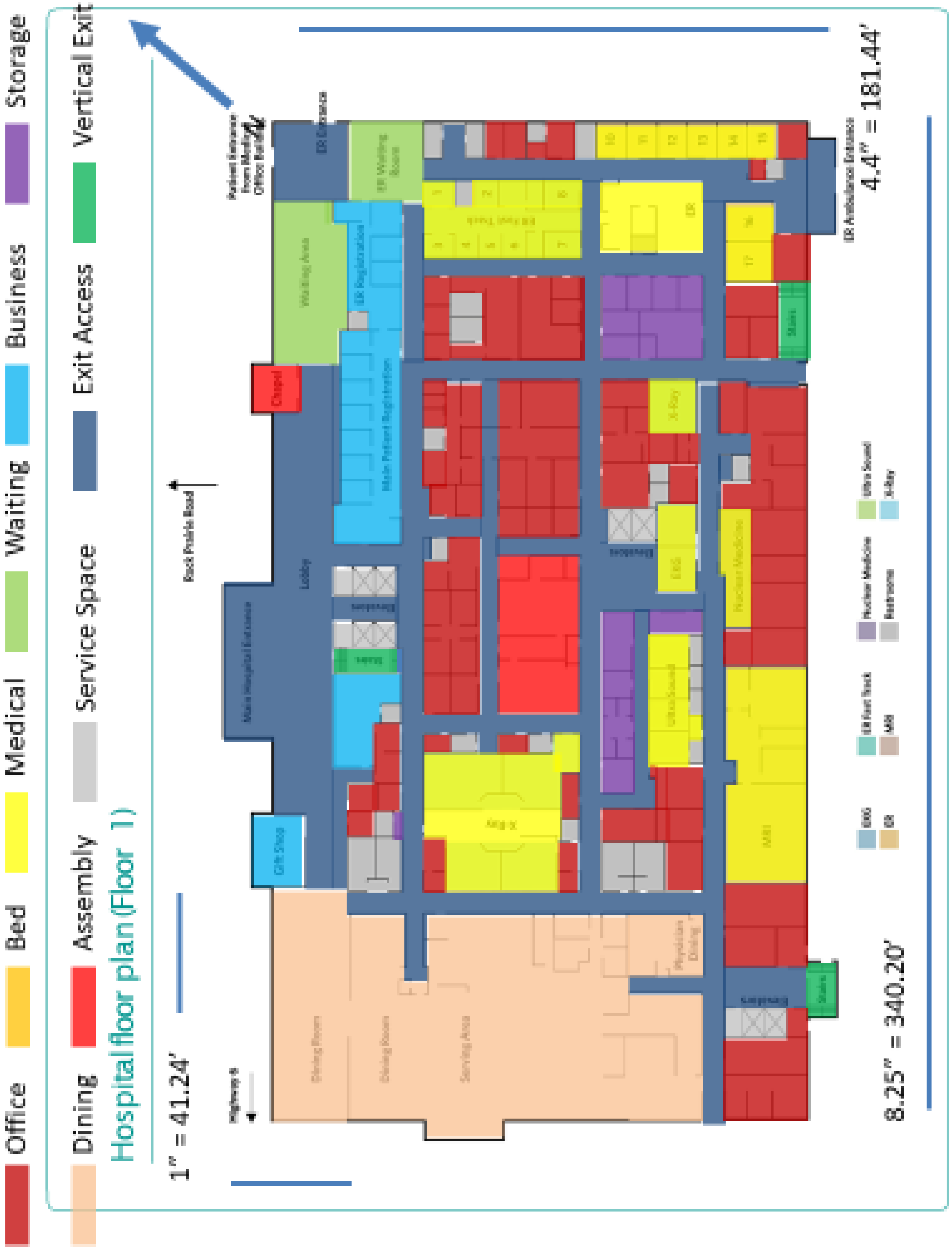


Figure # 20. Floor 1 Occupancy Classifications

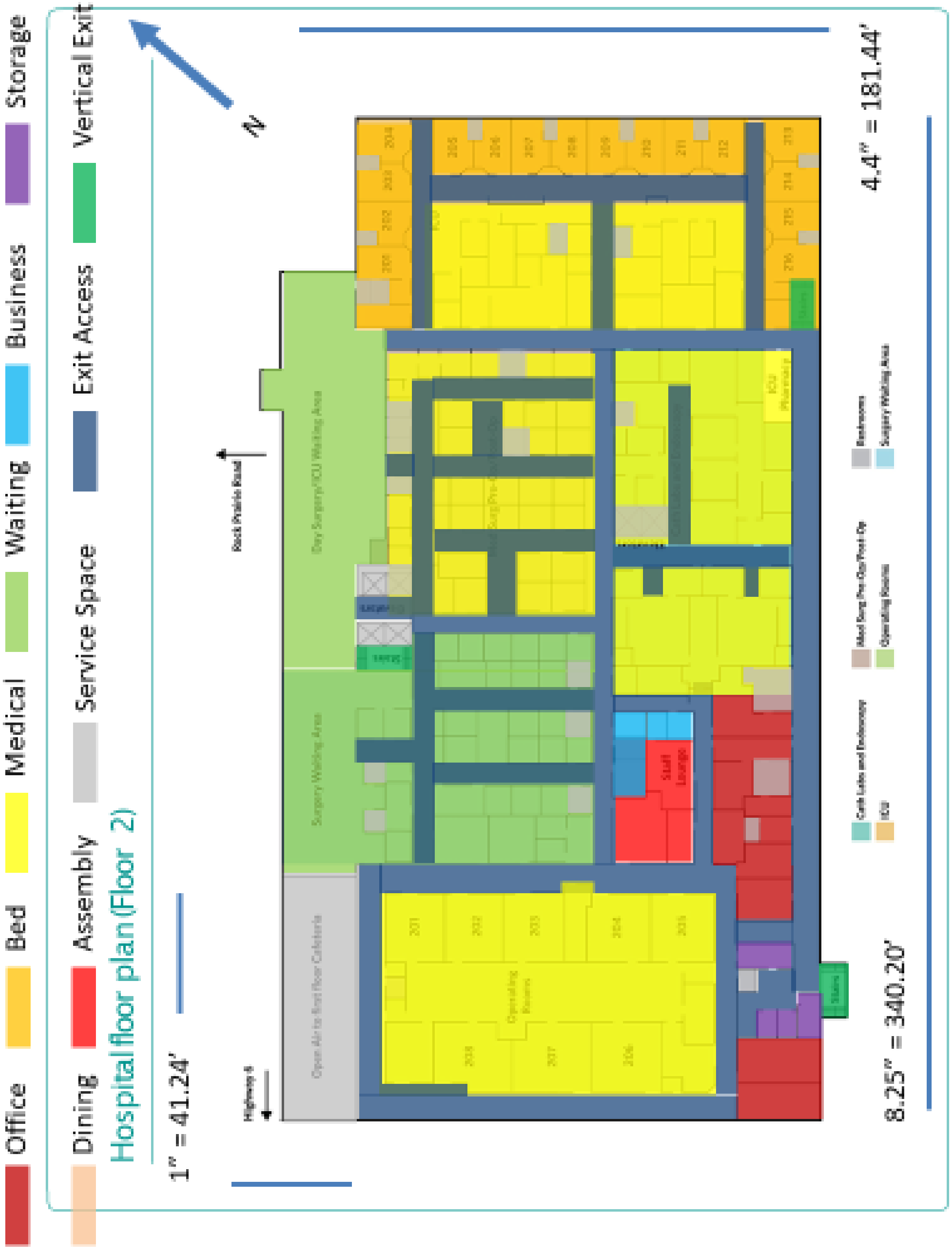


Figure # 21. Floor 2 Occupancy Classifications

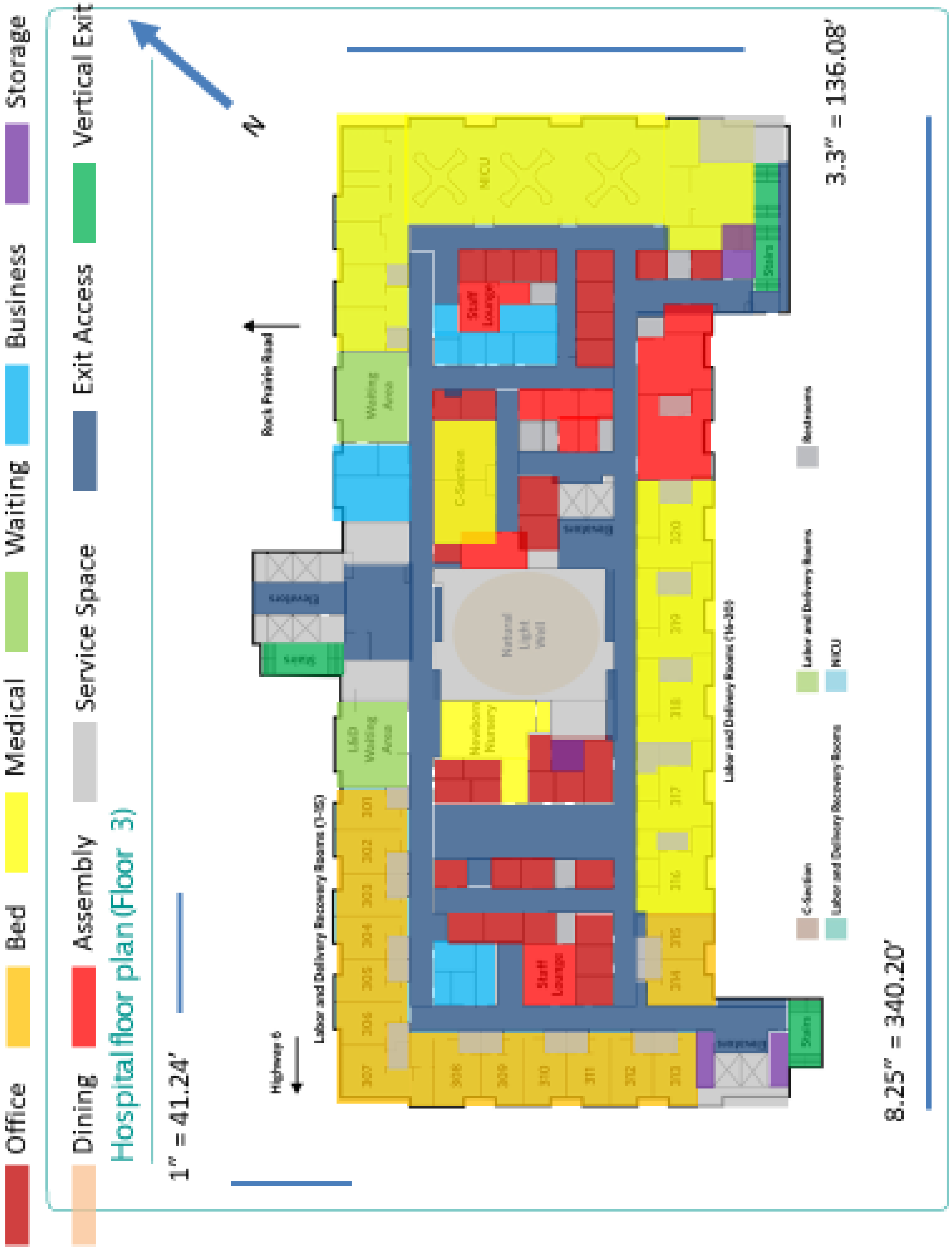


Figure # 22. Floor 3 Occupancy Classifications

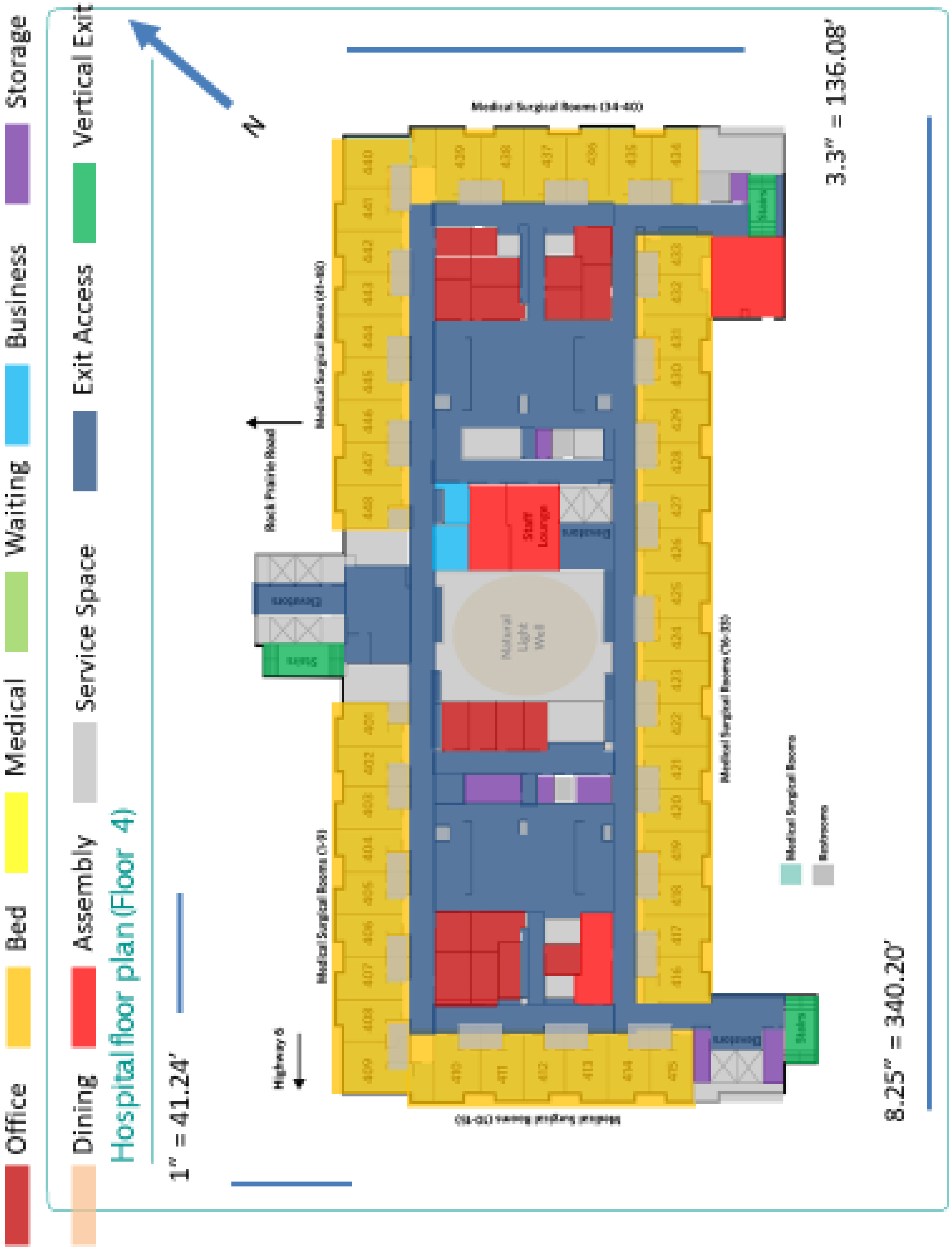


Figure # 23. Floor 4 Occupancy Classifications

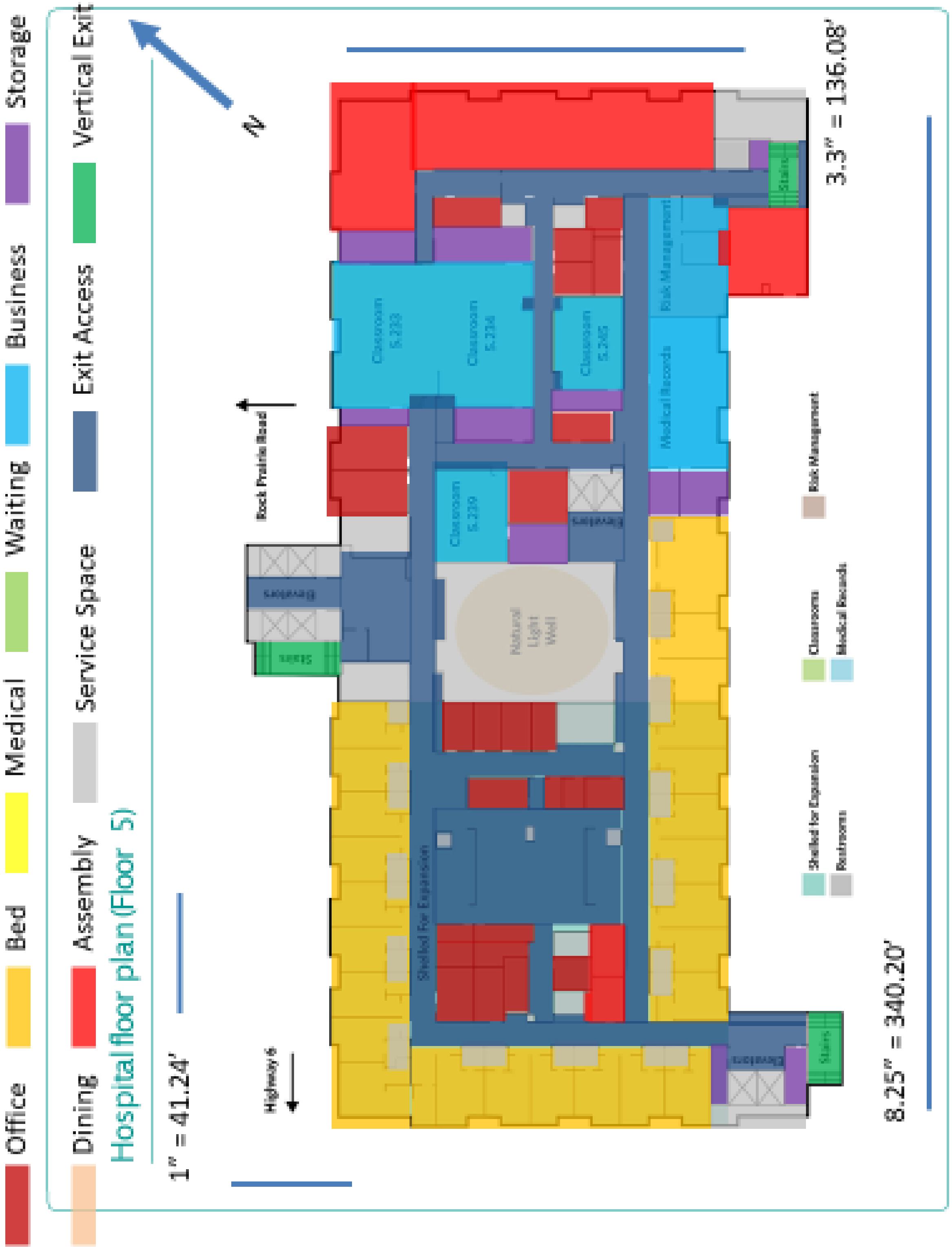


Figure # 24. Floor 5 Occupancy Classifications

Occupant Load Calculations

Using the occupancy drawings above, the occupant load of each floor/space is calculated using methods from Cal Poly SLO's FPE program and the 2018 LSC.

A summary is shown here in Table # 1, with more detailed calculations and references below in Tables # 2 – 7. Note, an excess number of significant figures is shown in the following tables, and in those later in the report; they are included to demonstrate that minimal rounding is used in intermediate calculations, until they are rounded up or down as appropriate for the final results.

Table # 1. Building Occupant Load

FLOOR	OCCUPANCY
Basement	76
1st	903
2nd	595
3rd	681
4th	451
5th	927
Total	3633

Table # 2. Basement Occupant Load Calculations

Use	Area (ft^2)	Table 7.3.1.2 Use	Occupant Load Factor (ft^2/person)	Estimated Net Area Multiplier	Estimated Applicable Area for Calculations (ft^2)	Occupant Load (persons)	Occupant Load, Rounded Up (persons)
Office	2700.583	Business Use	150 gross	N/A	2700.583333	18.00388889	19
Bed	0	Health Care Use, Sleeping departments	120 gross	N/A	0	0	0
Medical	10802.33	Health Care Use, Inpatient treatment departments	240 gross	N/A	10802.33333	45.00972222	46
Waiting	0	Assembly Use, Fixed seating	Use number of fixed seats	N/A	0	0	0
Business	0	Business Use, Collaboration rooms/spaces	<= 450 ft^2, 30 gross; > 450 ft^2, 15 gross	N/A	0	0	0
Storage	5401.167	Storage Use, In other than storage and mercantile occupancies	500 gross	N/A	5401.166667	10.80233333	11
Dining	0	Assembly Use, Less concentrated use, without fixed seating	15 net	0.8	0	0	0
Assembly	0	Assembly Use, Less concentrated use, without fixed seating	15 net	0.9	0	0	0
Service Space	35107.58	N/A	N/A	N/A	35107.58333	0	0
Total							76

An occupant load of 76 is calculated for the basement.

Table # 3. Floor 1 Occupant Load Calculations

Use	Area (ft^2)	Table 7.3.1.2 Use	Occupant Load Factor (ft^2/person)	Estimated Net Area Multiplier	Estimated Applicable Area for Calculations (ft^2)	Occupant Load (persons)	Occupant Load, Rounded Up (persons)
Office	10802.33	Business Use	150 gross	N/A	10802.33333	72.01555556	73
Bed	0	Health Care Use, Sleeping departments	120 gross	N/A	0	0	0
Medical	10802.33	Health Care Use, Inpatient treatment departments	240 gross	N/A	10802.33333	45.00972222	46
Waiting	2700.583	Assembly Use, Fixed seating	Use number of fixed seats	N/A	100	100	100
Business	5401.167	Business Use, Collaboration rooms/spaces	<= 450 ft^2, 30 gross; > 450 ft^2, 15 gross	N/A	5401.166667	180.0388889	181
Storage	2700.583	Storage Use, In other than storage and mercantile occupancies	500 gross	N/A	2700.583333	5.401166667	6
Dining	10802.33	Assembly Use, Less concentrated use, without fixed seating	15 net	0.5	5401.166667	360.0777778	361
Assembly	2700.583	Assembly Use, Less concentrated use, without fixed seating	15 net	0.75	2025.4375	135.0291667	136
Service Space	8101.75	N/A	N/A	N/A	8101.75	0	0
Total							903

An occupant load of 903 is calculated for the first floor.

Table # 4. Floor 2 Occupancy Load Calculations

Use	Area (ft^2)	Table 7.3.1.2 Use	Occupant Load Factor (ft^2/person)	Estimated Net Area Multiplier	Estimated Applicable Area for Calculations (ft^2)	Occupant Load (persons)	Occupant Load, Rounded Up (persons)
Office	5401.167	Business Use	150 gross	N/A	5401.166667	36.00777778	37
Bed	5401.167	Health Care Use, Sleeping departments	120 gross	N/A	5401.166667	45.00972222	46
Medical	18904.08	Health Care Use, Inpatient treatment departments	240 gross	N/A	18904.08333	78.76701389	79
Waiting	10802.33	Assembly Use, Fixed seating	Use number of fixed seats	N/A	200	200	200
Business	2700.583	Business Use, Collaboration rooms/spaces	<= 450 ft^2, 30 gross; > 450 ft^2, 15 gross	N/A	2700.583333	90.01944444	91
Storage	2700.583	Storage Use, In other than storage and mercantile occupancies	500 gross	N/A	2700.583333	5.401166667	6
Dining	0	Assembly Use, Less concentrated use, without fixed seating	15 net	0.5	0	0	0
Assembly	2700.583	Assembly Use, Less concentrated use, without fixed seating	15 net	0.75	2025.4375	135.0291667	136
Service Space	5401.167	N/A	N/A	N/A	5401.166667	0	0
Total							595

An occupant load of 595 is calculated for the second floor.

Table # 5. Floor 3 Occupancy Load Calculations

Use	Area (ft^2)	Table 7.3.1.2 Use	Occupant Load Factor (ft^2/person)	Estimated Net Area Multiplier	Estimated Applicable Area for Calculations (ft^2)	Occupant Load (persons)	Occupant Load, Rounded Up (persons)
Office	5401.167	Business Use	150 gross	N/A	5401.166667	36.00777778	37
Bed	8101.75	Health Care Use, Sleeping departments	120 gross	N/A	8101.75	67.51458333	68
Medical	16203.5	Health Care Use, Inpatient treatment departments	240 gross	N/A	16203.5	67.51458333	68
Waiting	5401.167	Assembly Use, Fixed seating	Use number of fixed seats	N/A	50	50	50
Business	5401.167	Business Use, Collaboration rooms/spaces	<= 450 ft^2, 30 gross; > 450 ft^2, 15 gross	N/A	5401.166667	180.0388889	181
Storage	2700.583	Storage Use, In other than storage and mercantile occupancies	500 gross	N/A	2700.583333	5.401166667	6
Dining	0	Assembly Use, Less concentrated use, without fixed seating	15 net	0.5	0	0	0
Assembly	5401.167	Assembly Use, Less concentrated use, without fixed seating	15 net	0.75	4050.875	270.0583333	271
Service Space	5401.167	N/A	N/A	N/A	5401.166667	0	0
Total							681

An occupant load of 681 is calculated for the third floor.

Table # 6. Floor 4 Occupancy Load Calculations

Use	Area (ft^2)	Table 7.3.1.2 Use	Occupat Load Factor (ft^2/person)	Estimated Net Area Multiplier	Estimated Applicable Area for Calculations (ft^2)	Occupant Load (persons)	Occupant Load, Rounded Up (persons)
Office	5041.167	Business Use	150 gross	N/A	5401.166667	36.00777778	37
Bed	21604.67	Health Care Use, Sleeping departments	120 gross	N/A	21604.16667	180.0347222	181
Medical	0	Health Care Use, Inpatient treatment departments	240 gross	N/A	0	0	0
Waiting	0	Assembly Use, Fixed seating	Use number of fixed seats	N/A	0	0	0
Business	2700.583	Business Use, Collaboration rooms/spaces	<= 450 ft^2, 30 gross; >450 ft^2, 15 gross	N/A	2700.583333	90.01944443	91
Storage	2700.583	Storage Use, in other than storage and mercantile occupancies	500 gross	N/A	2700.583333	5.401166666	6
Dining	0	Assembly Use, Less concentrated use, without fixed seating	15 net	0.5	0	0	0
Assembly	2700.583	Assembly Use, Less concentrated use, without fixed seating	15 net	0.75	2025.4375	135.0291667	136
Service Space	18904.08	N/A	N/A	N/A	10802.3333	0	0
Total							451

An occupant load of 451 is calculated for the fourth floor.

Table # 7. Floor 5 Occupancy Load Calculations

Use	Area (ft^2)	Table 7.3.1.2 Use	Occupant Load Factor (ft^2/person)	Estimated Net Area Multiplier	Estimated Applicable Area for Calculations (ft^2)	Occupant Load (persons)	Occupant Load, Rounded Up (persons)
Office	5401.167	Business Use	150 gross	N/A	5401.166667	36.00777778	37
Bed	13502.92	Health Care Use, Sleeping departments	120 gross	N/A	13502.91667	112.5243056	113
Medical	0	Health Care Use, Inpatient treatment departments	240 gross	N/A	0	0	0
Waiting	0	Assembly Use, Fixed seating	Use number of fixed seats	N/A	0	0	0
Business	10802.33	Business Use, Collaboration rooms/spaces	<= 450 ft^2, 30 gross; > 450 ft^2, 15 gross	N/A	10802.33333	360.0777778	361
Storage	5401.167	Storage Use, In other than storage and mercantile occupancies	500 gross	N/A	5401.166667	10.80233333	11
Dining	0	Assembly Use, Less concentrated use, without fixed seating	15 net	0.5	0	0	0
Assembly	8101.75	Assembly Use, Less concentrated use, without fixed seating	15 net	0.75	6076.3125	405.0875	405
Service Space	10802.33	N/A	N/A	N/A	10802.33333	0	0
Total							927

An occupant load of 927 is calculated for the fifth floor.

Exit Capacity Calculations and Number and Arrangement of Means of Egress

The egress capacity of each floor is calculated using methods from Cal Poly SLO's FPE program and the 2018 LSC. The report then compares this number to the expected occupant load to determine if the exit capacities are adequate for each floor.

The egress capacity is found based on the following assumptions:

The aisles, corridors, and ramps are 8 feet in clear and unobstructed width (18.2.3.4 NFPA 101).

Cross-corridor door openings have a clear width of 6 feet 11 inches for pairs of doors and 41-1/2 inches for single doors (18.2.3.4 (6) NFPA 101).

Egress doors, including stairway doors, are a minimum of 41-1/2 inches (18.2.3.6 NFPA 101), and are assumed to be 42 inches for construction and calculations.

Because of the total cumulative occupant load assigned to the stairs, the load of the 2nd – 5th floors divided by 3 would be far below 2000 persons (and this is true when assigning the basement occupant load to one of the three stairs). For this reason, this building would only need 44 inch stairs by Table 7.2.2.2.1.2(B) NFPA 101. However, when using this stair width with 42 inch doors, this report finds that it is a significant limiting factor. If the calculations instead use 56 inch wide stairs, the egress capacity for the stairs and doors are much more similar; the stairs are still the limiting factor, but only by a few people. Additionally, the calculations show that even with this increase in stair widths, there is still insufficient egress for some floors, so it seems prudent to try to increase the egress capacity as much as possible. Finally, the 56 inch stairs seem to 'fit' the drawings, and assuming the drawings are to scale, this would also be another reasons to support using these larger stairs. For that reason, the report assumes that the stairs will be 56 inches wide.

A summary is shown here in Table # 8, with more detailed calculations and references below. Note, egress from the first floor (the ground floor) is assumed to take place using all the exits along the perimeter of the building, not including the three staircases.

Table # 8. Exit Capacity Summary

FLOOR	OCCUPANCY	EGRESS CAPACITY
Basement	76	201, OK
1st	903	3741, OK
2nd	595	603, OK
3rd	681	603, NOT OK
4th	451	603, OK
5th	927	603, NOT OK

Exit Capacity from Each Floor/Space

The report now exams the egress capacity calculations for each floor in more detail.

Table # 9. Basement Exit Capacity Calculation

Exit	Stairway width (in.)	Door width (in)	Capacity Factor, Stairways, width/person (in)	Capacity Factor, Doorways, width/person (in)	Stair Egress Capacity	Door Egress Capacity	Effective Egress Capacity
Main (Western)	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Total							201

The calculations from Table # 9 show an egress capacity of 201 for the basement. Compared to the occupant load of 76 for the basement, there is sufficient egress capacity. Note, if this report used 44 inch wide stairs, the egress capacity would not be sufficient.

Table # 10. Floor 1 Exit Capacity Calculation

Exit	Stairway width (in.)	Door width (in)	Capacity Factor, Stairways, width/person (in)	Capacity Factor, Doorways, width/person (in)	Stair Egress Capacity	Door Egress Capacity	Effective Egress Capacity
Main (Western)	56	408	146.7+(Wn-44)/0.218	0.2	201.7459	2040	2040
Doors (5)	56	60	146.7+(Wn-44)/0.218	0.2	201.7459	300	1500
Next to stairs (1)	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Total							3741

The calculations from Table # 10 show an egress capacity of 3741 for the first floor. Compared to the occupant load of 903 for the first, there is sufficient egress capacity. Note, this report uses the seven exits along the perimeter of the building in this calculation, and assume no occupants exit through the two stairwells along the east side of the building.

Table # 11. Floor 2 Exit Capacity Calculation

Exit	Stairway width (in.)	Door width (in)	Capacity Factor, Stairways, width/person (in)	Capacity Factor, Doorways, width/person (in)	Stair Egress Capacity	Door Egress Capacity	Effective Egress Capacity
Main (Western)	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Northeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Southeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Total							603

The calculations from Table # 11 show egress capacity of 603 for the second floor. Compared to the occupant load of 595 for the second floor, there is sufficient egress capacity.

Table # 12. Floor 3 Exit Capacity Calculation

Exit	Stairway width (in.)	Door width (in)	Capacity Factor, Stairways, width/person (in)	Capacity Factor, Doorways, width/person (in)	Stair Egress Capacity	Door Egress Capacity	Effective Egress Capacity
Main (Western)	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Northeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Southeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Total							603

The calculations from Table # 12 show an egress capacity of 603 for the third floor. Compared to the occupant load of 681 for the third floor, there is not sufficient egress capacity. This deficiency is primarily caused by the assembly and business spaces on the third floor, which, at 271 and 181 occupants respectively, consist of over 66 percent of the total occupant load of 681 of that floor. It is recommended that some of the assembly and business spaces be converted to other uses, such as office space or medical space, until the point where the egress capacity of the floor is greater than its occupant load. Alternatively, some AHJ's have allowed the use of horizontal exits to increase the exit capacity (and thus the allowable occupant load) of a floor. It should be confirmed whether or not this is an option for this project.

Table # 13. Floor 4 Exit Capacity Calculation

Exit	Stairway width (in.)	Door width (in)	Capacity Factor, Stairways, width/person (in)	Capacity Factor, Doorways, width/person (in)	Stair Egress Capacity	Door Egress Capacity	Effective Egress Capacity
Main (Western)	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Northeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Southeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Total							603

The calculations from Table # 13 show an egress capacity of 603 for the fourth floor. Compared to the occupant load of 216 for the fourth floor, there is sufficient egress capacity.

Table # 14. Floor 5 Exit Capacity Calculation

Exit	Stairway width (in.)	Door width (in)	Capacity Factor, Stairways, width/person (in)	Capacity Factor, Doorways, width/person (in)	Stair Egress Capacity	Door Egress Capacity	Effective Egress Capacity
Main (Western)	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Northeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Southeast	56	42	146.7+(Wn-44)/0.218	0.2	201.7459	210	201
Total							603

The calculations for Table # 14 show an egress capacity of 603 for the fifth floor. Compared to the occupant load of 927 for the fifth floor, there is not sufficient egress capacity. This deficiency is primarily caused by the assembly and business spaces on the fourth floor, which, at 405 and 361 occupants respectively, consist of over 82 percent of the total occupant load of 927 of that floor. It is recommended that some of the assembly and business spaces be converted to other uses, such as office space or medical space, until the point where the egress capacity of the floor is greater than its occupant load. Alternatively, some AHJ's have allowed the use of horizontal exits to increase the exit capacity (and thus the allowable occupant load) of a floor. It should be confirmed whether or not this is an option for this project.

Additionally, since corridors are 8 feet wide, or 96 inches, the corridor width equates to a corridor egress capacity of 385 persons. Comparing this to the occupancies and number of exits, the calculations show that the corridor egress capacity is more than sufficient even for the first and fifth floors, the floors with the highest occupancy loads.

Number of Exits

This report expands on the work on egress capacities above, and next analyzes if the number of exits is sufficient. The primary reference for this will be 7.4.1.1 and 7.4.1.2 NFPA 101, and what was presented in the Cal Poly FPE program.

Table # 15. Number of Exit Summary

FLOOR	OCCUPANCY	EGRESS CAPACITY	NUMBER OF EXITS
Basement	76	201, OK	1, NOT OK
1st	903	3741, OK	7, OK
2nd	595	603, OK	3, OK
3rd	681	603, NOT OK	3, OK
4th	451	603, OK	3, OK
5th	927	603, NOT OK	3, OK

Table # 15 shows that all floors except for the basement have an adequate number of exits. Because the basement has over 50 occupants, it should have two exits, but only has one. Additionally, under 18.2.4.2, each story should have at least two exists, and the basement does not satisfy this requirement.

Arrangements of Exits

The report expands on the work on egress capacities and number of exits to next analyze if the exit arrangement is satisfactory. The report considers 2018 LSC references such as 7.5.1.1, 7.5.1.1.1, 7.5.1.1.4, 7.5.1.3, 7.5.1.3.1, 7.5.1.3.2, etc. (more references below), and the material discussed in the Cal Poly FPE program to determine if the arrangement of exits is appropriate. Most spaces have multiple exits that obviously meet the ½ diagonal minimum as set forth in IBC Section 1007.1.1. The exit separation distance is confirmed because when exits are at two ends of the longer wall of its rectangular perimeter. Secondary analysis confirms these measurements by hand, using a protractor to measure the distance between exits, and comparing this to half of the diagonal. Alternatively, the distance separation calculation can also be accomplished by comparing the length of the line between the exits and half of the diagonal (note that this can be done manually by hand or digitally via computer). At this point, in the absence of information about the fixtures and furniture in each space, this report assumes that a straight path between each exit is possible, so a direct path between exits as both a possible and probable option.

Additionally, under 18.2.4.3 of the 2018 LSC, new health care facilities should have at least two exits accessible on each floor, and it should be noted that all floors except the basement are able to meet this requirement.

Table # 16. Arrangement of Exit Summary

FLOOR	OCCUPANCY	EGRESS CAPACITY	NUMBER OF EXITS	EXIT ARRANGEMENT
Basement	76	201, OK	1, NOT OK	NOT OK
1st	903	3741, OK	7, OK	OK
2nd	595	603, OK	3, OK	OK
3rd	681	603, NOT OK	3, OK	OK
4th	451	603, OK	3, OK	OK
5th	927	603, NOT OK	3, OK	OK

Regulatory Requirements for Egress Systems

Horizontal Exits

Horizontal exits for this hospital are governed by several parts of the 2018 LSC (detailed references below). There is no requirement that horizontal exits be required, but horizontal exits complying with 7.2.4 NFPA 101 'shall be permitted' by 18.2.2.5 NFPA 101.

Based on the simplified floorplans used for the report have, horizontal exits that are used in the building cannot be positively identified, but it is assumed to be highly likely that they are present, given the 'total concept' of a health care facility in minimizing the possibility of a fire emergency requiring the evacuation of occupants (18.1.1.3, 18.1.1.3.1, 18.1.1.3.2 NFPA 101).

The requirements for smoke barriers to divide every story into two or more smoke compartments (407.5 IBC) lends itself to the placement of horizontal exits on each story. It is anticipated that horizontal exists will coincide with the requirements for subdivision and smoke barriers for health care facilities, in that the horizontal exists will be present between smoke compartments (18.3.7, 18.3.7.1 NFPA 101). With this in mind, the report has shown horizontal exits along with vertical exits on floorplans earlier in this report.

Note, while the number of horizontal exits are generally limited to one-half the total number of exits on a floor (1026.1 IBC), an exception for Group I-2 occupancies permit horizontal exits to comprise two-thirds of the required exits from any building or floor area.

Fire Resistance Ratings for Corridors and Stairways in the Building

Because the stairways in the hospital connect 5 or more floors, they require a 2-hour fire resistance rating per 7.1.3.2.1 of the 2018 LSC.

One would expect a 1-hour fire resistance rating for the corridors under 7.1.3.1 NFPA 101. For the corridors, 18.3.6.2.2 from Chapter 18 NFPA 101 for new health care occupancies construction states that no fire resistance rating shall be required for corridor walls. However, there are mixed occupancies in this hospital, and so may require 1-hour fire resistance rating in accordance with Section 8.3 for certain hazardous areas by 18.3.2.1.2 NFPA 101, or even 2-hour fire resistance rating in accordance with Chapter 8 for other occupancies by 18.1.3.4 NFPA 101. Rather than try to selectively use 1-hour and 2-hour fire resistance ratings for the corridors in certain places where the corridor borders an occupancy that requires that level of protection (and having to remodel them if occupancies change in the future), this report recommends using 2-hour fire resistance ratings throughout the hospital for all corridors for consistency, ease of construction, and flexibility for future occupant changes and tenant improvements.

Note, the fire resistance rating for stairways would be placed along the perimeter of the green areas (vertical exists) on the colored diagrams in the section on occupancy loads, while the fire resistance rating for corridors would be placed along the perimeter of the dark blue areas (exit access), except perhaps for the perimeters of the corridors that are along the other perimeter of the building itself (though this situation is only widely present on the second floor that it may again make more sense just to use 2-hour fire resistance rated material for all the corridors to avoid any mistakes or oversight during construction/installation).

Also note, that for unsprinklered corridors, a ½-hour fire resistance rating is required by 18.4.4.7.1.1 NFPA 101, but this report assumes that this building will be sprinklered (as required by 18.3.5.1 NFPA 101). Even if it is not, the 2-hour fire resistance rating will provide more than the minimum level of protection required by this section of the code.

As mentioned in A.18.6.3.2 NFPA 101, it is the intent of the code that there be no required fire resistance or area limitations for vision panels in corridor walls and doors, and these can be examined on a case-by-case basis should they be present.

Exit Signs

Exit signs are placed according to the requirements from the 2018 LSC, with particular attention to 7.10.1.5.1 and 7.10.1.5.2.

The main considerations used to place the exit signs were to make sure there was at least one sign visible at all times along the exit access, and they were within 100 feet of each other. The report assumes that the exit signs selected will be rated for a viewing distance greater than 100 feet, so the 100 feet requirement of 7.10.1.5.2 becomes the limiting factor.

Exit sign placement is shown in Figure # 25 – 30:

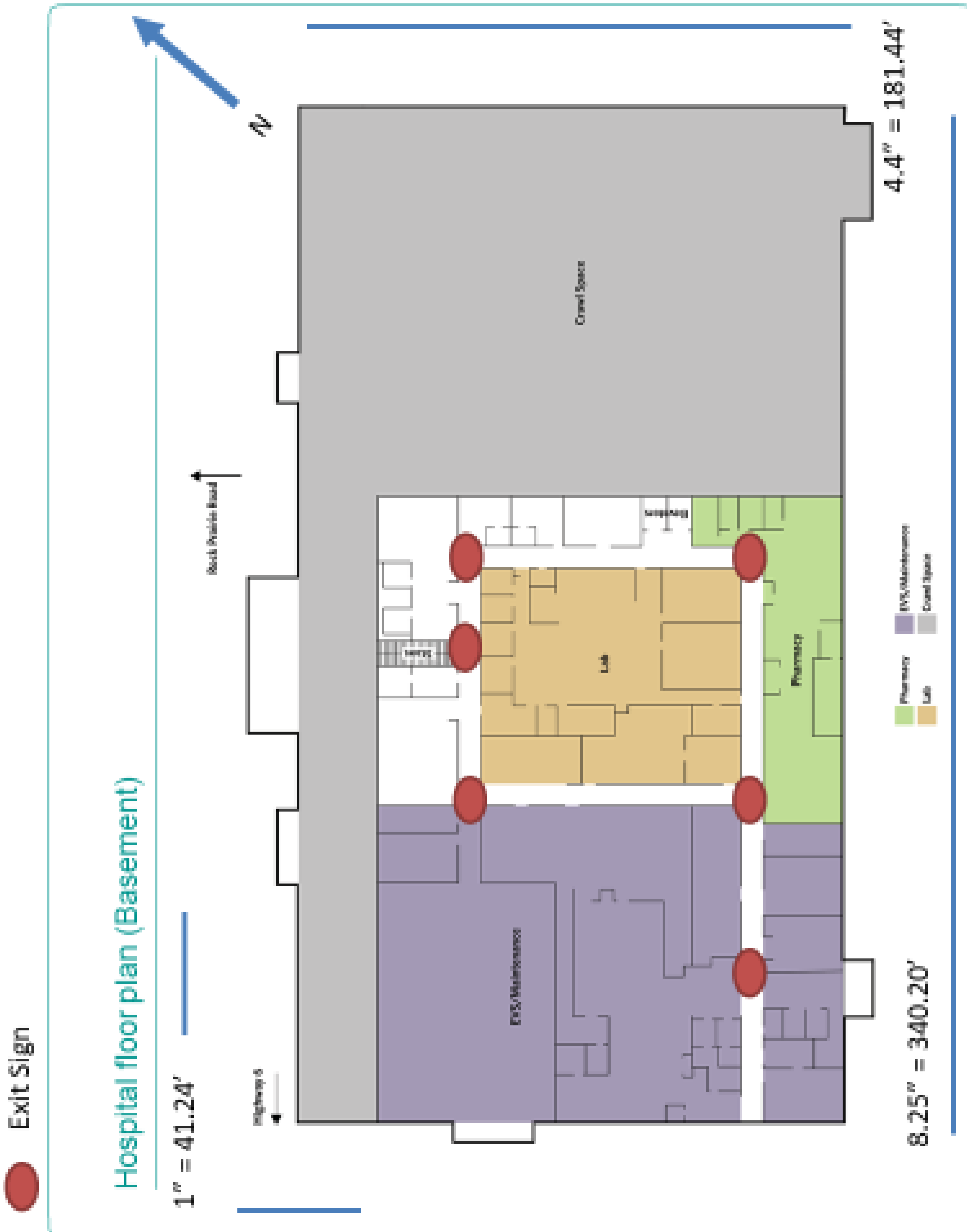


Figure # 25. Basement Exit Signs

Figure # 26. Floor 1 Exit Signs

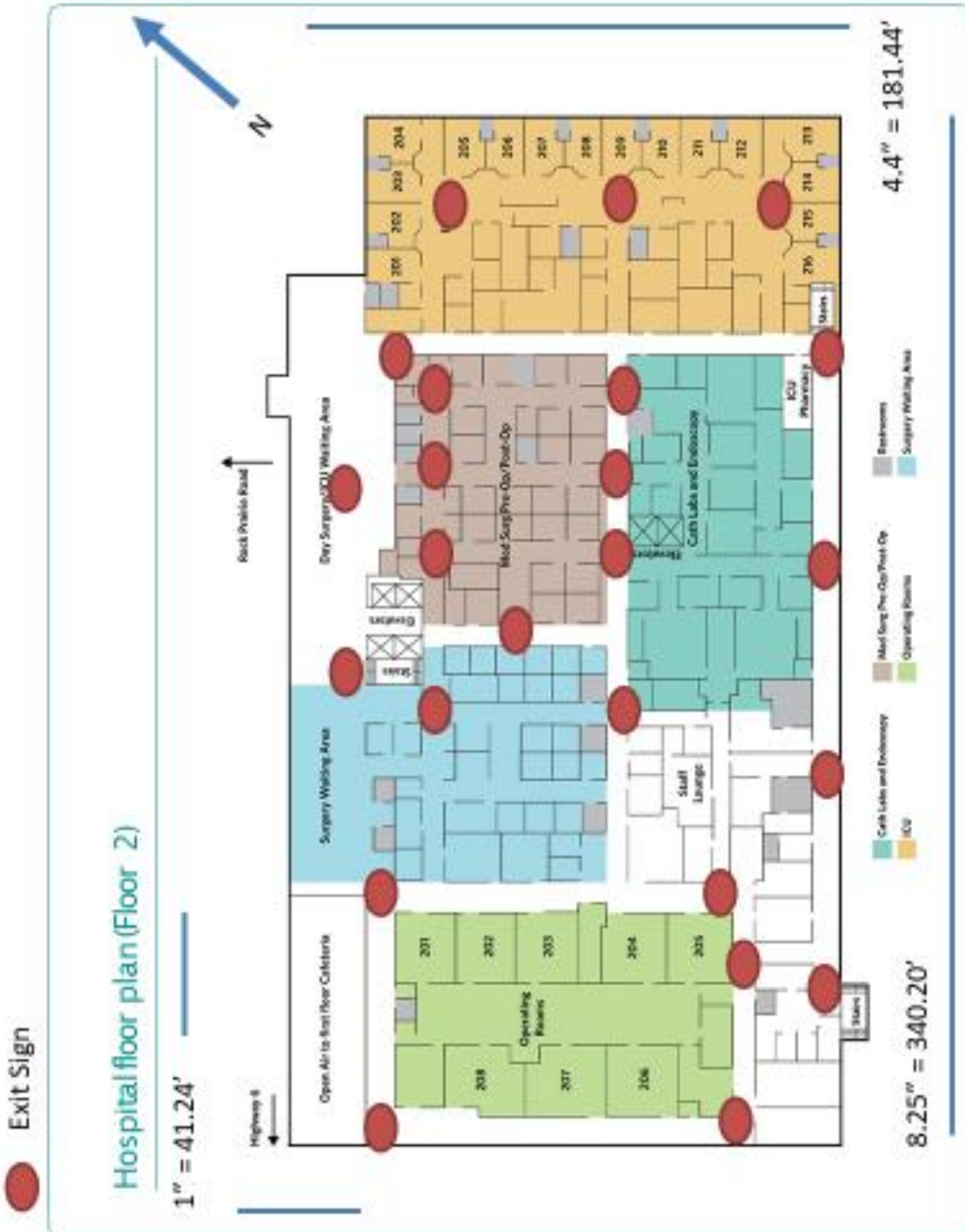


Figure # 27. Floor 2 Exit Signs

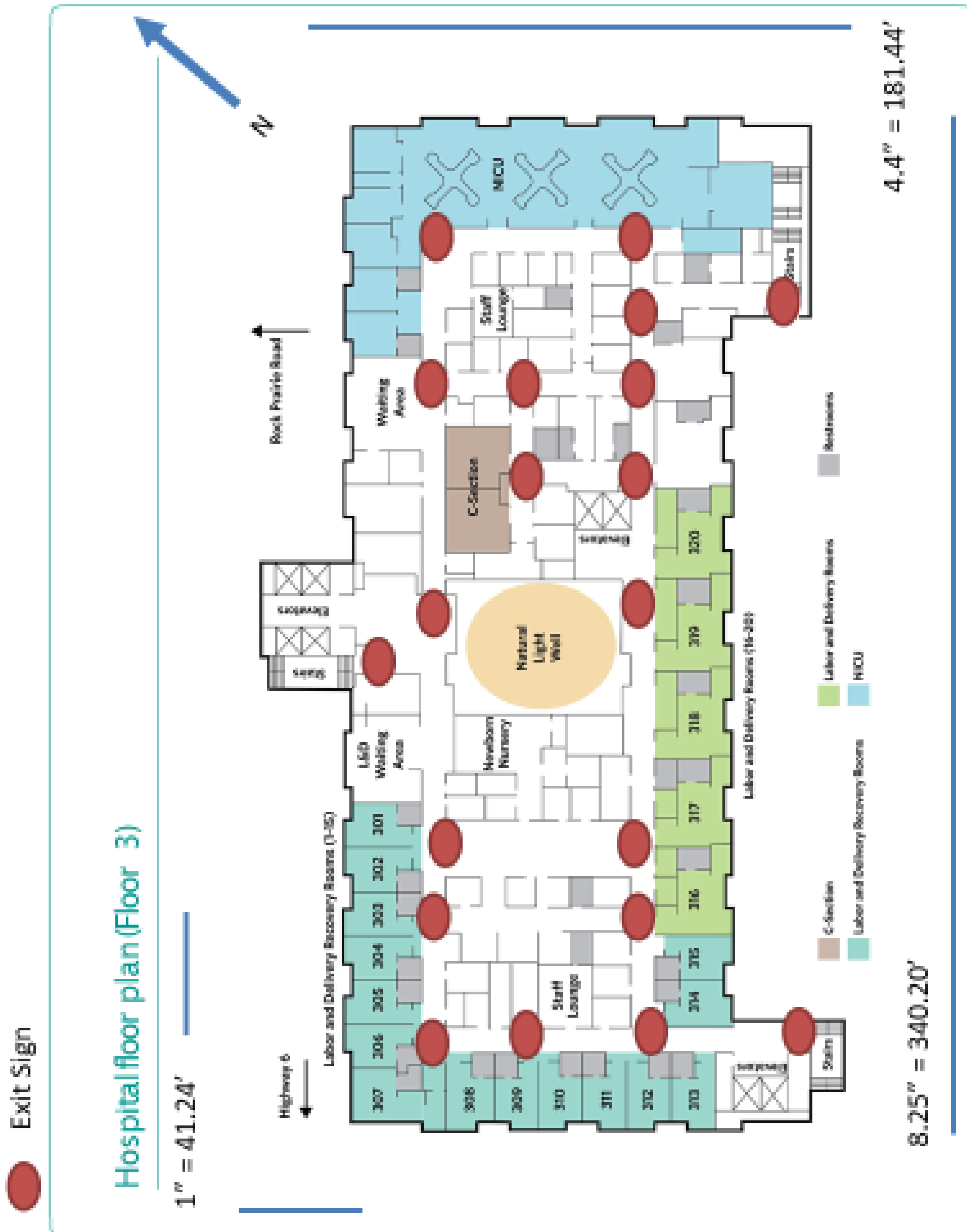


Figure # 28. Floor 3 Exit Signs

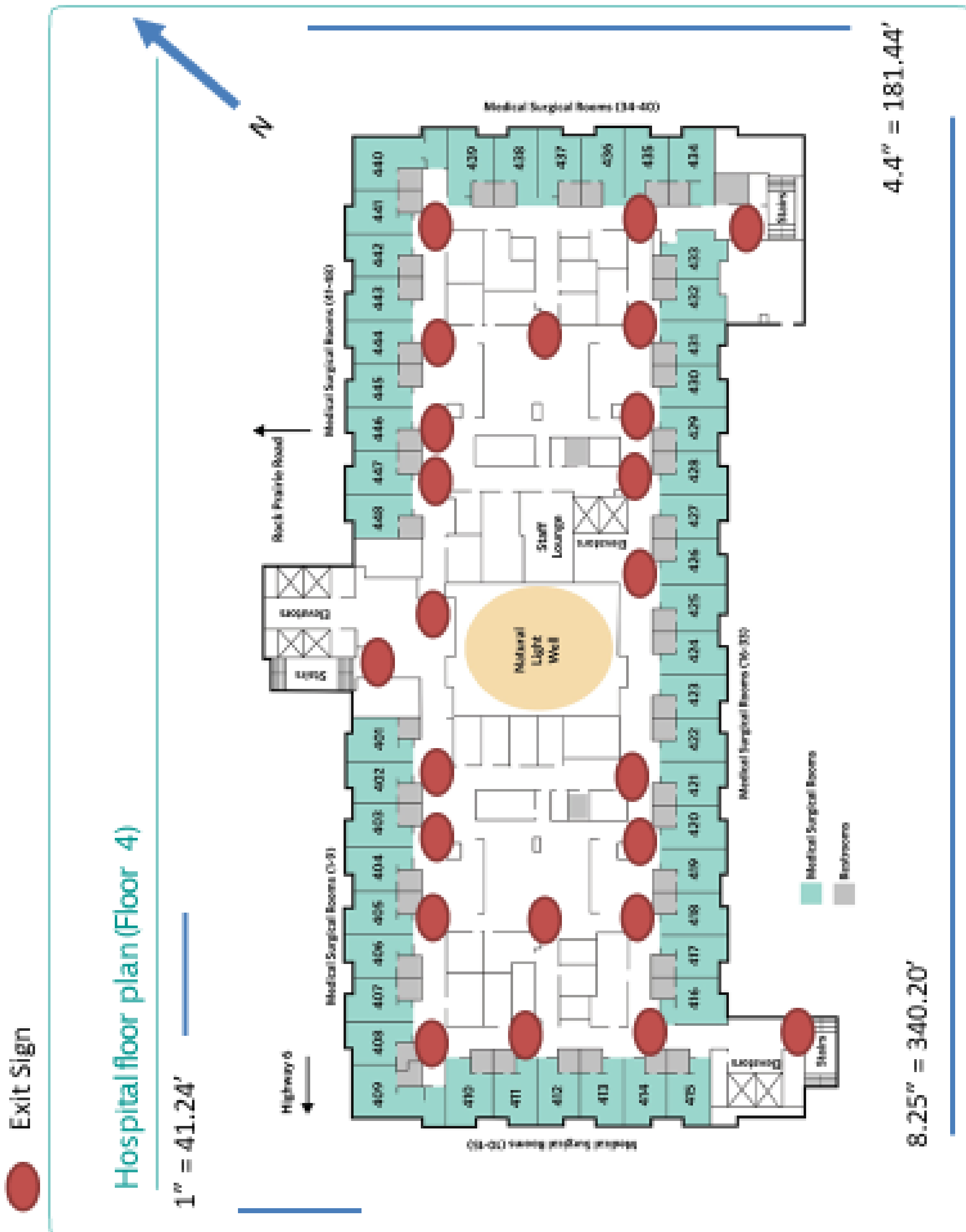


Figure # 29. Floor 4 Exit Signs

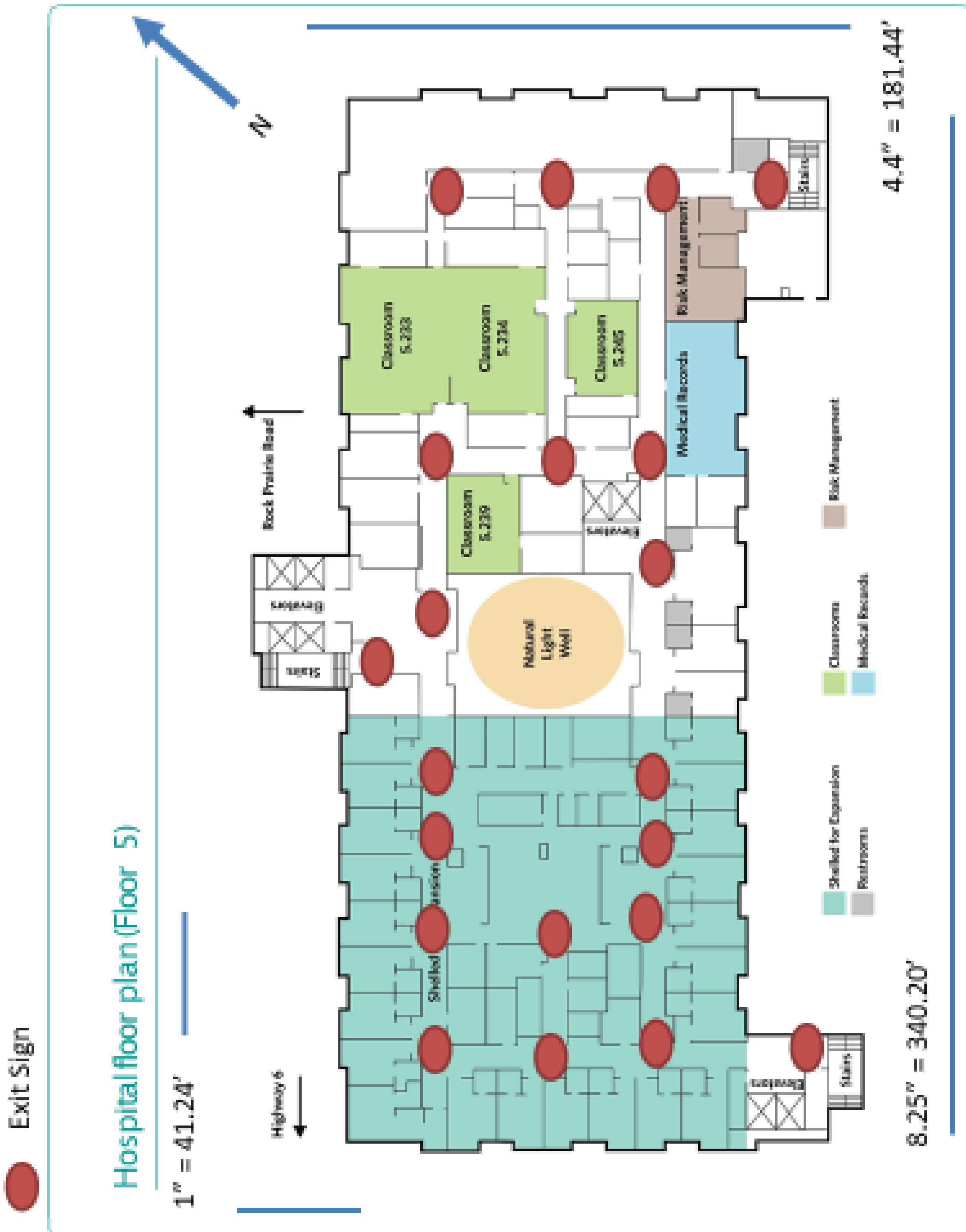


Figure # 30. Floor 5 Exit Signs

Note, at times the exit signs may seem to overlap, but this placement was necessitated by either obstructions to viewing them (e.g. partitions, walls), over closely spaced and parallel corridors.

Interior Finish Requirements for Exits, Corridors and Other Spaces

The interior finish requirements for exits, corridors, and other spaces are primarily governed by 7.1.4.1, 7.1.4.2, and Chapter 10.2 (including 10.2.3, 10.2.3.4, 10.2.7.1, 10.2.7.3, 10.2.7.2., 10.2.7.4, Table A.10.2.2, among others) of the 2018 LSC.

From Table A.10.2.2, new Health Care occupancies are required to have Class A interior wall and ceiling finishes (flame spread index, 0-25 (new applications); smoke developed index, 0-450) for exits, exit access corridors, and other spaces. There are allowances for Class B interior wall and ceiling finishes (flame spread index, 26-75 (new applications); smoke developed index, 0-450) for the lower portion of corridor walls or in small individual rooms, but no such allowance for corridors. This report also finds that exits and exit access corridors are required to have Class I or II interior floor finishes (critical radiant flux, not less than 0.45 W/cm^2 for Class I, critical radiant flux, not more than 0.22 W/cm^2, but less than 0.45 W/cm^2 for Class II), but there are no requirements for floor finishes for other spaces.

Human Behavior in Fire

Occupant Characteristics

The SFPE Guide to Human Behavior in Fire provides an extensive list of occupant characteristics to be used in describing occupants. For the purpose of this report, this information is assumed to be true, and the example of Table 57.2 from the SFPE Handbook was used to create Table 17 below to highlight characteristics that can affect occupant behavior and movement during a fire event.

Table # 17. Occupant Characteristics

Characteristic	Hospital Staff	Patients	Visitors
Population Numbers and Density	Relatively high and steady	Variable	Variable, mainly concentrated during business hours
Alone or with Others	With others	Varies	Varies
Familiarty with the Building	High	Low	Low
Distribution and Activities	Distributed throughout facility, working	In medical spaces and bedrooms, recovering	In waiting spaces and bedrooms, visiting
Alertness	Awake	Awake/asleep	Awake
Physical and Cognitive Ability	High ability to sense, respond, and react to cues	Low ability to sense, respond, and react to cues	High ability to sense, respond, and react to cues
Social Affiliation	Caregiver for patients, will react as a member of a group	Recipient of care, will react as an individual	Family/friends of patients, will react as a member of a group
Role and Responsibility	Responsible for well-being of patients, will lead others	Recipient of care, will follow others	May feel responsible for patients, will follow others
Location	Distributed throughout facility	In medical spaces and bedrooms	In waiting spaces and bedrooms
Commitment/Investment	High commitment to patients and facility	Commitment to self-safety	Commitment to patient and self-safety
Focal Point	Work, including patients	May vary	Patients
Occupant Condition	Good	May vary	May vary
Other Factors	Has Training	Will need assistance	May be able to assist staff

Pre-movement Activities and Times

This report uses empirical data for pre-movement activities and times that are appropriate for health care facilities based on the relevant occupant characteristics.

Based on Table 64.4 (shown below in Table 19) and Table 64.5 of the SFPE Handbook 1 minute should be used for health care occupancies. This assumes that the pre-movement times of this building matches the mid- to upper-ranges of health care occupancies as reported by Gwynne et al. and Purser and Bensilum (shown below in Table 18), and that the building pre-evacuation time can also be approximated as that of medium egress time of high-rise office buildings (Table 19). Relying on trained staff, pre-movement activities may include moving to patients that need movement assistance, securing wheelchairs and rolling beds, and securing medical equipment. It should be noted that the data below is measured at outpatient hospitals, and that the scale involved (19 patients, over 225 patients) is much smaller than that of our building. However, even the differences between these examples from Table 18, the pre-movement time does not dramatically increase. We assume that the size of a hospital is not as important a factor then; rather, other factors such as time of day and staff training may explain discrepancies in pre-movement time. On that note, while this data is for outpatient hospitals, our building will have non-ambulatory occupants. This is an important fact that we will model later in this report in Pathfinder. The movement speeds of such occupants may also be accounted for in hand calculations. However, for the purpose of pre-movement time, we take it as the amount of time that lapses before evacuation begins, and the response time of staff and occupants in that sense will not be largely effected by whether there are ambulatory patients or not: staff and patients will still have a period of time while they consider whether or not the fire alarm valid or not, and then will have to react afterwards.

In fact, comparing Tables 18 and 19, the health care facilities show a shorter pre-movement time than hotels, office buildings, and apartment buildings. As discussed in Fire Protection Engineering courses and literature, the environment and expectations for locations may bias occupant behavior, and skew pre-movement times. Given the considerations of pre-movement vs movement, and the performance of health care occupancies outlined above, it is assumed in this report that the presence of non-ambulatory occupants will affect the movement time and total egress time, and not the pre-movement time. As a final note, this 1 minute pre-movement time may be too optimistic; acceptance by the AHJ, field experiments at other hospitals, and other steps may be taken to verify if this is appropriate.

Table # 18. Pre-evacuation Time, Health Care Occupancies

Table 64.10 Pre-evacuation time—health care occupancy

Occupancy	Source	Observational conditions (L: location, N: nature, SC: spatial configuration, P: participants, E: environment, V: variable)	Procedure: Strategy	Procedure: Staff	Procedure: Technology	Sample: Collection method	Sample: Size	Results (secs): Mean [S.D., range]	Additional information
Health care	Gwynne et al. [75, 76]	L: UK	Full	14	AL	Video, observer, survey	S1: patients: 19	50.8 [–, 30–66]	[a]Times for staff to react to a call in an area
		N: UE, 2000					S2: staff: 14	44.1 [–, 16–91][a]	Results presented by area
		SC: outpatients hospital P: 19 patients V: S1–2 different population types							A bell was used
	Purser and Bensilum [10]	L: UK N: UE, 1996 SC: [outpatients hospital, 2 floors; 2 areas examined: SC1, SC2] P: >225 V: different spaces evacuated SC1–2	Full	–	PV English (24 s)/Urdu (29 s)	Video (handheld)	SC1: 14 SC2: 7	–[–, 21–29] –[–, 20–29]	Results presented by area

Table # 19. Delay Times Derived from Actual Fires, and Evacuation Exercises

Table 64.4 Delay times (min) derived from actual fires and evacuation exercises reported in the referenced literature [37]

Event description	*N*	Min	1st Q	Median	3rd Q	Max	Mean	Factors
High-rise hotel	536	0	3.3	60.0	130.9	290	NA	MGM Grand Hotel fire, no alarm notification, grouped data from questionnaires
High-rise hotel	47	0	2.0	5.0	17.5	120	NA	Westchase Hilton Hotel fire, no alarm in early stages, grouped data from questionnaires
High-rise office building	85	0	2.0	5.0	10.0	245	11.3	World Trade Center explosion and fire, no alarm notification (building closer to explosion)
High-rise office building	46	0	4.5	10.0	31.5	185	28.4	World Trade Center explosion and fire, no alarm notification (building farther from blast)
High-rise office building	107	1.0	1.0	1.0	1.0	≈6.0	NA	Fire incident, no alarms, data from interviews with occupants of four floors of building (11 interviewees were trapped)
High-rise office building	12	0.5	NA	1.0	NA	2.3	1.2	Unannounced drill on three floors; data for first person to reach each of four stairwell doors to wait for voice instruction; trained staff; data from video recordings
Mid-rise office building	92	0	0.4	0.6	0.8	<4	0.6	Unannounced drill, good alarm performance; fire wardens; warm day
Mid-rise office building	161	0	0.5	0.9	1.4	<5	1.1	Unannounced drill, good alarm performance; fire wardens; cool day
One-story department store	95	1	0.2	0.3	0.5	0.9	0.4	Unannounced drill; trained staff; data here derived from grouped data for 95 participants
Three-story department store	122	0.05	NA	NA	NA	1.6	0.6	Unannounced drill; trained staff; times distilled from analysis of videotapes
One-story department store	122	0.07	NA	NA	NA	1.7	0.5	Unannounced drill; trained staff; times distilled from analysis of videotapes
One-story department store	71	0.03	NA	NA	NA	1.0	0.4	Unannounced drill; trained staff; times distilled from analysis of videotapes
High-rise apartment building	NA	0	NA	NA	NA	NA	10.5	Forest Laneway fire; for occupants who attempted to evacuate in the first hour, based on questionnaire responses
	219	0	NA	187.8	NA	720	190.8	Forest Laneway fire, for all occupants
High-rise apartment building	33	0.3	0.8	1.3	4.4	10.2	2.8	Unannounced drill; good alarm performance
High-rise apartment building	93	0.4	1.5	3.6	6.9	18.6	5.3	Unannounced drill; good alarm performance; heavy snow during drill
High-rise apartment building	27	1.0	2.0	8.0	14.0	>20	NA	Fire incident in early morning, alarm functioned, fewer than half the occupants evacuated
Mid-rise apartment building	42	0.6	1.0	1.4	3.0	>14	2.5	Unannounced drill; good alarm performance
Mid-rise apartment building	55	>0.5	1.6	4.4	13.5	>21	8.4	Unannounced drill; poor alarm performance
Mid-rise apartment building	77	>0.3	1.9	7.7	19.1	>24	9.7	Unannounced drill; poor alarm performance
Mid-rise apartment building	80	>0.3	1.2	2.5	3.7	>12	3.1	Unannounced drill; good alarm performance
Training facility	566	<0.2	0.7	1.1	1.5	>5	NA	Testing sleeping subjects at a training facility

NA not reported

Based on the Cal Poly SLO FPE Program, this report recognizes that premovement time consists of recognition (or reaction) time and response (or pre-evacuation activity) time, whereas movement time consists of the travel time. The reaction time in turn consists of perception and interpretation time. It is expected that the reaction time should be low, considering the presence of trained medical staff, and that the majority of the pre-movement time is spent on response time in preparing patients for transport.

Emergency Movement and Egress Models

Hydraulic Model

This report uses a first-order approximation of the hydraulic model to estimate the egress time from the building. Assumptions and references are below.

Assumptions

This report makes several assumptions when calculating the egress time

1. Floor-to-floor height is 12 ft.
2. Stair risers are 7 in. wide; treads are 11 in. high.
3. Each stair is 44 in. wide (tread width) with handrails protruding 2.5 in.
4. There are two 4 ft x 8 ft landings per floor of stairway travel.
5. There is one 36 in. clear width door at each stairway entrance and exit.
6. The first floor does not exit through stairways.
7. This report does not consider the first floor in this egress calculation.
8. The prime controlling factor will be either the stairways or the door discharging from them.
9. Queuing will occur; therefore, the specific flow, F_s, will be the maximum specific flow, F_{sm}.
10. All occupants start egress at the same time.
11. The population will use all facilities in the optimum balance.
12. Assume egress time due to travel within the floor is negligible compared to queue times; in other words, egress time is a function of people waiting to reach an exit, not travel from their space on the floor towards an exit (and its queue).
13. This report assumes a first-order approximation of the hydraulic model can be used to estimate the egress time, as described in class, NFPA Fire Protection Handbook Chapter 4-2 Calculation Methods for Egress Prediction, and SFPE Handbook of Fire Protection Chapter 59 Employing the Hydraulic Model in Emergency Movement.

Additionally, in this calculation, this report assumes that all occupants are mobile, and are moving at a 'healthy' speed, as is 'built-in' for the default values and tables below. There are more accurate speeds from the NFPA Handbook that can be used to modify this behavior, and this will be done in the section on performance-based analysis in this report (at which time this report will also explore additional features, such as egress elevators and horizontal exits). Also, occupants begin to move immediately during this calculation, so this report adds a premovement time based on Table 64.4 and Table 64.5 for health care occupancies.

Calculation

This report first estimates the flow capacity through a door. From Table 59.1 of the SFPE Handbook, the effective width, W_e, of each door is 42 – 12 = 30 in. (2.5 ft). From Table 59.5, maximum specific flow through any 42 in. door is 24 persons/min/ft effective width. Therefore, using equation

59.8, from the SFPE Handbook, the flow through any door is limited to 24 x 2.5 = 60 persons/min. Therefore, 60 persons/min will be the rate at which occupants in the floor can enter the stairway.

To double-check that the stairway does not have a lower flow capacity (thus restricting occupant egress, causing a bottleneck on the stairs and longer-than-expected queue to form by the doors, and throwing off the calculated flow capacity above), this report performs flow capability calculations on the stairs.

From Table 59.1, the effective width, W_e, of each stairway is 56 – 12 in. = 44 in. (3.67 ft). From Table 59.5, maximum specific flow for the stairway is 18.5 persons/min/ft effective width. Specific flow, F_s, equals maximum specific flow, F_{sm}. Therefore, using equation 59.6, the flow from each stairway is limited to 18.5 x 3.67 = 67.8 persons/min. The stairways has a higher flow capacity than the doors, so the queues will form at the doors, not the stairways.

This report estimates the speed of movement for estimated stairway flow. From equation 59.5, S = k – akD, and the appropriate factors from Table 59.2, the speed of movement down the stairs is 212 – (2.86 x 212 x 0.175) = 105 ft/min. Note, this report assumes a D of 0.175, because this density produces the maximum achievable flow rate (SFPE Handbook, 5th ed., page 2125). The travel distance between floors (using the conversion factor from Table 59.3) is 12 x 1.85 = 22.2 ft on the stair slope plus 8 ft travel on each of the two landings, for a total floor-to-floor travel distance of 22.2 + (2 x 8) = 38.2 ft. The travel time for a person moving with the flow is 38.2/105 = 0.36 min/floor.

If all of the occupants in the building start evacuation at the same time, each stairway can discharge 48 person/min. The population of 2,654 persons above the first floor will require approximately 2654 persons / 60 persons/min/exit / 3 exits = 14.74 minutes to pass through the exits. This report must also account for the 76 people in the basement leaving through one exit, which gives 76 persons / 60 persons/min/exit / 1 exit = 1.27 min. An additional 0.36 minute travel time is required for the movement from the second floor to the exit, and from the basement to the exit. The total minimum evacuation time for the 2654 persons located on floors 2 through 5 and 76 persons located in the basement is estimated at 14.74 min + 0.36 min + 1.27 min + 0.36 min = 16.73 min, or, rounding up, approximately 16.8 minutes. The results of these calculations are summarized in Table 20 below.

Table # 20. Hydraulic Model Egress Travel Time

Occupants (persons)	Calculated Flow (persons/min)	Egress Time per Exit (min)	Number of Exits	Egress Time (min)	Additional Transit (min)	Total Egress Time (min)
Floors 2-5: 2654 Basement: 76	48	Floors 2-5: 40.3 Basement: 1.3	Floors 2-5: 3 Basement: 1	Floors 2-5: 13.4 Basement: 1.3	0.36	16.8

As stated before, this calculation is for the travel time. If premovement time is also needed, 1 minute should be used, based on SFPE Handbook Table 64.4 and Table 64.5 for health care occupancies.

Uses and Limitations of this Analysis

The egress analysis above focuses on 'traditional' egress means and features. Under traditional egress means and features, it is assumed occupants move at normal speeds and complete a full evacuation of the building. This serves to provide a 'best case' scenario of full evacuation. In the computer-based egress model below, it was determined that the fifth floor takes the longest to evacuate. Given the fact that this floor primarily consists of a large number of classrooms and business offices, this model likely reflects reality. However, considering the nature of the occupants in this building, it is more likely that a defend-in-place strategy with horizontal exits would be used during a fire event. The evacuation strategy for this building will be examined more in the performance-based analysis portion of this report.

Computer-based Egress Model

The building and its occupants were modeled in Pathfinder in order to see if the Hydraulic Model hand calculations match with that estimated by industry tools. Because this report had access to floorplans but not CAD drawings, each floorplan was imported as a background image, then each feature was 'traced' over by hand to create the model.

The simulation was run in both SFPE and Steering Modes. A table comparing the egress time that was calculated to the model predictions is below in Table # 19, and screenshots from the program are also shown here as Figures 31 – 33. A special thanks to Daniel Swenson from Thunderhead Engineering and the whole Thunderhead Engineering team for their help in resolving problems encountered when building this model.

Table # 21. Comparison of Egress Travel Times by Model

Egress Model Summary	
Egress Model	Time (min)
Hydraulic Model	16:44
Pathfinder, SFPE Mode	18:09
Pathfinder, Steering Mode	16:58

Figure # 31. Z-axis View of Pathfinder Model

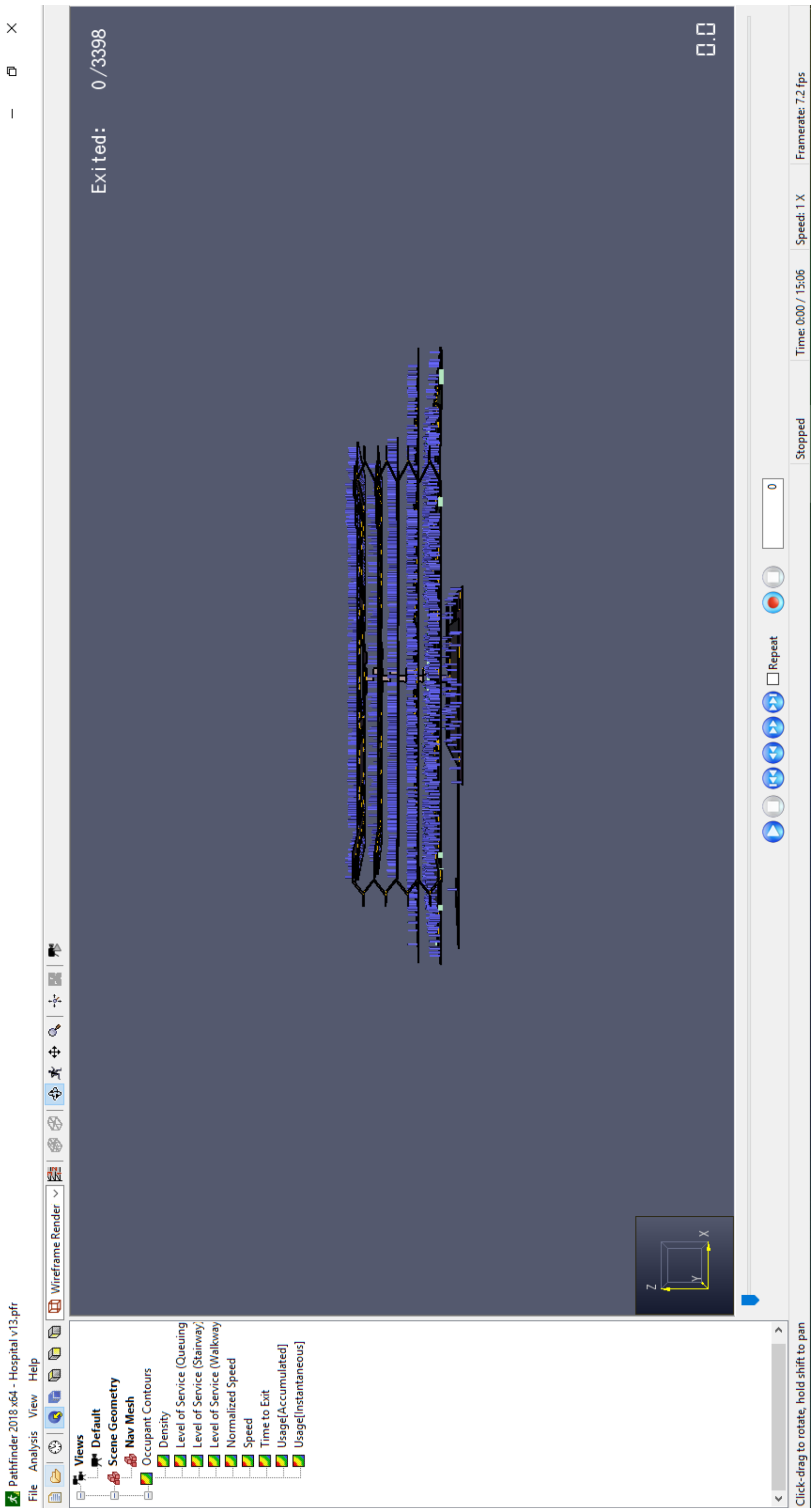


Figure # 32. X-axis View of Pathfinder Model

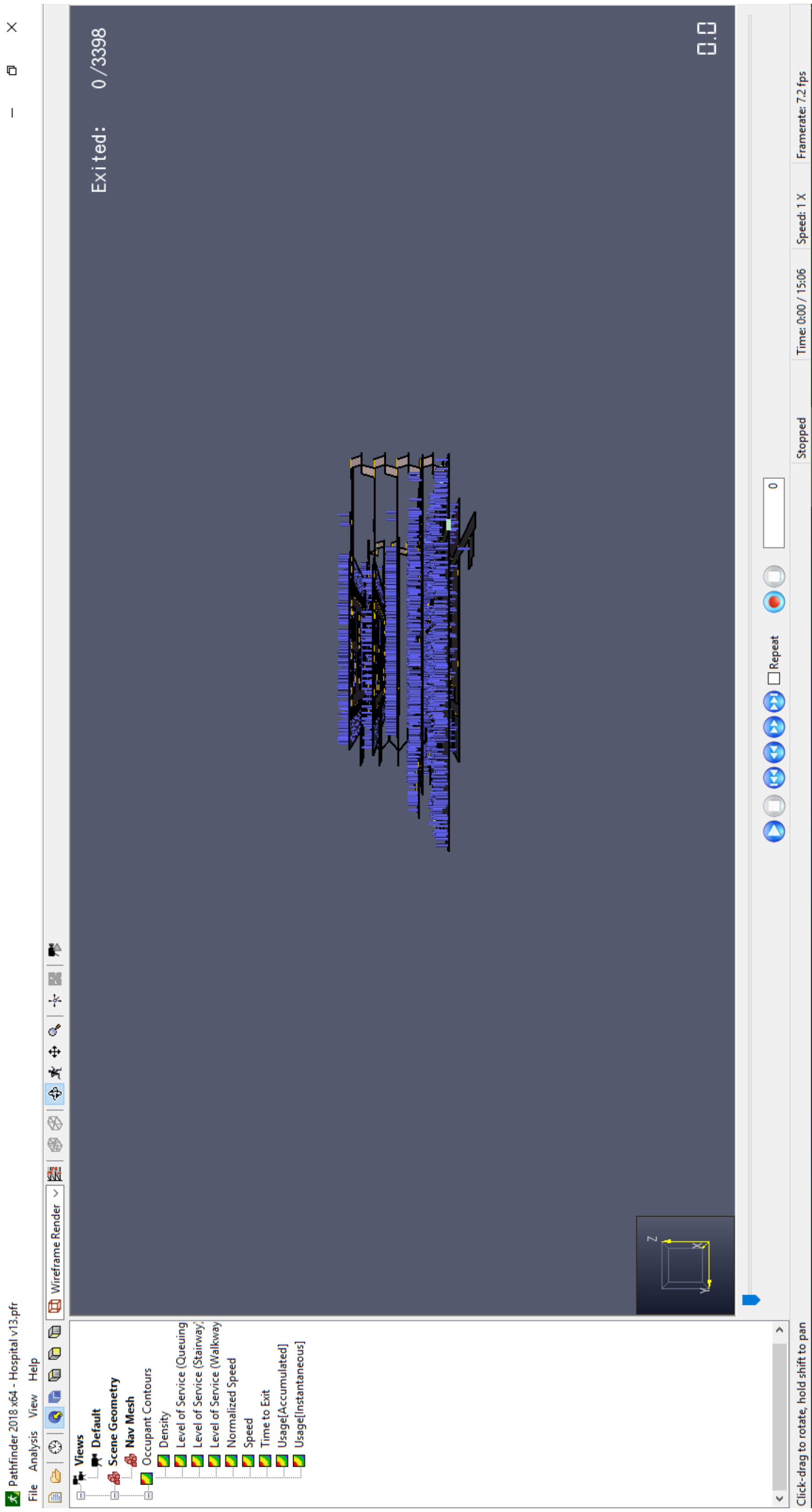


Figure # 33. Y-axis View of Pathfinder Model

The Pathfinder model produced is attached for review. Note, in order to see both run times shown here, one must run the simulation in both SFPE and Steering Modes. It is recommended that two copies of the underlying file be created, with different file names to distinguish them and their result files (e.g. Hospital SFPE.pth, Hospital Steering.pth).

Comparing egress times in Table # 19 above, the Hydraulic Model calculation performed earlier yielded a slightly longer egress time than Pathfinder in Steering Mode, but a shorter time than Pathfinder in SFPE Mode. In reviewing the three-dimensional results over time of occupant egress, it is clear that there are at least two major differences between the Hydraulic Model calculation and Pathfinder:

1. Perhaps most importantly, there is a sub-optimal utilization of the stairs: Pathfinder modeled the majority of occupants as using the western staircase. Though there was some movement between queues to try to find a faster egress, by the end the western staircase by the main entrance remained fully utilized for some minutes even as the two staircases at the eastern end of the building were not.
2. Travel time from different spaces on the floor to and from the stairs was explicitly accounted for in the model. In contrast, the hydraulic model neglected travel to and from the stairs because the dominating term was the stair queueing. Not accounting for travel to and from the stairs is one reason why there is an increase in the estimated egress time in the SFPE mode.

Assumptions

Many of the same assumptions made for the Hydraulic Model also apply to he Pathfinder model. Some Pathfinder-specific assumptions in this first pass include distributing the occupant load of the floor across all the occupied spaces. From different iterations of the model, the 'critical path' of egress seems to primarily depend on 'bottlenecks' that develop at the entrance to the staircases, so occupant distribution among individual floors seem to have little effect (because no matter where they start, occupants will end up queuing at the stairs anyway). As before, movement speeds were left on the default for healthy, mobile adults, and will be updated in the performance-based analysis section of this report.

Uses and Limitations of this Analysis

As for the hydraulic model, the Pathfinder model does not take into account horizontal exits or areas of refuge, and instead focuses on full egress at this level. The Pathfinder model then serves as a 'best case' scenario. However, the model shows that the fifth floor takes the longest to evacuate (with its classrooms, business offices, assembly spaces, etc.), and, assuming that these occupants will be mobile, alert adults, this model may not be so far off in estimating a full egress time. A full analysis, the modeling and hospital beds requiring assistance to travel (something that Pathfinder supports), will be conducted in the performance-based analysis section of this report.

Tenability Analysis

Tenability Performance Criteria

This report uses several sources to set tenability limits for the project building, taking into account the occupant characteristics associated with this hospital. This report categorizes the tenability criterial into three broad categories: visibility/smoke density, heat effects, and toxic/irritant gases.

Visibility and Smoke Density

For visibility/smoke density, this report relies on Chapter 61 of the SFPE Handbook. From Table 61.3 and Table 61.4, this report assumes occupants who are unfamiliar with the inside of the building as a conservative estimate, and uses a smoke density (extinction coefficient) of 0.15 1/m and visibility of 13 m (42.6 ft). Note, these limits are close to those proposed by fire researchers such as Kawagoe (0.1 1/m) and the Los Angeles Fire Department (45 ft, 13.5 m).

Heat Effects

For heat effects, this report turns to Chapter 63 of the SFPE Handbook, and uses Table 63.20, Table 63.28, Table 63.29

From these tables, it can be determined that typically occupants can be exposed to radiation intensity of 2.5 kW/m^2 for 30 seconds less, and that they experience convection of 100^{o}C at < 10 % H_2O for less than 12 minutes. Because of the potential weakened state of patients, this report can apply a safety factor of 20% - 50% to these limits, as to be agreed upon by stakeholders (client, AHJ, etc.).

Toxic and Irritant Gases

For toxic and irritant gases, this report uses the materials from the Cal Poly SLO FPE Program, and Chapter 63 of the SFPE Handbook (including the Appendix, and relevant equations such as 63.15, 63.35, 63.38, 63.39, 63.18, Table 63.4, Figure 63.20, Table 63.10, etc.) to set limits and calculate the FED, Fractional Effective Dose.

As discussed in Cal Poly SLO's FPE Program and in the SFPE Handbook, Chapter 63, pages 2352 – 2356, the exposure dose (percent COHb) for incapacitation, D, varies depending on the level of activity. This report selects the appropriate values of D to use in these calculations from the curves in Figure 63.20 and from Table 63.10.

This report use D = 50 %COHb as the lethal level based on Table 63.4, and because "50 %COHb is usually considered as an average lethal level (SFPE Handbook, 5th ed., page 2347).

This report assumes that 40 %COHb would lead to loss of consciousness for healthy resting individuals, but this can occur at even lower levels for more susceptible resting subjects, and lower levels can be dangerous for subjects with compromised cardiac function.

For this reason, this report would take a tenability limit of 20 %COHb, 100 ppm HCN for 10 minutes (Table 63.12), and CO_2 limits should be examined based on the FED model, in conjunction with other gases.

For irritants, this report takes half of the levels from Table 2-6.12 of the NFPA Handbook, as shown in Table 22 below:

Table # 22. Irritant Gas Levels (ppm)

Gas	Limit (ppm)
HCl	100
HBr	100
HF	100
SO2	12
NO2	35
CH2CHO	2
HCHO	3

Methodology to Evaluate Building Performance Objectives under Section 502 of the LSC

In order to evaluate whether or not the building meets the performance objectives for tenability, there are several methods in A.5.2.2. Of the four methods presented, it is in the report author's engineering judgement that Methods 3 (smoke layer will never descend below 6 feet above the floor) and 4 (fire will not spread to occupied rooms) will be extremely difficult to achieve with such a large and complex hospital building for this project, so this report will not use those methods. Of the remaining two methods, Method 1 (PFD, using tools such as FED) and 2 (evacuation before smoke layer descends to below 6 feet above the floor) both have pros and cons associated with them.

Method 1 has the benefit of being more flexible in a way; there is no 'red line' like Method 2, tying evacuation time to smoke level descent. Rather, FPE's are allowed the freedom to use all manner of tools available to them to prevent occupants from experiencing untenable conditions. The strength of using this method for this project is that FPE's are able to use multiple strategies to protect occupants. The weakness is that FPE's must account for all variables that might threaten their safety, and ensure that no tenability limits are breached.

Method 2 has a more straight-forward and easily measurable metric, and in conjunction with the expectation of trained staff and horizontal exits, it is expected that the necessary evacuation time can be achieved in this project building. While this method does not explicitly list protection from all tenability criteria, it seems reasonable to assume that if the smoke layer does not descend below 6 feet, other tenability criteria such as toxic gas concentration and visibility would also be met.

For these reasons, this report would recommend to the client that Method 2 be pursued at this time to show that the building meets performance objectives outlined in Section 502 of the LSC. Simultaneously, the report author would understand if the AHJ would require the use of Method 1 instead of Method 2, and would also be able to use this method.

Conclusion

This chapter serves as a basic egress analysis and design for the Baylor, Scott & White Hospital in College Town, TX. Additional refinements have been identified at several points (movement speed, elevators, etc.), and these will be forth-coming in the performance-based design section below. This report next examines the suppression system in this building.

Suppression

Introduction

Sprinkler systems are a common sight in many facilities. For this building, they are required by code: an automatic sprinkler system shall be provided throughout buildings with a Group I fire area (2018 IBC, 903.2.6).

Where the provisions of this code require a building or portion thereof be equipped throughout with an automatic sprinkler system in accordance with this section, sprinklers shall be installed throughout in accordance with NFPA 13. (2018 IBC, 903.3.1.1).

The applicable sprinkler standard for this project is the 2016 edition of NFPA 13. From NFPA 13, several requirements for sprinklers in hospitals are present:

Hospitals will be protected with an approved, supervised automatic sprinkler system in accordance with Section 9.7 (2018 NFPA 101, 18.3.5.1).

Listed quick-response or listed residential sprinklers shall be used throughout smoke compartments containing patient sleeping rooms (2018 NFPA 101, 18.3.5.6).

Body

Water Supply Information

The building fire water supply information shown in Table # 23 below was estimated based on websites of College Station, TX water utility, building department, and fire department, as well as calls to those parties.

This report assumes that the water flow shown in Table # 23 was measured at a Point of Connection (POC) separate from the Base of the Riser (BOR). The report includes a sprinkler system design using Schedule 40 Steel with a Hazen Williams Coefficient C = 120. In the absence of further information, this report will assume that the City Water supply is also provided in the same type of pipe. The calculations based on this assumption should be updated if additional information becomes available.

Table # 23. Water Supply Information

Static pressure	80 psi
Residual pressure	60 psi
Flow	1000 gpm

Building Occupancy Classifications

This report determined the building occupancy classifications based on Chapter 5 of NFPA 13, and the various tables including Table 5.6 of Annex A of NFPA 13. Two sections in particular that are applicable to the building are as follows:

A.5.2 Light hazard occupancies, including churches, education, hospitals, libraries, nursing or convalescent homes, residential, restaurant seating areas, theaters and auditoriums (2016 NFPA 13, A.5.2).

A.5.3.1 Ordinary hazard (Group 1) occupancies, including laundries, mechanical rooms (2016 NFPA 13, A.5.3.1).

Based on A.5.2 and A.5.3.1 of NFPA 13, this report is likely able to apply the requirements for light hazard occupancies to the majority of the building. However, based on the presence of mixed-use spaces, and the potential for occupants changing the use of a space, it is recommended to apply ordinary hazard (group 1) throughout the entire hospital to be conservative.

Automatic Sprinkler System

This report next shows the design a wet-pipe sprinkler system for this building. Due to the building's location in College Town, TX, this report assumes a maximum ceiling temperature of 112°F and choose an ordinary temperature classification, with a sprinkler temperature rating of 175-225°F from Table 6.2.5.1 NFPA 13.

From 8.2.1 NFPA 13, this report obtains the maximum floor area for each sprinkler system riser as shown in Table 24 below. This report will use these numbers for each Space, and determine how many risers are needed.

Table # 24. System Protection Area Limitations

Occupancy Classification	Maximum floor area to be protected by sprinklers supplied by any one sprinkler system riser or combined system riser:
Light hazard	52,000 ft^2
Ordinary hazard	52,000 ft^2
Extra hazard	40,000 ft^2
Storage	40,000 ft^2

From the calculations for each space below, this report will show that two risers for each of the bottom three floors (the Basement, Floor 1, and Floor 2) are required, while one riser for each of the top three floors (Floor 3, Floor 4, and Floor 5) is sufficient.

This report will also determine the sprinkler system type for each floor, and provide calculations supporting that design. For all floors, the sprinkler system design will be a Control Mode Density Area (CMDA) system.

The layout of the sprinkler piping system is based on the requirements in NFPA 13. Note, this report uses a simple tree system as was discussed in the Cal Poly FPE 523 Module 6 lectures. In practice, a grid layout or some other alternatives may be used, but for the purposes of this report, a simple layout is used.

A design area is selected, and pipe sizes are determined with hydraulic calculations (shown in the next section of this report). Depending on the AHJ, additional information may be needed. Computer programs used in the Fire Protection Engineering industry would likely be of great help in this regard. From the calculations shown below, a design area that is the most hydraulically demanding area of each sprinkler system is found.

For each Floor, this report sets the sprinklers at the finished from the ceiling (10’ high). The risers run 10’-6” high to the feeder mains and cross mains. There is a decrease of 6” of elevation to the branch lines and sprinklers.

Sprinkler Risers

Through examining the square footage of each floor, it can be determined that the lower floors have a large enough area that they require multiple risers, while the upper floors are small enough that they only require one riser each. Table # 25 below summarizes the specific requirements, and below Table # 25 are Figure # 34 – 39 showing dimensions and areas for each floor that this report will us for the Suppression section.

Table # 25. Floor Riser Requirements

Floor	Number of Risers
Basement	2
Floor 1	2
Floor 2	2
Floor 3	1
Floor 4	1
Floor 5	1

Basement

The Basement is classified as Ordinary Hazard, Group I.

The Basement is calculated to have a floor area of 61,263 ft^2 (Figure # 34 below). The floor area of the Basement is over the 52,000 ft^2 threshold from 8.2.1 NFPA 13, so two sprinkler risers are needed for the Basement.

Floor 1

Floor 1 is classified as Ordinary Hazard, Group I.

Floor 1 is calculated to have a floor area of 62,263 ft^2 (Figure # 35 below). The floor area of Floor 1 is over the 52,000 ft^2 threshold from 8.2.1 NFPA 13, so two sprinkler risers are needed for Floor 1.

Floor 2

Floor 2 is classified as Ordinary Hazard, Group I.

Floor 2 is calculated to have a floor area of 61,340 ft^2 (Figure # 36 below). The floor area of Floor 2 is over the 52,000 ft^2 threshold from 8.2.1 NFPA 13, so two sprinkler risers are needed for Floor 2.

Floor 3

Floor 3 is classified as Ordinary Hazard, Group I.

Floor 3 is calculated to have a floor area of 46,009 ft^2 (Figure # 37 below). The floor area of Floor 3 is under the 52,000 ft^2 threshold from 8.2.1 NFPA 13, so one sprinkler riser is needed for Floor 3.

Floor 4

Floor 4 is classified as Ordinary Hazard, Group I.

Floor 4 is calculated to have a floor area of 44,568 ft^2 (Figure # 38 below). The floor area of Floor 4 is under the 52,000 ft^2 threshold from 8.2.1 NFPA 13, so one sprinkler riser is needed for Floor 4.

Floor 5

Floor 5 is classified as Ordinary Hazard, Group I.

Floor 5 is calculated to have a floor area of 44,568 ft^2 (Figure # 39 below). The floor area of Floor 5 is under the 52,000 ft^2 threshold from 8.2.1 NFPA 13, so one sprinkler riser is needed for Floor 5.

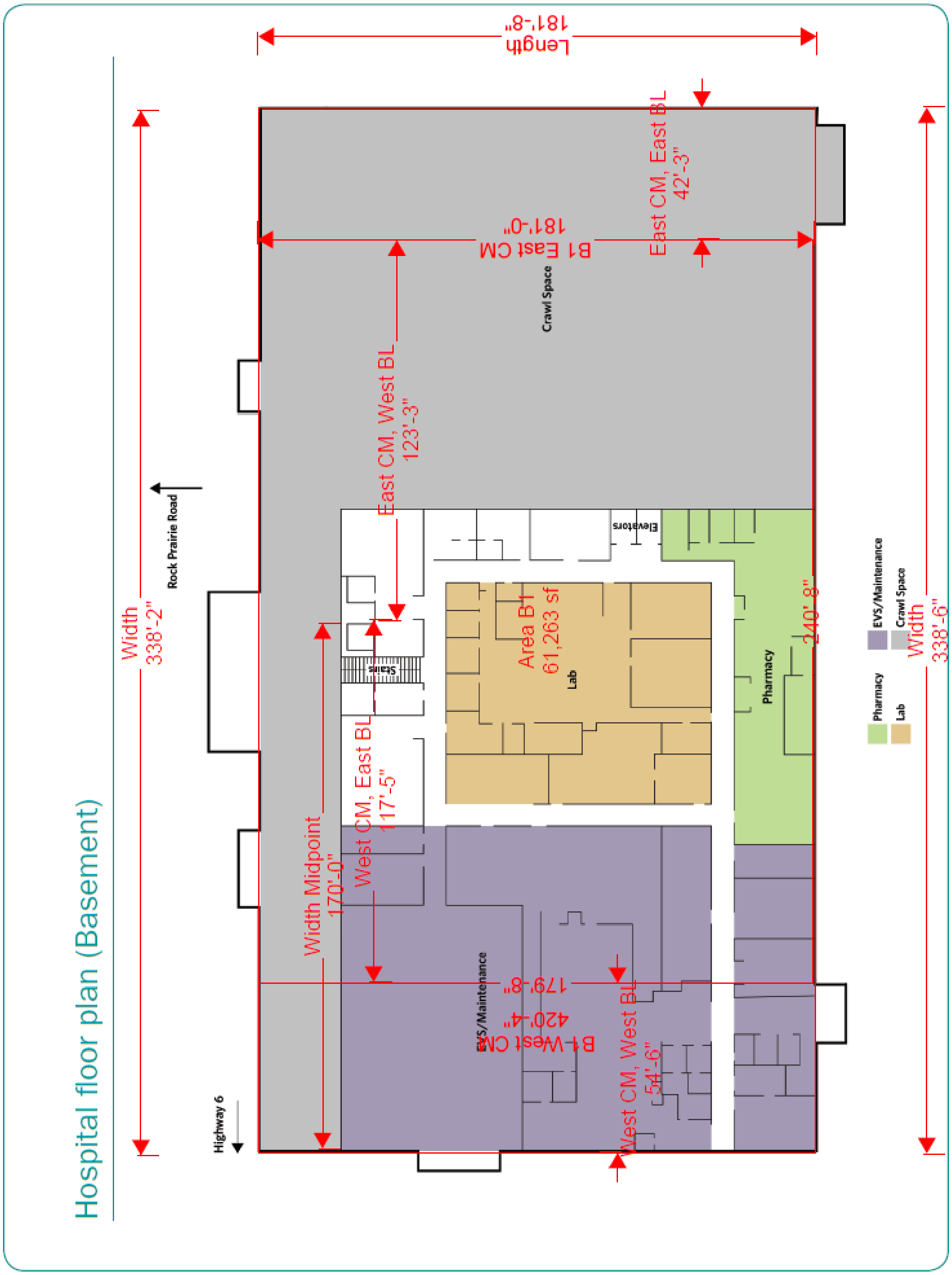


Figure # 34. Basement Sprinkler Area and Dimensions

Figure # 35. Floor 1 Sprinkler Area and Dimensions

Figure # 36. Floor 2 Sprinkler Area and Dimensions

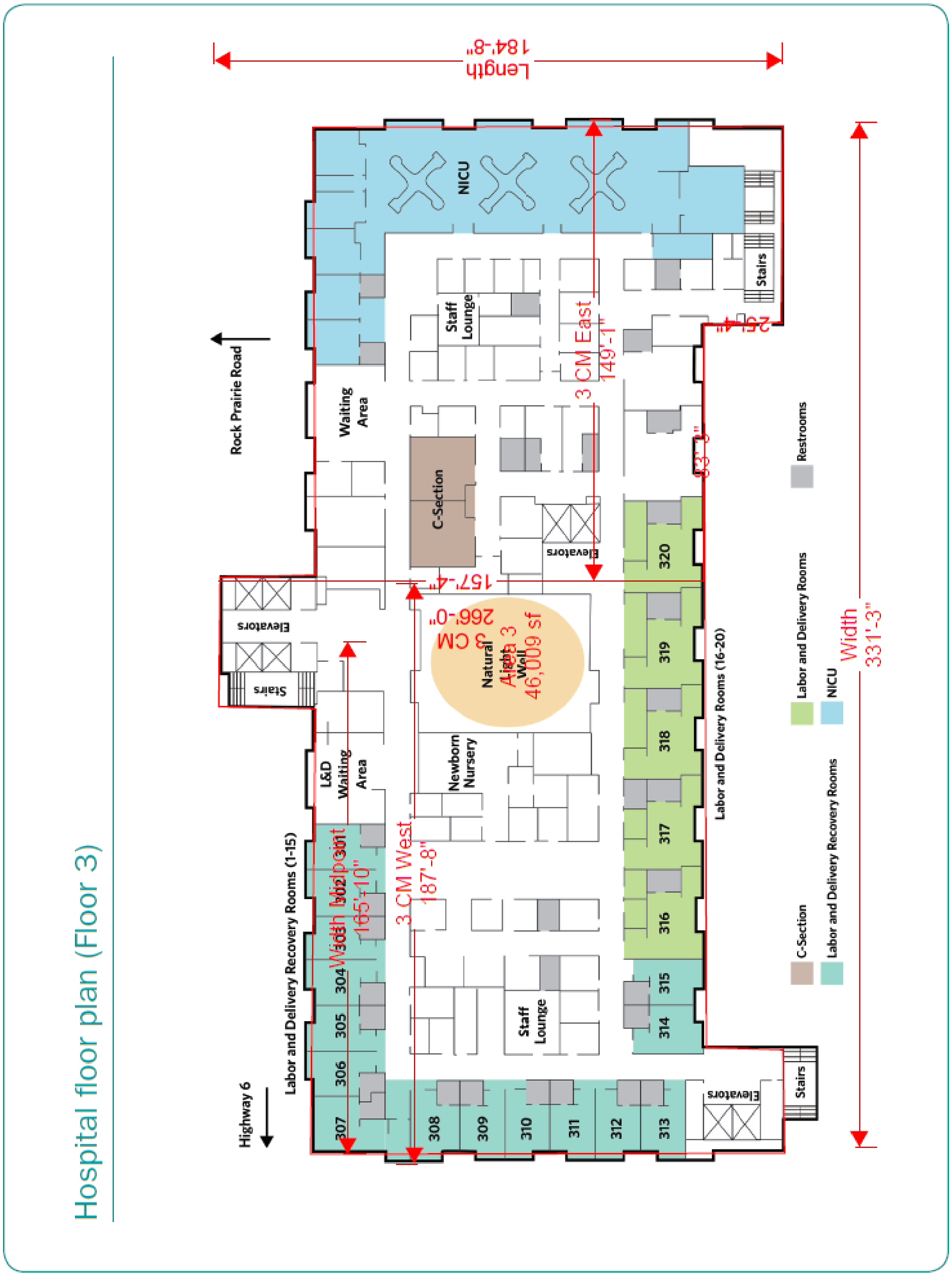


Figure # 37. Floor 3 Sprinkler Area and Dimensions

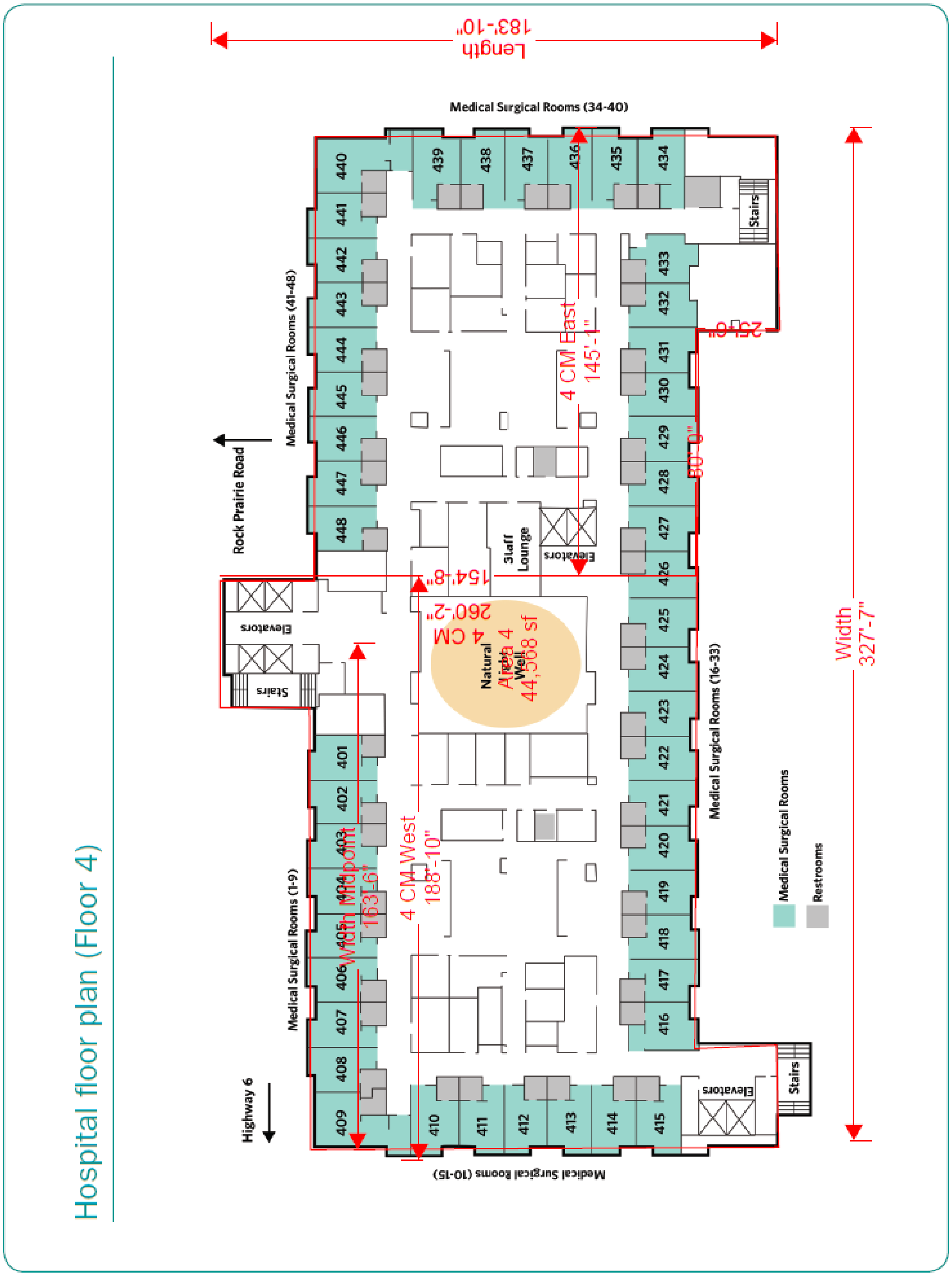


Figure # 38. Floor 4 Sprinkler Area and Dimensions

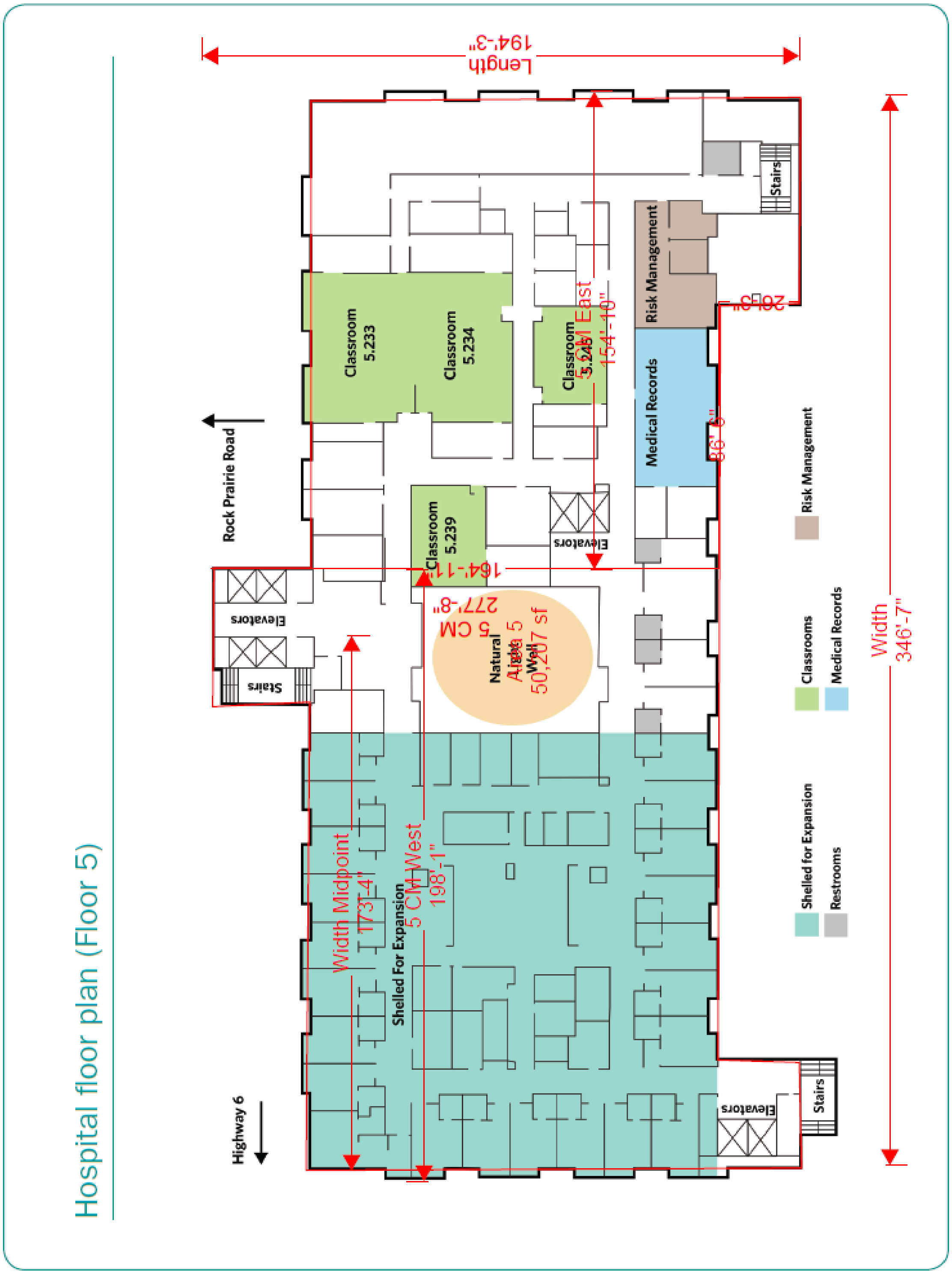


Figure # 39. Floor 5 Sprinkler Area and Dimensions

Sprinkler System Type

For past projects, different type of sprinklers (CMDA, CMSA, ESFR) were analyzed to find which one has the lowest total nominal water demand. For the purpose of this project, it is assumed that a CMDA system, and find a total nominal water demand as shown below.

For Ordinary Hazard Group 1, a CMDA water demand analysis is performed per NFPA 13 as follows:

From Figure 11.2.3.1.1, design criteria would be 0.15 gpm/S.F. over 1,500 S.F.

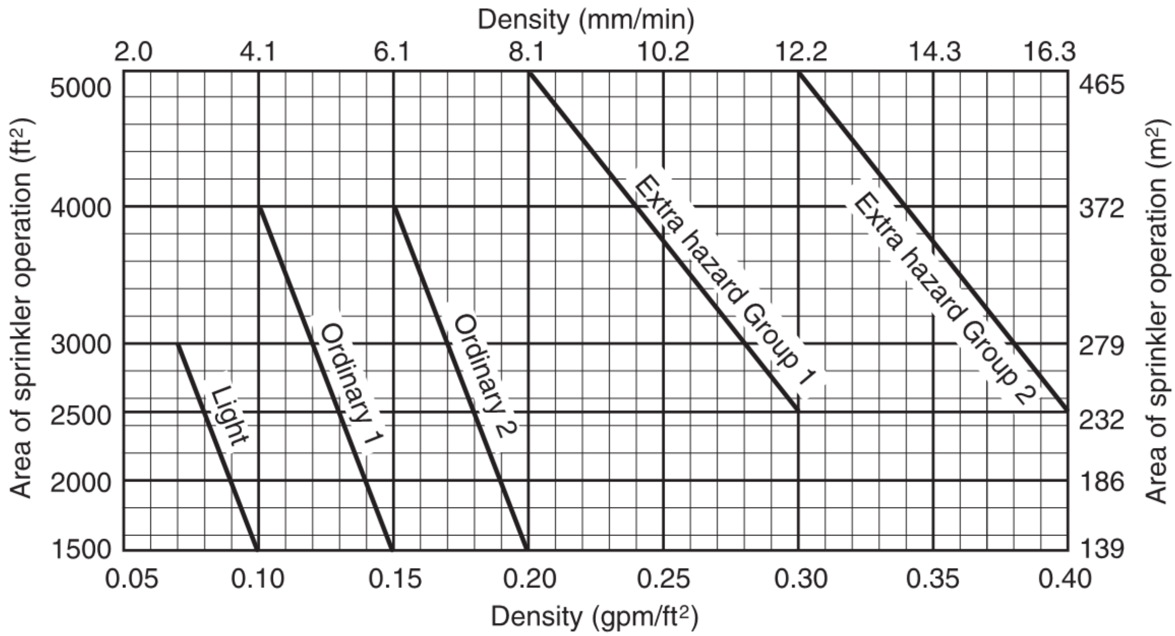


FIGURE 11.2.3.1.1 Density/Area Curves.

From Table 11.2.3.1.2 of NFPA 13, HSA = 250 gpm and duration is 60-90 min.

Table 11.2.3.1.2 Hose Stream Allowance and Water Supply Duration Requirements for Hydraulically Calculated Systems

Occupancy	Inside Hose		Total Combined Inside and Outside Hose		Duration (minutes)
	gpm	L/min	gpm	L/min	
Light hazard	0, 50, or 100	0, 190, or 380	100	380	30
Ordinary hazard	0, 50, or 100	0, 190, or 380	250	950	60–90
Extra hazard	0, 50, or 100	0, 190, or 380	500	1900	90–120

Total flow rate is (0.15 gpm/ft^2 x 1,500 ft^2 + 250 gpm) x 60 min = 28,500 gallons.

The total nominal water demand is 28,500 gallons.

From Section 11.2.3.2.3.2 of NFPA 13, 'The number of sprinklers in the design area shall never be less than five.'

From Table 8.6.2.2.1(b) of NFPA 13, the Protection Area is 130 S.F., with a Maximum Spacing of 15'.

From Section 23.4 of NPFA 13, the number of sprinklers in design area Ns is given by Ns = area of operation/area per sprinkler = 1,500 S.F./130 S.F./sprinkler = 11.54 sprinklers -> 12 sprinklers

Considering the entire Space area of 61,263 S.F., this implies the need for 61,263 S.F./130 S.F./sprinkler = 471.25 sprinklers -> 472 sprinklers

For completeness, this report performs the same CMDA water demand analysis per NFPA 13 for Light Hazard as follows:

From Figure 11.2.3.1.1 of NFPA 13 (shown above in Ordinary hazard calculation), design criteria would be 0.10 gpm/S.F. over 1,500 S.F.

From Table 11.2.3.1.2 of NFPA 13 (shown above in Ordinary hazard calculation), HSA = 100 gpm and duration is 30 min.

Total flow rate is (0.1 gpm/ft^2 x 1,500 ft^2 + 100 gpm) x 30 min = 7,500 gallons.

The total nominal water demand is 7,500 gallons.

From Section 11.2.3.2.3.2 of NFPA 13, ‘The number of sprinklers in the design area shall never be less than five.’

From Table 8.6.2.2.1(a) of NFPA 13, the Protection Area is 225 S.F., with a Maximum Spacing of 15’. This is true whether the construction type is noncombustible unobstructed or combustible unobstructed with no exposed members, so long as the system type is hydraulically calculated.

From 23.4, the number of sprinklers in design area Ns is given by Ns = area of operation/area per sprinkler = 1,500 S.F./225 S.F./sprinkler = 6.67 sprinklers -> 7 sprinklers.

Sprinkler Layout

From the previous sections, the number of risers needed per floor was determined, as well as the protection area and maximum spacing for this project (130 sq. ft. and 15 feet for Ordinary Hazard Group 1).

The protection area, not the maximum spacing, is the limiting factor, such that branch lines can be placed 13 feet apart, with sprinklers on each branch 10 feet apart. To account for the need to ‘shift’ sprinkler placement in the field due to factors such as ceiling tile patterns and obstructions (e.g. exit signs), this report chooses a sprinkler layout with a more conservative spacing—branch lines are placed 12 feet apart, and keep sprinklers on each branch 10 feet apart.

A rough layout of the sprinkler system is shown below in Figures 40 – 45. Note, at times, an additional branch line is added to each cross main, if it seen that additional coverage is needed, such as if a corridor is between two branch lines. Additionally, care is taken to add sprinklers to each room. All of these sprinkler placements should be re-verified in the field, and the final placement will be contingent on what is actually built.

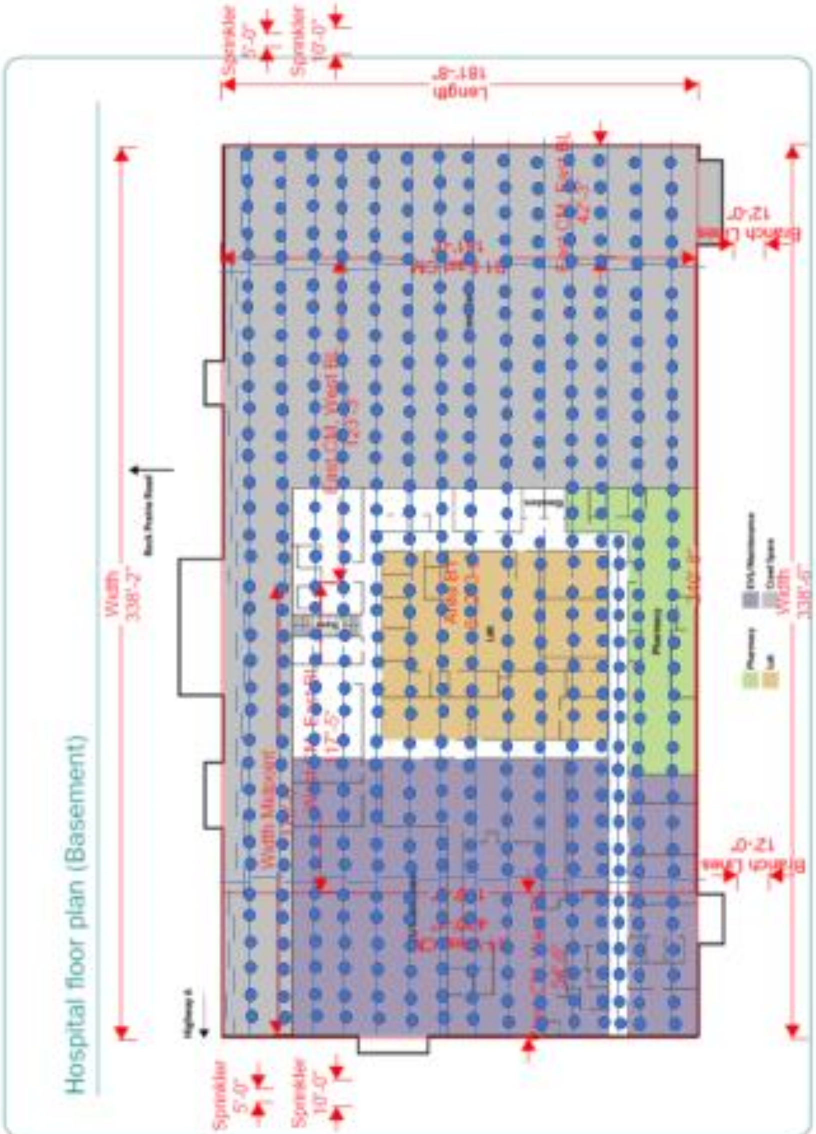


Figure # 40. Basement Sprinkler Layout

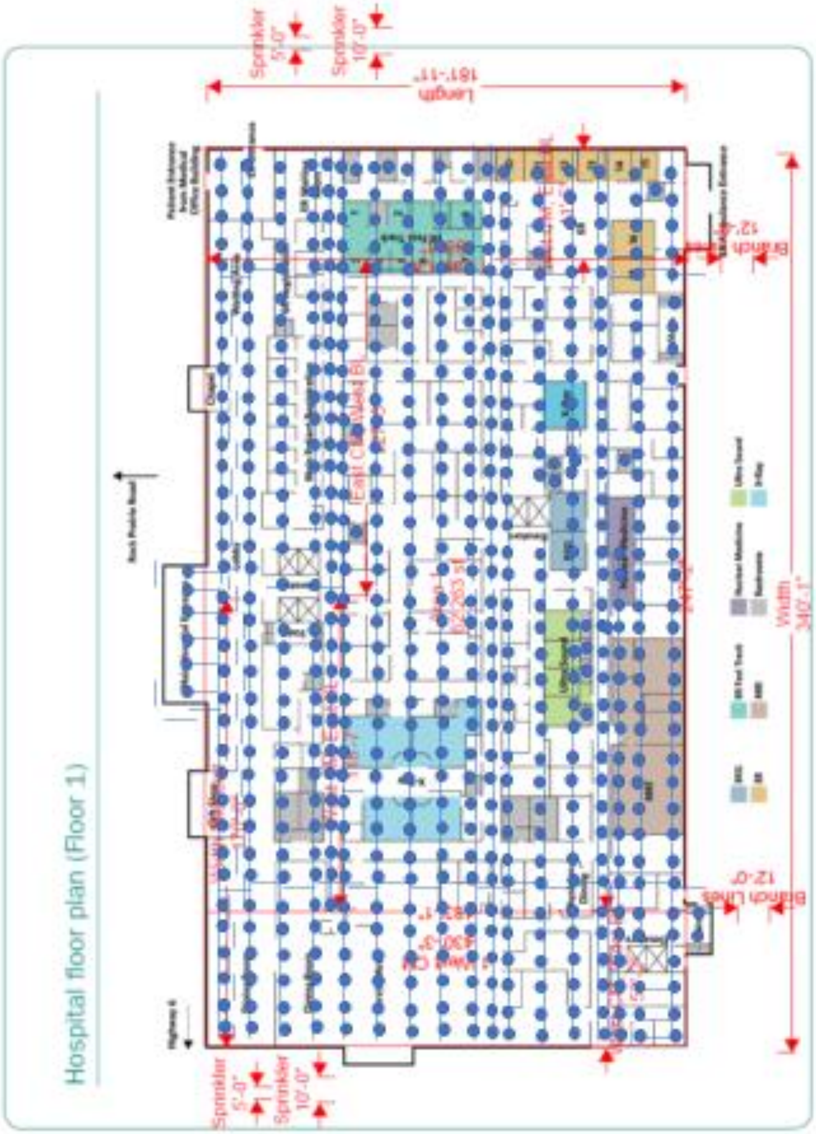


Figure # 41. Floor 1 Sprinkler Layout

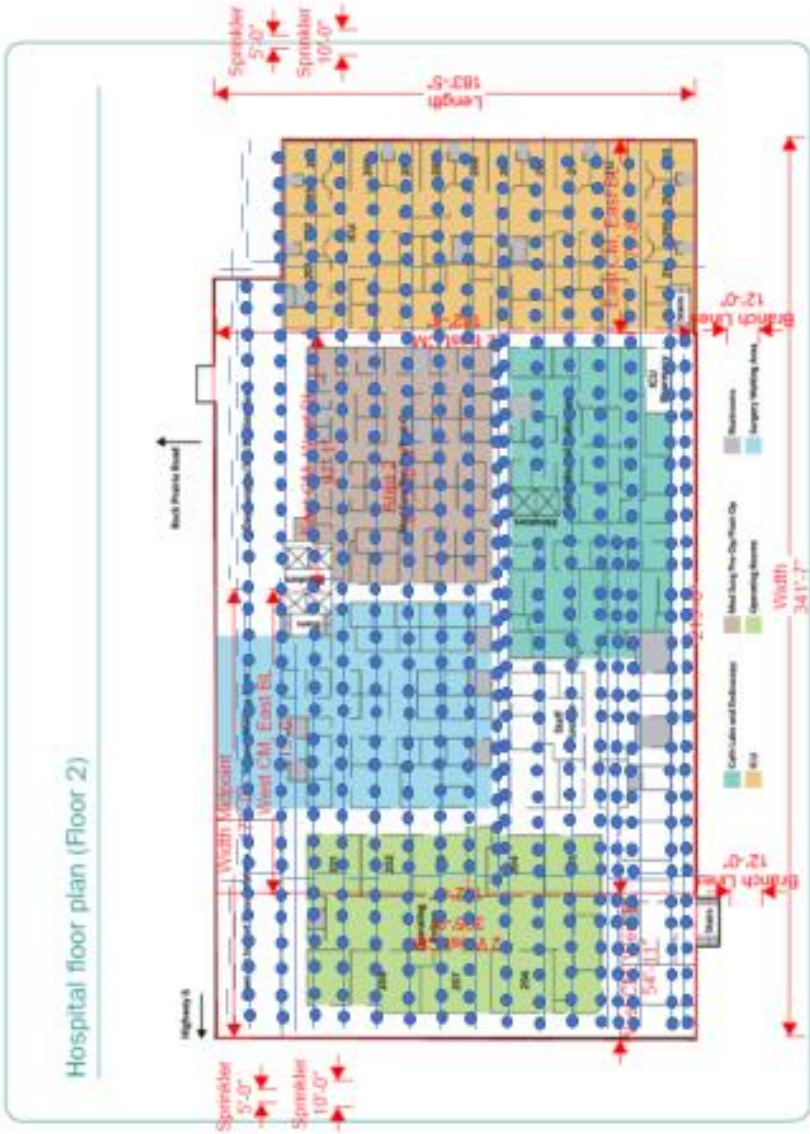


Figure # 42. Floor 2 Sprinkler Layout

Figure # 43. Floor 3 Sprinkler Layout

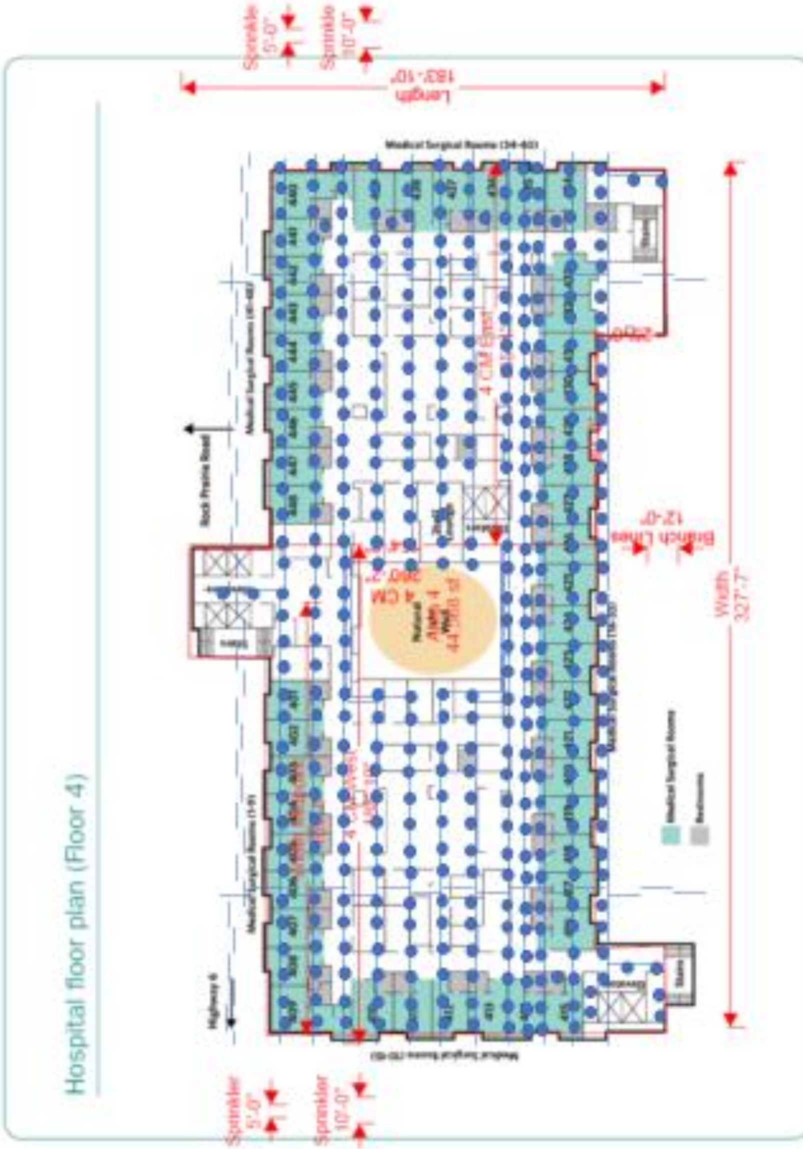


Figure # 44. Floor 4 Sprinkler Layout

Figure # 45. Floor 5 Sprinkler Layout

Design Area

By Section 8.3.4 of NFPA 13, this report uses sprinklers with a K-factor of 5.6 and ½ NPT.

From Section 11.2.3.2.3.2 of NFPA 13, 'The number of sprinklers in the design area shall never be less than five.'

With a width of 40', this report finds a length of 37'-6" for the design area (1500/40 = 37.5). In such an area, there would be 3 branch lines (branch lines spaced 12 feet apart). Each branch line has 4 sprinklers in this area. This report thus considers 12 sprinklers in the design area (4 branch lines x 3 sprinklers per branch line = 12 sprinklers).

A design area for each floor and each riser may be calculated. Such calculations would be assisted by commercial software. For the purpose of this report, it is assumed that an 'overall' design area can be found by finding the most remote area of any floor, and 'adding' the highest elevation to this, in order to find a conservative design area that will dictate the size of fire pump, without detailed analysis for each floor or riser. Naturally, the use of an overall design as described would be a more general solution, and a more detailed analysis may be desired to arrive at a design area that is less conservative. This solution is presented to illustrate an understanding of the concepts and calculations of water-based fire suppression.

Neglecting for the moment, from the sprinkler layout in the previous section, the most demanding design area is on Floor 1, by the main entrance (Figure # 46 below). This is because Floor 1 is the largest floor, and the distance traveled to the main entrance is the furthest horizontal run between the fire pump (and the areas directly above or below the fire pump) to the very end of the cross main and branch lines. In this design area, the extremes of three branch lines, with 4 sprinklers each, are encompassed in this design area. It is to this horizontal travel distance that the vertical height of the highest sprinklers in the building on Floor 5 is added, in order to arrive a general, overall design as described in the preceding paragraph. This overall design is the hypothetical, most demanding area of the sprinkler system that is then used to size the fire pump and estimate sprinkler pipe diameters.

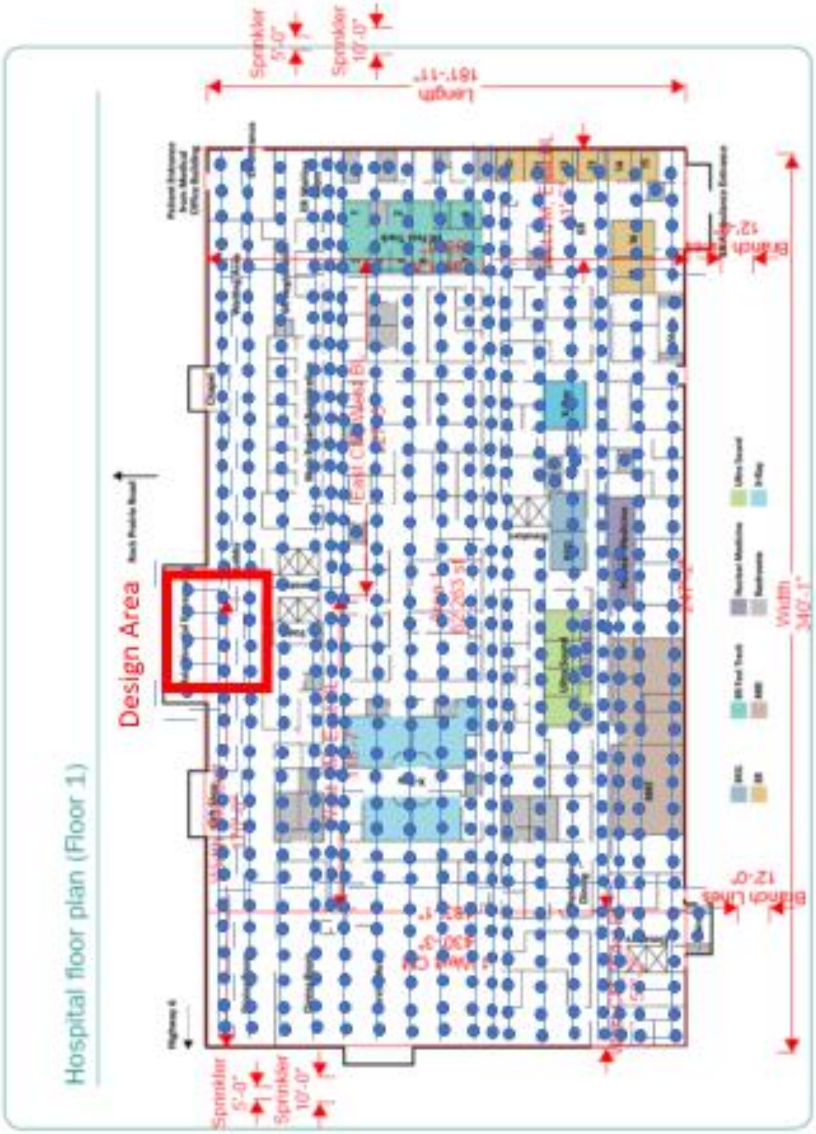


Figure # 46. Sprinkler Design Area

Pipe Sizing

Using the Hydraulic Calculations shown in the next section, this report sizes the sprinkler pipe as Schedule 40 steel with a Hazen Williams Coefficient C = 120 as shown in the next section. The pipe sizes are based on the goal of achieving a friction loss of psi/ft of between 0.1 – 0.2 psi/ft, with a preference towards going below 0.1 psi/ft instead of above 0.2 psi/ft if there was a choice.

Hydraulic Calculations and Graphs

Summary

Hydraulic calculations and graphs are shown in Tables # 26 – 27 and Figures # 47 – 48 for the design area. Additional ones may be generated for each floor and riser, but as discussed in the previous section, this report has combined the most remote section of any floor with the total elevation of the building, to create a conservative design area that can apply to all of the systems. This report uses this design area and determine that the sprinkler demand necessitates the use of a fire pump. A theoretical fire pump based on a 10% safety factor is specified with a rated flow and pressure. One should select the next largest, nominal size of fire pump for installation (as opposed to ordering a custom-built fire pump that matches the theoretical flow and pressure).

As mentioned in the Water Supply section, without more information on the connection between the BOR and POC, this report assumes the pipe used there is the same as is used in the sprinkler system. Depending on one's engineering judgement, the assumption of the same type of pipe used in both the sprinkler and between the BOR and POC does not seem unreasonable, but this assumption can and should be revised once new information comes to light.

Note, this report uses total pressure method only, since it is more conservative than the velocity pressure method.

For a fire pump, this report creates a fire pump curve based on the following points for a given flow and pressure rating:

1. 120% of pressure at churn (0 gpm) – this is more conservative than 140% of pressure at churn
2. 65% of pressure at 150% of flow

To calculate other points on the graphs, this report uses the Hazen Williams formula:

Pa = Ps – (Ps – Pr) * ((Qa / Qt) ^ 1.85), where

Pa is the available pressure

Ps is the static pressure

Pr is the residual pressure

Qa is the actual flow

Qt is the test pressure

This report can rearrange this equation from finding a pressure given a certain flow, to finding the flow given a certain pressure:

Pa = Ps – (Ps – Pr) * ((Qa / Qt) ^ 1.85)

$Pa + (Ps – Pr) * ((Qa / Qt) ^ 1.85) = Ps$

$(Ps – Pr) * ((Qa / Qt) ^ 1.85) = Ps – Pa$

$(Qa / Qt) ^ 1.85 = (Ps – Pa) / (Ps – Pr)$

$Qa / Qt = ((Ps – Pa) / (Ps – Pr)) ^ (1/1.85)$

$Qa = Qt * ((Ps – Pa) / (Ps – Pr)) ^ (1/1.85)$

This report applies this formula to each of the Spaces and graphs above, to find the difference between the City Supply and the Sprinkler Demand curves, in order to find the pump specification (rated pressure/flow).

Hydraulic Calculations

The Sprinkler Demand as shown in Tables # 26 – 27 and Figures # 47 – 48 is 573.7 gpm at 151.1 psi. The available Water Supply is 573.7 gpm at 72.8 psi. With a 10% safety factor, this building would require a fire pump rated for at least 573.7 gpm at 86.2 psi.

Table # 26. Sprinkler Hydraulic Calculations

Step No.	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure		Notes D = 0.2 gpm/S.F. K = 5.6	
1	1	BL-1	q		1-1/4"		L	10	C=	120	Pt	21.6	Pt		Q=	26
							F				Pe		Pv			q = k * (Pt)^1/2
			Q	26.0			T	10	pf	0.055	Pf	0.6	Pn		Pt=	21.6
2	2		q	26.3	1-1/2"		L	10	C=	120	Pt	22.1	Pt		q=	26.33217396
							F				Pe		Pv			
			Q	52.3			T	10	pf	0.096	Pf	1.0	Pn			
3	3		q	26.9	2"		L	10	C=	120	Pt	23.1	Pt		q=	26.8952543
							F				Pe		Pv			
			Q	79.2			T	10	pf	0.061	Pf	0.6	Pn			
4	4	DN	q	0.0	2"	T-15'	L	80	C=	120	Pt	23.7	Pt		q=	
		RN				E-7'	F	22			Pe	0.4	Pv		Pe=	0.433
			Q	79.2			T	102	pf	0.061	Pf	6.2	Pn			
5		CM	q	0.0	2"		L	12	C=	120	Pt	30.3	Pt		q=	
		to					F				Pe		Pv			
		BL-2	Q	79.2			T	12	pf	0.061	Pf	0.7	Pn		K=	14.4
6		BL-2	q	80.2	2-1/2"		L	12	C=	120	Pt	31.1	Pt		q=	80.17783151
		CM to					F				Pe		Pv			
		BL-3	Q	159.4			T	12	pf	0.094	Pf	1.1	Pn			
7		BL-3	q	81.6	3"		L	12	C=	120	Pt	32.2	Pt		q=	81.61618298
		CM					F				Pe		Pv			
			Q	241.0			T	12	pf	0.070	Pf	0.8	Pn			
8		CM	q	82.7	3"	3E-21'	L	460	C=	120	Pt	33.0	Pt		q=	82.67373847
		to				GV-1'	F	38			Pe		Pv			
		FIS	Q	323.7		AV-16'	T	498	pf	0.121	Pf	60.2	Pn			
9		UG	q	0.0	3"	E-7'	L	241	C=	120	Pt	93.2	Pt		q=	
		to				GV-1'	F	23			Pe	26.0	Pv		Pe=	25.98
		main	Q	323.7		T-15'	T	264	pf	0.121	Pf	31.9	Pn			
			q	250.0			L		C=		Pt	151.1	Pt		HSA	250
							F				Pe		Pv			
			Q	573.7			T		pf		Pf		Pn			

Table # 27. Fire Pump Calculation

Q=	323.7	gpm
HSA=	250	gpm
Q+HSA=	573.7	gpm
Q=	323.7	gpm
HSA=	250	gpm
Q+HSA=	573.7	gpm
Qt=	1000	gpm
Ps=	80	psi
Pr=	60	psi
Pa=	20	psi
Qa=	1810.937	gpm
Qt=	1000	gpm
Ps=	80	psi
Pr=	60	psi
Qa=	573.7	psi
Pa=	72.84532	psi
90% Pa=	64.84532	
Delta P=	86.2	psi
Pump		
P	86.2	psi
Q	573.7	gpm
120% P	103.4599	psi
0% Q	0	gpm
65% P	56.04079	psi
150% Q	860.5428	gpm
Combined		
P	159.1	psi
Q	573.7	gpm
120% P	183.4599	psi
0% Q	0	gpm
65% P	120.8927	psi
150% Q	860.5428	gpm

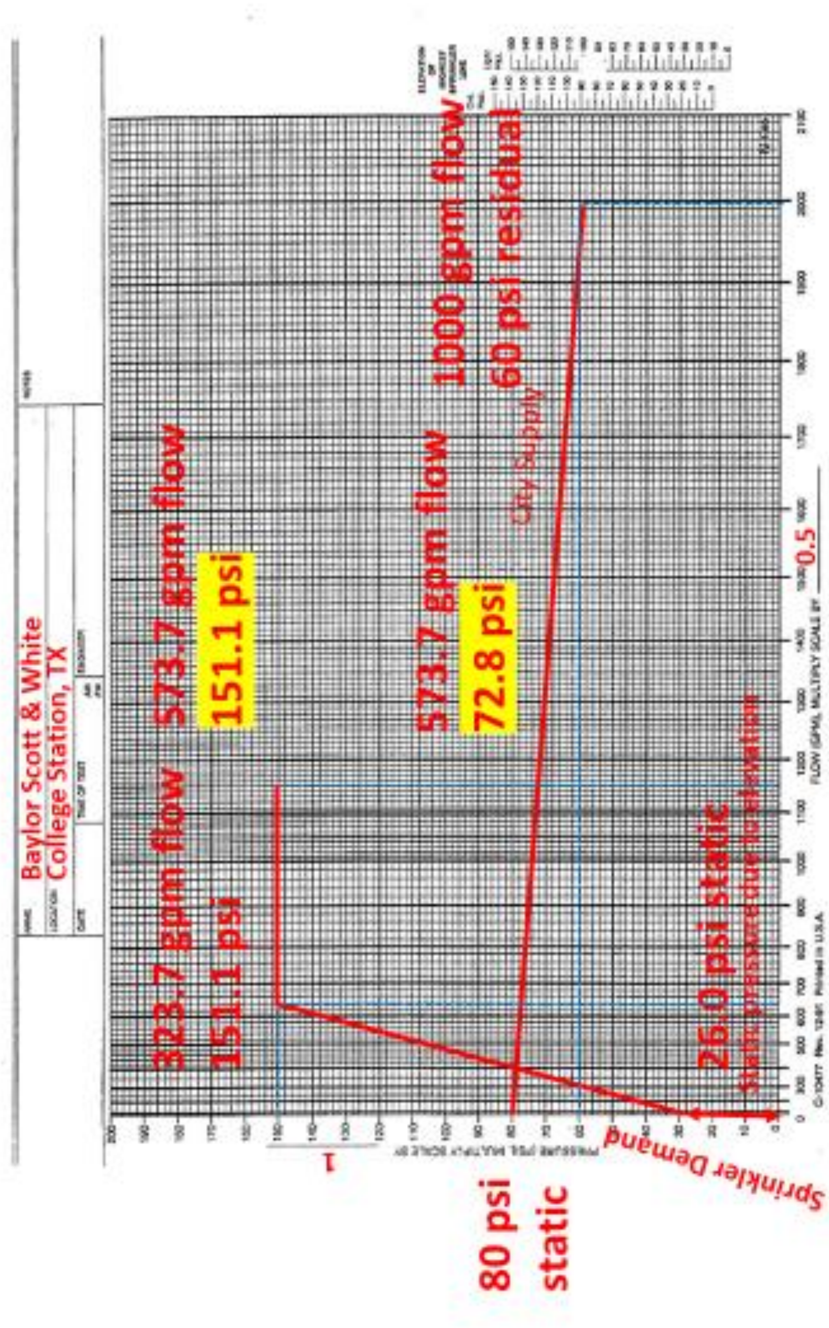


Figure # 47. Sprinkler Demand Curve

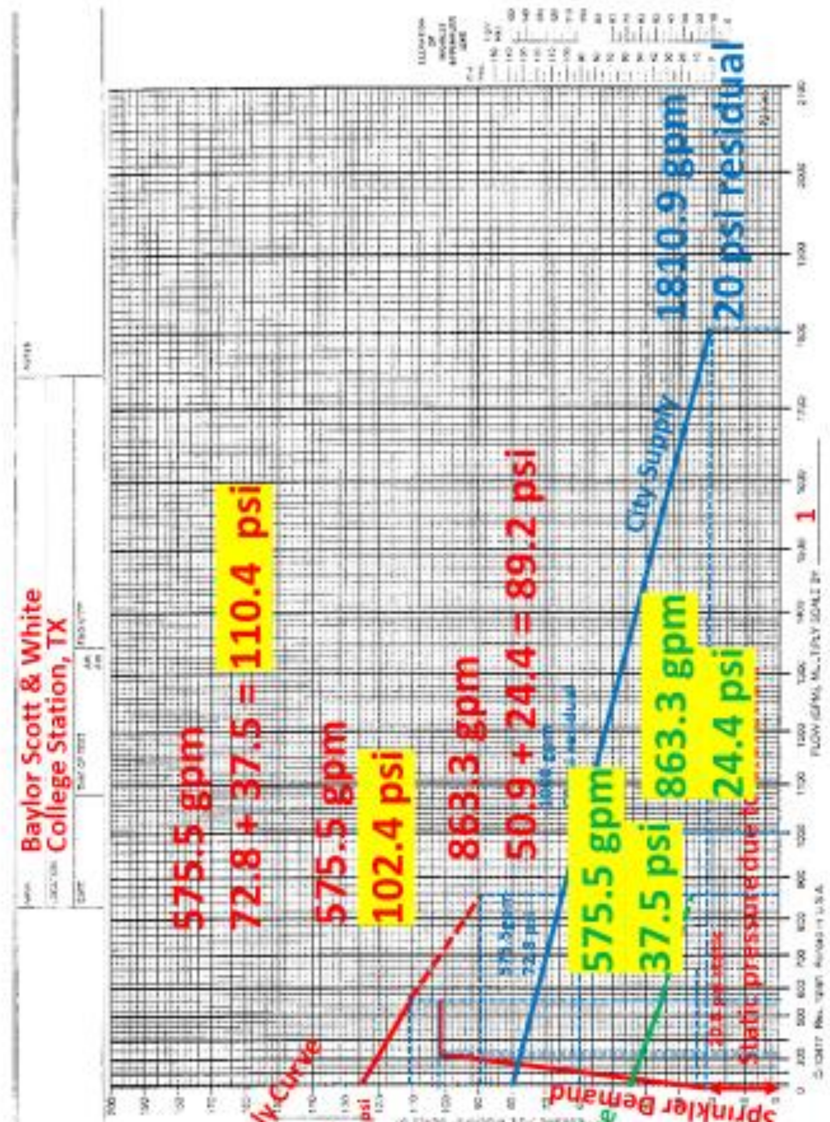


Figure # 48. Combined Supply Curve

Inspection, Testing, and Maintenance Requirements

Inspection, testing, and maintenance (ITM) should be performed according to NFPA 25. Note, while experts and contractors may be used, ITM it is ultimately the property owner's responsibility (Baylor Scott & White Medical Center in this case).

NFPA 25 requires quarterly and annual tests. Quarterly tests include visual checks of valves, gauges, water flow and supervisory alarms, nameplates, fire department connections, and pressure-reducing valves and relief valves. Annual tests include visual checks of all sprinkler heads, stocks of spare sprinkler heads, the interior of dry valves, and a main drain water flow test. Fire pumps also have monthly or quarterly tests (depending if a diesel or electric fire pump is installed), as well as an annual test. NFPA 25 discusses fire pump ITM, and NFPA 20 also has more details regarding fire pump ITM.

It is also recommended that visual inspections of the sprinkler system by staff take place on a regularly scheduled basis as part of routine maintenance, beyond the requirements of NFPA 25. These maintenance rounds can include checking for missing sprinklers, damaged pipe, vandalism, signs of corrosion, and obstructions to equipment.

Engineering reevaluations of the sprinkler system may also be done, especially and if the building or spaces are modified.

Conclusion

This report considered a design to provide protection to the Baylor Scott & White Medical Center in College Station, TX through a water-based fire suppression system, in the form of a wet pipe sprinkler systems. The calculations divided the total area under consideration into separate Spaces, and considered each individually. This report specified sprinkler types, pipe layout and sizing, and fire pumps per FPE 523 and NFPA 13.

The approach taken in this chapter is a simple one by choice. It is likely another engineer can identify improvements to the designs proposed here—the choice of a tree layout instead of a grid, the specific pipe sizes used, and research into the piping between the BOR and POC are some low-hanging fruit that come to mind. However, it is hoped that this chapter demonstrates sound engineering judgement, as well as a basic understanding of water-based fire suppression systems. This report next examines the notification systems of this building.

Alarms

Introduction

Unless otherwise noted, all code references in this chapter come from the 2016 edition of NFPA 72: National Fire Alarm and Signaling Code. Other codes referenced include the 2018 edition of NFPA 99: Heath Care Facilities Code and the 2018 edition of NFPA 101: Life Safety Code, as well as the 2018 addition of the International Fire Code and International Building Code.

Body

Fire Alarm and Communication Systems

Type of Fire Alarm

As a first stage, the fire alarm and communication system for the project building is designed as a protected premises (local) system. It is the intent that this system be designed in anticipation of 'upgrading' to another type of system, such as a remote or proprietary supervising system (whether in the future or as a modification of this design per stakeholder desires).

EVACS or MNS may also be considered, depending on other infrastructure such as PA speakers or video screens. The use of EVACS or MNS is discussed in more detail in the Emergency Communication System section of this report.

Operating Characteristics

This fire alarm system is designed to be a private alarm system. In conjunction with AHJ, building owners, staff, and other stakeholders, the intent of this design is one of extensive detection, with controlled and measured alarm, response, and movement. To that effect, this report uses multi-sensor detectors throughout the facility. These will serve to decrease fire detection times, over relying on water flow activation switches from water-based fire suppression system this report has discussed in chapters above.

Model and Location of Fire Alarm Control Panel

In keeping with the design philosophy of anticipating additional upgrades, this report selects a fire alarm control panel that can be adapted for future demands. A EST3-Sixty Fire Alarm Control Panel is used, and is located by the main entrance of the hospital. Cut sheets for this equipment are attached as a supplement to this report, separate from the Appendixes, and its location can be seen on plan views.

Fire signatures and detection devices

Types and locations of initiating devices installed in the building

This building uses both smoke detectors and manual fire pull boxes as the initiating devices. A plan view of the device placement is shown in Figures 49 – 54. Devices are placed per the IFC, IBC, NFPA 72, NFPA 70, NFPA 99 Health Care Facilities Code, NFPA 101 Life Safety Code. Though no MEP systems such as ductwork and HVAC are not shown, smoke duct detectors must also be installed to shut down fans and close dampers to prevent smoke from traveling from one smoke compartment to another through ductwork. Additional discussion of duct detectors and HVAC system operation, as well as a Sequence of Operations, is in Appendix D of this report.

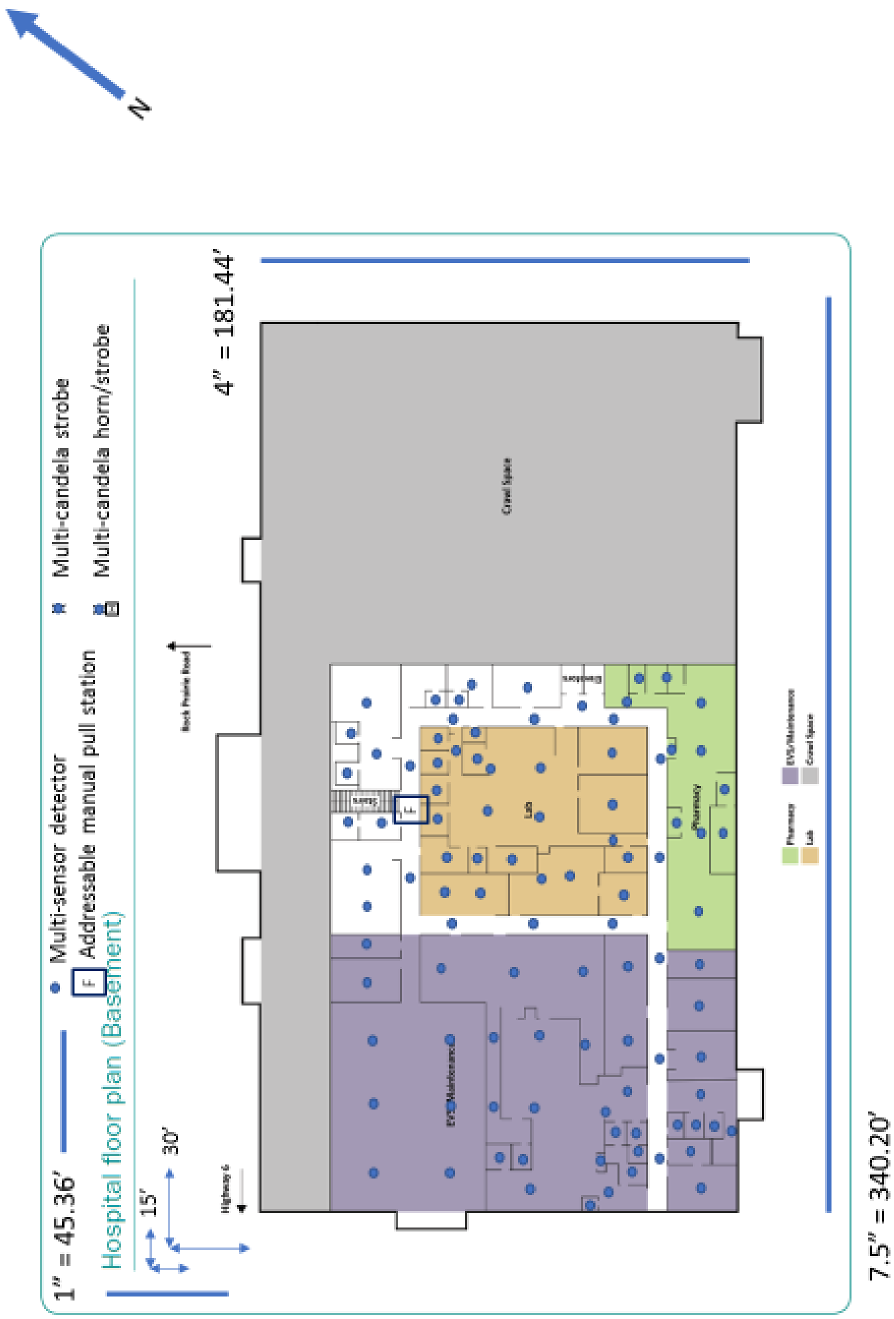


Figure # 49. Basement Initiating Device Locations

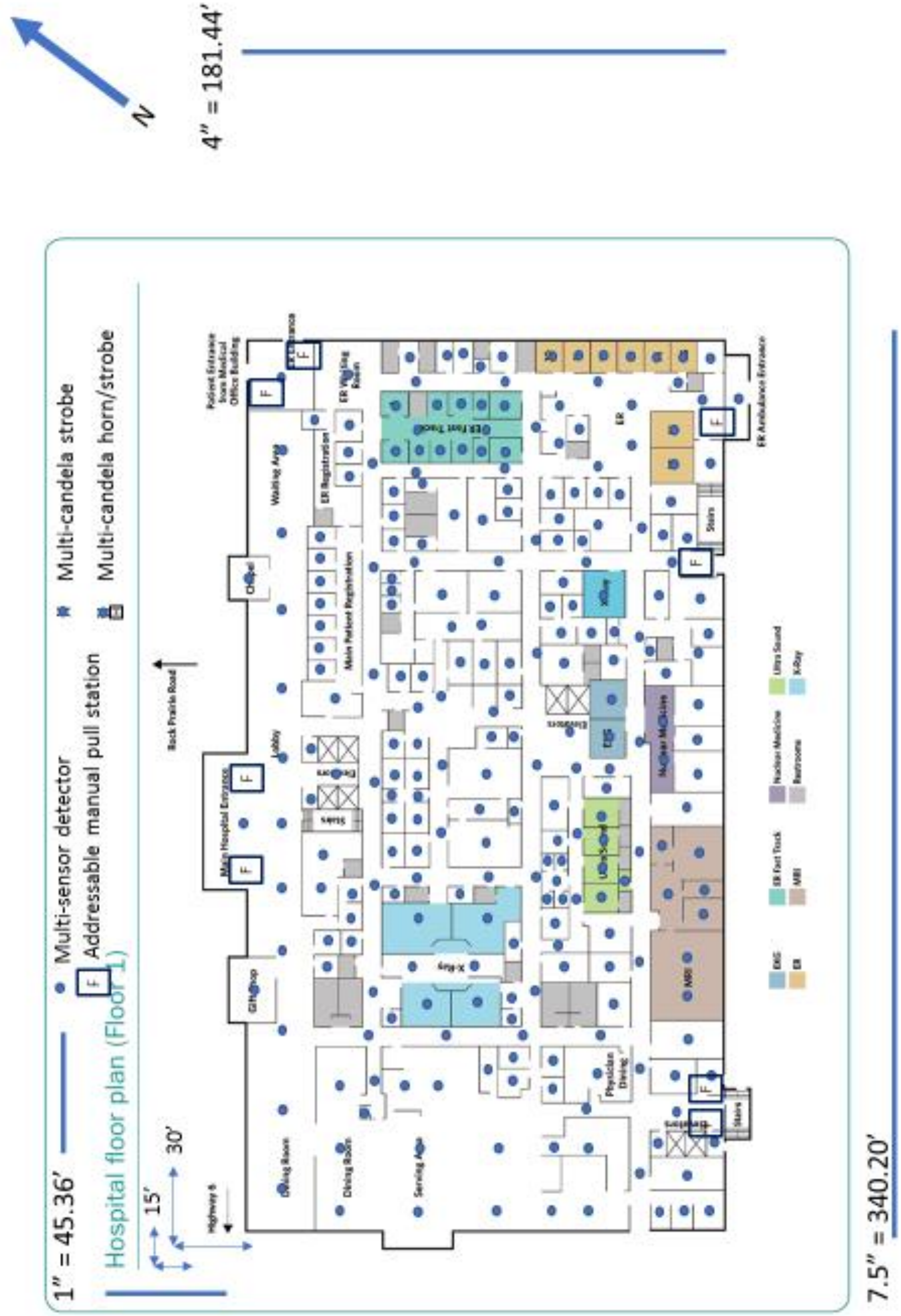


Figure # 50. Floor 1 Initiating Device Locations

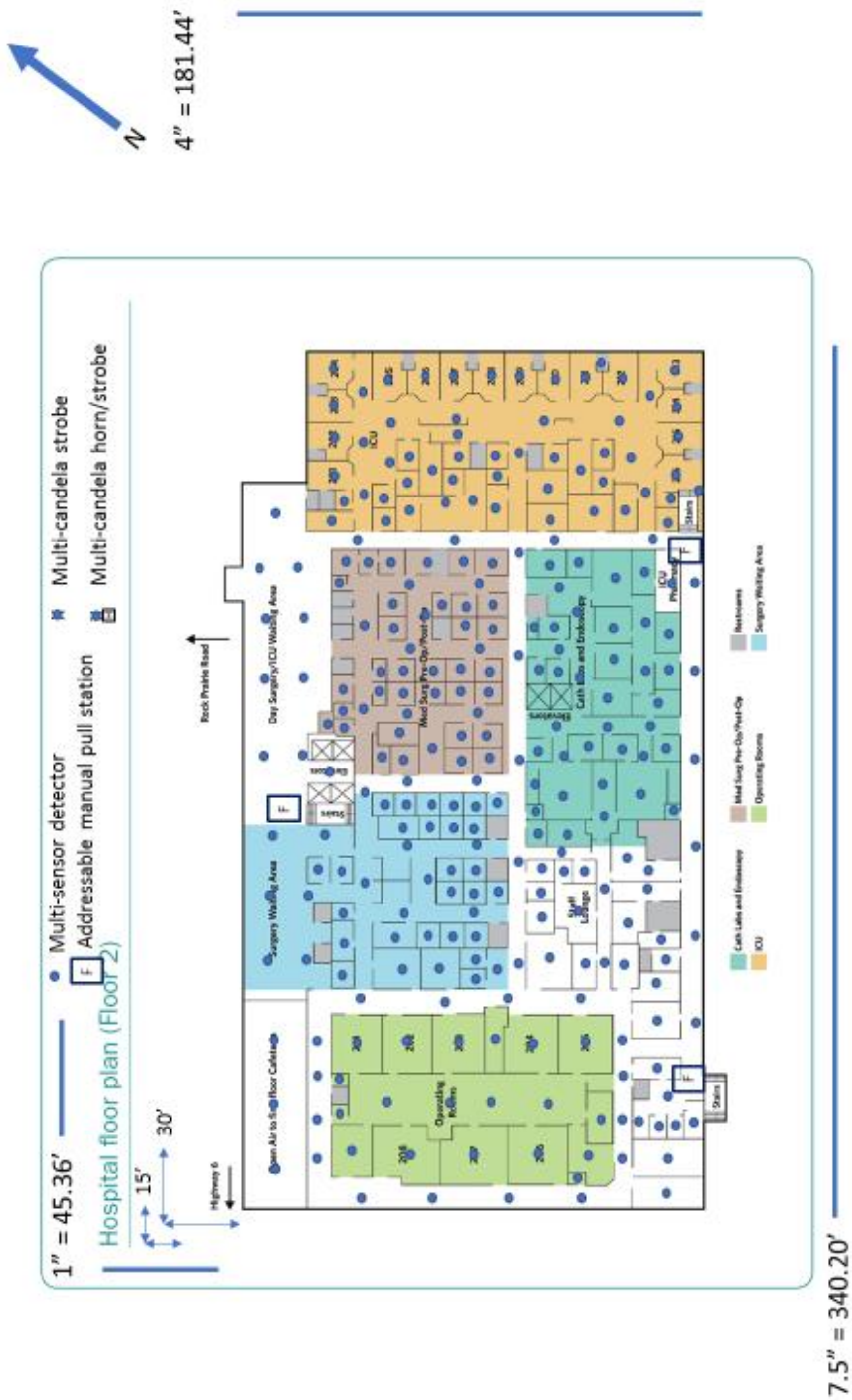


Figure # 51. Floor 2 Initiating Device Locations

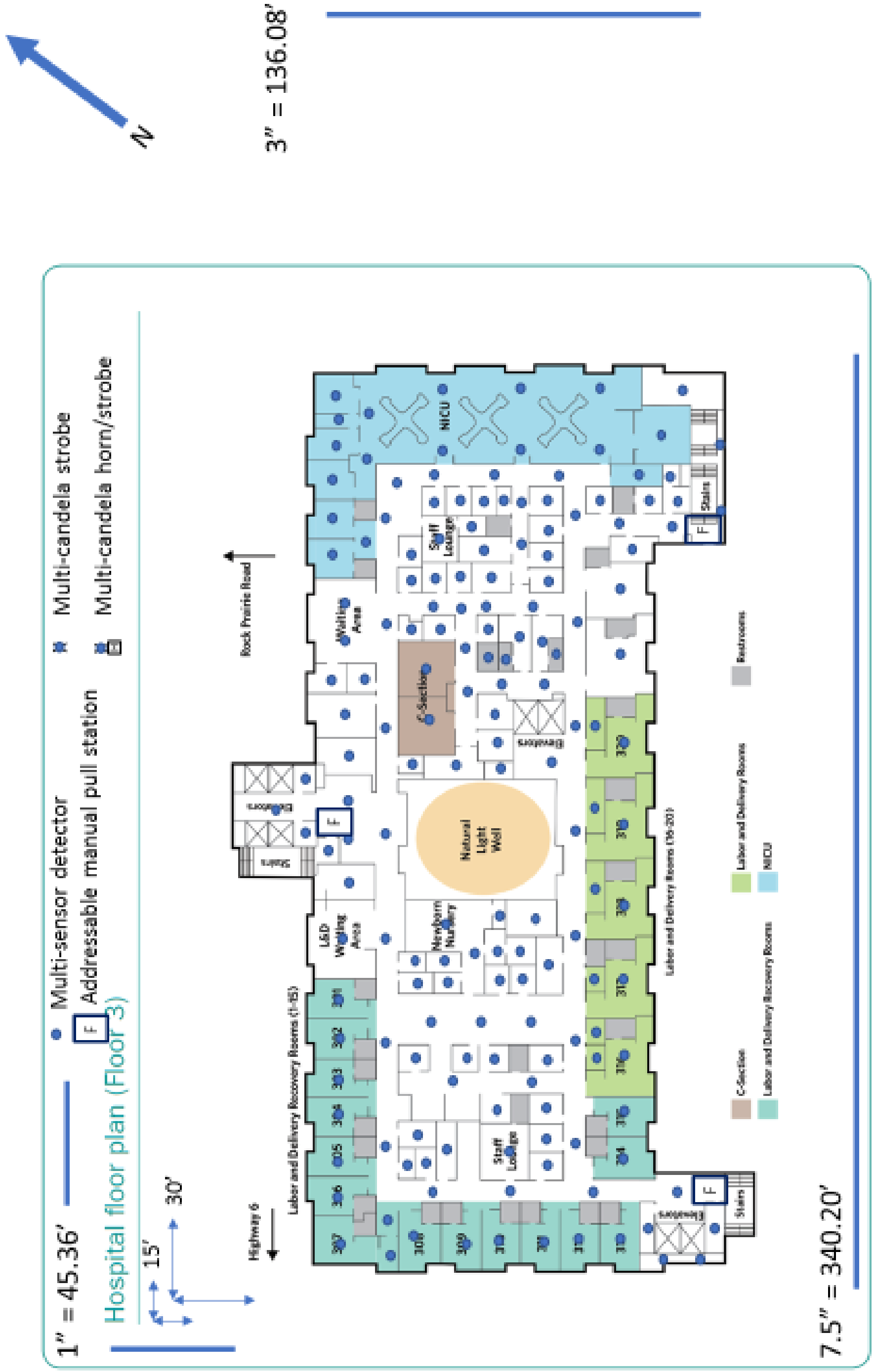


Figure # 52. Floor 3 Initiating Device Locations

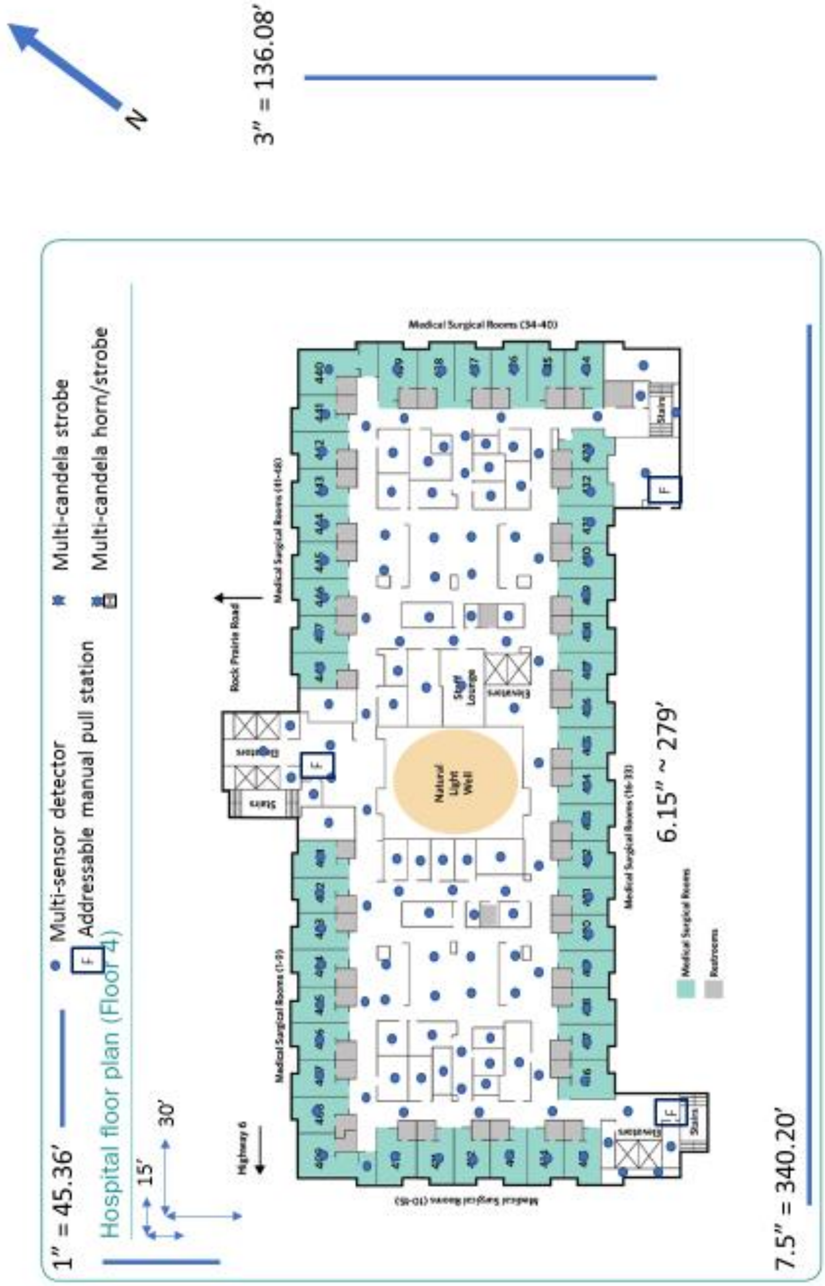


Figure # 53. Floor 4 Initiating Device Locations

Figure # 54. Floor 5 Initiating Device Locations

Location, spacing and placement of fire detection devices

Location, spacing and placement of the fire detection devices installed in the building, and compliance with the requirements of the National Fire Alarm and Signaling Code

This report developed a design for the location, spacing, and placement of the fire detection devices in compliance with the requirements of the National Fire Alarm and Signaling Code. In doing so, several assumptions were made:

1. Assume smooth, flat 10' ceilings.
2. From NFPA 99, 16.7.3 Smoke Detectors, this report designs the smoke detector system in accordance with NFPA 72.
3. From NFPA 101, 9.1.5 Health Care, this report references Chapters 18 and 19 for requirements.
4. From NFPA 101, 9.6 Fire Detection, Alarm, and Communications Systems, this report references see Chapters 18 and 19 for requirements.

By 27.6.2.1.7, a publicly accessible alarm box is placed at the main entrance.

This report set the smoke detector spacing according to 17.7.3.2.3.1, with a nominal 30' spacing and coverage so distances are equal to or less than 0.7 times the nominal 30' spacing between any detectors. Additional guidance can be found in Annex A, e.g. Figure A.17.6.3.1.1(h) Smoke or Heat Detector Spacing Layout in Irregular Areas.

This report also set smoke detector spacing based on 17.6.3.1, 17.7.3, 17.7.6.3.3, Table 17.7.6.3.3.2, 23.8.5.4.4, A.17.6.3.1.1, A.17.6.3.1.3.1, A.17.7.3.1 to A.17.7.3.7.88, A.17.7.6.3.3, B.4. This report also reviewed the following code references sections for detector location and spacing on ceilings: 17.6.3, 17.7.3, 29.5.1.3.1, 29.5.1.3.2, 29.8.3.1 to 29.8.3.4, 29.8.4, A.17.6.3.1.1 to A.17.6.3.6, A.17.7.3.1 to A.17.7.3.7.8, A.29.5.1.3.1, A.29.8.3.1 to A.29.8.3.4(11), A.29.8.4, Annex B. A plan view of the device placement is shown in Figures 55 – 60.

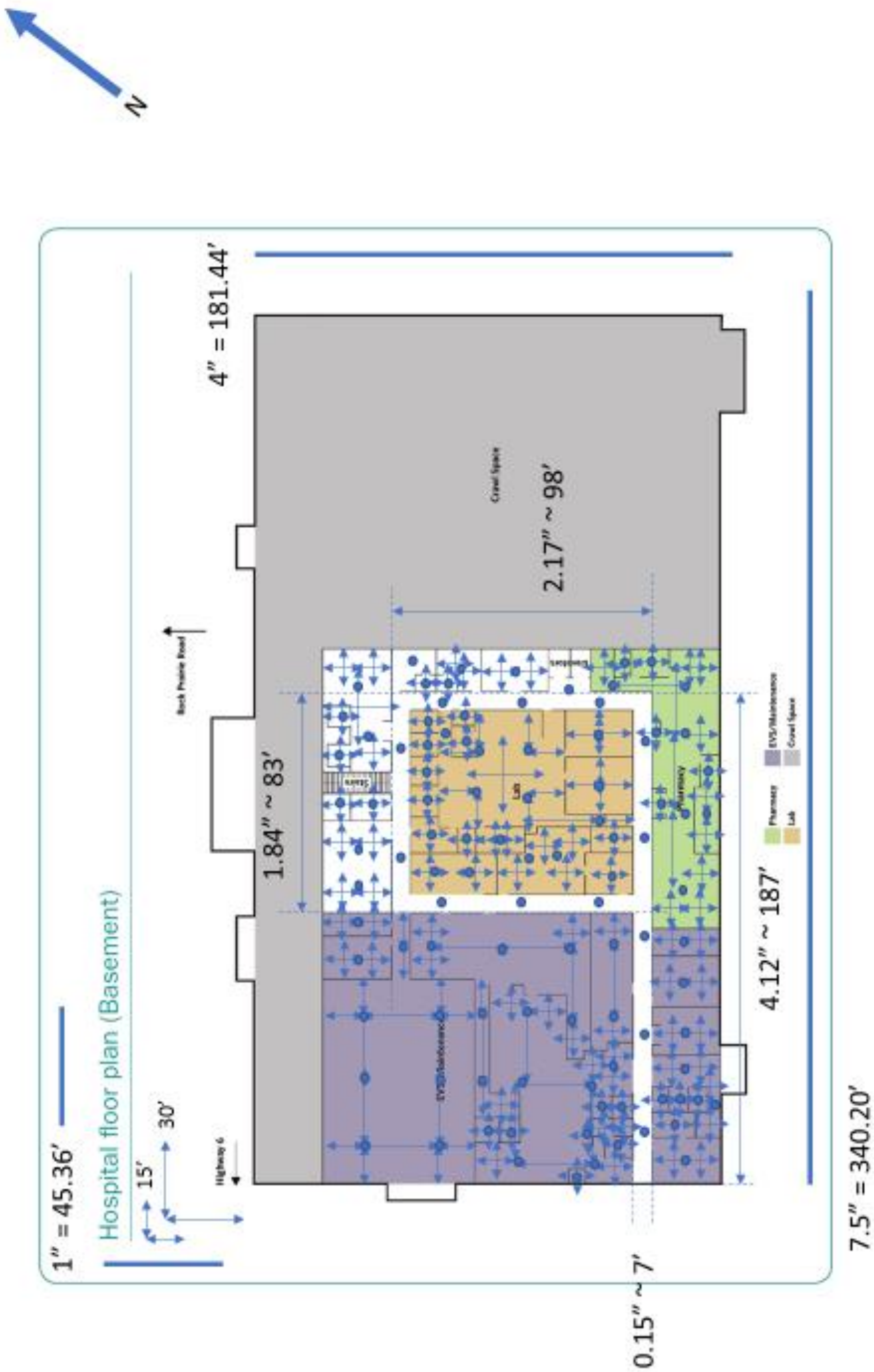


Figure # 55. Basement Location, Spacing, and Placement of Fire Detection Devices

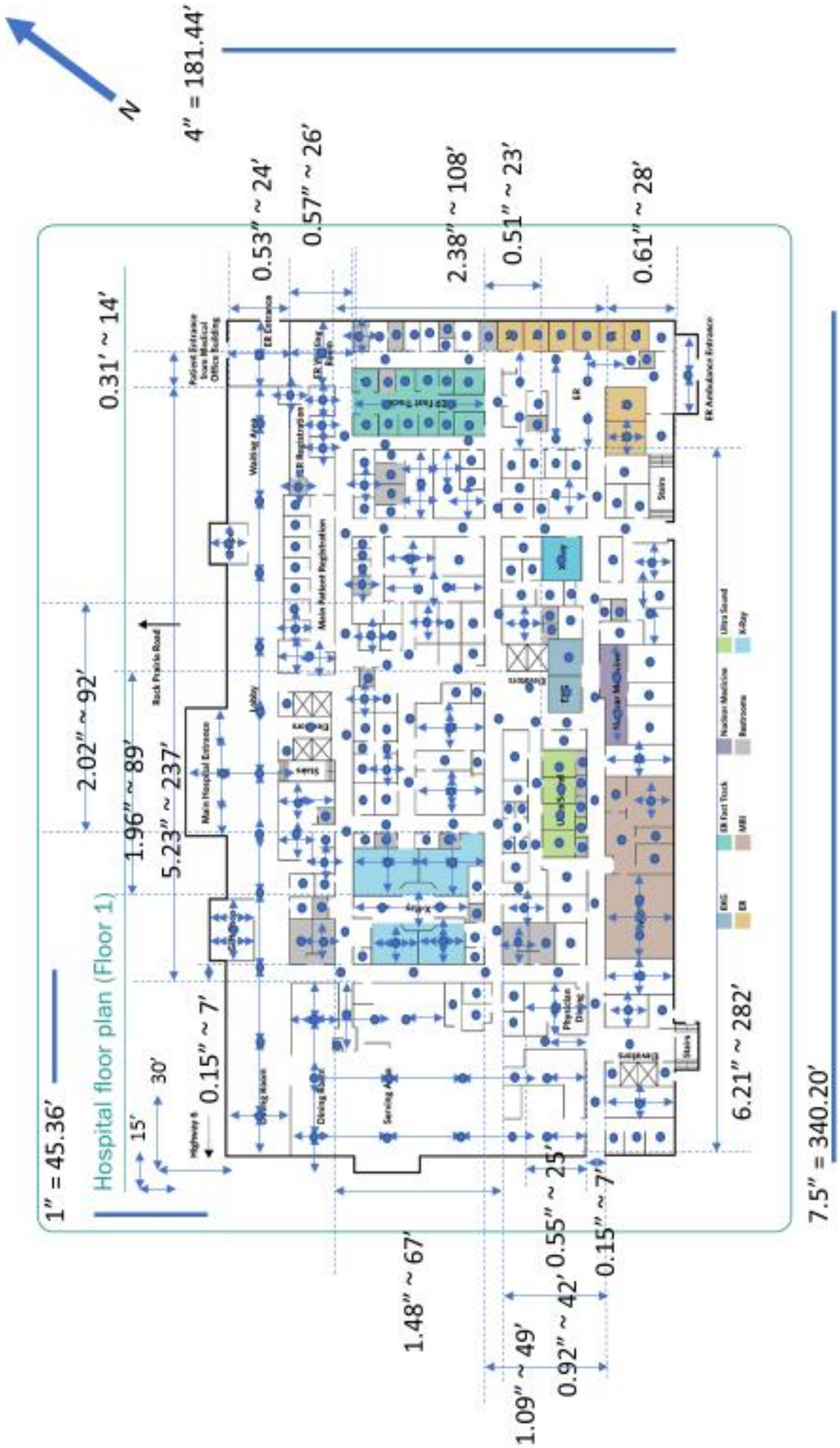


Figure # 56. Floor 1 Location, Spacing, and Placement of Fire Detection Devices

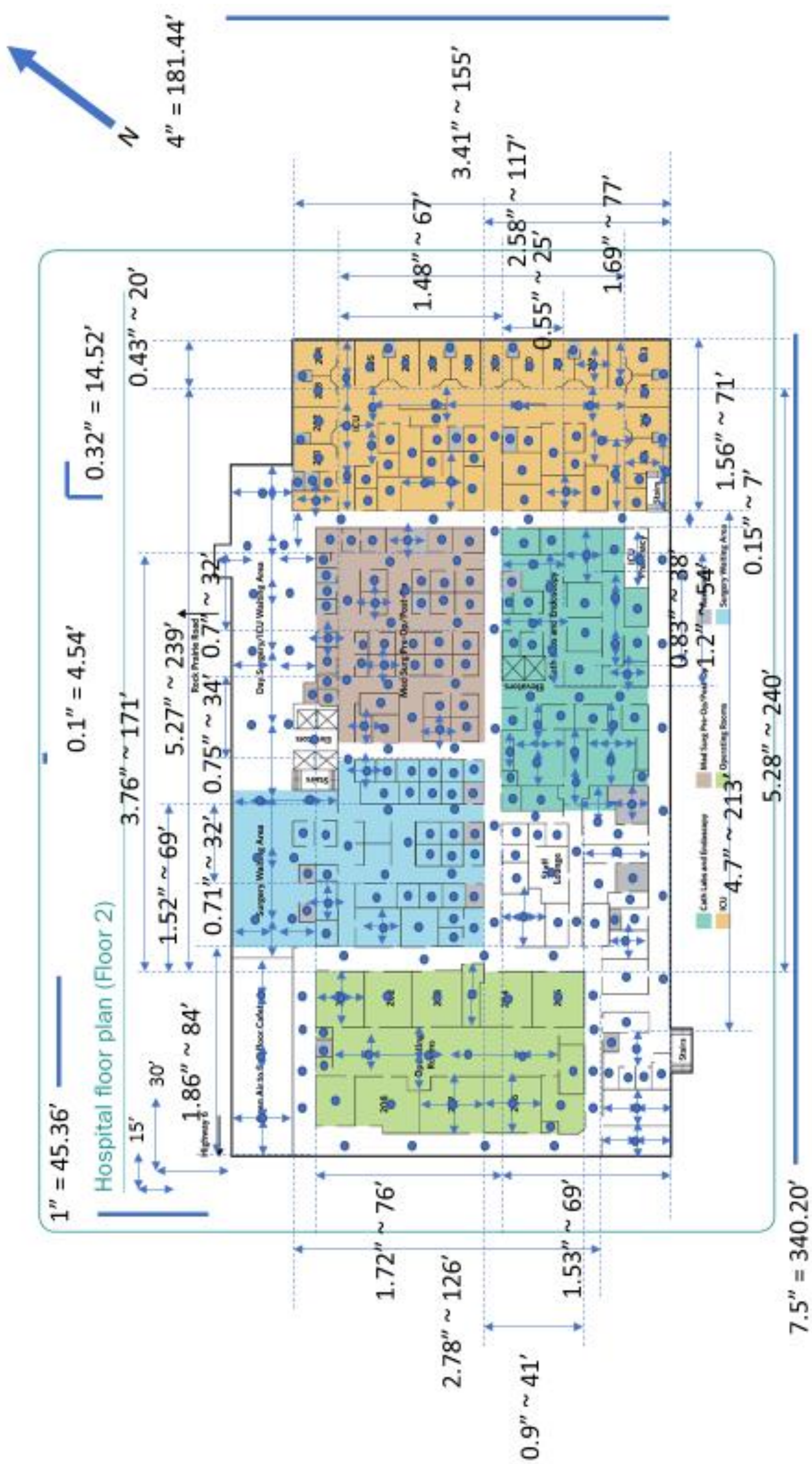


Figure # 57. Floor 2 Location, Spacing, and Placement of Fire Detection Devices

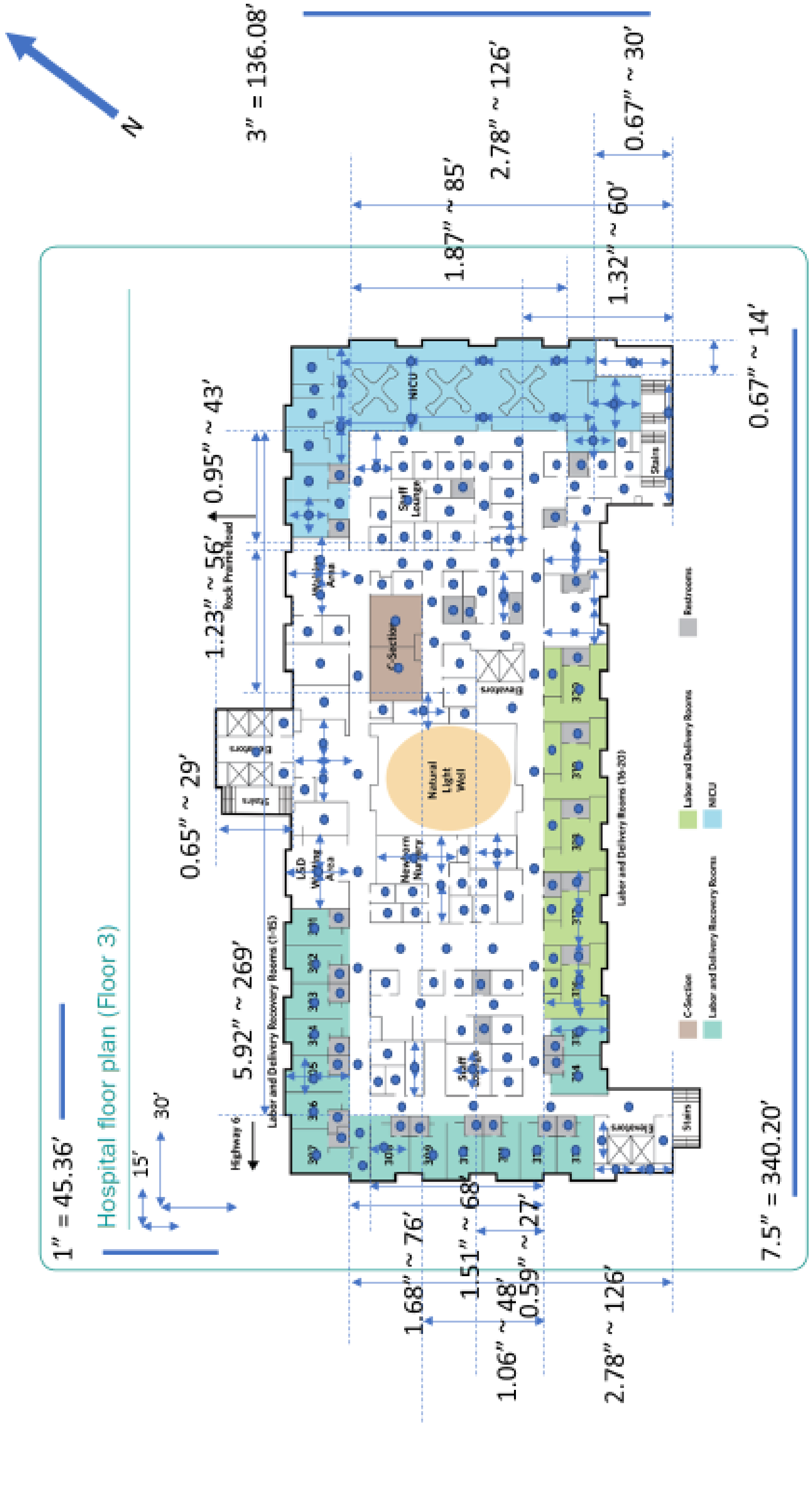


Figure # 58. Floor 3 Location, Spacing, and Placement of Fire Detection Devices

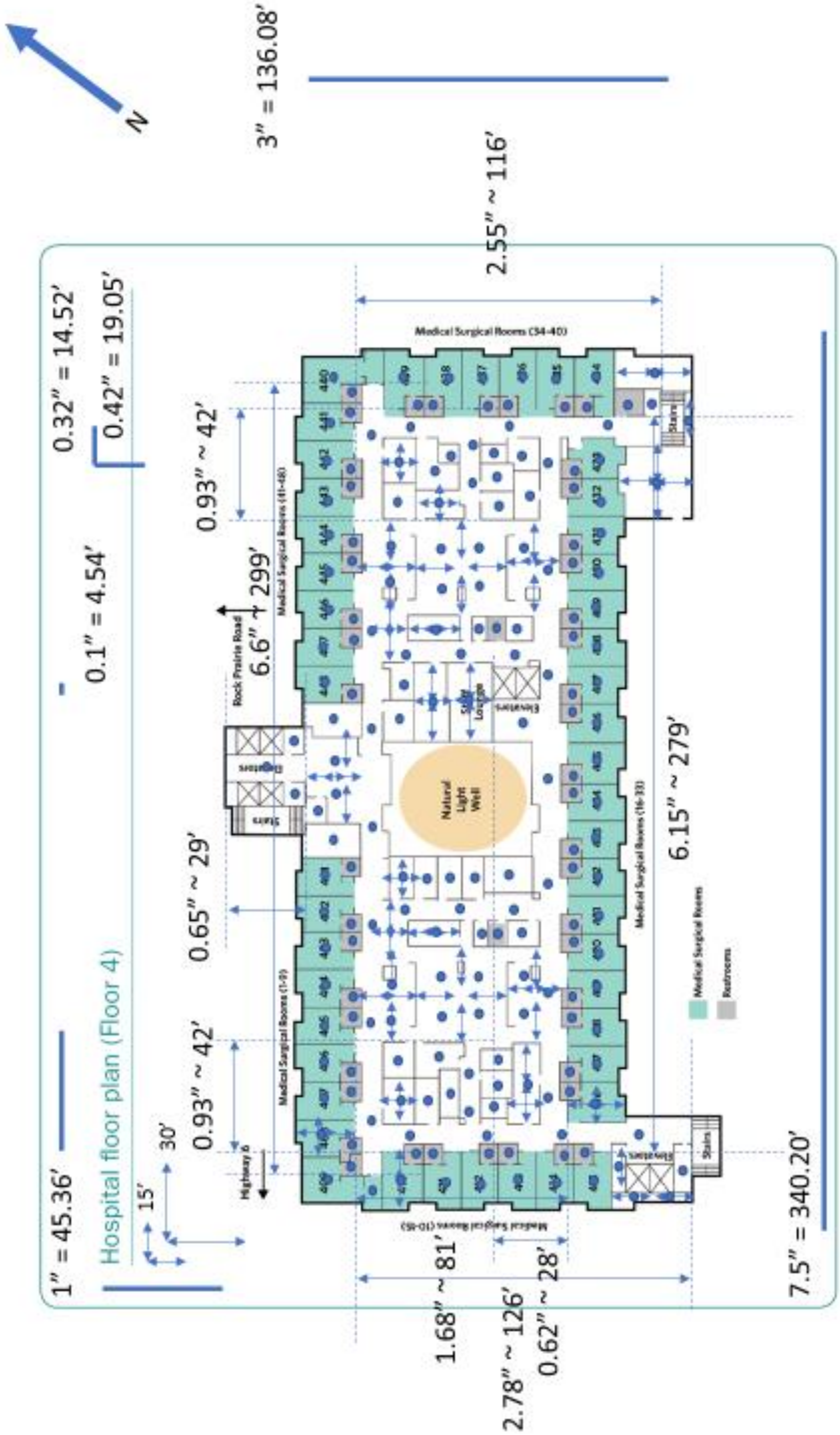


Figure # 59. Floor 4 Location, Spacing, and Placement of Fire Detection Devices

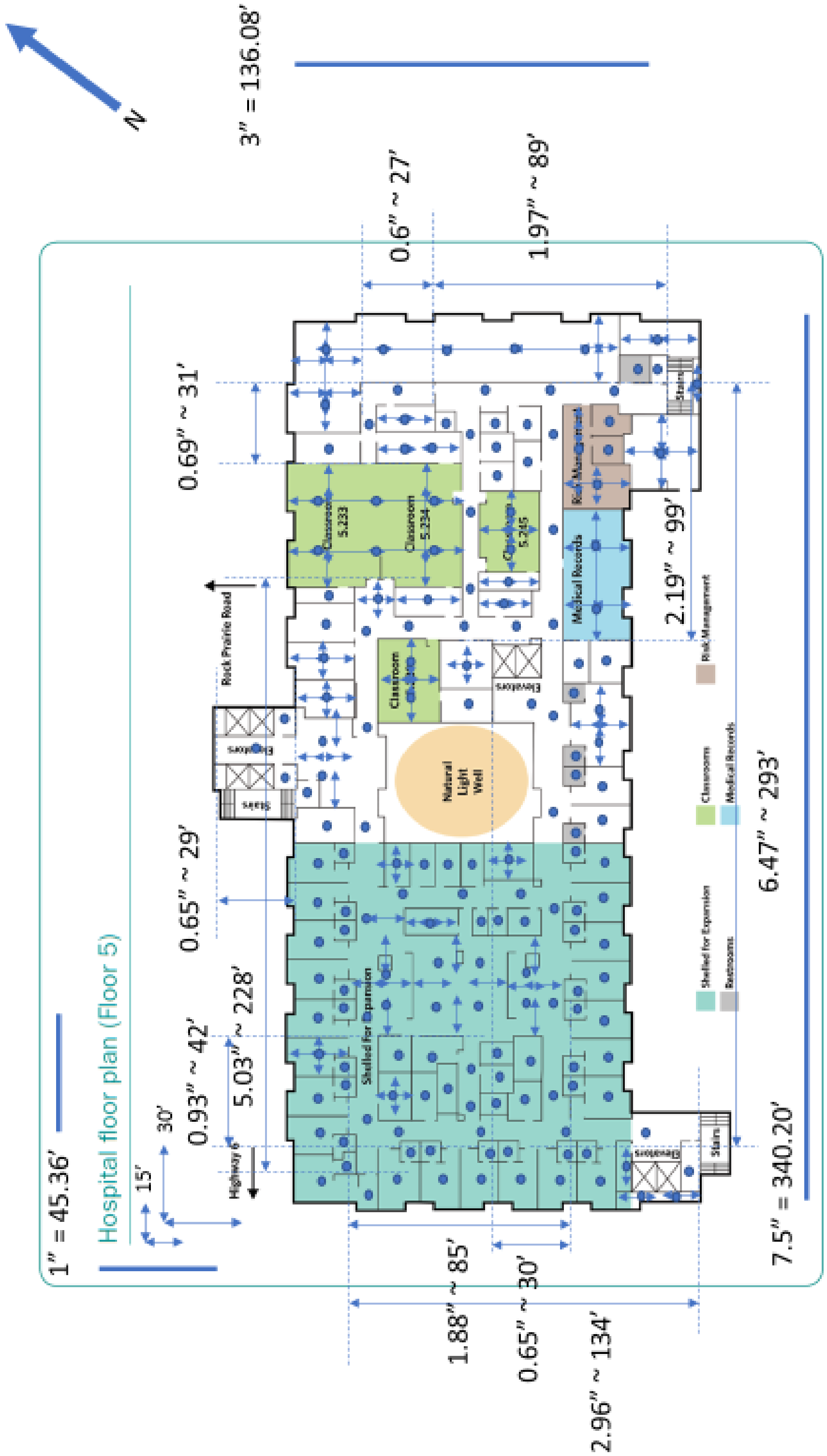


Figure # 60. Floor 5 Location, Spacing, and Placement of Fire Detection Devices

Fire Alarm System Types and Requirements

Type of Fire Alarm System

Cut sheets describing the model, make, equipment that is connected are attached at the end of this report. This report designed for a protected premises (local), while also selecting equipment to lay a foundation that may be incorporated into upgrades/expansions (e.g. emote supervising station).

Requirements for the Disposition of Alarm, Supervisory and Trouble Signals

Alarm, Supervisory and Trouble Signals are defined in NFPA 72-201 (3.3.58.1.1, 3.3.58.1.3, and 3.3.58.1.4 respectively). This report also includes discussions from FPE 522 below:

Alarm: in general, alarm signals mean that there is a fire condition. Someone pulls the fire alarm, you get a sprinkler water flow, a smoke detector activates. Fire pump starts running (falls in the middle, can treat as a supervisory signal). More information in 23.8.5.1.
Supervisory: is your system in its normal operating condition? Are the valves open (valve tamper switches)? Do we have adequate air pressure, do we have adequate water temperature, etc. More information in 23.8.5.6.
Trouble: the system monitoring itself, annunciating if it is an off-normal situation, where it cannot perform its functionality.

From NFPA 72-2016 and class, this report has the following information for disposition (additional details in the code):

Table A26.1
26.1.1
26.2.1 Alarm signal disposition
26.2.2 Other signal disposition

(1) alarm (26.3.7.1, 26.3.7.2)
warning of fire danger that requires immediate action
(2) supervisory (26.3.7.3)
action is needed in connection with the operation of other fire protection systems that are being monitored by the fire alarm system
(3) trouble
fault in a monitored circuit or component of the fire alarm system or the disarrangement of the primary of secondary power supply

Alarm Notification Appliances

Types and Locations of Alarm Notification Devices

This report uses strobe lights as the alarm notification devices in this building. These devices are placed per the IFC, IBC, NFPA 72, NFPA 70, NFPA 99 Health Care Facilities Code, NFPA 101 Life Safety Code. The presence of these devices—and the lack of horn alarm notification devices—was set in accordance with these codes.

This report does not use any audible alarm notification devices in the notification design. This is permitted by code for the occupancy, and is consistent with the principles of life safety. This is because it is reasonable to assume many patients in this hospital will be unable to self-evacuate (as a result of whatever treatments they have led them to the hospital in the first place). With that in mind, an audio notification does not serve its purpose in notifying occupants of a fire so that they can move to safe location, whether that is a shelter or out of the building. Instead, this might have the contrary effect of creating panic (perhaps unduly, in the case of false alarms) and causing difficulties for the staff in calming and moving the patients. Instead, this report relies on the presence of a trained staff, following emergency plans as required in the IFC and IBC.

This design does include the installation of visual strobe light alarm notification devices at staff/nurse control stations on each floor, as well as in corridors on floors that would likely have able-bodied visitors (first two floors of the building, which house visitor registration, the pharmacy, and the top floor, which has classrooms). A plan view of the appliance placement is shown below in Figures 61 – 66.

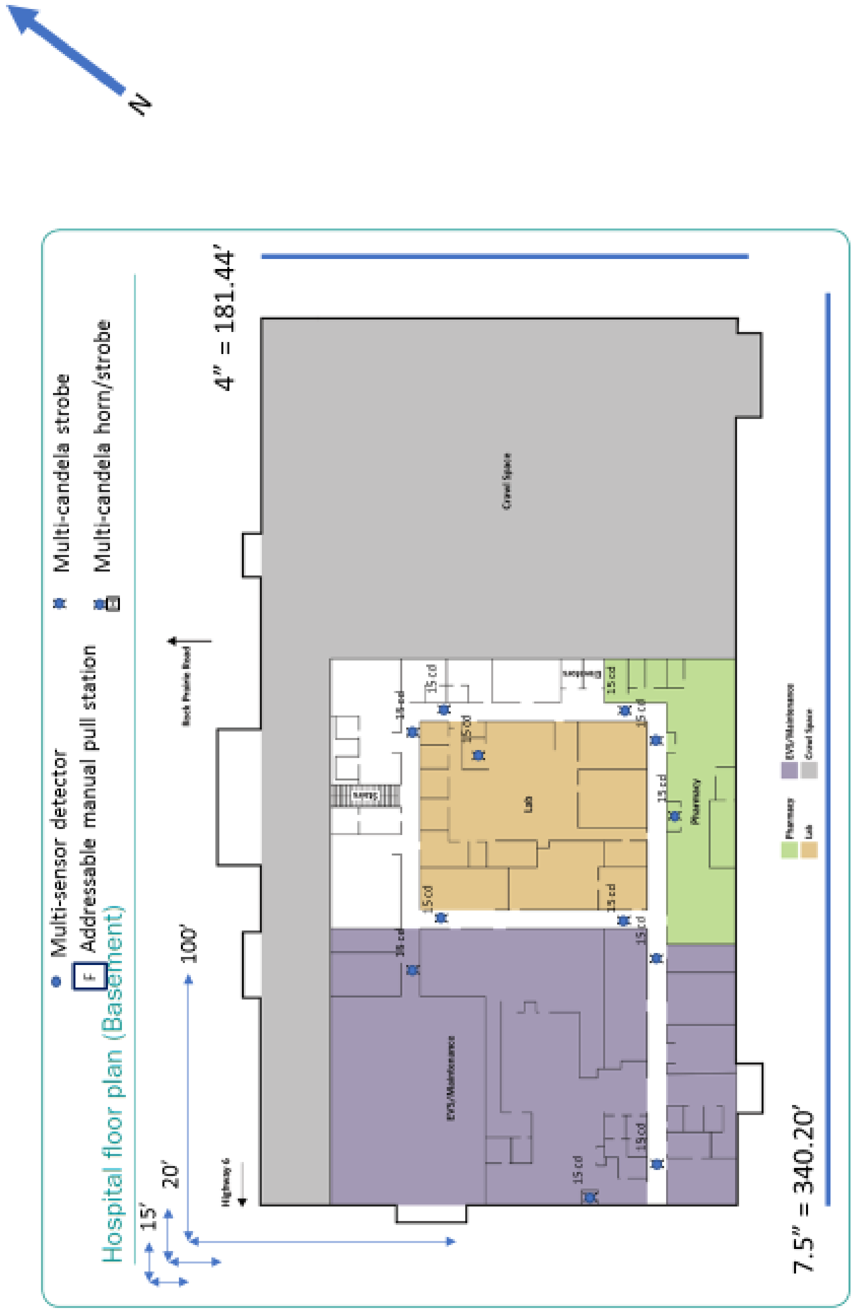


Figure # 61. Basement Types and Locations of Alarm Notification Devices

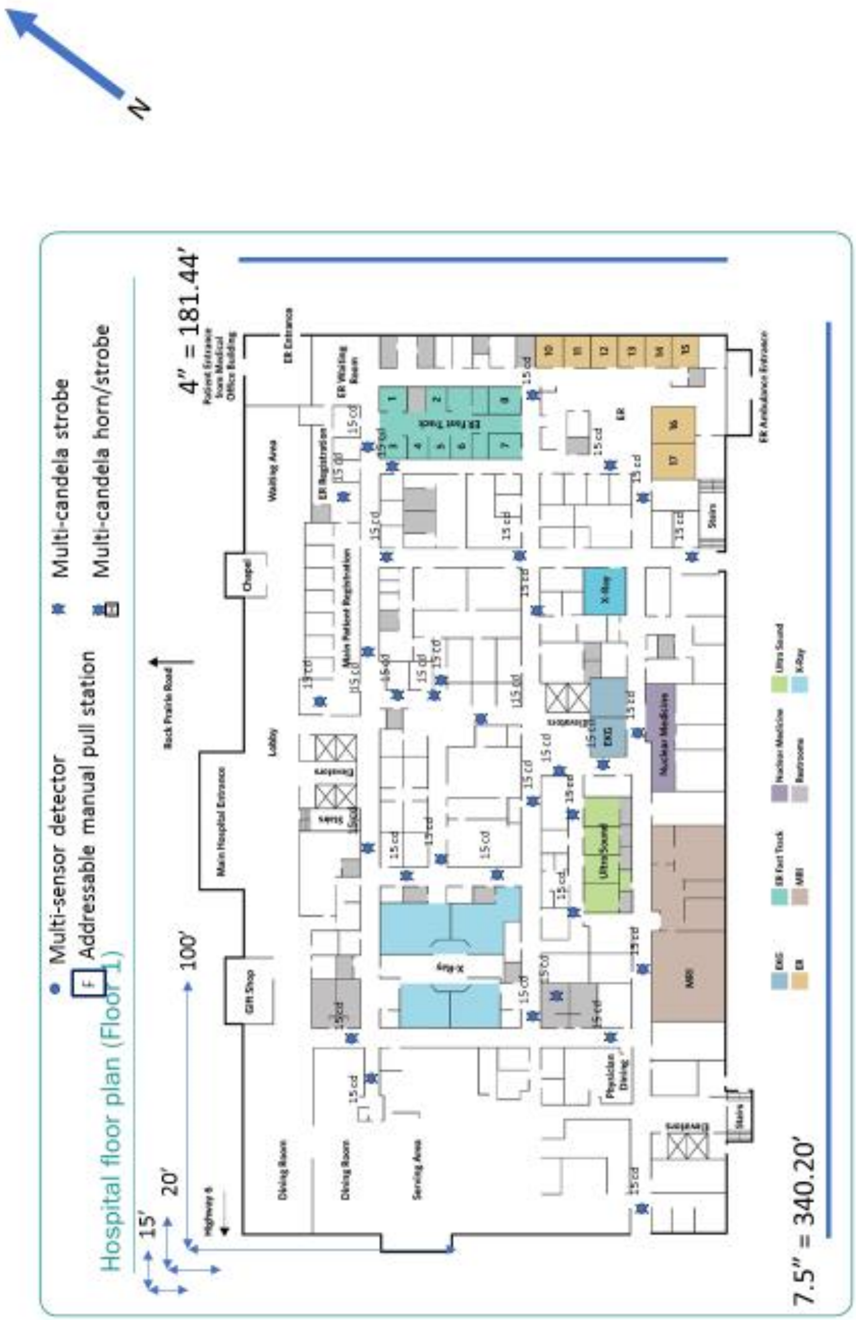


Figure # 62. Floor 1 Types and Locations of Alarm Notification Devices

Figure # 63. Floor 2 Types and Locations of Alarm Notification Devices

Figure # 64. Floor 3 Types and Locations of Alarm Notification Devices

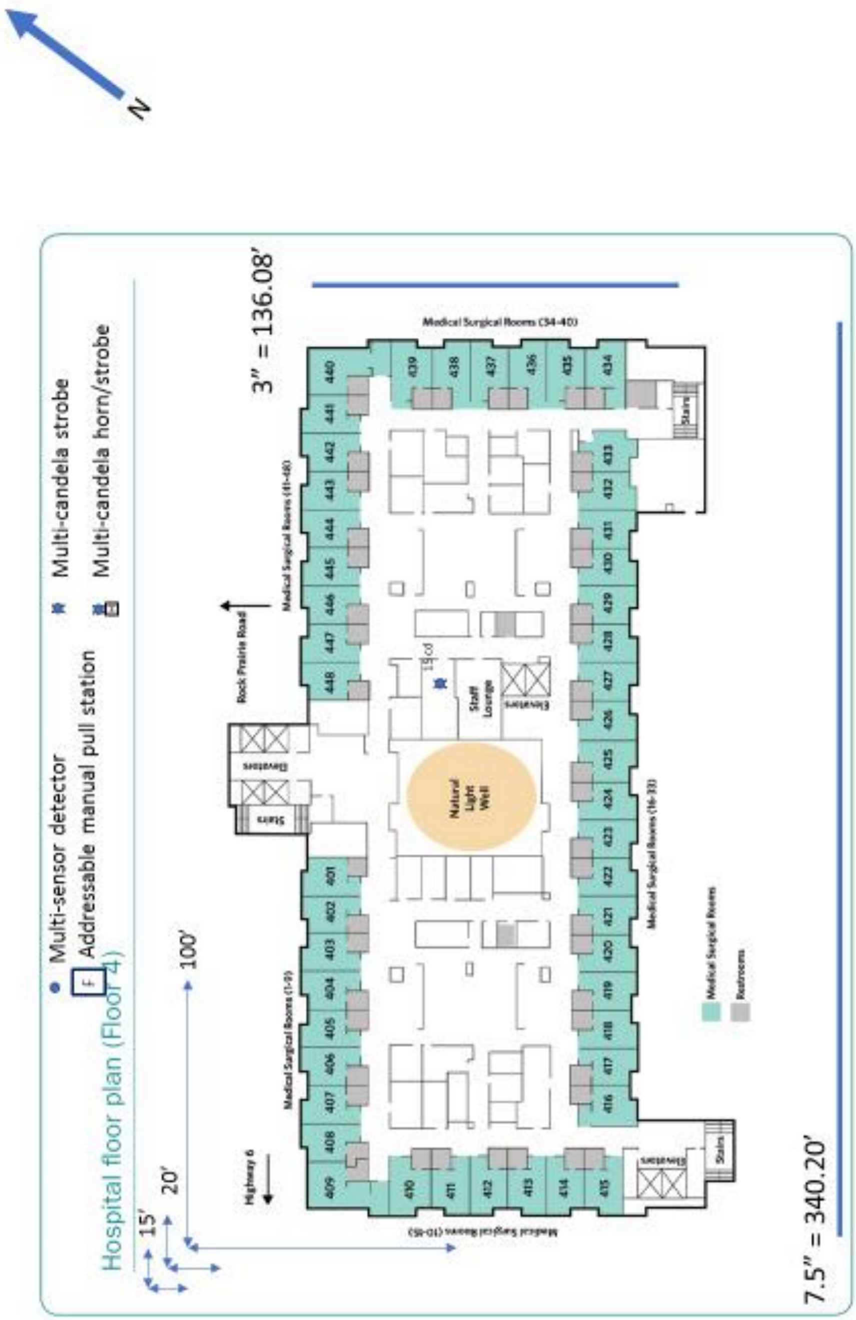


Figure # 65. Floor 4 Types and Locations of Alarm Notification Devices

Figure # 66. Floor 5 Types and Locations of Alarm Notification Devices

Location, spacing and placement of the alarm notification appliances installed in the building, and compliance with the requirements of the National Fire Alarm and Signaling Code

This report developed a design for the location, spacing, and placement of alarm notification appliances in compliance with the requirements of the National Fire Alarm and Signaling Code. In doing so, this report use the same assumptions that were made for initiating devices for alarm notification appliances. Additionally, this report assumes no audio reverberations (though this does not directly apply here, since this report has chosen to use a private mode alarm system for a hospital, Institutional Group I-2 Condition 2 occupancy).

This report set the visible notification appliance spacing based on 18.5.5.4, 18.5.5.5, A.18.5.5.4, and A.18.5.5.5.

There are also parts of the IFC and IBC that address this issue, including:

[F] 907.2.6 Group I.
A manual fire alarm system that activates the occupant notification system in accordance with Section 907.5 shall be installed in Group I occupancies. An automatic smoke detection system that activates the occupant notification system in accordance with Section 907.5 shall be provided in accordance with Sections 907.2.6.1, 907.2.6.2 and 907.2.6.3.3.
Exceptions:
2. Occupant notification systems are not required to be activated where private mode signaling installed in accordance with NFPA 72 is approved by the fire code official and staff evacuation responsibilities are included in the fire safety and evacuation plan required by Section 404 of the International Fire Code.

[F] 907.5.2.1 Audible alarms.
Audible alarm notification appliances shall be provided and emit a distinctive sound that is not to be used for any purpose other than that of a fire alarm.
Exceptions:

1. Audible alarm notification appliances are not required in critical care areas of Group I-2, Condition 2 occupancies that are in compliance with Section 907.2.6, Exception 2.
2. A visible notification appliance installed in a nurses' control station or other continuously attended staff location in a Group I-2, Condition 2 suite shall be an acceptable alternative to the installation of audible alarm notification appliances throughout the suite in a Group I-2, Condition 2 occupanices that are in compliance with Section 907.2.6, Exception 2.
3. Where provided, audible notification appliances located in each enclosed occupant evacuation elevator lobby in accordance with Section 3008.9.1 shall be connected to a separate notification zone for manual paging only.

[F] 907.5.2.3 Visible alarms.

Visible alarm notification appliances shall be provided in accordance with Sections 907.5.2.3.1 through 907.5.2.3.3

Exceptions:

2. Visible alarm notification appliances shall not be required in exists as defined in Chapter 2.

3. Visible alarm notification appliances shall not be required in elevator cars.

4. Visual alarm notification appliances are not required in critical area areas of Group I-2, Condition 2 occupancies that are in compliance with Section 907.2.6, Exception 2.

This is in agreement with NFPA 101:

9.6.3.6.3 Where occupants are incapable of evacuating themselves because of age, physical or mental disabilities, or physical restraint, all of the following shall apply:

(1) The private operating mode, as described in NFPA 72 shall be permitted to be used.

(2) Only the attendants and other personnel required to evacuate occupants from a zone, area, floor, or building shall be required to be notified.

(3) Notification of personnel as specified in 9.6.3.6.3 (2) shall include means to readily identify the zone, area, floor, or building in need of evacuation.

A plan view of the device placement is shown below in Figures 67 – 72.

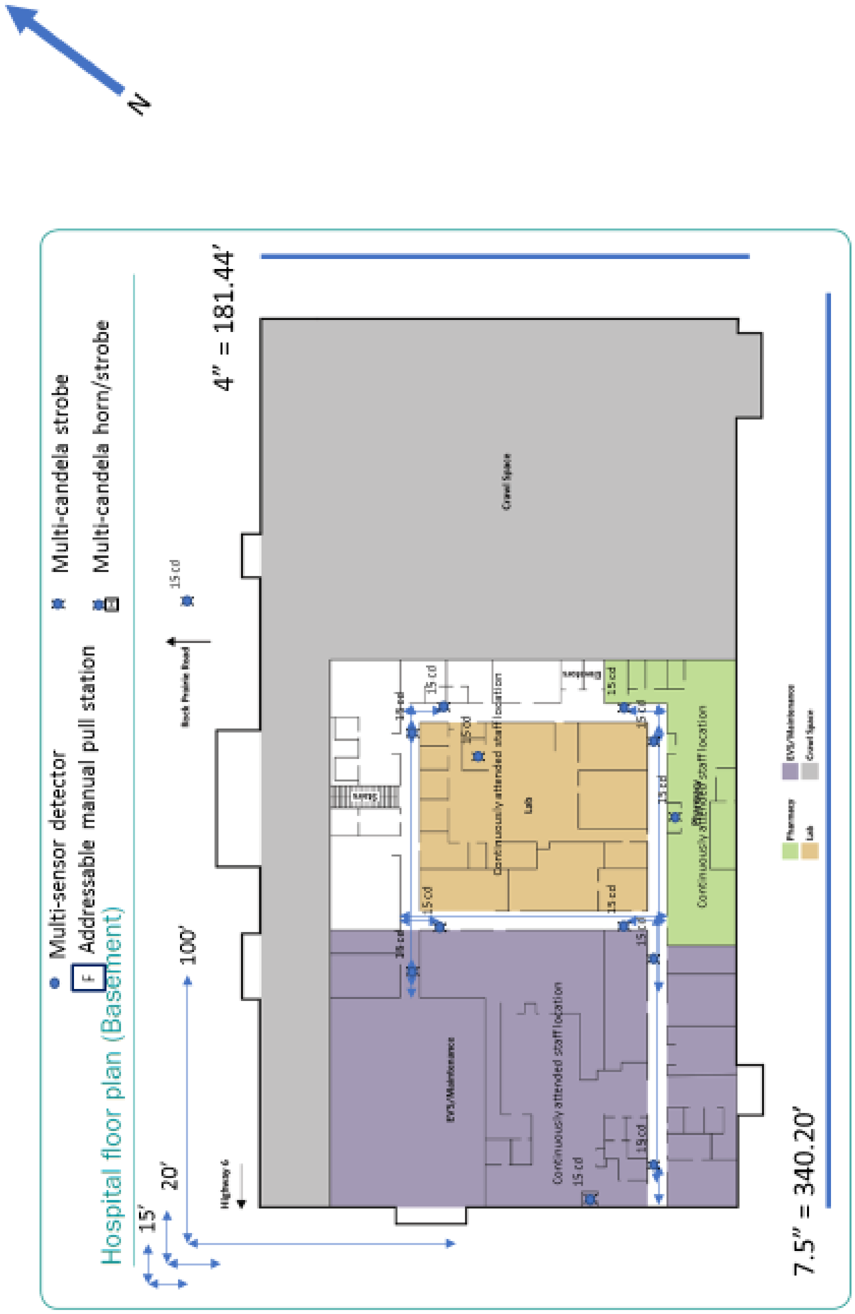


Figure # 67. Basement Spacing of Alarm Notification Devices

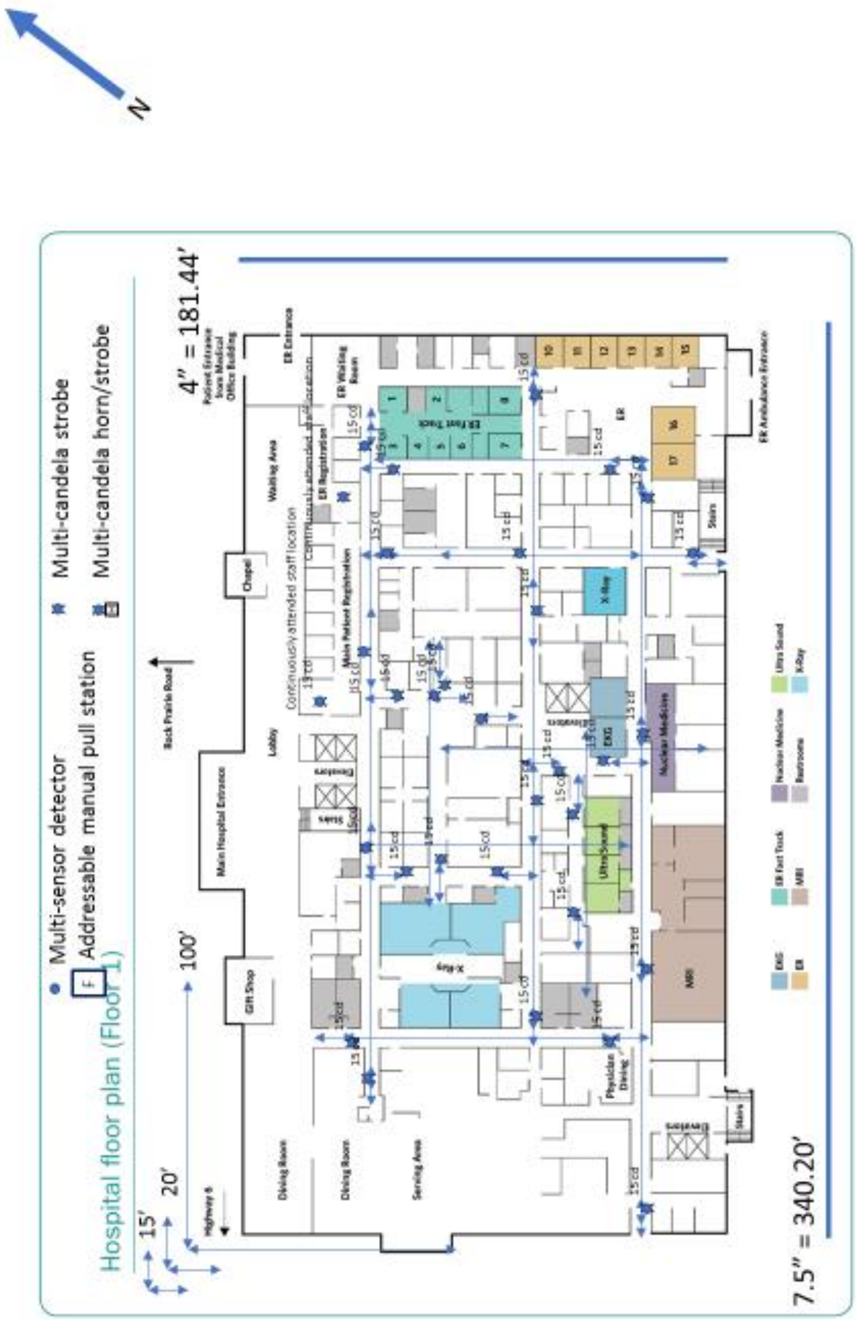


Figure # 68. Floor 1 Spacing of Alarm Notification Devices

Figure # 69. Floor 2 Spacing of Alarm Notification Devices

Figure # 70. Floor 3 Spacing of Alarm Notification Devices

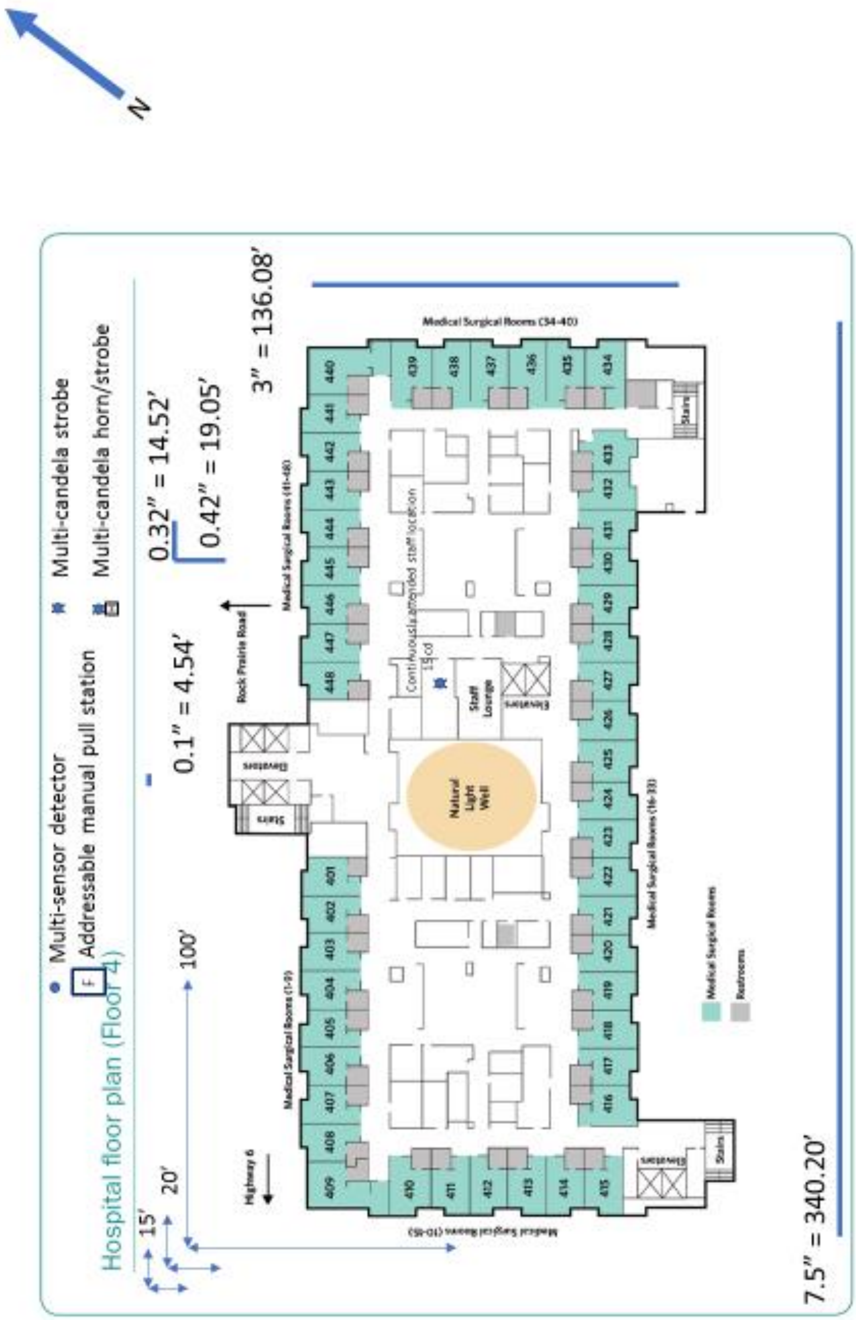


Figure # 71. Floor 4 Spacing of Alarm Notification Devices

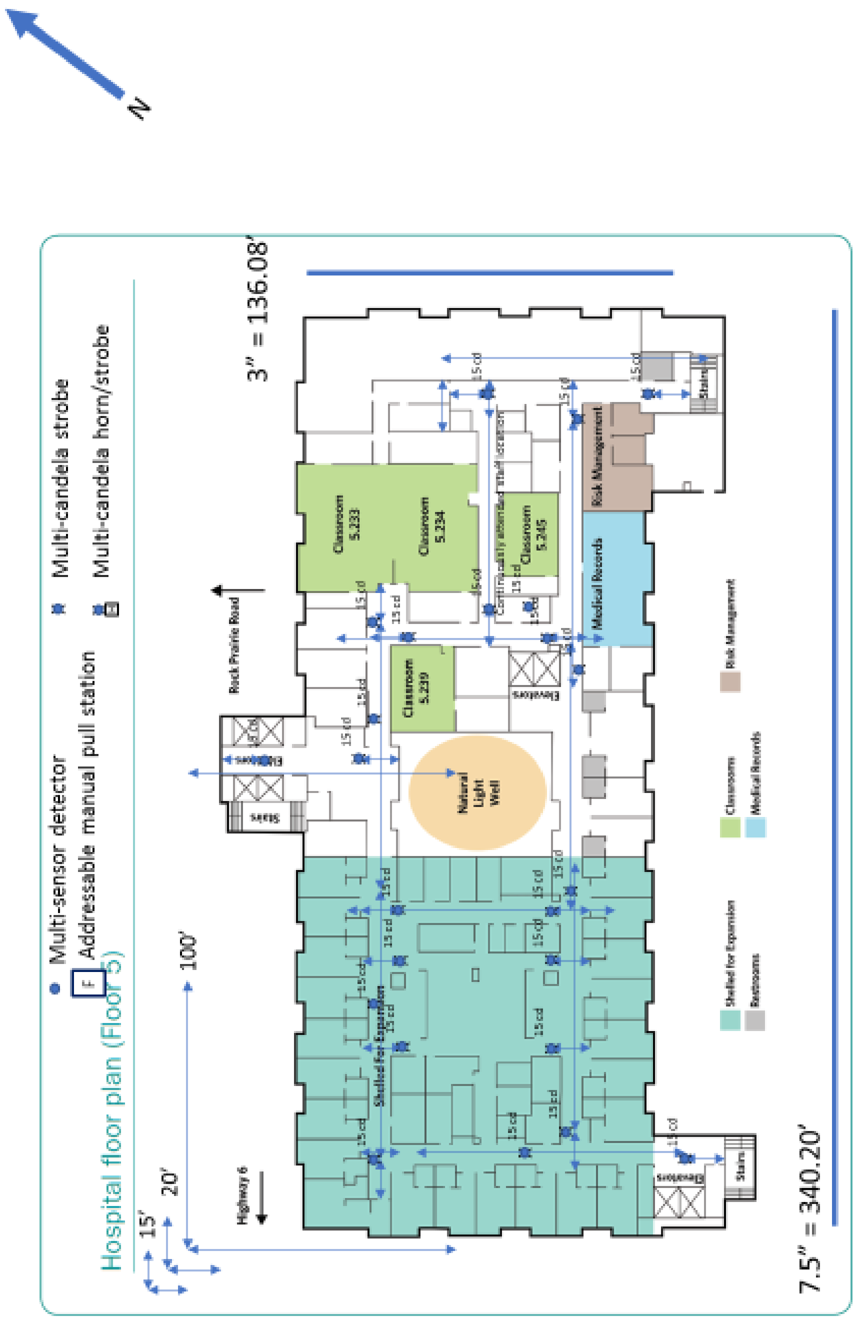


Figure # 72. Floor 5 Spacing of Alarm Notification Devices

As desired by stakeholders, audible alarms may be installed per the requirements of Chapter 18 of NFPA 72-2016, and A.18.4.3 and Table A.18.4.3. Code references are provided here, and examples of their application to portions of the first two floors of this project building are shown below.

A.18.4.3 The typical average ambient sound level for the occupancies specified in Table A.18.4.3 (shown as Table # 28 below) are intended only for design guidance purposes. The typical average ambient sound levels specified should not be used in lieu of actual sound level measurements.

Sound levels can be significantly reduced due to distance and losses through building elements. Every time the distance from the source doubles, the sound level decreases by about 6 decibels (dB). Audible notification appliances are typically rated by manufacturers' and testing agencies at 10 ft from the appliance. Subsequently, at a distance of 20 ft from an audible appliance rated at 84 dBA, the sound level might be reduced to 78 dBA. At a closed door, the loss might be about 10 dB to 24 dB or more depending on construction. If the opening around the door is sealed, this might result in a loss of 22 dB to 34 dB or more.

Table # 28. Average Ambient Sound Level According to Location from NFPA 72-2016

Table A.18.4.3 Average Ambient Sound Level According to Location

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

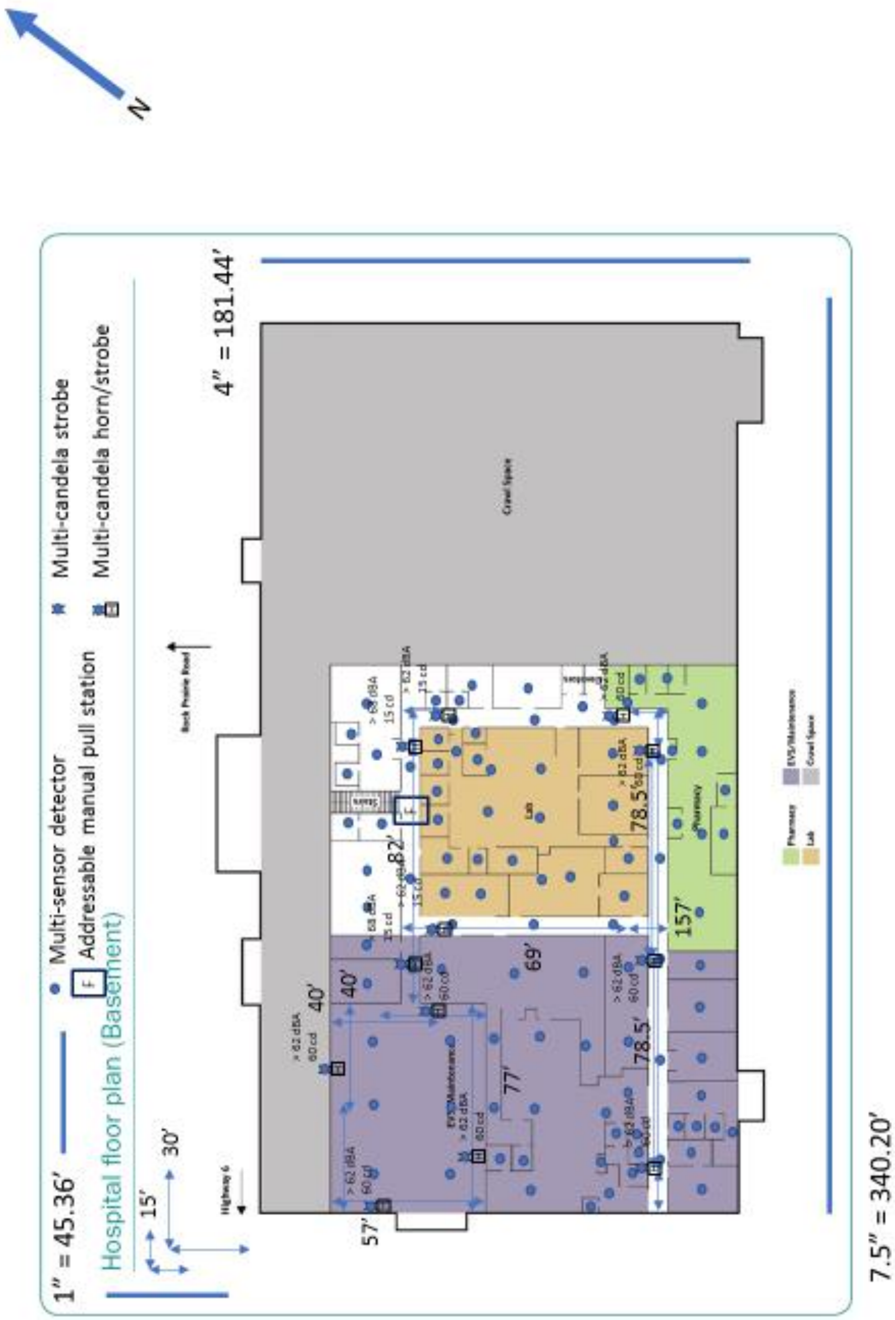


Figure # 73. Basement Horn/Strobes

In the above example, Figure 73, a horn/strobe notification device might be placed in the large room at the west corner of the building, and the corridors. The device placement in the room, and audio and visible settings are based on public mode audible requirements, including 18.4.3.1, the 6 dBA rule-of-thumb from A.18.4.3, Table A.18.4.3 Average Ambient Sound Level According to Location, and Table 18.5.5.4.1(a) Room Spacing for Wall-Mounted Visible Appliances. The horn/strobes in the corridors followed many of the same code requirements, as well as 18.5.5.5 Spacing in Corridors, particularly 18.5.5.5.3 and 18.5.5.5.5.

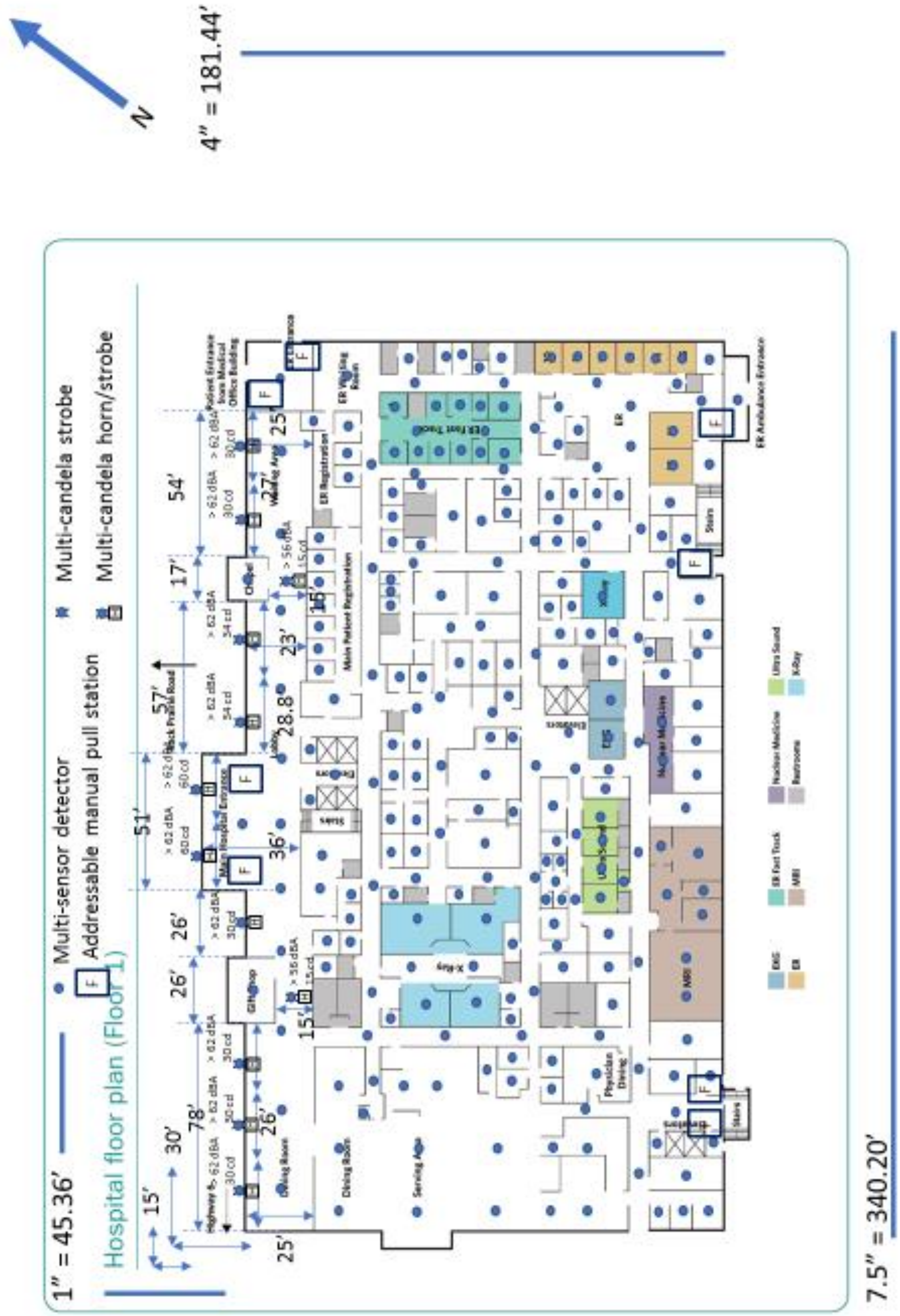


Figure # 74. Floor 1 Horn/Strobes

In the above example, Figure 74, a horn/strobe notification device might be placed in the large hallway by the main entrance, along the north-west side of the building. The device placement in the room, and audio and visible settings are based on public mode audible requirements, including 18.4.3.1, the 6 dBA rule-of-thumb from A.18.4.3, Table A.18.4.3 Average Ambient Sound Level According to Location, and Table 18.5.5.4.1(a) Room Spacing for Wall-Mounted Visible Appliances. In places where the hallway narrowed to 20 ft or less, settings based on 18.5.5.5 Spacing in Corridors, particularly 18.5.5.5.3 and 18.5.5.5.5, were used.

Emergency Communication Systems

Analysis of the expected performance of the audible and visible notification appliances based on their location, spacing and placement

The expected performance of audible notification appliances is not applicable to this design, because this report has chosen to use a private alarm mode that does not use any audible notification appliances. Background information regarding this is in the previous section, Alarm Notification Appliances.

The visible notification appliances have been designed to comply with Chapter 18 of NFPA 72-2016. Additional equipment may be considered to more effectively aid in EVACS. This is discussed in the following subsection.

Proposed revised speaker layout that ensures intelligibility for a voice system

In order to implement EVACS, a speaker system would need to be installed. As a rule-of-thumb covered in class, there should be a speaker at a linear distance of twice the ceiling height from each other. For this hospital with a 10’ ceiling height, this would correspond to a nominal spacing of 20’. This report would use this nominal spacing in corridors and common areas, while most bedrooms are small enough that a single speaker could be used. Note, speakers can be used for regular public announcements, or to page doctors, nurses, and other occupants in non-fire situations.

To complement the auditory EVACS system, a series of visual screens for mass notification systems (MNS) that would normally display other information might also be considered. This would be in the same vein as airport terminal screens that display information under normal conditions, but can be used to display fire and evacuation information when the need arises. Such a system can help in communicating with those that are deaf or hearing impaired.

More information on speakers can be found in 18.8.1, 23.8.4.5, 24.4.2.2.1, 24.4.6, 24.4.8.4, A.18.8.1.2, A.24.4.2.2.2, A.24.4.6.1, and F.1. High power speaker array (HPSA) information is found in 24.6.5 to 24.6.9, and A.24.6.5 to A.24.6.9.

Intelligibility requirements are set forth in 24.3.1.2, A.24.3.1, and A.24.3.1.2.

Power Requirements for Fire Alarm and Communication Systems

Secondary Power Supply Requirements for the Fire Alarm System

This report uses NFPA 70, NFPA 72, and what was presented in Cal Poly FPE 522 to calculate the secondary power supply requirements for the fire alarm system.

First, this report considers plan views and riser diagrams for the initiating devices and notification appliances in Figures 75 – 86 below. Note, abbreviations are used here. More conventionally, a typical room or floor plan and riser diagram may be prepared.

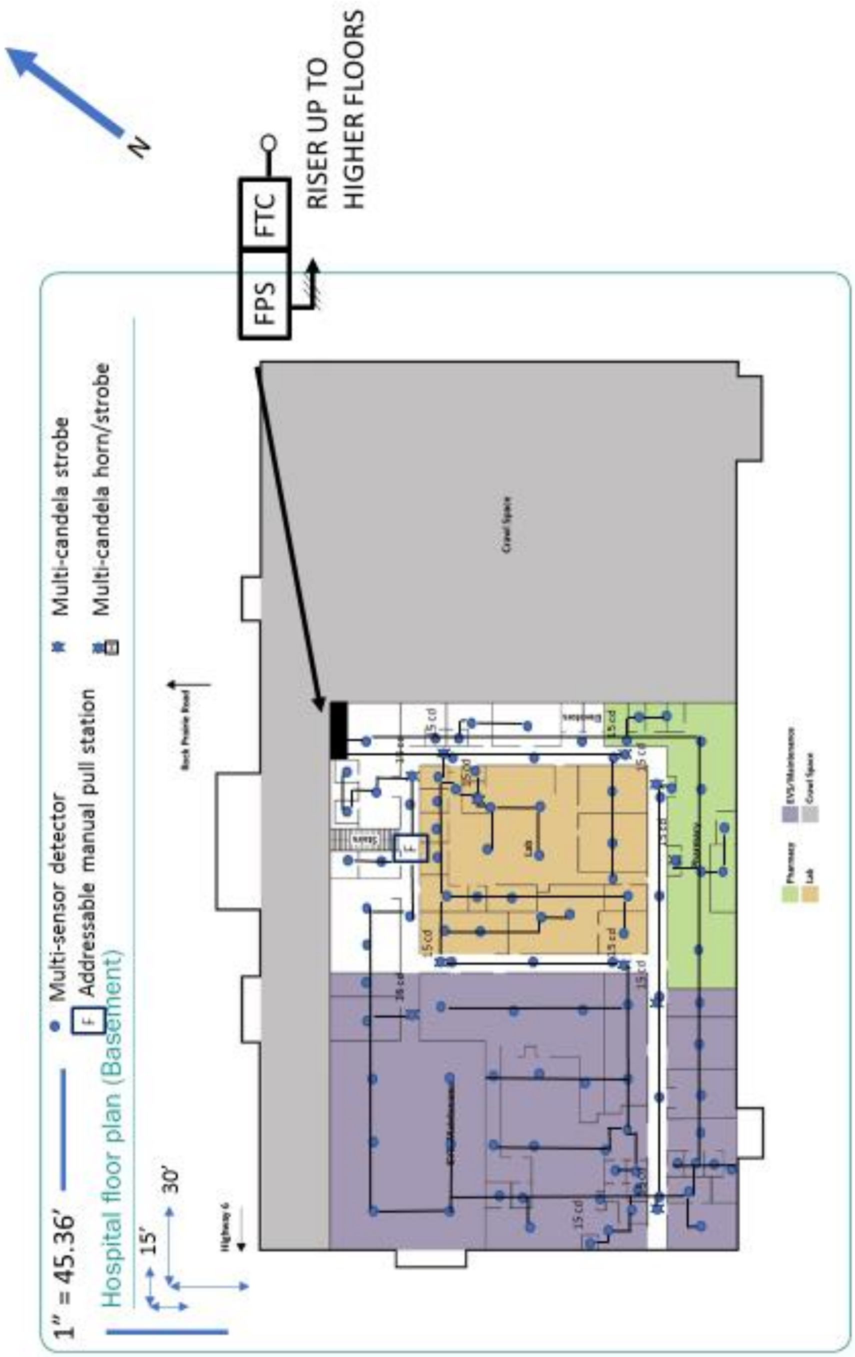


Figure # 75. Basement Riser Diagram

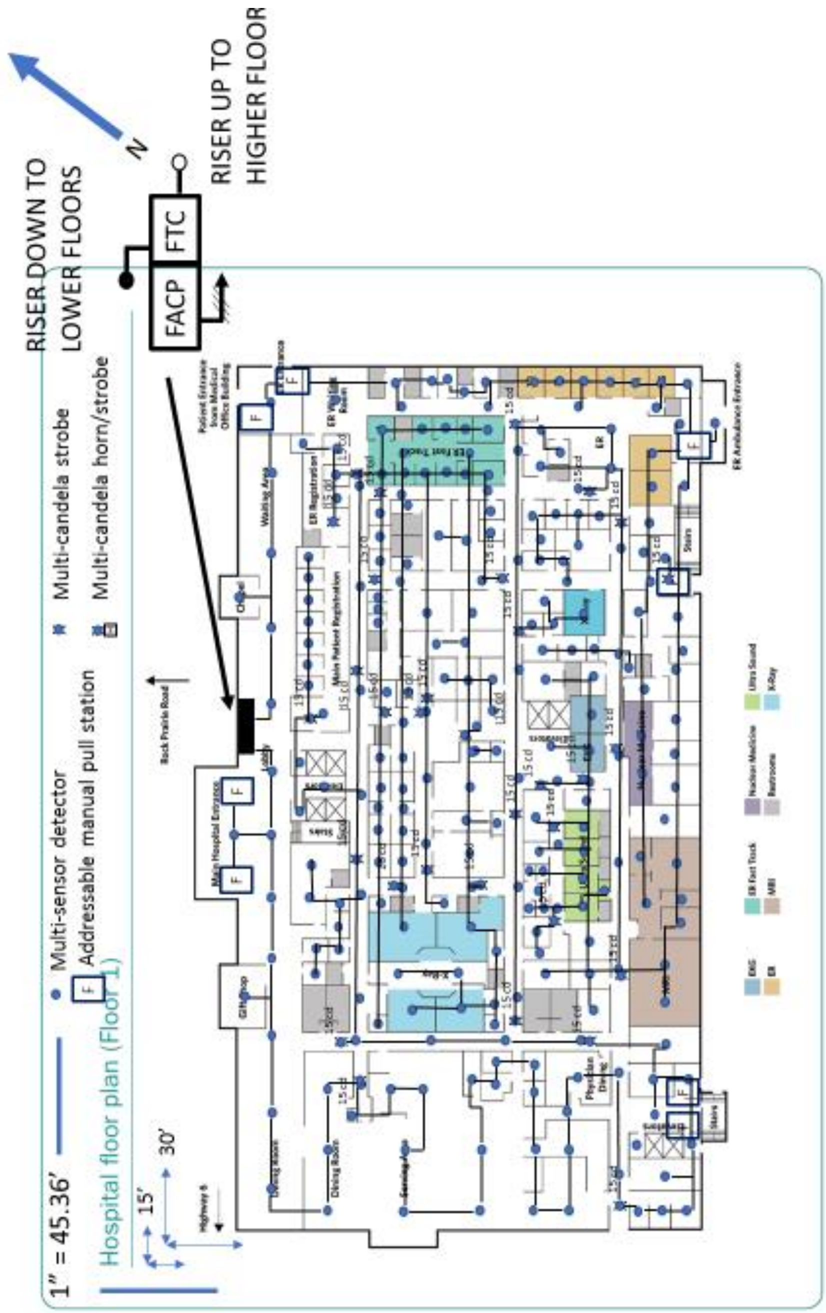


Figure # 76. Floor 1 Riser Diagram

Figure # 77. Floor 2 Riser Diagram

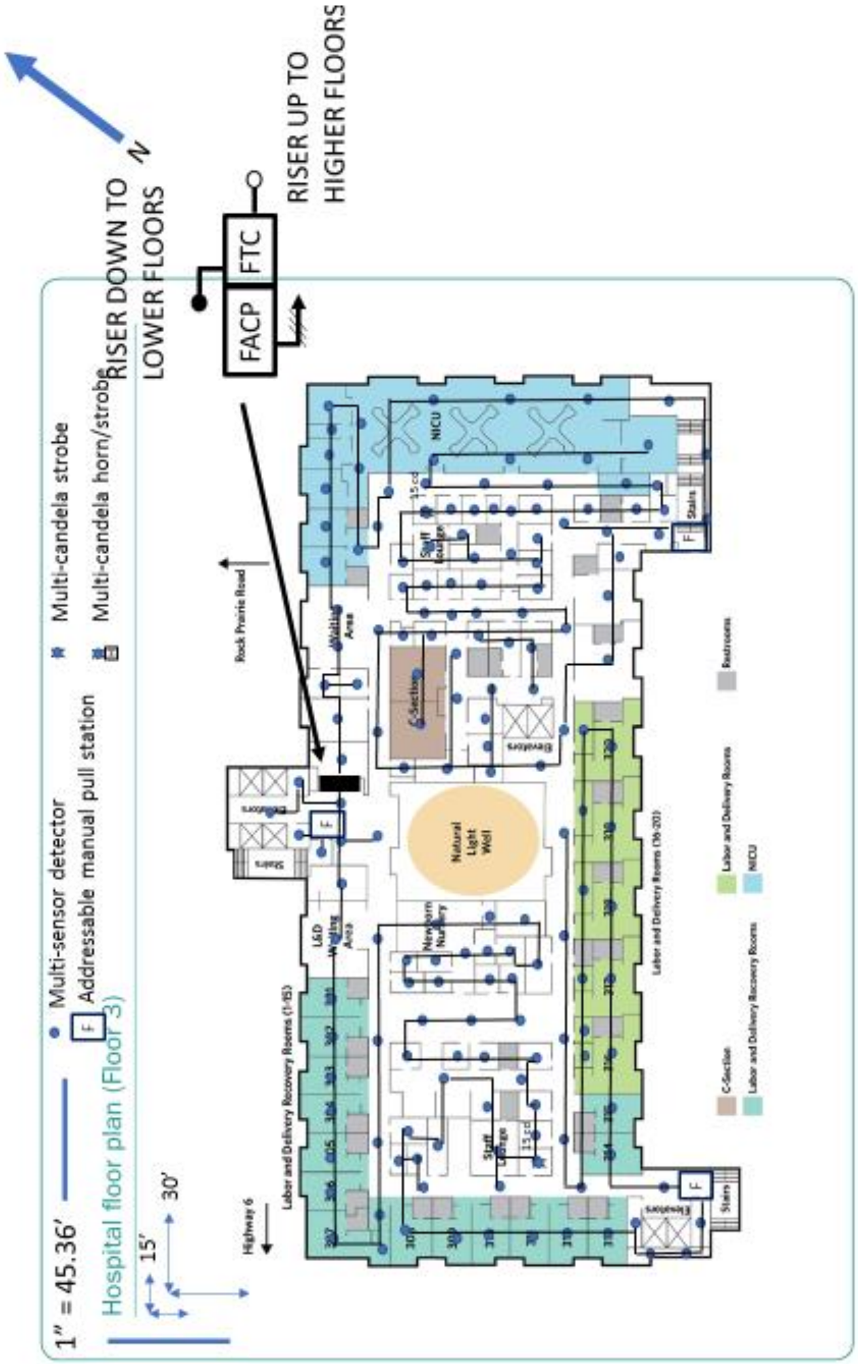


Figure # 78. Floor 3 Riser Diagram

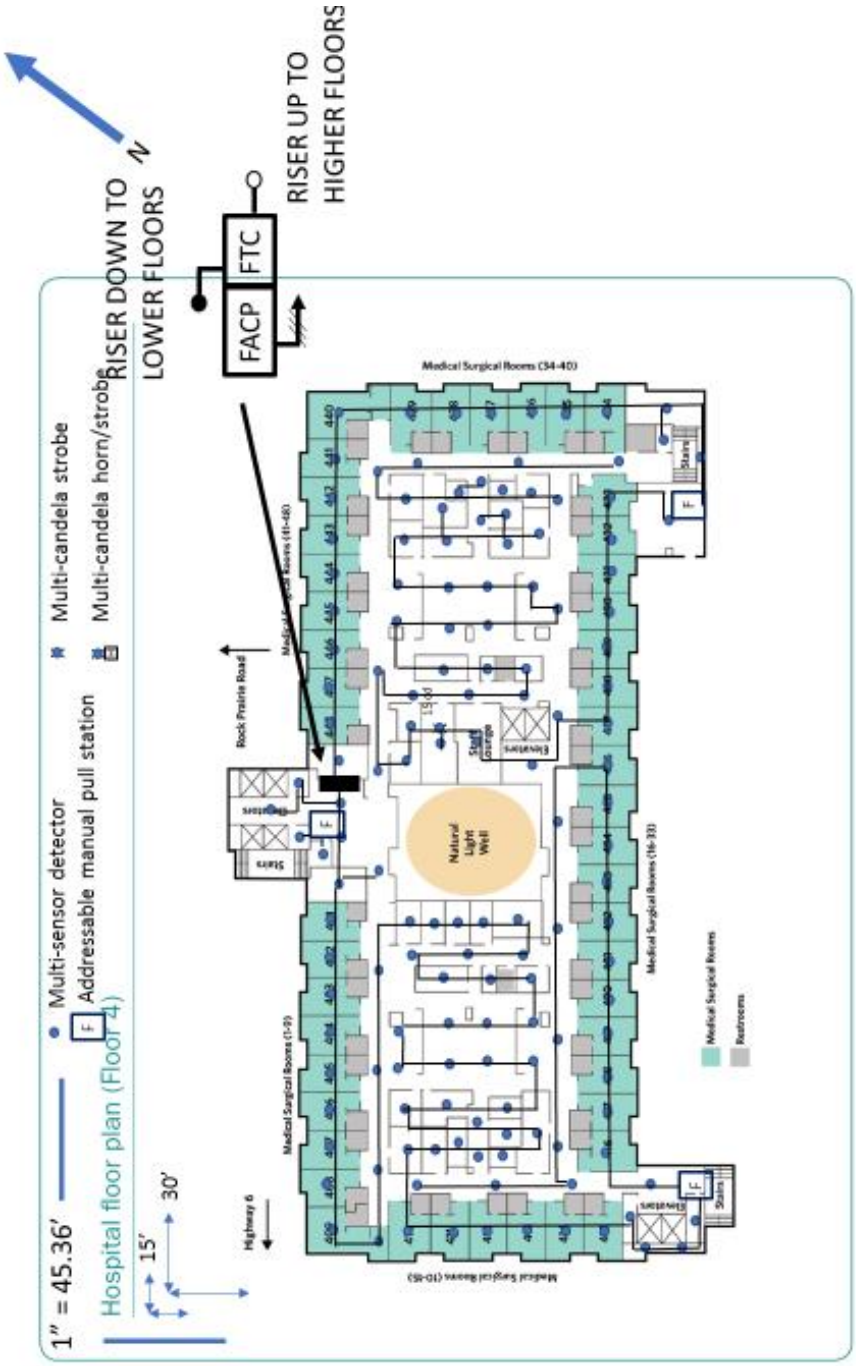


Figure # 79. Floor 4 Riser Diagram

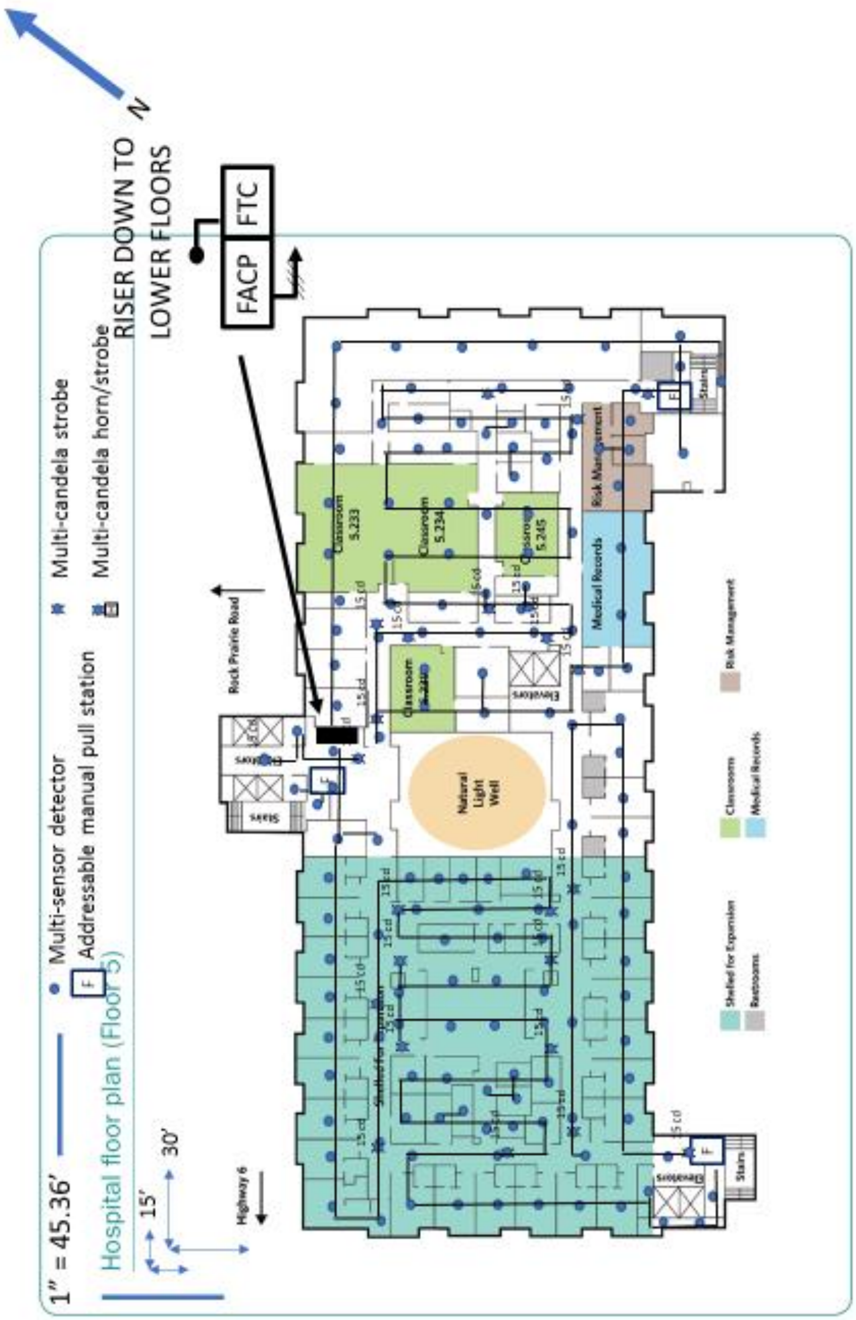


Figure # 80. Floor 5 Riser Diagram

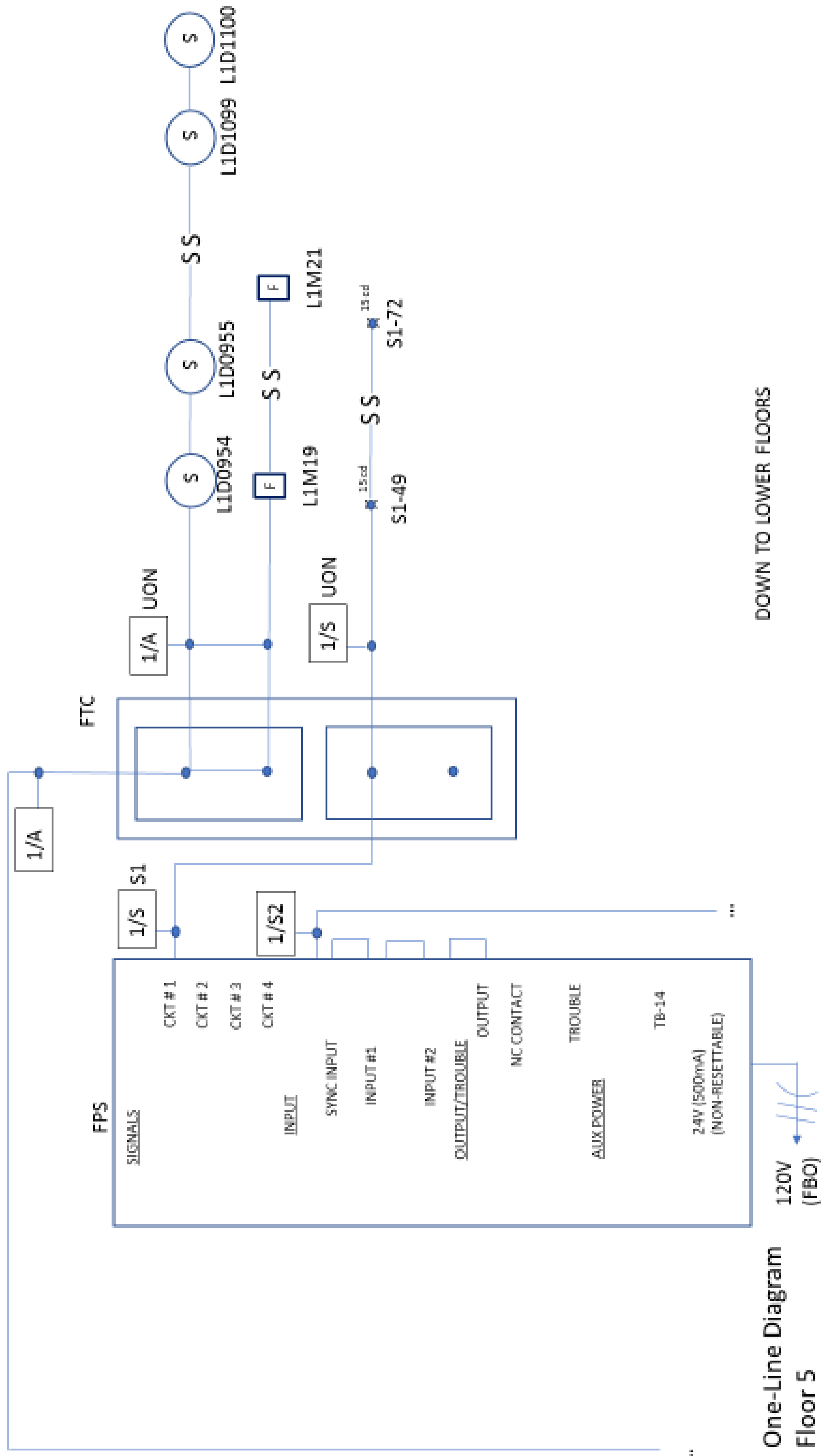


Figure # 81. Floor 5 One-Line Diagram

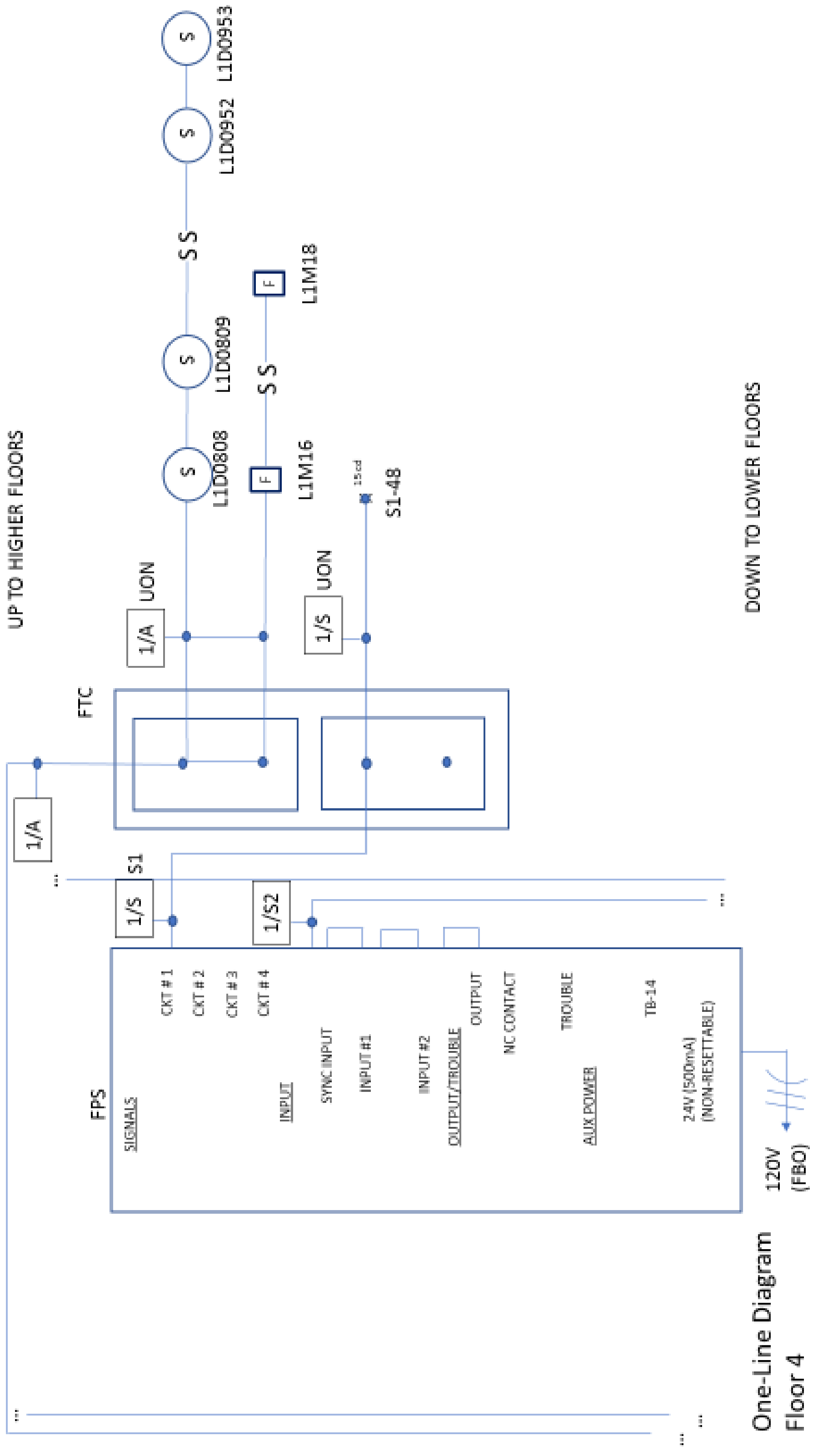


Figure # 82. Floor 4 One-Line Diagram

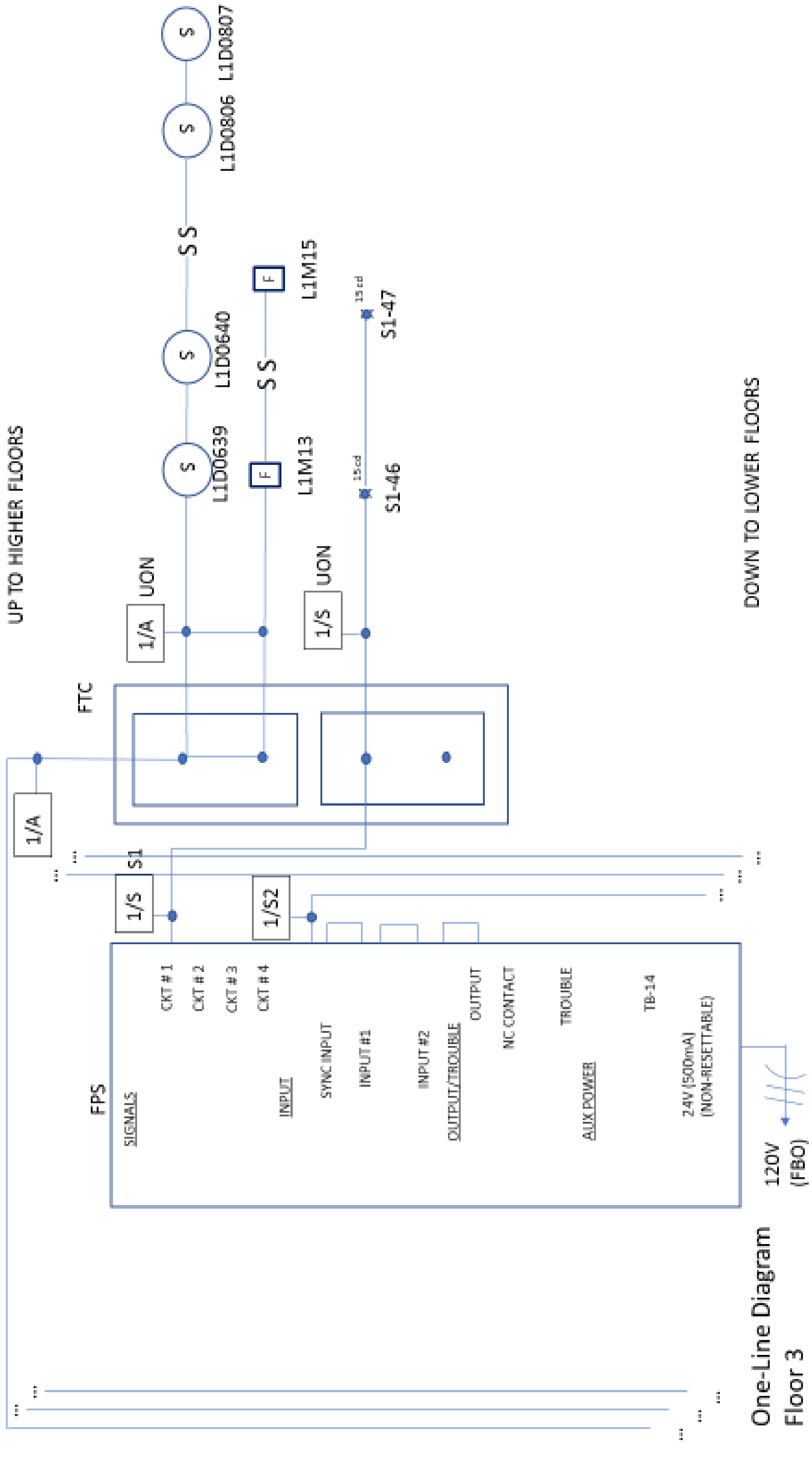


Figure # 83. Floor 3 One-Line Diagram

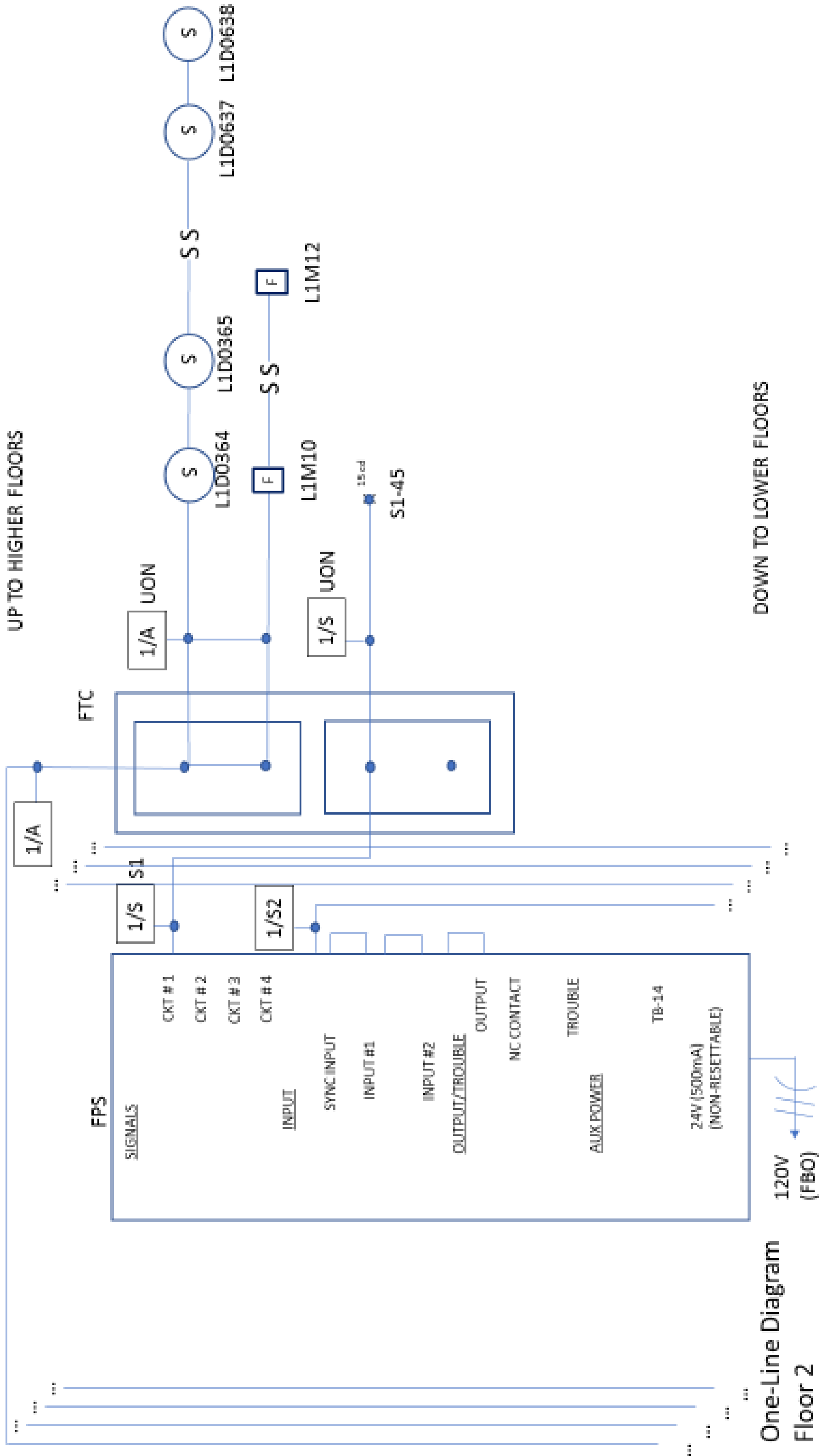


Figure # 84. Floor 2 One-Line Diagram

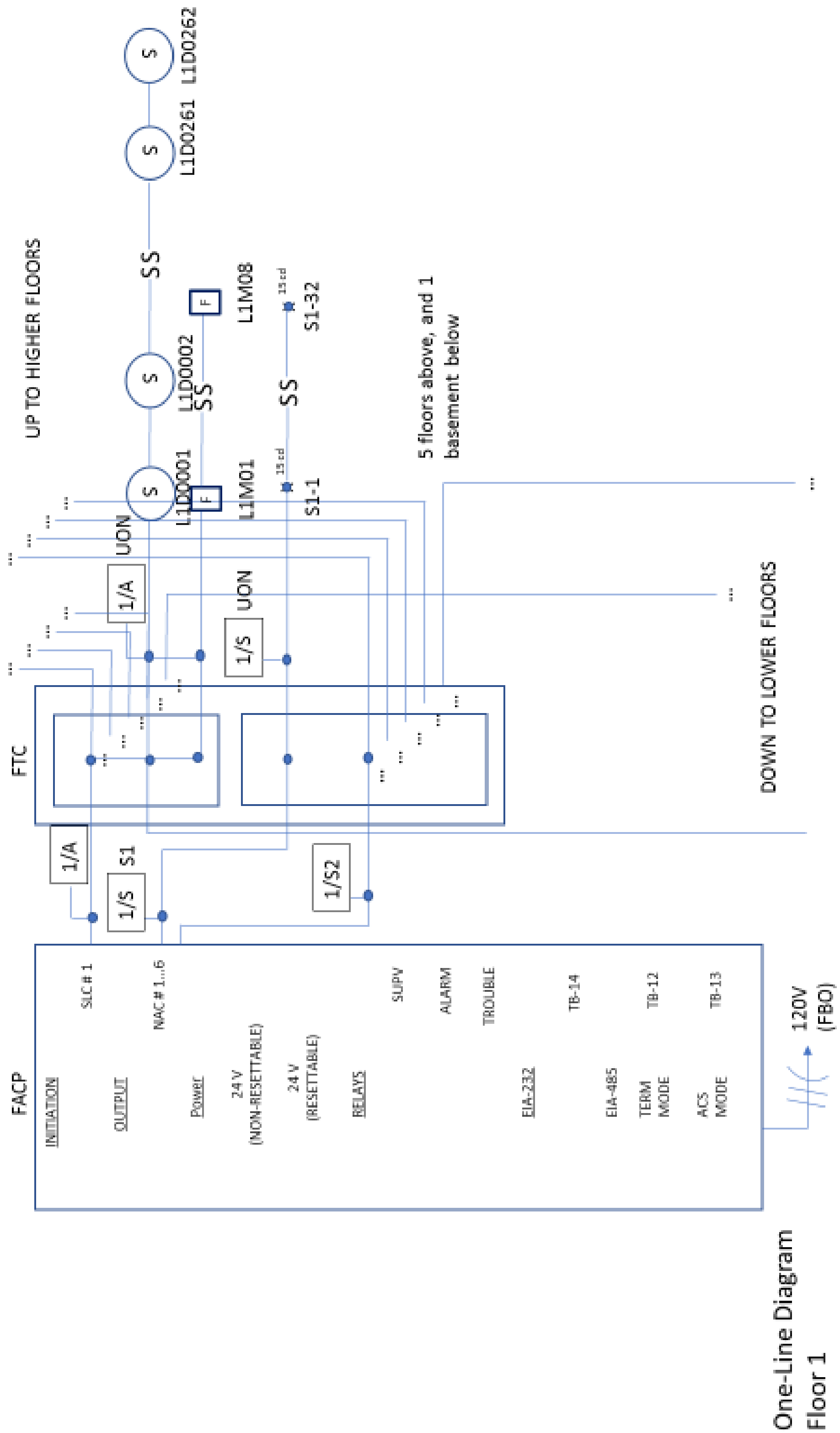


Figure # 85. Floor 1 One-Line Diagram

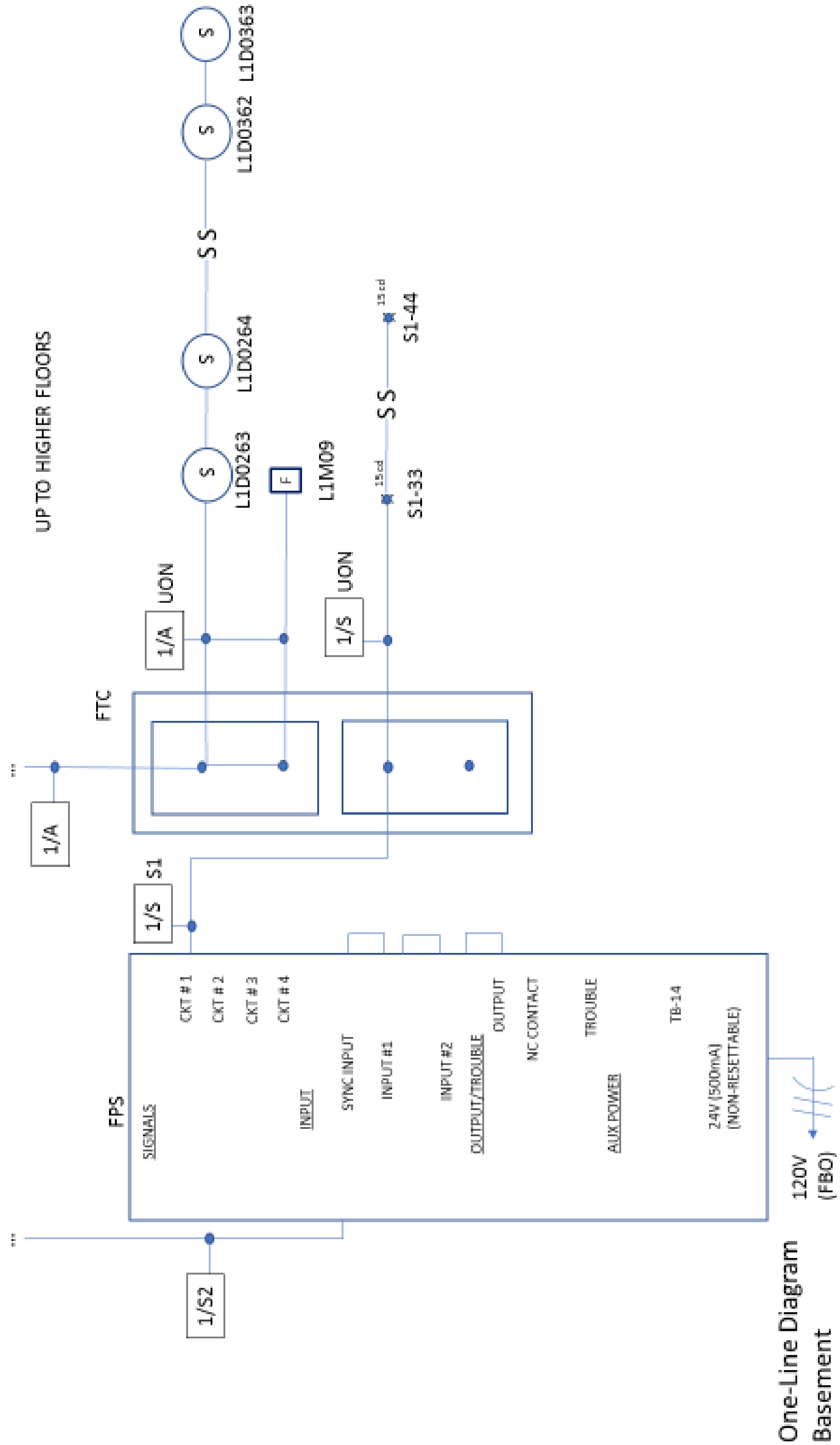


Figure # 86. Basement One-Line Diagram

This report then examines two scenarios: first, with private mode operation as shown in Table 29 below, then considering using sounder bases for the smoke detectors as a future audible alarm devices as shown in Table 30 below. Note, this report assumes the use of high dBA alarm bases on 24 Vdc in non-reverberant rooms.

Table # 29. Secondary Power Supply Requirements, Private Mode

Equipment		Quantity	Supervisory Current (in amps)		Alarm Current (in amps)	
			Unit	Total	Unit	Total
1	Manual Pull Station	21	0.000396	0.008316	0.00068	0.01428
2	Smoke Detectors	1100	0.000045	0.045	0.000045	0.045
3	Strobes	72			0.063	4.536
Sub-totals (in amps)				0.057816		4.59978
Time Factor	24 hour standby			24		
	5 minutes in alarm					0.08333
	Standby Amphours			0.057816 x 24 = 1.387584		
	Alarm Amphours					4.59978 x 0.0833 = 0.383315
System Amphours				1.387584 + 0.383315 = 1.770899		
Plus 25% Derating				1.770899 x 1.25 = 2.213624		

Under a private mode scenario, a secondary power supply of at least 2.213624… ~ 2.3 amphours would be needed.

Table # 30. Secondary Power Supply Requirements, Public Mode

Equipment		Quantity	Supervisory Current (in amps)		Alarm Current (in amps)	
			Unit	Total	Unit	Total
1	Manual Pull Station	21	0.000396	0.008316	0.00068	0.01428
2	Smoke Detectors	1100	0.018	19.8	0.000045	0.045
3	Alarm Base	1100			0.041	45.1
4	Strobes	72			0.063	4.536
Sub-totals (in amps)			19.80832		69.45028	
Time Factor	24 hour standby		24			
	5 minutes in alarm				0.08333	
	Standby Amphours		19.80832 x 24 = 475.3996			
	Alarm Amphours				69.45028 x 0.0833 = 5.787523	
System Amphours			475.3996 + 5.787523 = 481.1871			
Plus 25% Derating			481.1871 x 1.25 = 601.4839			

Under a public mode scenario, a secondary power supply of at least 601.4839 … ~ 602 amphours would be needed.

Note, analysis of NACs (wire gauge, length, voltage drop, etc.) and discussions around the pros and cons of centralized and decentralized batteries are not covered here, but should be covered with all stakeholders.

Commissioning and Inspection, Testing and Maintenance (ITM) of Alarm Systems

Record of Completion

Record of Completion forms, to be filled out per NFPA 72 after system installation, are included as another attachment to this report. Refer to Chapter 7 (particularly 7.5) of NFPA 72 for more information.

Inspection, Test and Maintenance Requirements for the Fire Alarm System and Components

Inspection, Test and Maintenance forms, to be filled out per NFPA 72 after system installation, are included as another attachment to this report. Refer to Chapter 14 of NFPA 72 for more information.

Conclusion

This report aims to serve as a basic fire alarm system design for the Baylor, Scott & White Hospital in College Station, TX. This is a basic design, which does not explicitly list other systems that are expected to be present (such as sprinklers and PA speakers) that could also be integrated to form a more complete alarm system (through the use of sprinkler water flow devices, and the use of PA speakers for EVACS). Besides various NFPA codes and the International Fire Code and International Building Code, this report draws from the material presented in FPE 522 by Professor Mower and Professor Simonian. Turning from active fire protection systems to passive ones, this report will examine the structural fire protection aspects of this building in the next section.

Structural

Introduction

Structural Fire Protection is important in the overall Life Safety Plan for Health Care occupancies. The survivability of the structure, and spaces such as areas of refuge, stairwells, and means of fire service access are critical. The building's structural integrity is addressed by the construction type and protective measures. Exterior and interior construction types will be selected by several factors (proximity to other structures, type of occupancy, etc.) and are outlined by code. Spray-on insulation on steel structural members are designed to help keep the structure stable during a fire. Rated fire barriers and smoke barriers (and properly sealed penetrations through them) are designed to contain the spread of fire and smoke to allow occupants more time to safely evacuate.

This section of the report examines the proscriptive structural fire protection engineering aspects of the Baylor, Scott and White Medical Center in College Station, TX. The 2018 edition of the International Building Code serves as the governing code, and material from the Cal Poly Structural Fire Protection class, FPE 524, is also used. This report assumes that this building is of Type I-A construction, and that it is equipped throughout with an automatic sprinkler system.

Body

Required Construction Classification

Through examination of this building at the requirements of Chapter 5 of IBC-2018, it can quickly be found that the building is restricted to either at Type I-A or Type I-B. These construction types allow for unlimited building areas (Table 506.2) for the occupancies in the building, and the allowable building height above grade (Table 504.3) is well above that of the building. The key factor to consider is the allowable number of stories above grade (Table 504.4). Analysis finds that the 'closest' issue to a proscriptive limit is the 5 floor restriction for I-2 occupancies for Type I-B construction. For Type I-A construction, many restrictions are 'Unlimited,' rather than a set floor area or height. Given the potential for future expansion or construction, this report assumes that the building is of Type I-A construction.

Table 31 below shows the construction materials for the building. Because access to detailed structural plans was not available for this report, general assumptions were made as to what materials were used, based on engineering judgement in conjunction with personal work experiences with hospitals. Additionally, more specific assumptions will be made for the purposes of calculations later in this report, and such assumptions will be flagged at that time.

Table 31. Construction Material

Building Element	Construction Material
Columns	Steel, I-beam, W-shape, various
Beams	Steel, I-beam, W-shape, various
Floor Assembly	Concrete slab, thickness to be set by structural engineer
Roof Assembly	Concrete slab, thickness to be set by structural engineer
Exterior Walls	Curtain wall, metal composite material (MCM)
Interior Walls	Gypsum board over metal or wood studs, e.g. 3/4" sheetrock over metal/wood 2"x4"s

Door Openings	Door openings that are compliant with Section 716 of IBC-2018, with ratings as required by code
Joists	Steel, I-beam, W-shape, various
Penetrations	Penetrations protected per Section 714 of IBC-2018, e.g. fire caulk or rated assemblies
Partitions	Construction as required by code. Note, smoke partitions should comply with Section 710 of IBC-2018 (e.g. Corridor walls, Section 407.3 of IBC-2018). See also Sections 708 and 709

Fire Resistance Requirements for Building Elements

The requirements for fire-resistance rating requirements for building elements are found in Table 601 of IBC-2018. The following table, Table 32, summarizes the fire-resistive rating requirements for different building elements of this hospital as a Type I-A building.

Table 32. Fire Resistance Requirements for Building Elements

Building Element	Fire-Resistance Rating (Hours)
Primary Structural Frame	3
Bearing Walls – Interior	3
Bearing Walls – Exterior	3
Non-bearing Walls and Partitions – Exterior	0
Non-bearing Walls and Partitions – Interior	0
Floor Construction and Associated Secondary Members	2
Roof Construction and Associated Secondary Members	2

Note, for exterior walls, the rating is based on Table 602 of IBC-2018, and fire separation distance. From satellite pictures of the building, this report assumes that the fire separation distance is over 30 feet, and so 0 hours of fire-resistance rating is required for code for all construction types and all occupancies.

Table 508.4 of IBC-2018 includes information on required separation of occupancies in hours. However, it is assumed that this building has non-separated occupancies per the requirements of Section 508.3 of IBC-2018, with care especially given to Section 508.3.1.2 for Group I-2, Condition 2 occupancies, which this building is (as it is a hospital). Given that, all the most restrictive requirements of individual occupancies for height, number of stories, and area applied to the all occupancies as a whole. Note, given this design, the choice of a Type I-A construction is relevant as it may help preclude further difficulties beyond future expansion. This is because, as discussed earlier, the 5-floor restriction of I-2 occupancies for Type I-B construction would now apply to all occupancies, and any occupancy of the roof would be prohibited, which may not be desirable to the design team or tenants. Additionally, It is the author's understanding that non-separated occupancies are not uncommon for hospitals, which gives further credit to this design choice.

Besides the requirements above, the building also has the following requirements:

- Elevator shafts – 2-hour rating per Section 713.4 of IBC-2018, because the elevator shafts connect 4 stories or more.
- Exit stairs – 2-hour rating per Section 1023.2 of IBC-2018, because the exit stairs connect 4 stories or more.
- Exit corridors – 1-hour rating per Section 1024.3 of IBC-2018

Table 509 of IBC-2018 also contains pertinent requirements for Group I-2 occupancies. Specifically, the following rooms require 1-hour fire resistive ratings:

- Laundry rooms over 100 sq. ft.
- Patient rooms equipped with padded surfaces.
- Physical plant maintenance shops
- Waste and linen collection rooms with containers that have an aggregate volume of 10 cubic feet or greater
- Storage rooms over 100 sq. ft.

Fire Safety Strategy

The fire safety strategy of fire resistance in the building is based on implicit safety, or prescriptive-based design. Such a strategy is typical in the United States of America, as opposed to more explicit safety, or performance-based designs that are commonly found in other countries such as New Zealand.

Fire Resistance Diagram

Fire-resistance diagrams for each of the floors are shown in Figures 87 – 92 below. The primary areas shown are for the elevator shafts, exit stairs, and exit corridors. Building elements and other special cases for Group I-2 occupancies identified above should be labeled once that information becomes available. Note, the fire-resistance ratings are to be taken at the perimeter of the shaded areas.

Figure 87. Basement Fire Resistance Diagram

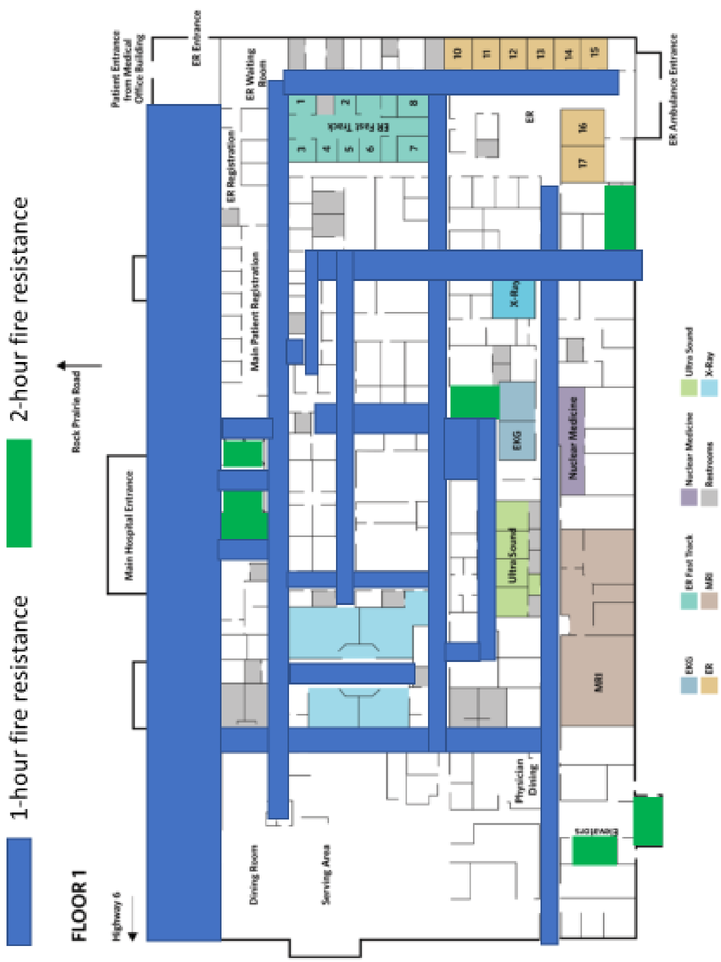


Figure 88. Floor 1 Fire Resistance Diagram

Figure 89. Floor 2 Fire Resistance Diagram

Figure 90. Floor 3 Fire Resistance Diagram

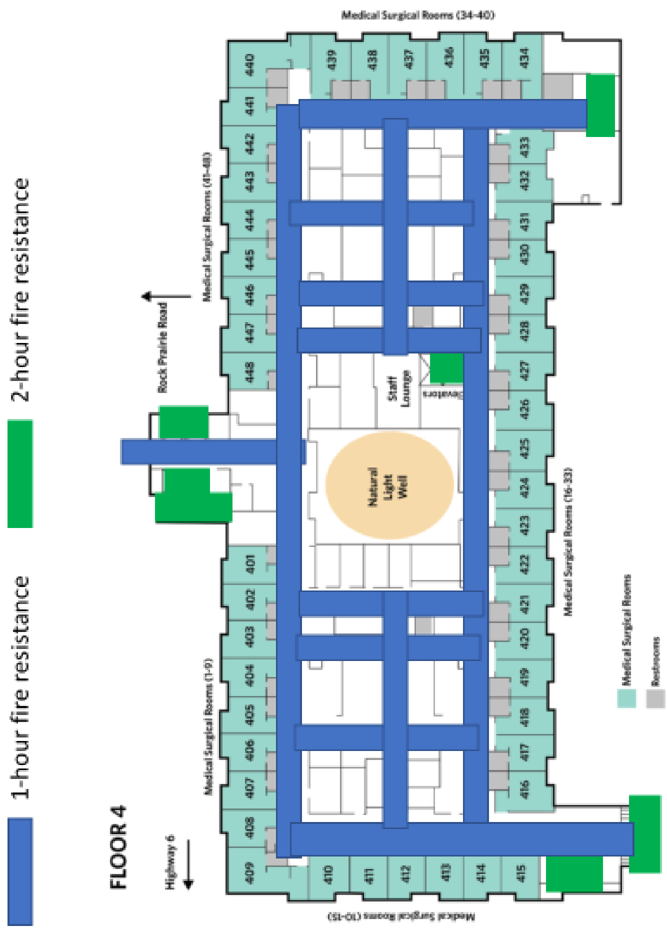


Figure 91. Floor 4 Fire Resistance Diagram

Figure 92. Floor 5 Fire Resistance Diagram

Conclusion

Structural fire protection engineering is important in increasing the chances of occupant safety during a fire. As a largely passive system, the benefits of these systems will continue even in the absence of water or electricity. From analysis of the material available, with reasonable assumptions "filling in the blanks," it can be determined that that there are no deficiencies with respect to structural fire protection features of this facility. However, this should be verified in the field. Additionally, on-going fire protection inspections should be undertaken, and, in relation to structural fire protection, care should be taken to ensure that that proscribed systems and assemblies are maintained, e.g. that penetrations through barriers are properly sealed. In addition to the construction material analysis in this structural fire protection section, flammability assessment methods are important to the overall fire protection strategy of a building, and this report covers those methods in the next section.

Flammability Assessment Methods

Introduction

While a building may be designed and built to specification, the fire protection engineering systems may be compromised in several ways. The material used may not function as intended, whether due to defects or previously unknown issues. An example of this is the metal composite materials used for exterior cladding, in which an expanded hydrocarbon core is encapsulated between metal sheets. These materials are generally thought to have played a role in the Dubai Torch Tower fires, and the UK Grenfell Tower fire. Furniture, fixtures, and equipment may also compromise the fire protection engineering systems as designed. Too large of a fire load can overwhelm systems, and dramatically reduce ASET for occupants. Flammability assessment methods, and other tests, can help determine the performance and impact of materials used to build and fill this project building.

Body

As discussed in the egress section of this report, flammability characteristics of building materials are set forth in the code.

Below is an excerpt from the egress section on flammability.

> *Interior Finish Requirements for Exits, Corridors and Other Spaces*
>
> The interior finish requirements for exits, corridors, and other spaces are primarily governed by NFPA 101 in 7.1.4.1, 7.1.4.2, and Chapter 10.2 (including 10.2.3, 10.2.3.4, 10.2.7.1, 10.2.7.3, 10.2.7.2., 10.2.7.4, Table A.10.2.2, among others).
>
> From Table A.10.2.2, new Health Care occupancies are required to have Class A interior wall and ceiling finishes (flame spread index, 0-25 (new applications); smoke developed index, 0-450) for exits, exit access corridors, and other spaces. There are allowances for Class B interior wall and ceiling finishes (flame spread index, 26-75 (new applications); smoke developed index, 0-450) for the lower portion of corridor walls or in small individual rooms, but no such allowance for corridors. This report also finds that exits and exit access corridors are required to have Class I or II interior floor finishes (critical radiant flux, not less than 0.45 W/cm^2 for Class I, critical radiant flux, not more than 0.22 W/cm^2, but less than 0.45 W/cm^2 for Class II), but there are no requirements for floor finishes for other spaces.

Flammability assessment methods are discussed in the IBC—and were also discussed in Cal Poly FPE 503 and 504—and cover ASTM and NFPA standards such as the Steiner Tunnel Test. As a whole, they seek to quantify the performance of material under set parameters to predict their behavior in a fire.

While it is possible to test each material and item, it is usually more practical and economical to purchase materials that have already been 'listed' by organizations such as UL, Underwriters Laboratories, instead of testing new items. There are cases where flammability assessment methods may be required, such as determining fuel loads for design fires under 5.5.3.6 of NFPA 101.

Conclusion

Flammability assessment methods are a powerful tool for the profession of fire protection engineering. They allow the industry to determine the performance of materials in a fire, and can help engineers and companies make choices as to what will be used to construct and fill buildings. They may also be used when evaluating unlisted materials or to investigate alternative methods. However, it is not anticipated that flammability assessment methods will be used specifically for this building. This is not the case for the next section, as this report transitions from passive fire protection measures back to active fire protection measures, and examines the smoke control design for this building.

Smoke Control

Introduction

Smoke control is a very important part of the approach to life safety for hospitals. There are several code requirements for new health care occupancies and new assembly occupancies that this report will examine here.

Body

Smoke control for this building involves a combination of active and passive measures. Active measures include stairway and elevator shaft pressurization, and smoke dampers on the HVAC systems. Passive measures include smoke compartments and smoke partitions.

Several sections of the code highlight the need to document smoke control for the building. This includes 18.7.7 of NFPA 101 for new health care occupancies. This is especially true for new assembly occupancies, where a life safety narrative (12.4.1.4.2 NFPA 101), facility management and operational plans (12.4.1.5.2 NFPA 101), and records (12.4.1.5.3 NFPA 101).

Additionally, IBC has requirements for separation and smoke barriers. Under 407.4.4.2 IBC, care suites are separated from other portions of the building, including other care suites, by smoke partitions. Under 407.5 IBC, smoke barriers are required to separate every story of the building into at least two smoke compartments. This is in alignment with 18.3.7.1 of NFPA 101, and this section of NPFA 101 places further restrictions on the size of such smoke compartments (e.g. 22,500 sq. ft. limit for compartments where patient sleeping rooms are configured for two or more patients). From the occupancy classifications and research for Health Occupancies, this report makes an educated assumption that the lower three floors (Basement, Floor 1, and Floor 2) satisfy the requirements of the 40,000 sq. ft. limit for smoke compartments (either because they contain patient sleeping rooms configured for no more than one patient, or they have no patient sleeping rooms at all), and that the upper three floors (Floor 3, Floor 4, and Floor 5) satisfy the requirements of the 22,500 sq. ft. limit for smoke compartments. In both cases, the travel distance from any point to reach a door in the smoke barrier does not exceed 200 ft. For real-world projects, this would need to be verified with stakeholders such as the architect, owner, and AHJ.

Figures 93 – 98 below show the division of each floor into smoke compartments, as well as the smoke compartments around each care suite.

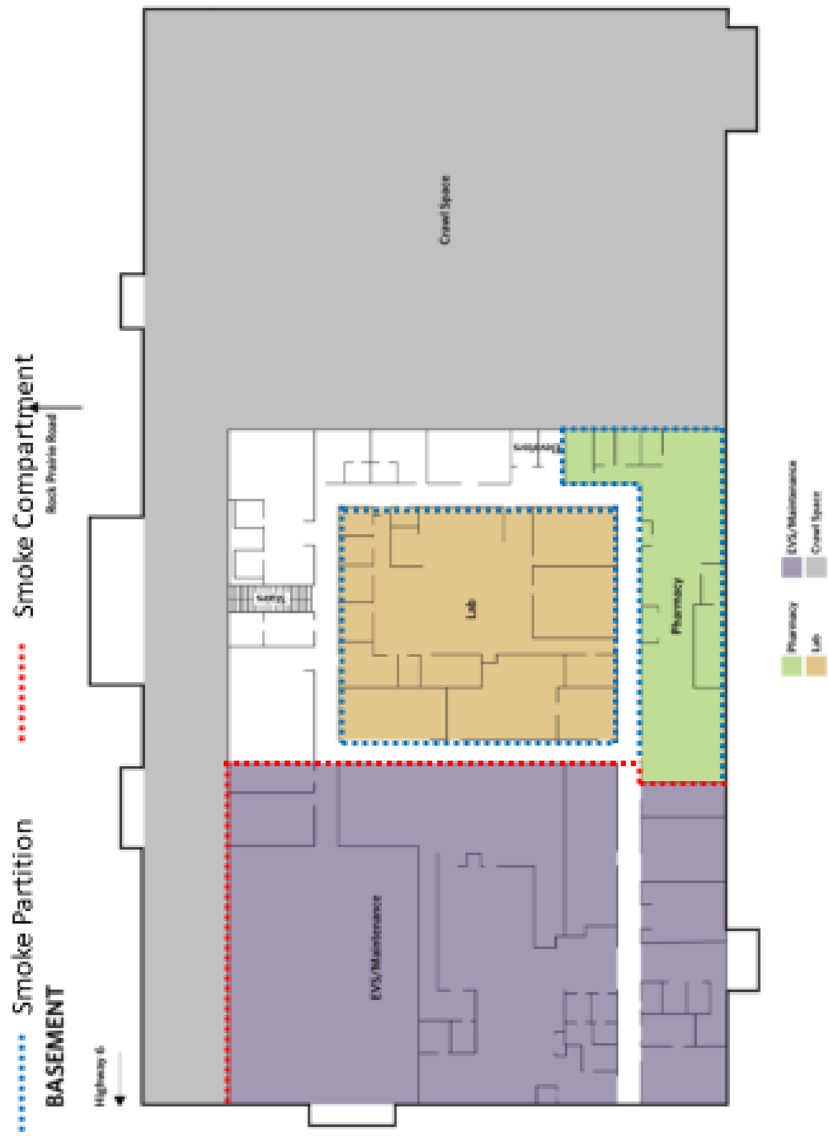


Figure # 93. Basement Smoke Control

Figure # 94. Floor 1 Smoke Control

Figure # 95. Floor 2 Smoke Control

Figure # 96. Floor 3 Smoke Control

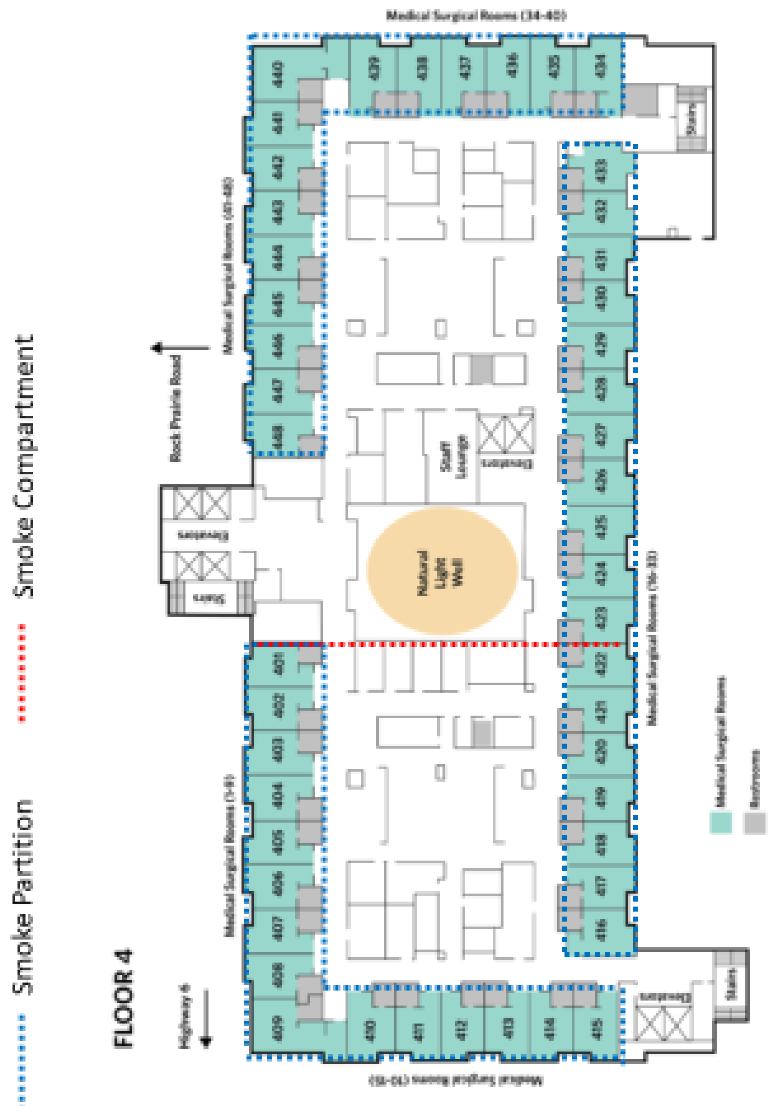


Figure # 97. Floor 4 Smoke Control

Figure # 98. Floor 5 Smoke Control

Per 9.3.1 of NFPA 101, smoke control is designed, installed, inspected, tested, and maintained in accordance with NFPA 92, NFPA 204, or other sources as approved by the AHJ. Additionally, under 9.3.4 of NFPA 101, smoke control systems are automatically activated by sprinkler waterflow or smoke detection systems, and also have the ability to be manually operated. The requirements for engineering analysis and calculations of active or passive smoke control is set forth in 12.4.1.4.4 of NFPA 101.

Conclusion

One may consider that there are both 'passive' and 'active' components of smoke control, that together form a coherent approach smoke control for life safety of health facilities. Some of the passive measures are in the construction of the smoke partitions and smoke barriers. Some of the active measures include documentation and staff training. Both are necessary components to smoke control in a health care occupancy. This concludes the prescriptive-based analysis of this hospital, and the performance-based analysis is covered next.

Performance-based Analysis

Introduction

The next several sections of this report aims to examine the Baylor, Scott, and White Medical Center, College Town, TX location through the lens of a performance-based analysis. Note, this performance-based design analysis conservatively assumes that an important fire protection feature is not present; specifically, it is assumed that the door to the room with the fire is opened to the corridor. The reason for this is that in researching other Cal Poly presentations and reports, if the door to the fire room were to remain closed, the tenability criteria for occupants would be maintained so that ASET >> RSET. Some of these same reports and presentations show that when those same models are rerun with the doors open, whether ASET is greater or less than RSET comes into question. It is for this reason that this report focuses on scenarios when the doors are open in this analysis. Additionally, the model explores the difference between a noncontrolled and a suppression controlled-fire.

Objectives

The life safety of occupants—patients, staff, and the public—is the paramount objective considered in this performance-based analysis.

Criteria

ASET should be greater than or equal to 150% of RSET. ASET in turns is based on tenability criteria for occupants, which is determined based on several categories below. These criteria were also discussed in the egress section, and they are included here again for convenience. This report summarizes the criteria that will be considered in the fire models in Table # 29 below.

Table # 33. Tenability Criteria

Tenability Criteria	Limit
Visibility	10 m
Heat	60 C
Radiation	2.5 kW/m^2
Carbon Monoxide FED	20% COHb (typically 1000 – 3000 ppm CO)

Note, based on the calculations and computer models from egress class Cal Poly FPE 521 and smoke management and special hazards class Cal Poly FPE 552, visibility serves as a 'canary in the coalmine' for tenability: if visibility is satisfied, the other criteria are usually satisfied during fires such as those that will be considering for this performance-based analysis. Also, this report assumes that the visibility limit for tenable conditions is 10 m, which seems to be a good middle ground of the range of values presented in Table 61.3 and Table 61.4 of the SFPE Handbook.

Tenability Performance Criteria

Several different sources are used to set tenability limits for the project building. Of importance is the need to take into account the occupant characteristics associated with this hospital. This report categorizes the tenability criterial into three broad categories: visibility/smoke density, heat effects, and toxic/irritant gases.

Visibility and Smoke Density

For visibility/smoke density, Chapter 61 of the SFPE Handbook is the primary reference that is relied upon in this report. From Table 61.3 and Table 61.4, this report assumes occupants who are unfamiliar with the inside of the building as a conservative estimate, and uses a smoke density (extinction coefficient) of 0.15 1/m and visibility of 13 m (42.6 ft). Note, these limits are close to those proposed by fire researchers such as Kawagoe (0.1 1/m) and the Los Angeles Fire Department (45 ft, 13.5 m).

Heat Effects

For heat effects, Chapter 63 of the SFPE Handbook is the primary reference that is relied upon in this report, and Table 63.20, Table 63.28, Table 63.29 are used extensively.

This report assumes that tenability limits for the typical occupant are breached if occupants are exposed to radiation intensity of 2.5 kW/m^2 for more than 30 seconds, or if occupants experience exposure to convection of 100°C at a humidity of less than 10 % H_2O for more than 12 minutes. Because of the potential weakened state of patients, this report can apply a safety factor of 20% - 50% to these limits, as agreed upon by stakeholders (client, AHJ, etc.).

Toxic and Irritant Gases

For toxic and irritant gases, this report uses the materials from the Cal Poly SLO FPE Program, and Chapter 63 of the SFPE Handbook (including the Appendix, and relevant equations such as 63.15, 63.35, 63.38, 63.39, 63.18, Table 63.4, Figure 63.20, Table 63.10, etc.) to set limits and calculate the FED, Fractional Effective Dose.

As discussed in Cal Poly SLO's FPE Program and in the SFPE Handbook, Chapter 63, pages 2352 – 2356, the exposure dose (percent COHb) for incapacitation, D, varies depending on the level of activity. From the SFPE Handbook, Figure 63.20 indicates that, with other factors being equal, increasing levels of activity lead to decreasing times to incapacitation. Similarly, Table 63.10 indicates increasing carboxyhemoglobin concentrations with increasing levels of activity with other factors being equal.

Fig. 63.20 Time to incapacitation by carbon monoxide for a 70 kg human at different levels of activity. *Curve A*—40 % carboxyhemoglobin V_E 8.5 L/min at rest sitting; *Curve B*—30 % carboxyhemoglobin V_E 25 L/min, light work (e.g., walking 6.4 km/h); *Curve C*—20 % carboxyhemoglobin V_E 50 L/min, heavy work (e.g., slow running 8.5 km/h, or for walking 5.6 km/h up a 17 % gradient)

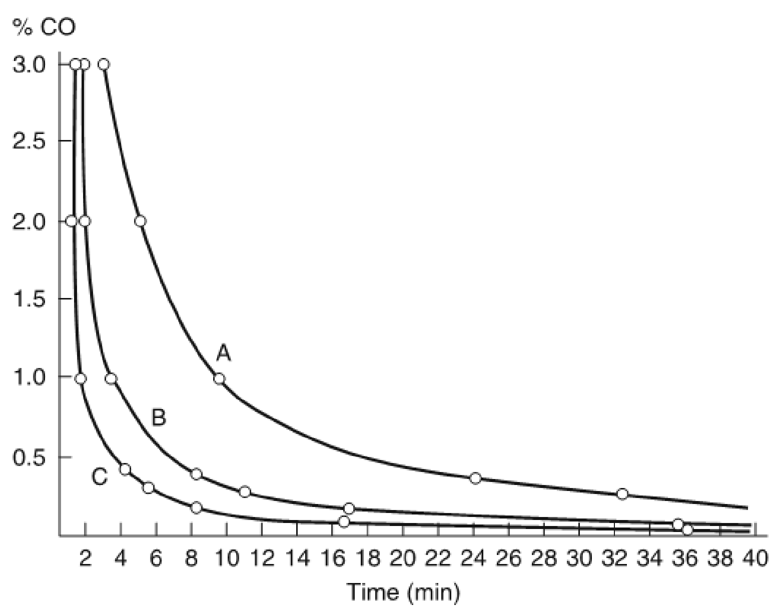


Table 63.10 Work rate, oxygen consumption and minute ventilation for different activities (for ~70 kg Bodyweight)

Activity	Speed km/h	Work kcal/ min	Work Watts	V_{O2} L/min STPD[a]	V_E l/m ATPS[b]
Sleeping and lying, includes turning over, getting up	0	1.1	77	0.22	4.9
Resting	0	1.26	88	0.252	5.6
Sitting, includes reading, eating, desk work	0	1.5	105	0.3	6.7
Sitting	0	1.9	133	0.38	8.5
Standing	0	1.875	131	0.375	8.4
Standing, includes activities like moving between rooms	0	2.5	174	0.5	11.2
Walking, outdoors, and other activities	3	3	209	0.6	13.4
Walking	4	3.8	265	0.76	17.0
Walking	5	4.45	311	0.89	19.9
Light industry,	5	5	349	1	22.3
Walking	6	5.15	359	1.03	23.0
Walking	6.4	5.6	391	1.12	25.0
Walking	7	5.8	405	1.16	25.9
Manual labor	7.24	8	558	1.6	35.7
Running	5.6	11.2	782	2.24	49.9
Running, climbing stairs, heavy manual work	8.9	11	768	2.2	49.0

[a]STPD = standard temperature (0 °C) and pressure (760 mmHg) dry
[b]ATPS = Ambient temperature and pressure saturated

This report uses D = 50 %COHb as the lethal level based on Table 63.4, and because "50 %COHb is usually considered as an average lethal level" (SFPE Handbook, 5th ed., page 2347).

It is assumed that 40 %COHb would lead to loss of consciousness for healthy resting individuals, but this loss of consciousness can occur at even lower levels for more susceptible resting subjects, and lower levels can be dangerous for subjects with compromised cardiac function. However, it should be noted that during the presentation of this report during the 2019 Cal Poly FPE Symposium, senior FPE's reported incidents of lethal CO concentrations for hospital patients that are approximately an order of magnitude less than the 1000 – 3000 ppm CO that are typically considered the tenability limits for healthy individuals.

For the reasons described in the previous paragraph, this report assumes that it is appropriate to assume a tenability limit of 20 %COHb, 100 ppm HCN for 10 minutes (Table 63.12), and CO_2 limits should be examined based on the FED model, in conjunction with other gases.

For irritants, this report takes half of the levels from Table 2-6.12 of the NFPA Handbook (which has been replicated in Table # 34 below):

Table # 34. Irritant Gas Levels (ppm)

Gas	Limit (ppm)
HCl	100
HBr	100
HF	100
SO2	12
NO2	35
CH2CHO	2
HCHO	3

Methodology to Evaluate Building Performance Objectives under Section 502 of the LSC

In order to evaluate whether or not the building meets the performance objectives for tenability, there are several methods in A.5.2.2. Of the four methods presented, it is in the report author's engineering judgement that Methods 3 (smoke layer will never descend below 6 feet above the floor) and 4 (fire will not spread to occupied rooms) will be extremely difficult to achieve with such a large and complex hospital building for this project, so this report will not use those methods. Of the remaining two methods, Methods 1 (PFD, using tools such as FED) and 2 (evacuation before smoke layer descends to below 6 feet above the floor) both have pros and cons associated with them.

Method 1 has the benefit of being more flexible in a way; there is no 'red line' like Method 2, tying evacuation time to smoke level descent. Rather, FPE's are allowed the freedom to use all manner of tools available to them to prevent occupants from experiencing untenable conditions. The strength of this method in the project is that FPE's are able to use multiple strategies to protect occupants. The weakness is that FPE's must account for all variables that might threaten their safety, and ensure that no tenability limits are breached.

Method 2 has a more straight-forward and easily measurable metric, and in conjunction with the expectation of trained staff and horizontal exits, it is expected that the necessary evacuation time can be achieved in this project building. While this method does not explicitly list protection from all tenability criteria, it seems reasonable to assume that if the smoke layer does not descend below 6 feet, other tenability criteria such as toxic gas concentration and visibility would also be met.

For these reasons, it is recommend that the client utilize Method 2 at this time to show that the building meets performance objectives outlined in Section 502 of the LSC. Simultaneously, it is understandable if the AHJ would require the use of Method 1 instead of Method 2. AHJ direction should be solicited so that the correct methodology may be pursued.

Analysis

The basis of the performance-based analysis for this report is based on one of the smoke compartments of Floor 4. The geometry is discussed further the design fire section below. This floor was selected as a starting point as representative of an area of the hospital that would be the most likely to be occupied by a greatest number of occupants needing assistance, relative to the staff and public who could assist them.

Proposed Design Fires

This report considers two design fires, both of which are set on the 4th floor: a 4-person workstation fire in an office, and a mattress fire in a patient bedroom. Figures of these two design fire locations are shown in Figures # 99 – 103. The 4-person workstation fire is in an office at the plan north-west side of the fourth floor. The mattress fire is in a patient bedroom on the plan south side of the fourth floor. For both design fire scenarios, it is assumed that both of these will draw on experimental data from the SFPE Handbook. Specifically, data for these fires came from Table 26.19 and Table 26.16, respectively. HRR curves and data were chosen so that the most conservative choices present were used for the model.

Table 26.19 Workstations tested by NRIFD

Test	Combustible mass (kg)	Type of workstation	No. of desk units	Partition panels	Peak HRR (kW)	Time to peak (s)
1	570	Clerical	4	N	3035	508
2	597	Clerical	4	Y	2476	616
3	1054	Engineering	4	N	2957	793
4	1086	Engineering	4	Y	2271	732
11	272	Engineering	1	Y	1602	441
12	264	Engineering	1	N	1870	412
14	263	Engineering	1	N	1219	601

Table 26.16 Some mattress HRR data; full-scale data include room effect of small bedroom

Padding material	Ticking material	Combustible mass (kg)	Peak HRR, full-scale (kW)	180 s avg HRR, bench-scale (kW m^{-2})
Polyurethane foam	Unidentified fabric	8.9	1716	220
Melamine-type PUR/cotton batting/polyester fiber pad	Polyester/ polypropylene	NA	547	169
Polyurethane foam/cotton batting/ polyester fiber pad	Unidentified fabric	NA	380	172
Polyurethane foam/polyester fiber pad	PVC	NA	335	195
Melamine-type PUR	FR fabric	15.1	39	228
FR cotton batting	PVC	NA	17	36
FR cotton batting	Polyester	15.7	22	45
Neoprene	PVC	14.9	19	31

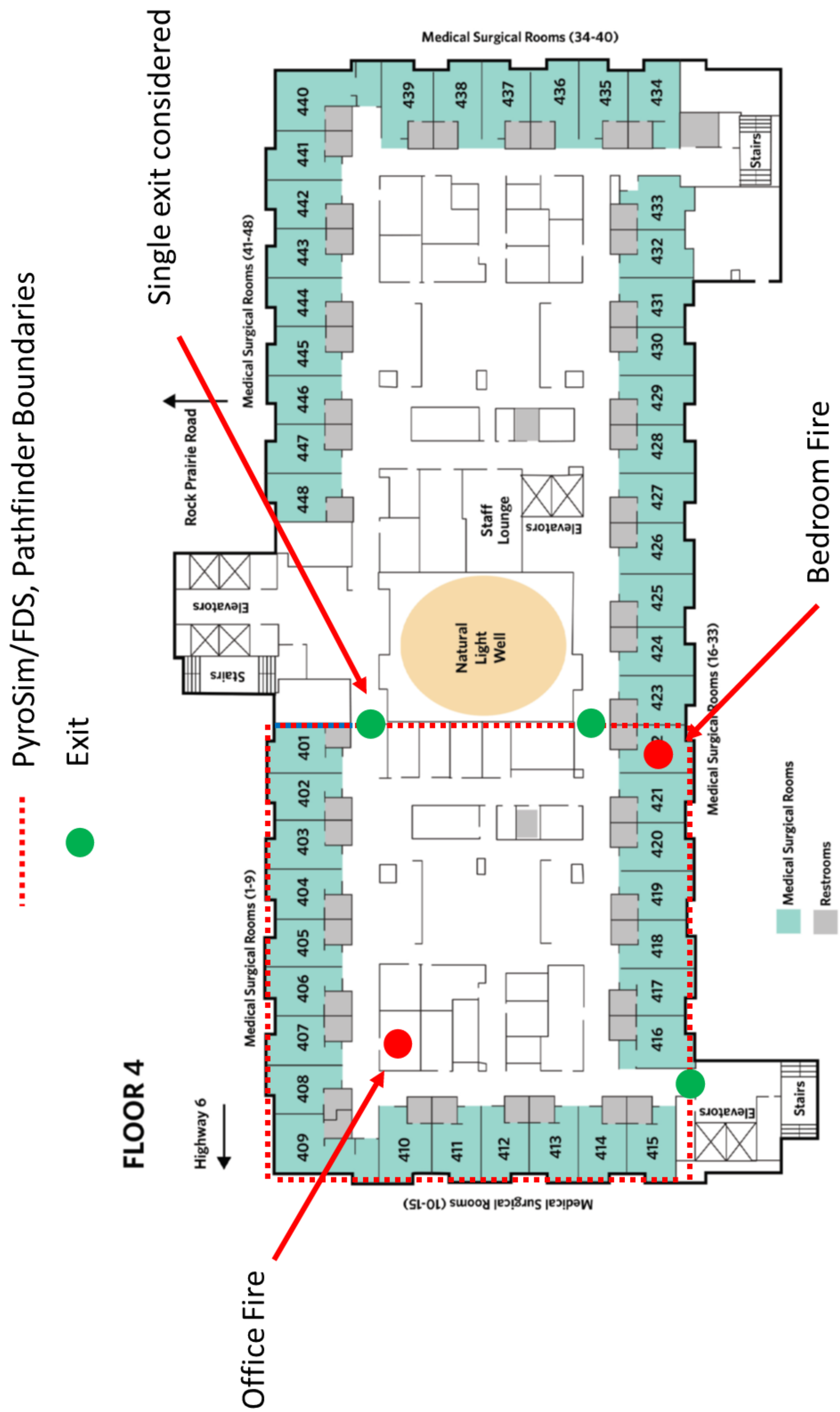


Figure # 99. Design Fire Diagram

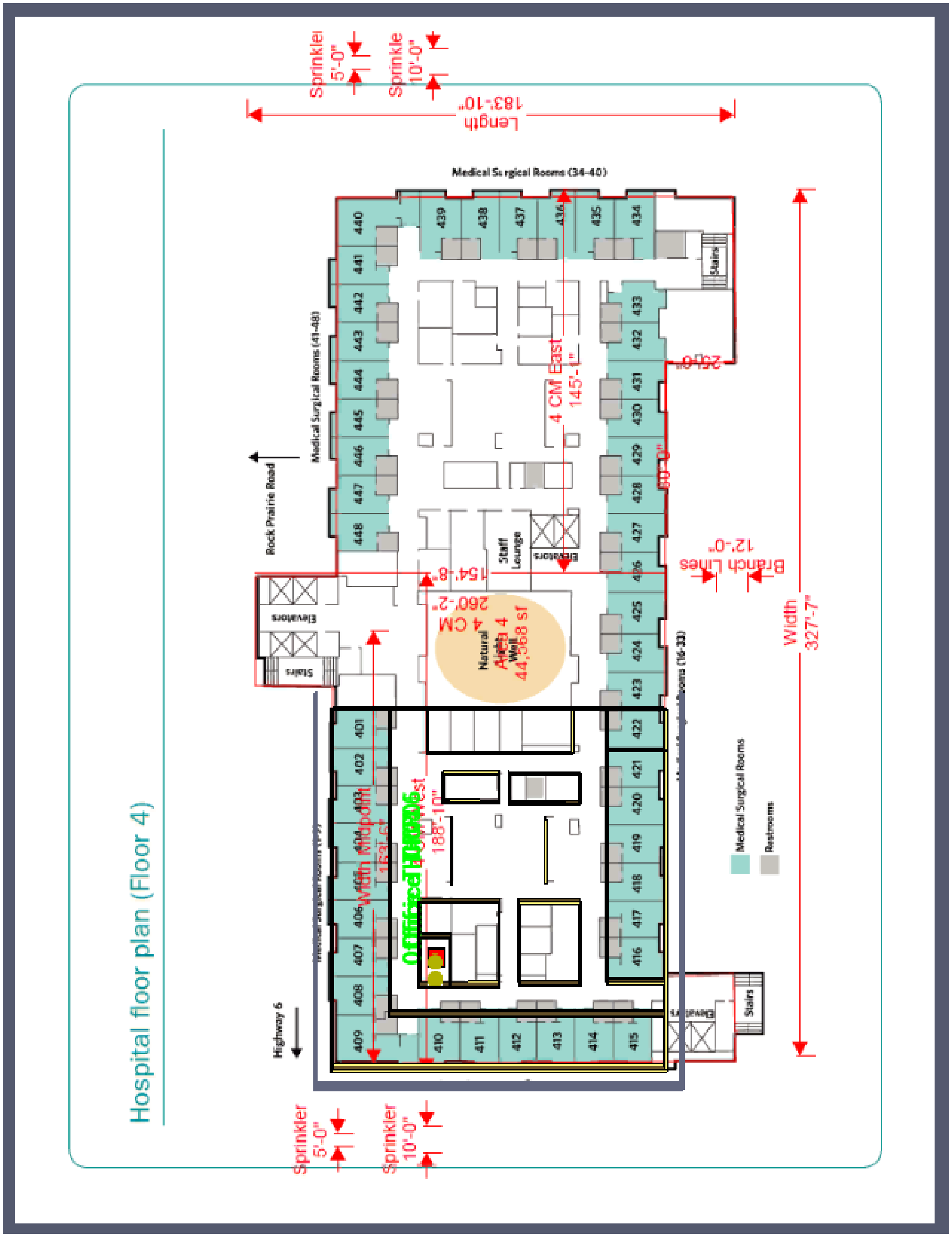


Figure # 100. Office Fire

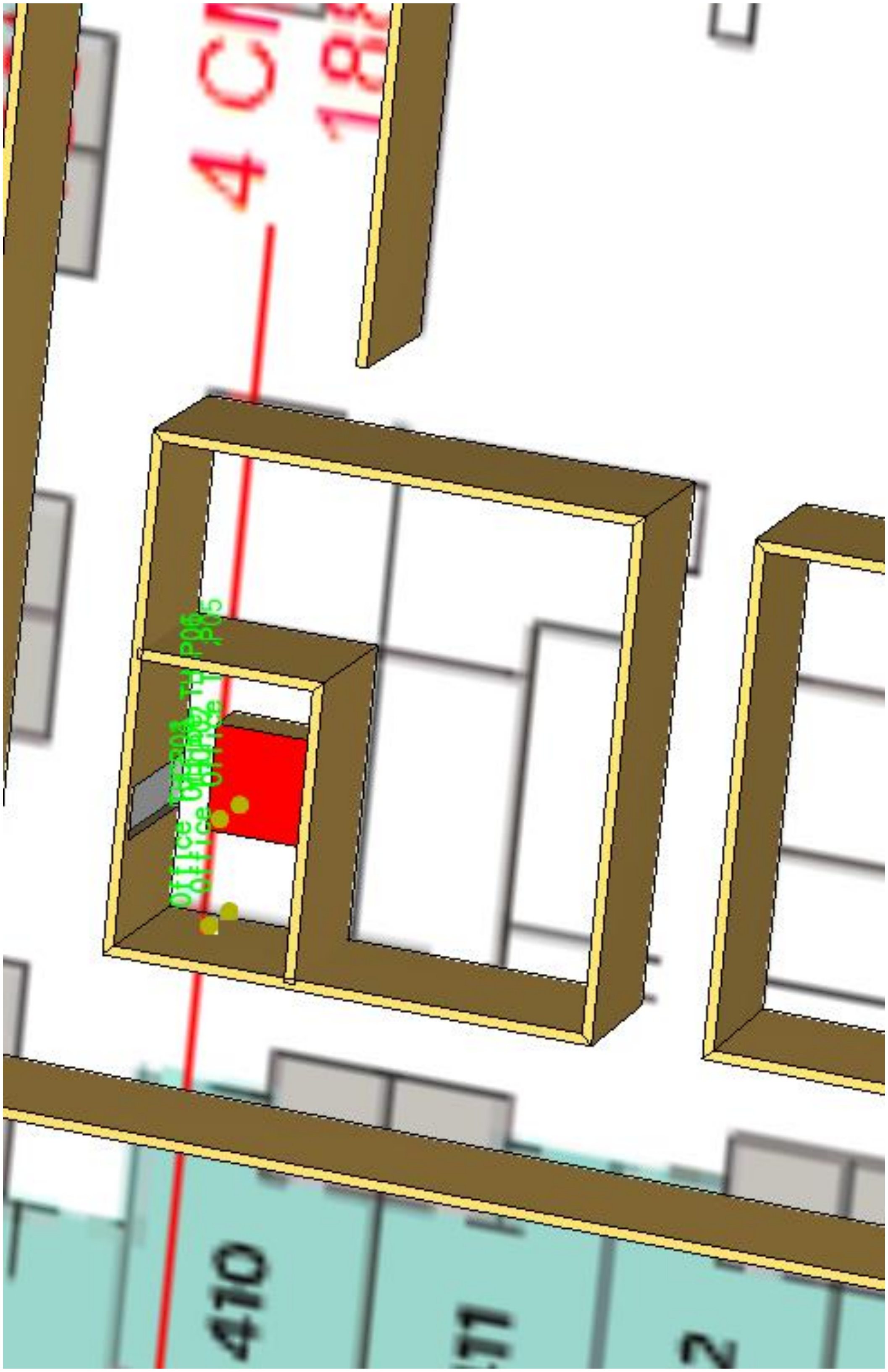


Figure # 101. Enlarged View of Office Fire

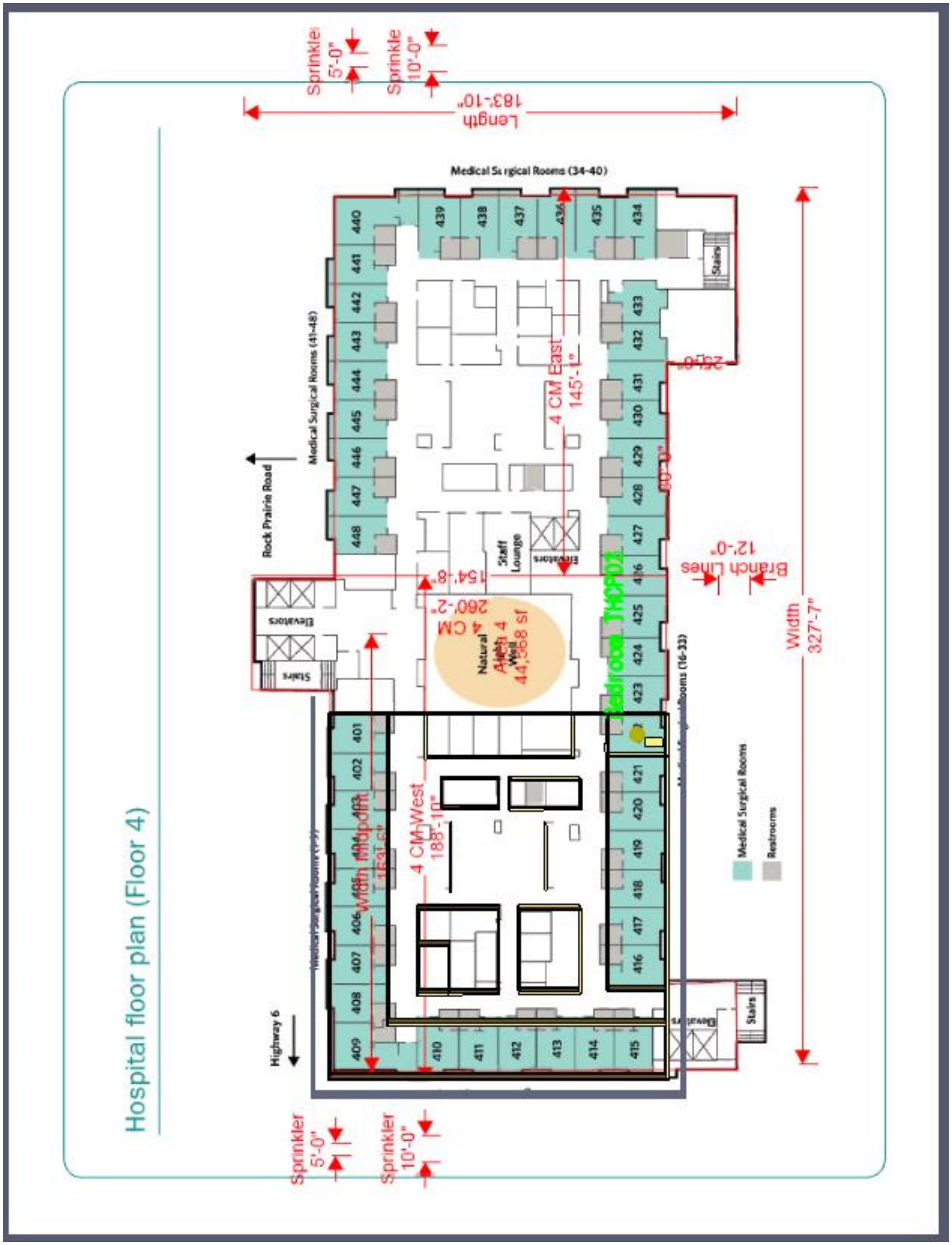


Figure # 102. Bedroom Fire

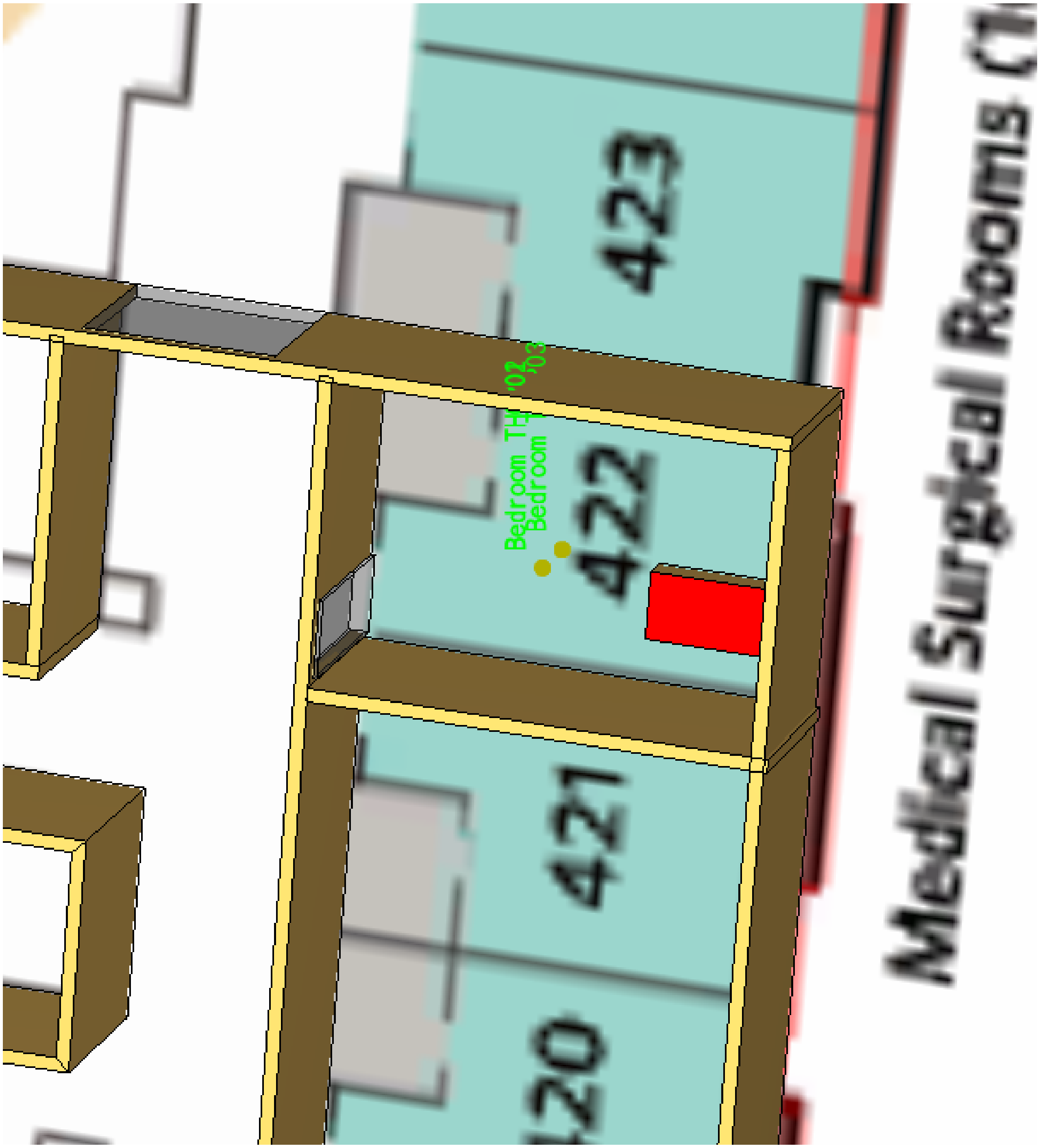


Figure # 103. Enlarged View of Bedroom Fire

Fire Models

PyroSim and FDS were used to model both of the design fires and the resulting impact on tenability criteria. Pathfinder was used to model the egress time for occupants in hospital beds, and requiring two assistants to move the patients to safety.

Slice files were placed at the 6 feet level in PyroSim, and the model was run to see when visibility dropped below 10 meters. Ceiling devices were also placed to gather data for smoke detector and fire sprinkler activation. Three egress scenarios in Pathfinder were also run, each removing a horizontal exit, until only one remained. Different egress scenarios were modeled because one of the three horizontal exits leads to a stairwell, whereas the other two lead to the second smoke compartment of Floor 4. It is likely that the majority of occupants would need to be evacuated to the second smoke compartment rather than the stairwell. Additionally, a single horizontal exit to the second smoke compartment was modeled to account for the scenario where a fire may be blocking access to the other one (e.g. if there was a fire in a bedroom next to that exit, as was modeled in PyroSim).

The HRR curve used for the design fires in FDS was based on data from the SFPE Handbook. The HRR curve for the office fire was based on the four-unit workstation of Figure 26.70 from the SFPE Handbook, and the HRR curve for the bedroom fire was based on Figure 26.64. Note, the HRR curve for the bedroom fire is for a king-size bed assembly. It is assumed that this can be used to model the hospital beds in this building; perhaps even two of them in a single bedroom, which could conservatively be assumed to be used as the design fire for the bedroom.

The fire models were run both as a non-controlled fire and a suppression-controlled fire (i.e. the fire scenarios were run with and without fire sprinkler activation). For the suppression-controlled fire, data from the non-controlled model was taken, and at the point that the ceiling device temperature reaches lower end of the 175-225°F range for the fire sprinklers that have been selected is the point that the report assumes that the sprinklers activate for the suppression-controlled iteration of this model. At the time of sprinkler activation, the HRR of the fire is then held steady—instead of the appropriate alpha t-squared fire ramping increase (based on a fast or ultrafast fire) to the maximum HRR from the SFPE Handbook. This is accomplished by manually reading the HRR from the non-suppression controlled model, then changing the maximum HRR from the one listed in the SFPE Handbook to the HRR at the time of sprinkler activation.

Fig. 26.70 HRR of four-unit workstations tested at NRIFD

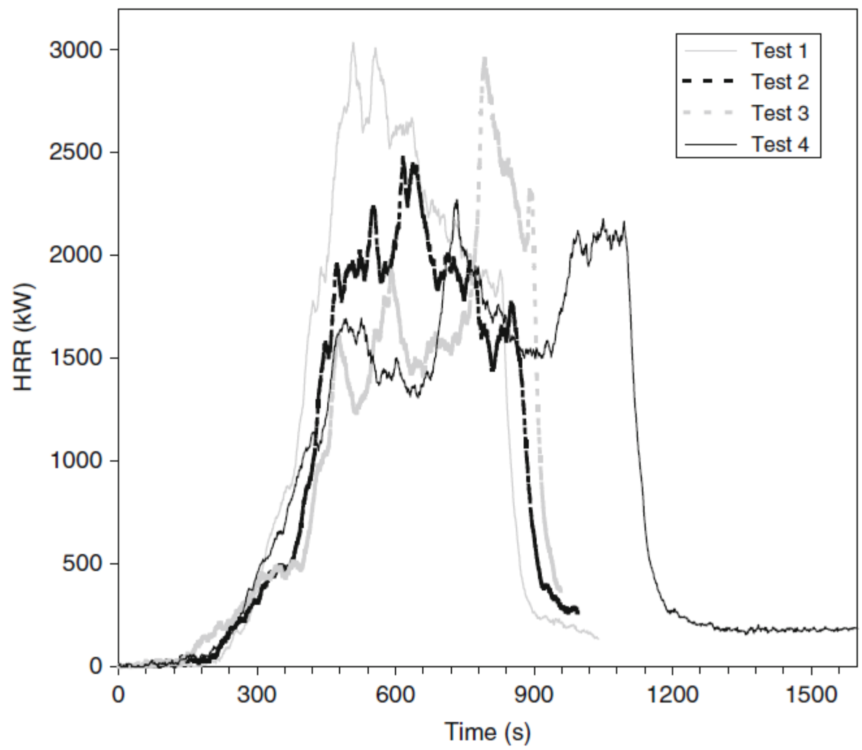
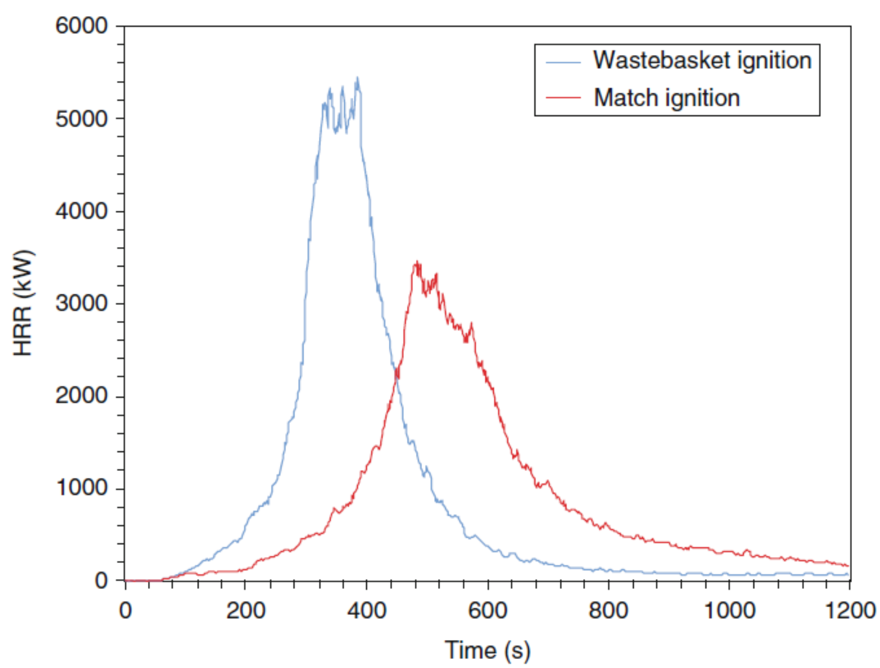


Fig. 26.64 Effect of ignition source on king-size bed assemblies



Pyrosim Office Fire

Based on the Office scenario, the visibility for this smoke compartment drops below 10 m for a sizeable portion of the corridor between five and six minutes. It should be reiterated that this design fire scenario is modeled with the office door open. The fire reaction is modeled as an oak wood reaction, as matching Table 36.11 of the SFPE Handbook, as an assumption that this closely resembles what the workspace desk is constructed of. Relevant figures are shown below in Figures # 104 – 107.

Table 36.11 Stoichiometric yields of major products[a]

Material	Formula	Ψ_O	Ψ_{CO_2}	Ψ_{CO}	Ψ_s	Ψ_{hc}	Ψ_{HCl}	Ψ_{HF}
Carbon-hydrogen atoms in the structure								
PE	CH_2	3.43	3.14	2.00	0.857	1.00	0	0
PP	CH_2	3.43	3.14	2.00	0.857	1.00	0	0
PS	CH	3.08	3.38	2.15	0.923	1.00	0	0
Expanded polystyrene								
GM47	$CH_{1\cdot1}$	3.10	3.36	2.14	0.916	1.00	0	0
GM49	$CH_{1.1}$	3.10	3.36	2.14	0.916	1.00	0	0
GM51	CH	3.08	3.38	2.15	0.923	1.00	0	0
GM53	$CH_{1.1}$	3.10	3.36	2.14	0.916	1.00	0	0
Carbon-hydrogen-oxygen-nitrogen atoms in the structure								
POM	CH_2O	1.07	1.47	0.933	0.400	0.467	0	0
PMMA	$CH_{1.6}O_{0.40}$	1.92	2.20	1.40	0.600	0.680	0	0
Nylon	$CH_{1.8}O_{0.17}\ N_{0.17}$	2.61	2.32	1.48	0.634	0.731	0	0
Wood (pine)	$CH_{1.7}O_{0.83}$	1.21	1.67	1.06	0.444	0.506	0	0
Wood (oak)	$CH_{1.7}O_{0.72}\ N_{0.001}$	1.35	1.74	1.11	0.476	0.543	0	0

PyroSim Bedroom Fire

Based on the Bedroom scenario, the visibility for this smoke compartment drops below 10 m for a sizeable portion of the corridor between five and six minutes. It should be reiterated that this design fire scenario is modeled with the bedroom door open. The fire reaction is modeled as a polyurethane GM27 reaction, as matching Table 36.11 of the SFPE Handbook, as an assumption that this closely resembles what the bed is constructed of. Relevant figures are shown below in Figures # 108 – 111.

Pathfinder Models

As discussed earlier, three Pathfinder models are considered: three exits, two exits, and one exits. This is to account for the fact that one exit is to a stair, which is not useful for evacuating patients in hospital beds, and that one of the remaining two horizontal exits may be blocked by a fire (which is assumed to be the case in this report). The results are summarized in the following table, Table # 35, and relevant figures are shown below in Figure # 112 – 114.

Table # 35. Pathfinder Results

Scenario	Egress Time (seconds)
Three Exits	147.0
Two Exits	194.3
One Exit	199.5

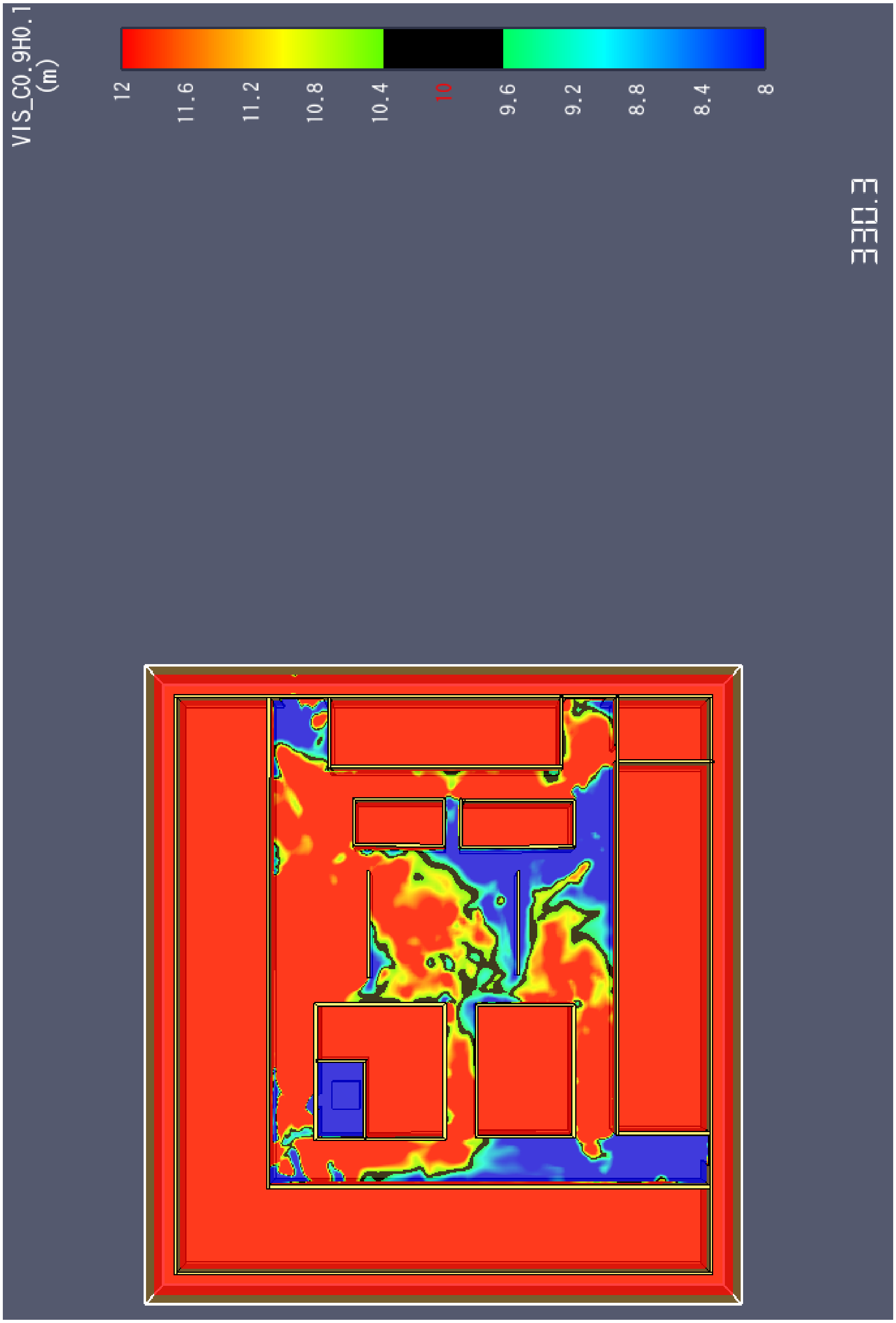


Figure # 104. Office Fire, Noncontrolled, Visibility, 330 Seconds

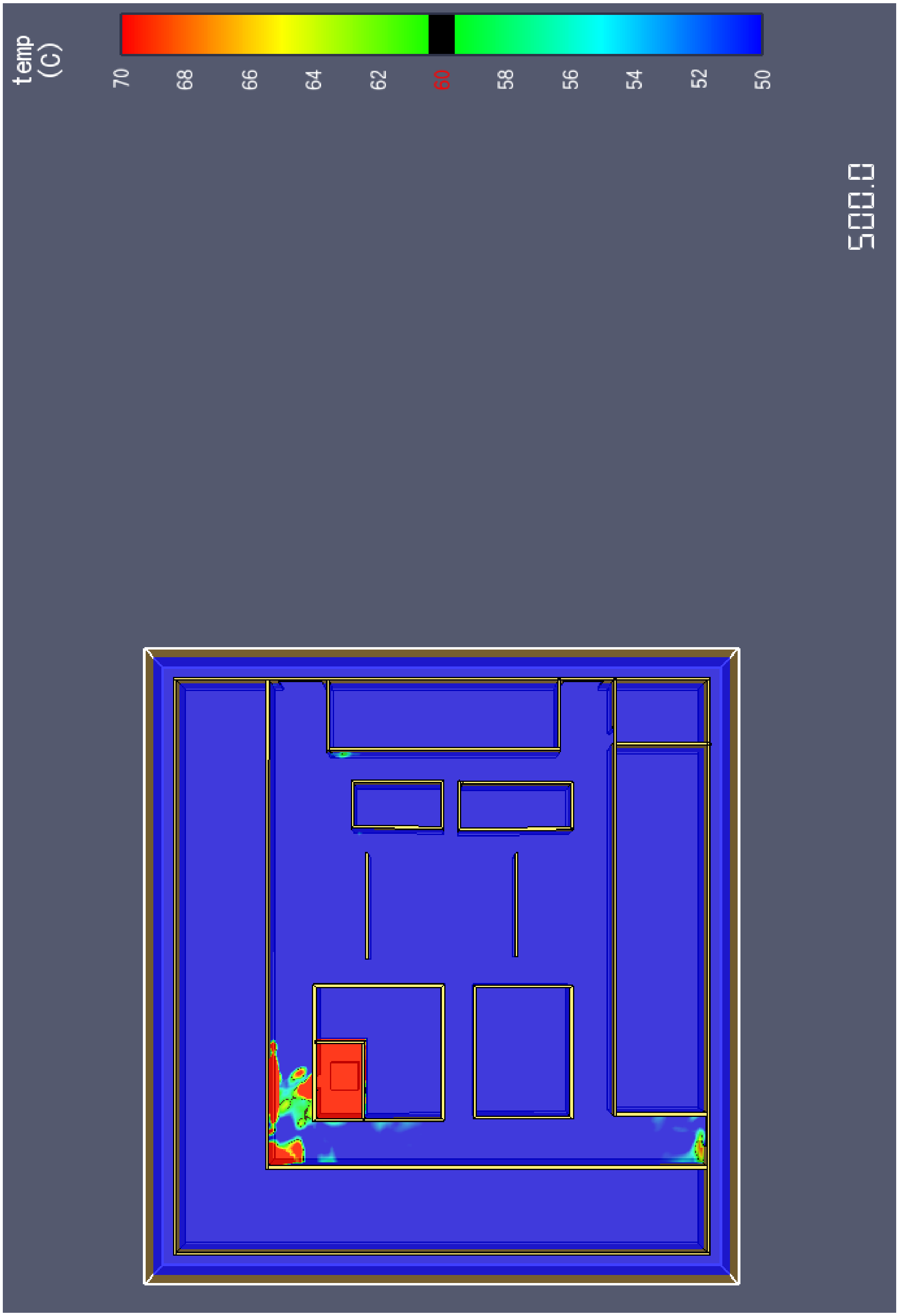


Figure # 105. Office Fire, Noncontrolled, Temperature, 500 Seconds

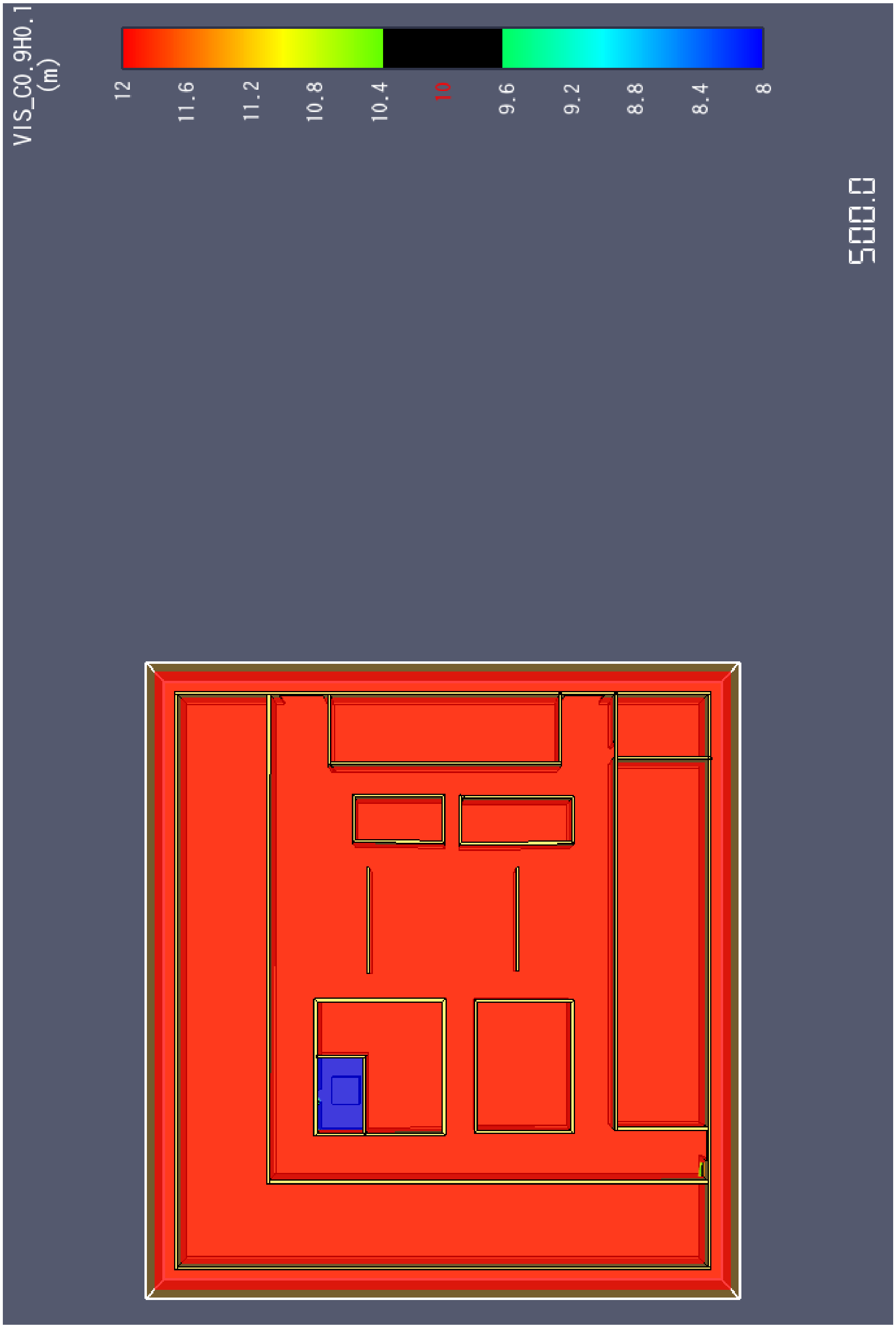


Figure # 106. Office Fire, Suppression-Controlled, Visibility, 500 Seconds

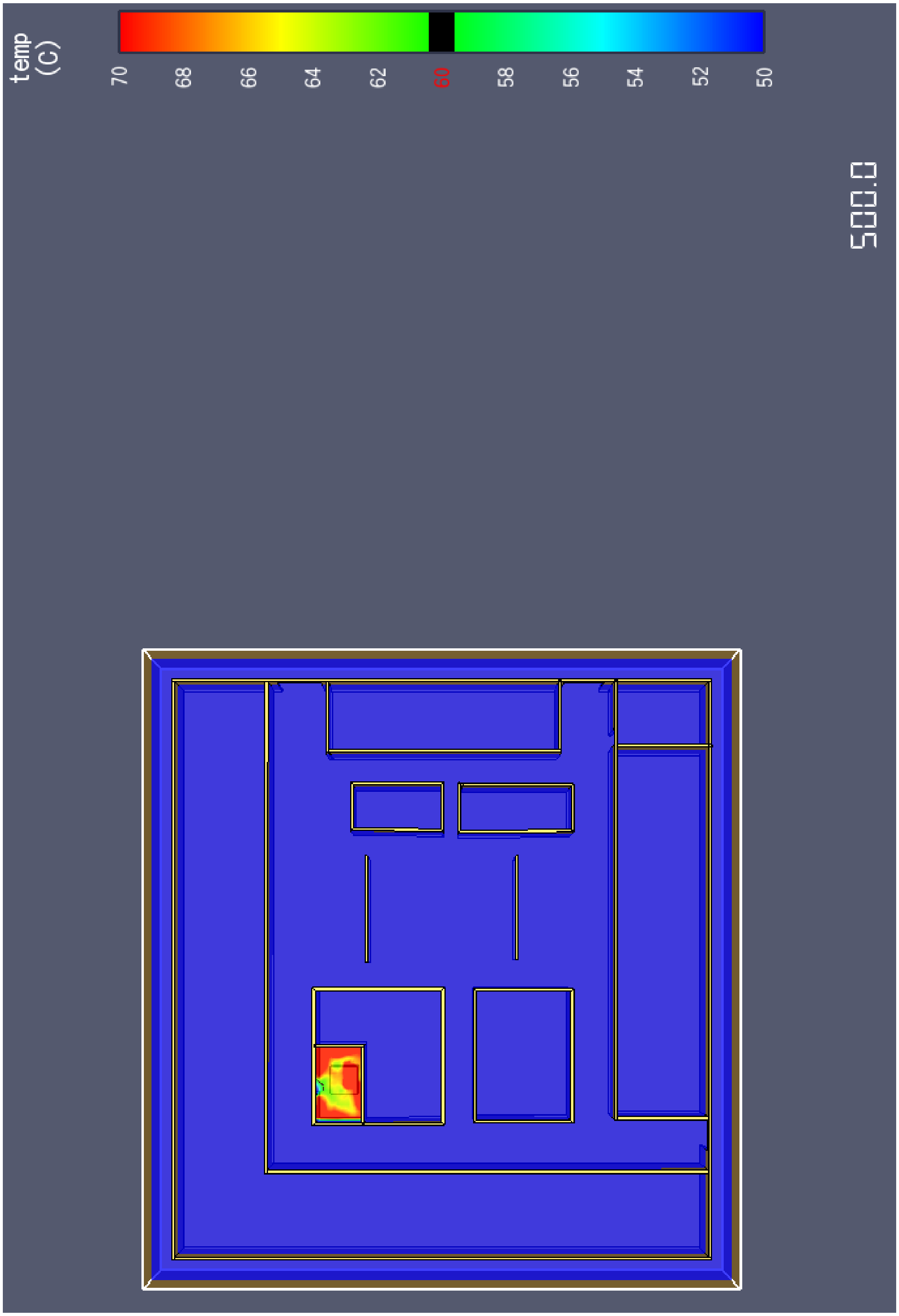


Figure # 107. Office Fire, Suppression-Controlled, Temperature, 500 Seconds

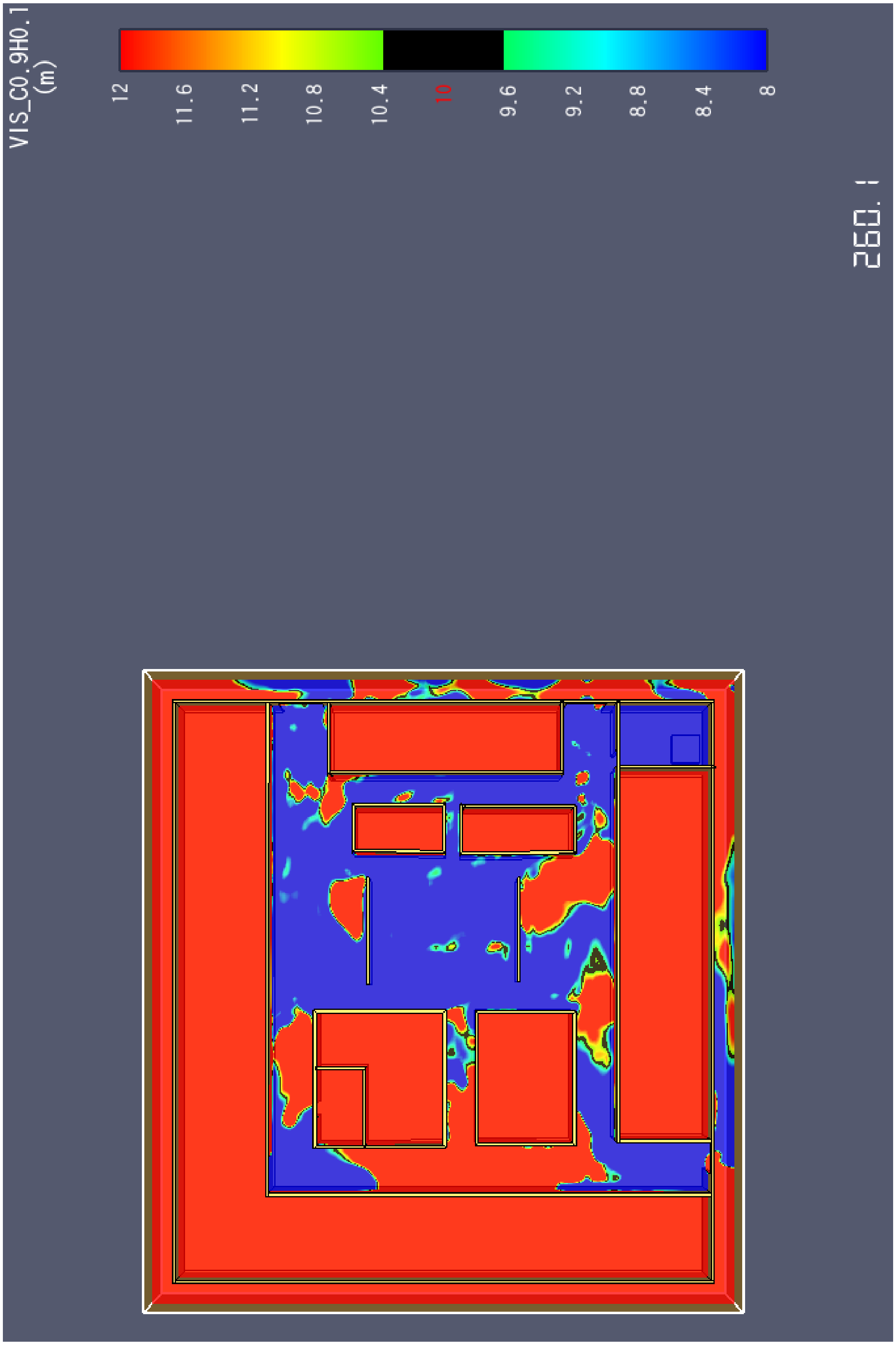


Figure # 108. Bedroom Fire, Noncontrolled, Visibility, 260 Seconds

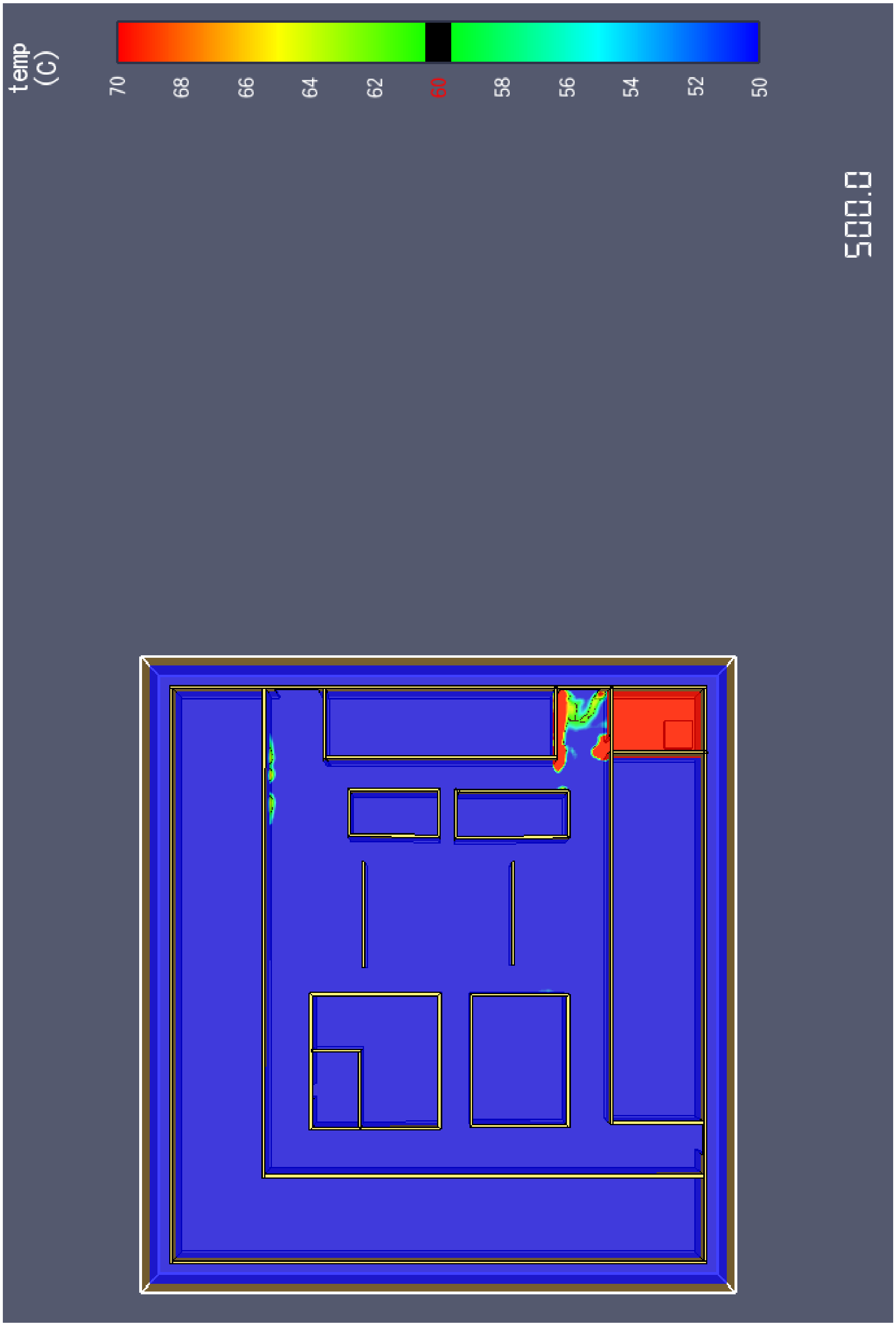


Figure # 109. Bedroom Fire, Noncontrolled, Temperature, 500 Seconds

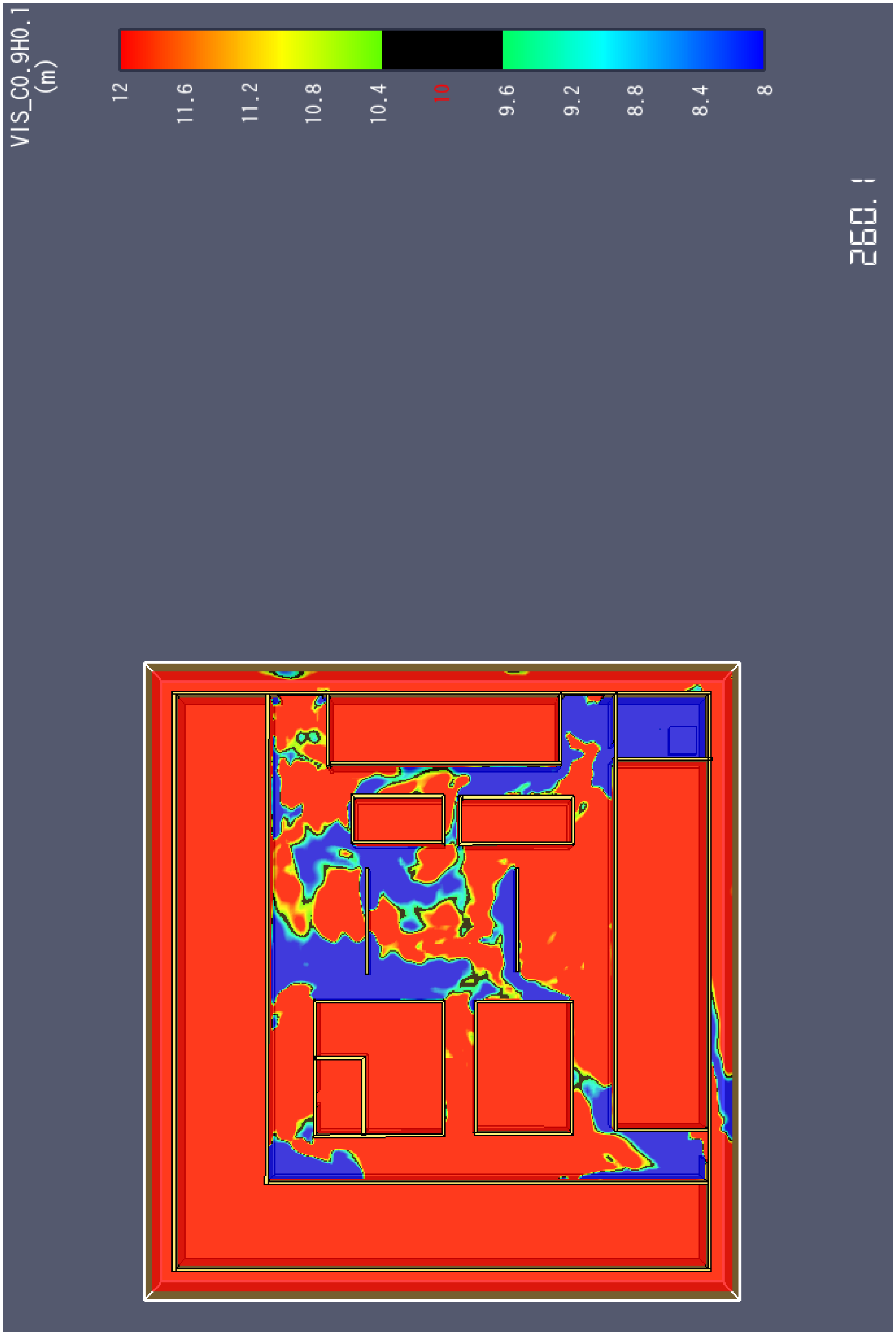


Figure # 110. Bedroom Fire, Suppression-Controlled, Visibility, 260 Seconds

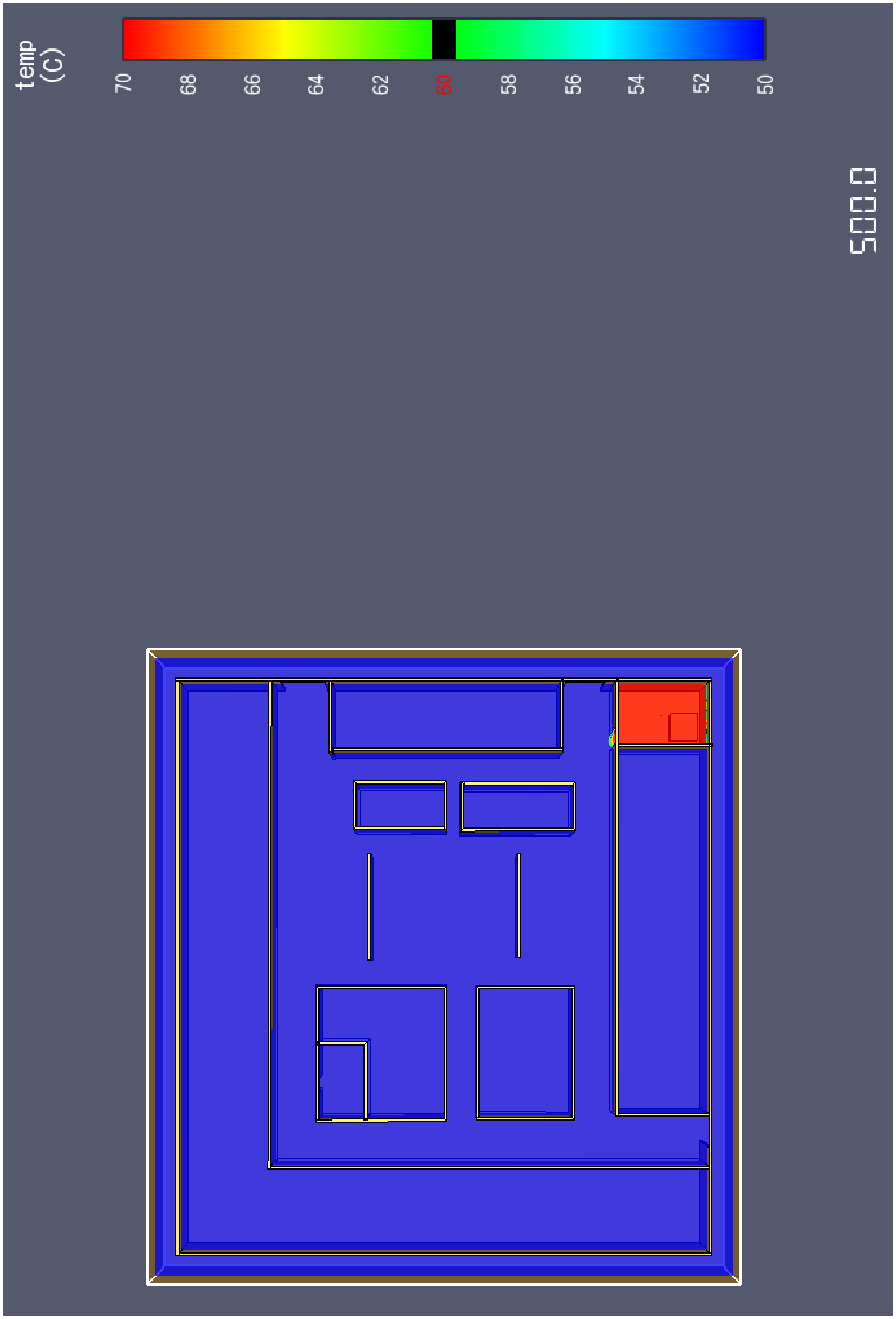


Figure # 111. Bedroom Fire, Suppression-Controlled, Temperature, 500 Seconds

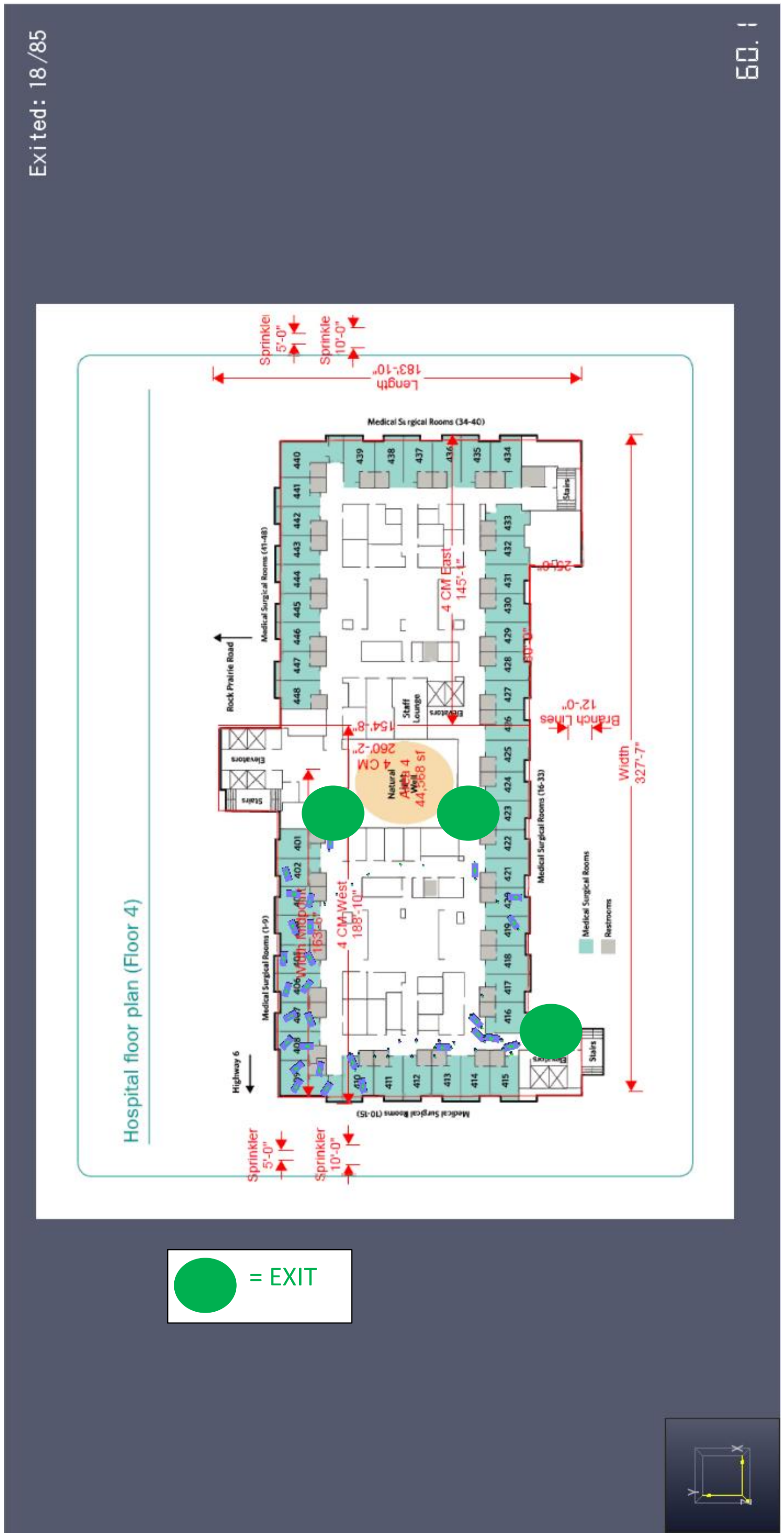


Figure # 112. Three-Exit Evacuation

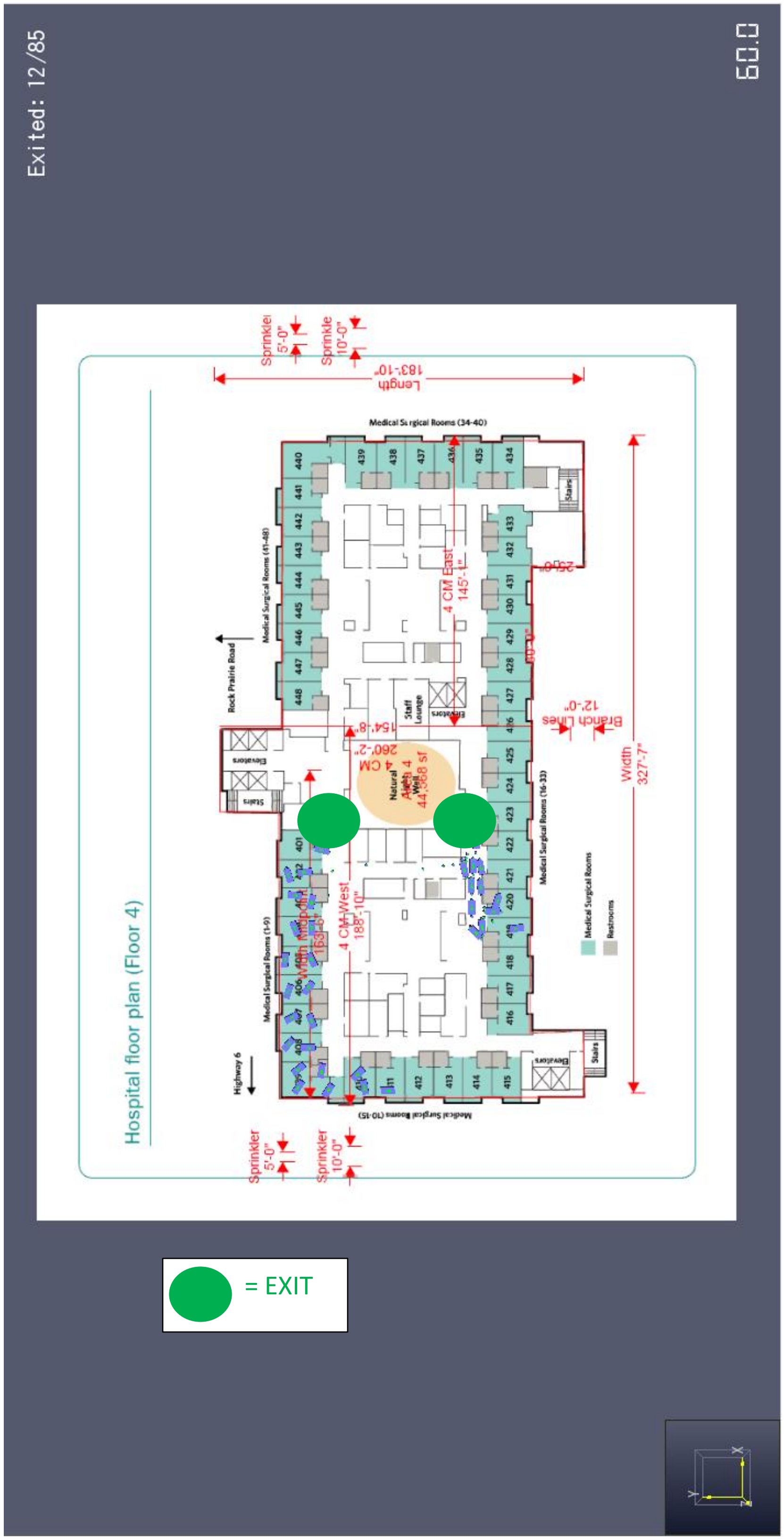


Figure # 113. Two-Exit Evacuation

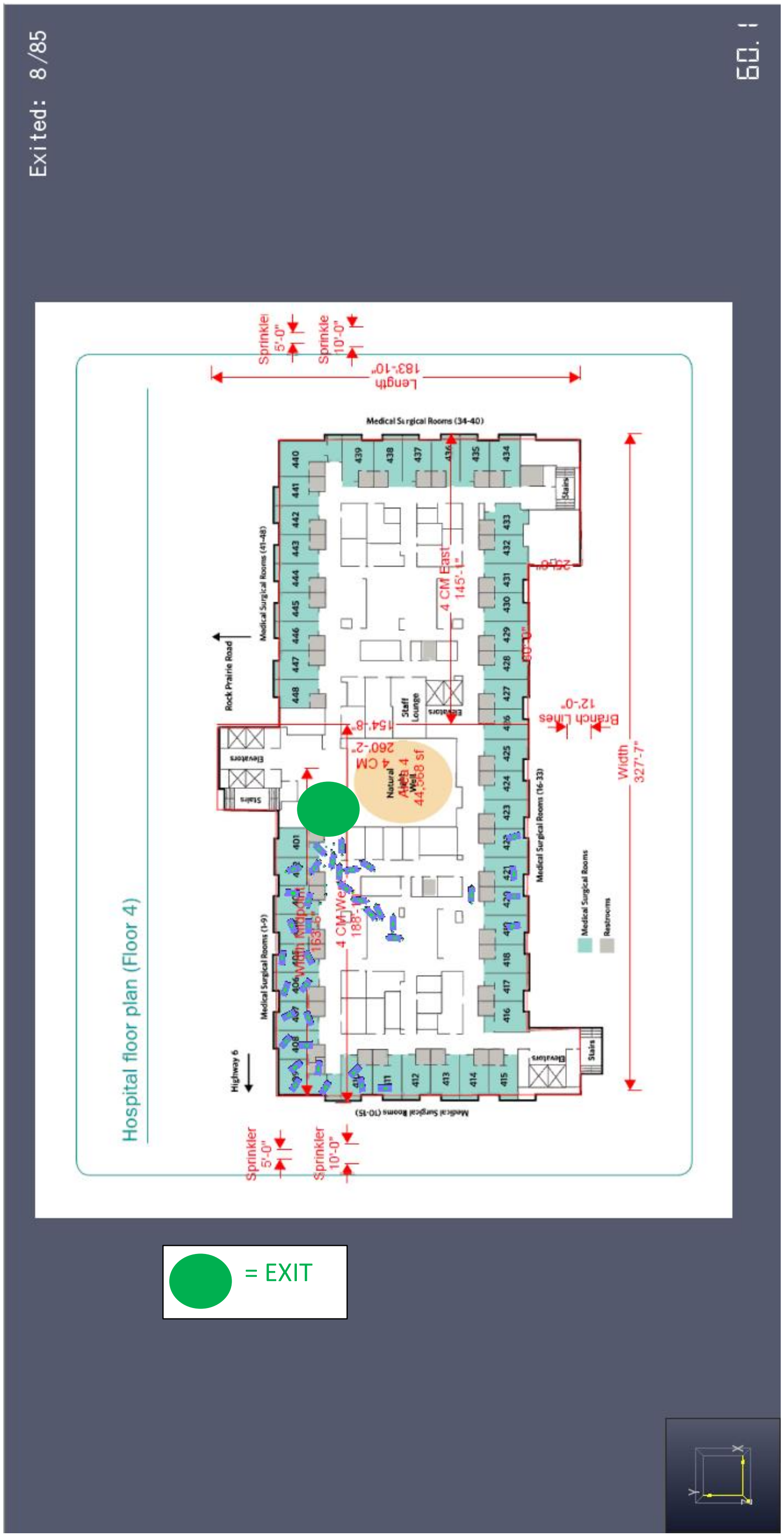


Figure # 114. One-Exit Evacuation

ASET vs RSET

RSET is based on the travel time, which is conservatively set as 199.5 seconds (the egress time calculated for a single exit). As discussed in the egress section (and referenced in the SFPE handbook), this report takes one minute as the premovement time for health care occupancies. Additionally, from the two scenarios above, the FDS model showed find an alarm activation time of 85 seconds for the office fire, and 129 seconds for the bedroom fire. Adding the premovement times, alarm activation times, and egress times leads to a total RSET of 344.5 for the office fire, and 388.5 for the bedroom fire.

In comparison to the RSET times calculated above, the ASET was found to be between 300 and 360 seconds in both scenarios. The ASET times was calculated as the time a tenability criteria was breached in the FDS models—specifically, the ASET time was found to be when the visibility dropped below 10 meters. Considering that ASET should be equal to or greater than 150% of RSET, this would imply that RSET should be between 200 and 240 seconds. The travel time alone is 199.5 seconds, and adding the premovement time of 60 seconds drives this to 260 seconds, irregardless of detection and notification time. For this reason, I would find that RSET exceeds ASET in both of the scenarios.

Structural Fire Analysis

Besides the question of ASET vs RSET, this report will also examine the structural fire protection requirements of the building through a performance-based analysis. In addition to the two design fires described above for the bedroom and the office, a hallway fire is also assumed, in order to present a more challenging fire from a structural fire protection perspective. This hallway fire is assumed to take place in the hallway outside of the bedroom fire location, assumes a row of beds lining the hallway as the fuel load.

Design Fires

For the design fires, this report considers three general scenarios: a pair of patient beds catching fire in a patient bedroom, a row patient beds catching fire in a long hallway, and a 4-person workstation catching fire in an office. Data for all of these fires comes from the SFPE Handbook, 5th edition. Note, the ignition source itself is not important for the purpose of this report, but it may be considered to be a generic event, such overheating or damaged cell phone being charged on a bed, an e-cigarette system malfunctioning, or other malfunction.

Bedroom Fire

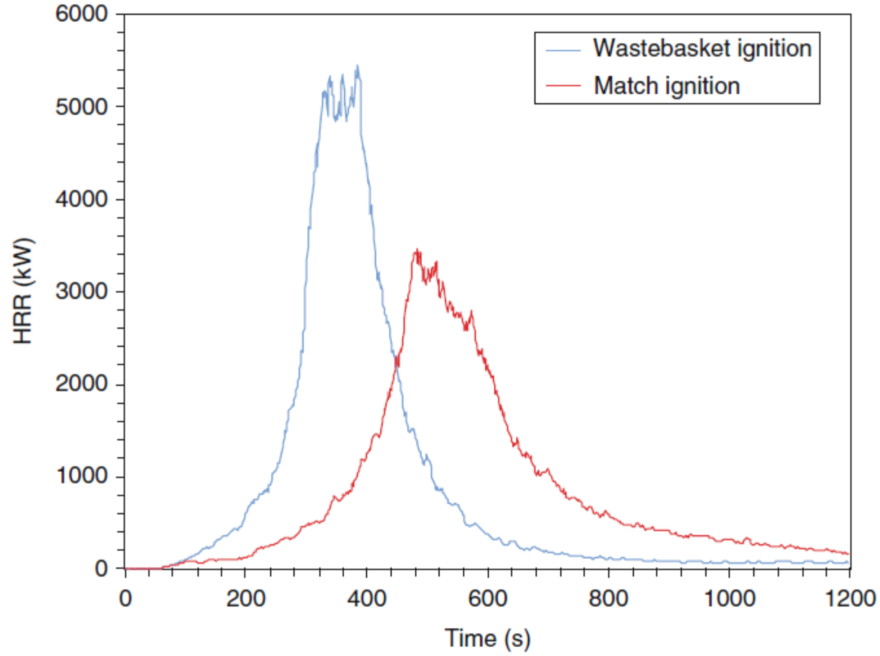
It is assumed a bedroom fire involving patient beds on the west wing of floor 4 of the hospital occurs, as one of the design fires. The report assumes that two patient beds in the bedroom are involved, which is more conservative, and also allows the scenario to more closely match the data from the SFPE Handbook.

Design Fire

Heat Release Rate

The heat release rate of the design fire is based on data from the SFPE Handbook, 5th edition. The graph of HRR is shown below.

Fig. 26.64 Effect of ignition source on king-size bed assemblies



Hallway Fire

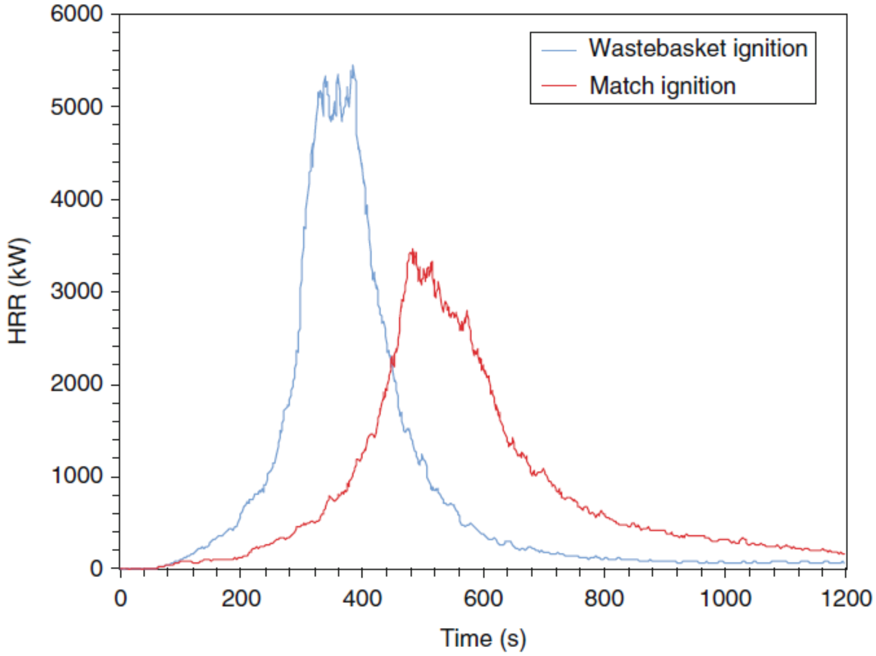
It is assumed a hallway fire involving patient beds on west wing of floor 4 of the hospital occurs, as one of the design fires.

Design Fire

Heat Release Rate

The heat release rate of the design fire is based on data from the SFPE Handbook, 5th edition. The graph of HRR is shown below.

Fig. 26.64 Effect of ignition source on king-size bed assemblies



Office Fire

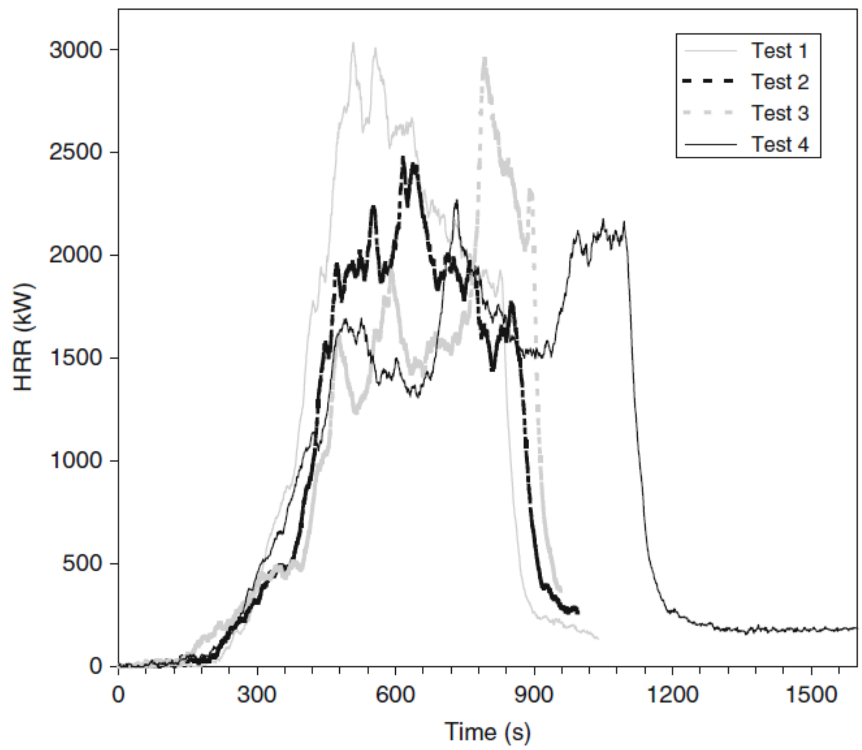
It is assumed a fire involving a four-unit workstation in an office on the west wing of floor 4 of the hospital occurs, as one of the design fires.

Design Fire

Heat Release Rate

The heat release rate of the design fire is based on data from the SFPE Handbook, 5th edition. The graph of HRR is shown below.

Fig. 26.70 HRR of four-unit workstations tested at NRIFD



Heat Transfer

Boundary Conditions on the Structural Members

While it is assumed that the building is designed for implicit safety, this report also examines standard design curves, such as ASTM E119, for boundary conditions on the structural members. The report also considered the Margaret Law time equivalency to the standard fire resistance test and Thomas plot with fuel load burning duration for the bedroom and office, and the traveling fire methodology for the hallway fire. This report focuses on the Thomas plot with fuel load burning duration for the bedroom and office, and the traveling fire methodology for the hallway.

The Biot Number for the steel structural members of W24x162 beams is calculated as:

$Bi = L_c h/k$

$Bi = (0.014033\ m) \times (20\ W/m^2\text{-}K) / (45.8\ W/m\text{-}K)$

$Bi = 0.006128 << 1$

Note, this report uses spreadsheets from Carboline to find W/D for W24x162 beams, 1.88 inches and convert this to A/P by the ratio 144/490, and convert this to meters by the ratio 0.0254 m / in to arrive at 0.014033 m. A/P (cross-sectional area of the beam / heated perimeter) is a normalized equivalent to L_c (instead of the volume of the beam / heated surface area).

From the Biot Number calculation above, the W24x162 has been determined to be a thermally thin material, and apply a lumped capacitance approach to find the boundary conditions on the structural members. The boundary conditions on the structural members is assumed to be the temperature of the gas layer from the fire, and is shown in the attached spreadsheets in Appendix E.

Bedroom Fire

This report assumes that the bedroom is 5 meters by 5 meters, and 3.6 meters tall, with a 1 meter by 2 meter door. This report assumes general properties and variables that have been used in the Cal Poly FPE 524 class and in the reference material for that class; these variables are listed in the attached spreadsheet. By applying the calculations for Thomas Plot, this report conservatively applies a 700°C fire to the beam. This report also conservatively sets the exposure time towards the maximum time from the SFPE Handbook HRR curve data, 20 minutes.

Hallway Fire

This report assumes the hallway is 50 meters long, 3.6 meters wide, and 3.6 meters tall. This report assumes general properties and variables that have been used in the Cal Poly FPE 524 class and in the reference material for that class; these variables are listed in the attached spreadsheets in Appendix E. Using the traveling fire methodology, this report iterated through different possibilities to find the most conservative values to use in this analysis.

Office Fire

This report assumes the office is 5 meters by 5 meters, and 3.6 meters tall, with a 1 meter by 2 meter door. This report assumes general properties and variables that have been used in the Cal Poly FPE 524 class and in the reference material; these variables are listed in the attached spreadsheets in Appendix E. By applying the calculations for Thomas Plot, this report conservatively applies a 700°C fire to the beam. This report also conservatively set the exposure time towards the maximum time from the SFPE Handbook HRR curve data, 25 minutes.

Structural Fire Protection Analysis

For the dead load, it is assumed that the building has a 100 mm thick concrete slab, with a weight per unit area of 2.360 kN/m^2, or approximately 50 psf. This is based on 2012 Bangladesh Building Code (https://law.resource.org/pub/bd/bnbc.2012/gov.bd.bnbc.2012.06.02.pdf). This is also in line with publications from the Housing and Urban Development Department of the United States of America, which lists concrete (normal weight with light reinforcement) as having a density of 145-150 pcf (https://www.huduser.gov/Publications/pdf/res2000_2.pdf). With 100 mm approximately 1/3 of a foot, this also corresponds to 50 psf, as with the Bangladesh Building Code. The dead load that is assumed also matches that of previous FPE 524 projects (example projects on shown on the FPE 524 Summer 2019 PolyLearn site).

From Table 1607.1 of IBC-2018, the uniform live loads for Hospitals range from 40 psf in patient rooms, 60 psf for operation rooms and laboratories, and 80 psf for corridors above the first floor. From this same table, other occupancy types found in the building (assembly, office, and stairs and exits) have a uniform live load of 100 psf, so it appears that the 100 psf live load can be conservatively applied for throughout all of the floors. Besides being conservative for the current configuration, this design will allow occupants the flexibility to rearrange areas and occupancies without having to first modify the structural elements of the building.

Time to Failure

Bedroom Fire

For the bedroom fire, this report uses the Thomas Plot with the fuel load burning duration from the SFPE handbook data as a compartment fire methodology to calculate if a failure time is reached for insulated and non-insulated beams in the bedroom.

With Insulation

With insulation, the beam does not fail either in terms of moment capacity or deflection adequacy. This is true even if the fire time is extended from 20 minutes to over 200 minutes. Graphs demonstrating the moment capacity and deflection adequacy for this fire scenario are show below in Figures 115 – 117. The result that may be drawn from these figures is that the structural fire protection of the building is adequate for the bedroom fire scenario used in this report.

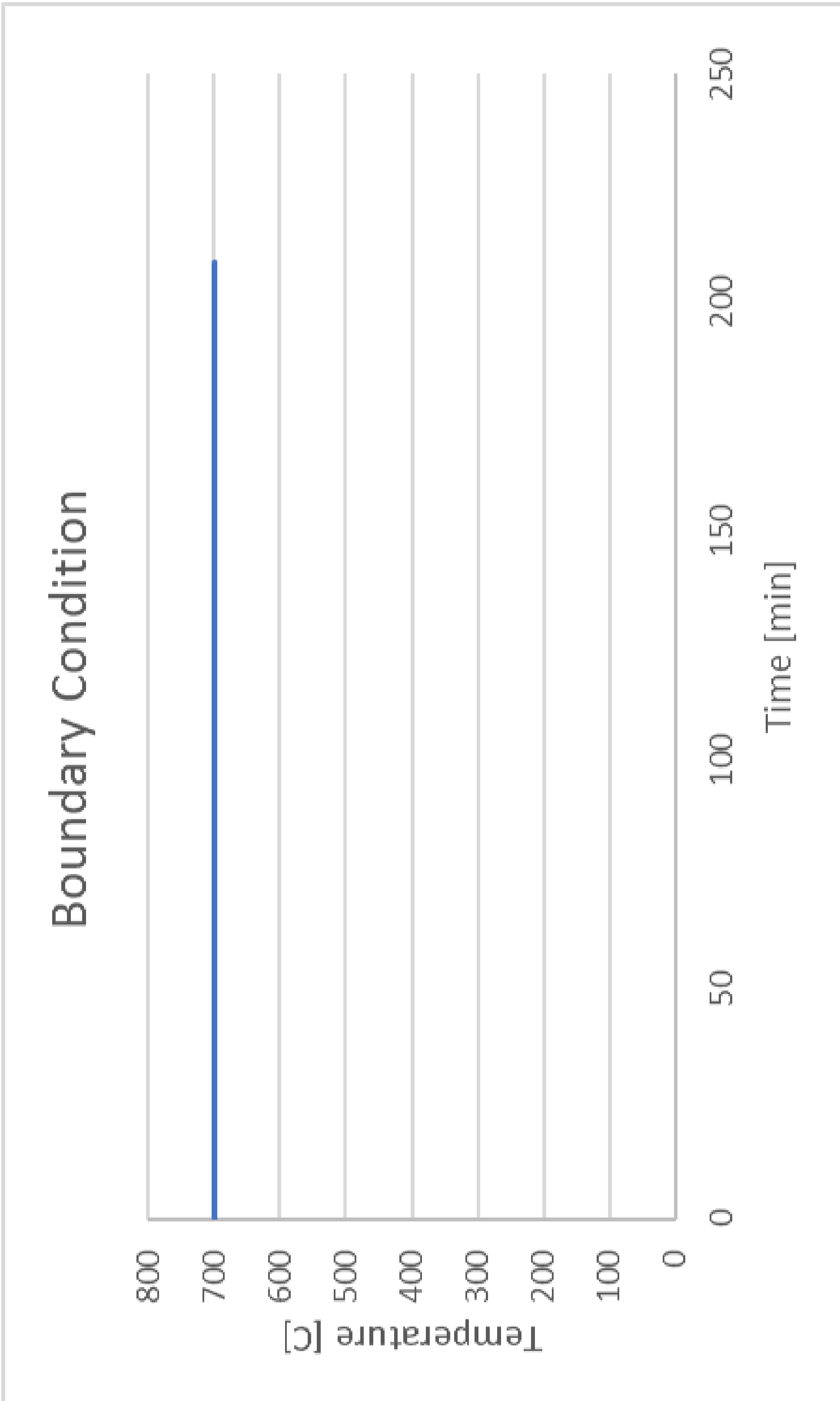


Figure # 115. Bedroom Structural Member Boundary Condition, Insulated

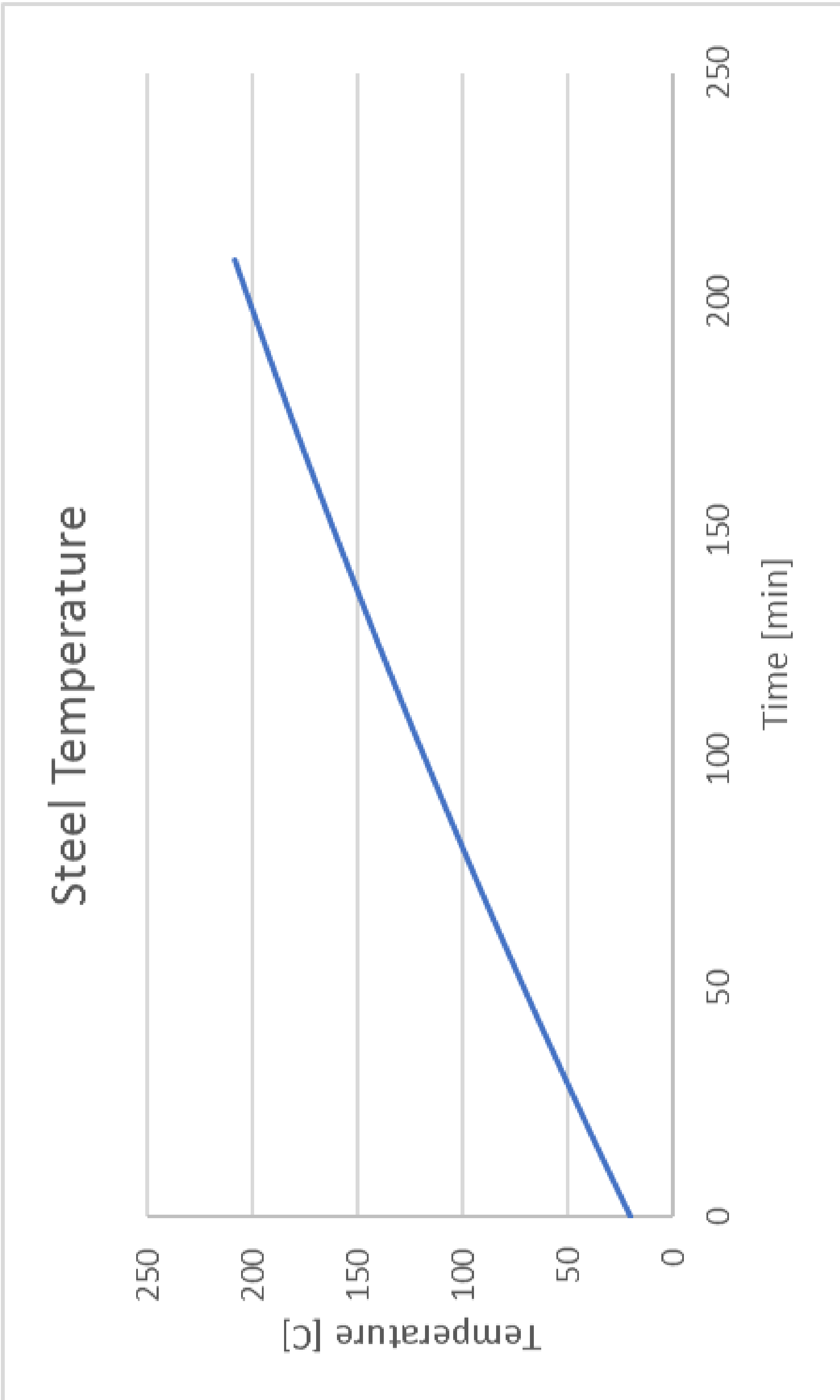


Figure # 116. Bedroom Structural Member Steel Temperature, Insulated

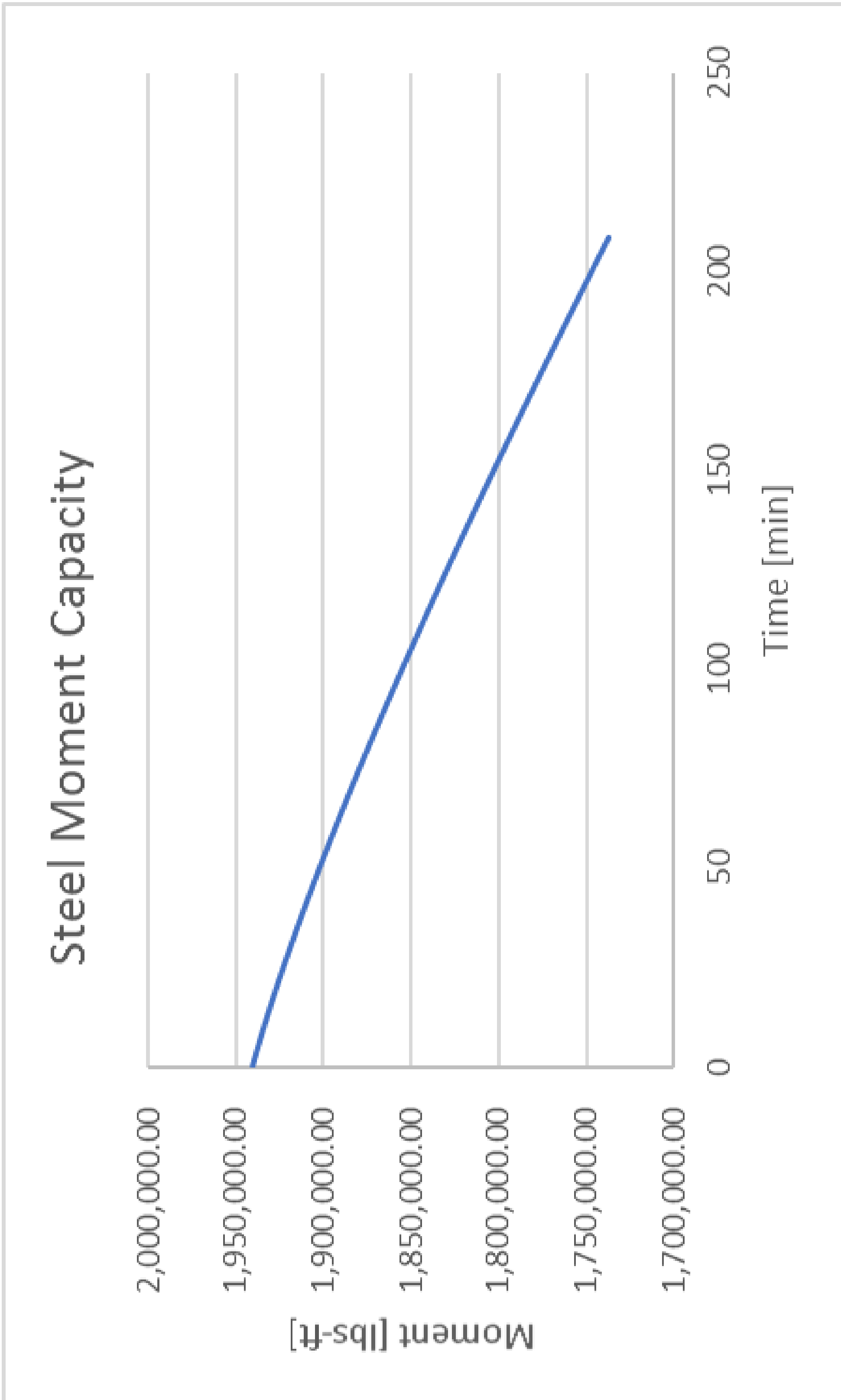


Figure # 117. Bedroom Structural Member Steel Moment Capacity, Insulated

Without Insulation

Without insulation, the beam does not fail either in terms of moment capacity or deflection adequacy. This is true even if the fire time is extended from 20 minutes to over 200 minutes (a steady-state is reached). Graphs demonstrating the moment capacity and deflection adequacy for this fire scenario are show below in Figures 118 – 120. The result that may be drawn from these figures is that even without the structural fire protection of the building, the underlying strength of the structural elements is adequate for the bedroom fire scenario used in this report.

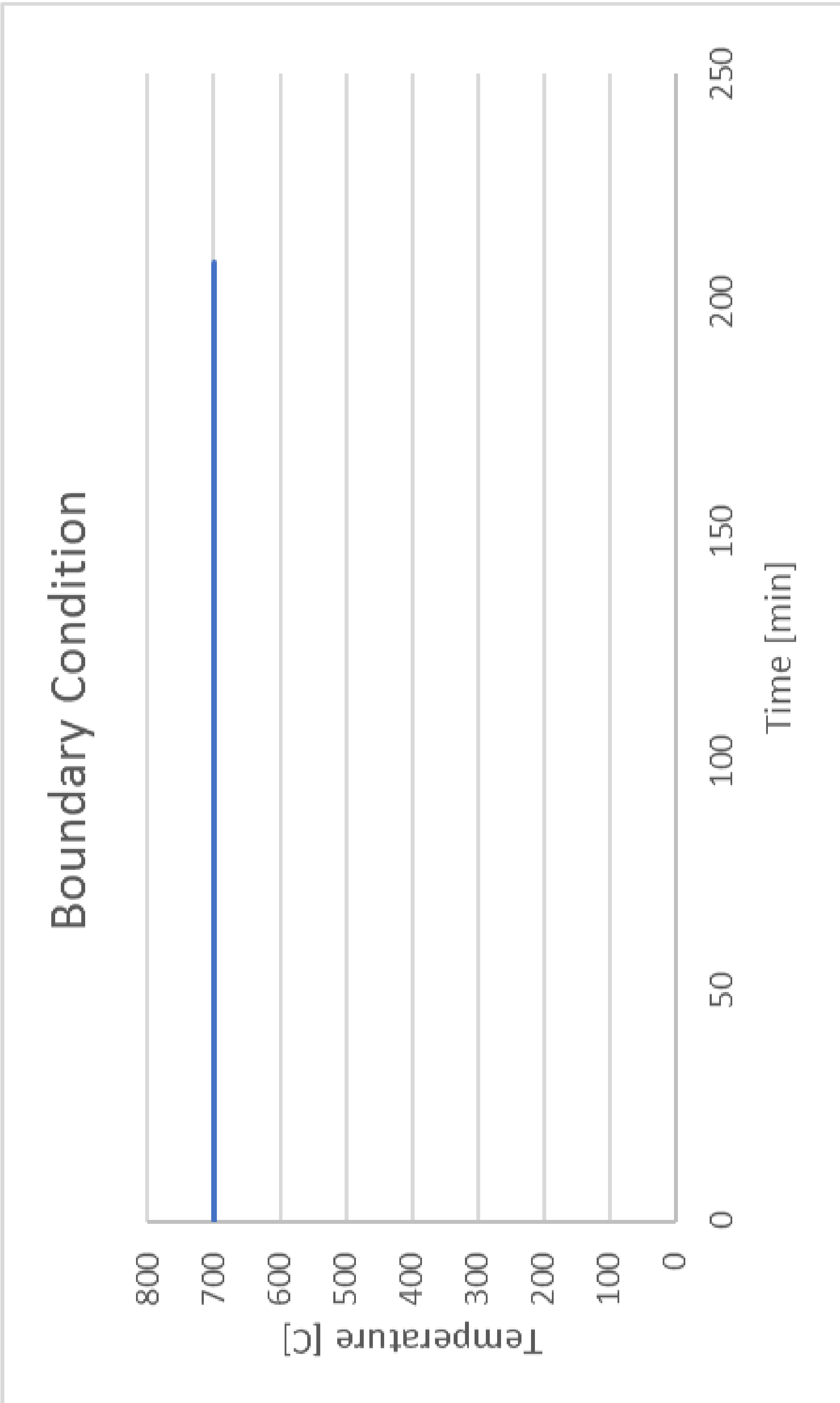


Figure # 118. Bedroom Structural Member Boundary Condition, Uninsulated

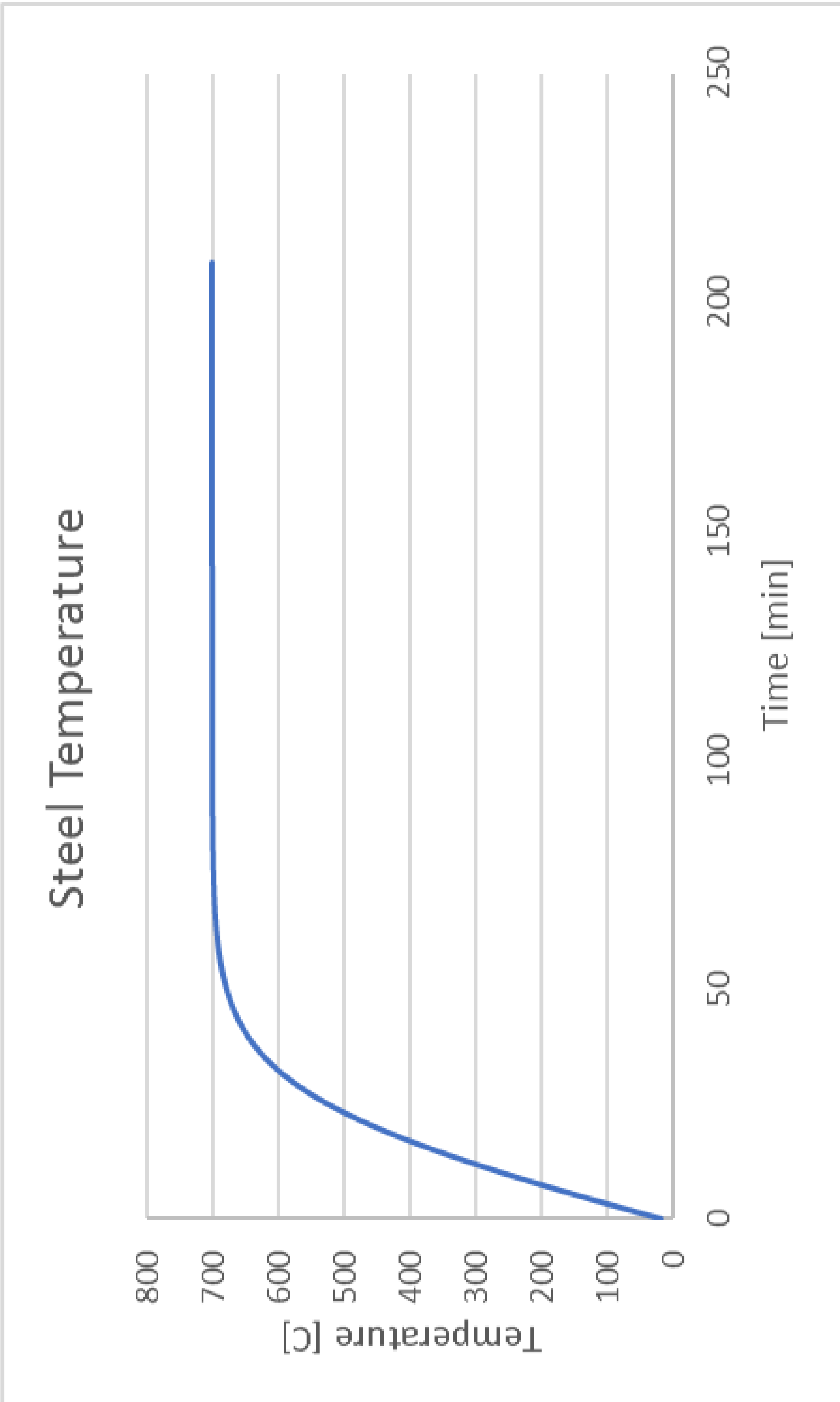


Figure # 119. Bedroom Structural Member Steel Temperature, Uninsulated

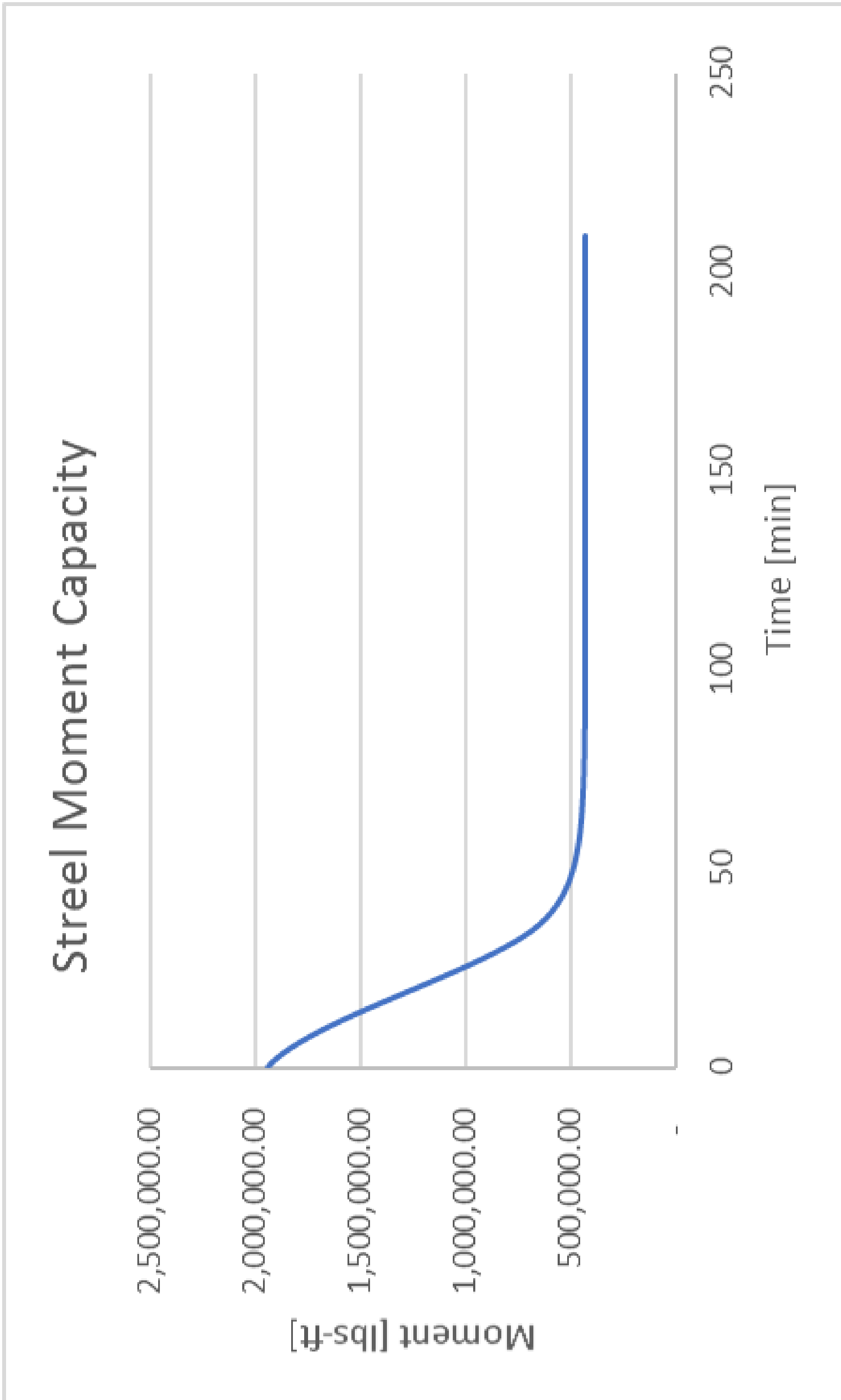


Figure # 120. Bedroom Structural Member Steel Moment Capacity, Uninsulated

Hallway Fire

For the hallway fire, this report uses the Traveling Fire Methodology discussed in Cal Poly FPE 524 to evaluate if a failure time is reached for insulated and non-insulated beams in the hallway.

With Insulation

With insulation, the beam does not fail either in terms of moment capacity or deflection adequacy. This is at a beam location of 22 meters from the start of the fire, which was iteratively determined to be the most conservative position in terms of moment capacity decrease. Graphs demonstrating the moment capacity and deflection adequacy for this fire scenario are show below in Figures 121 – 123. The result that may be drawn from these figures is that the structural fire protection of the building is adequate for the traveling hallway fire scenario used in this report.

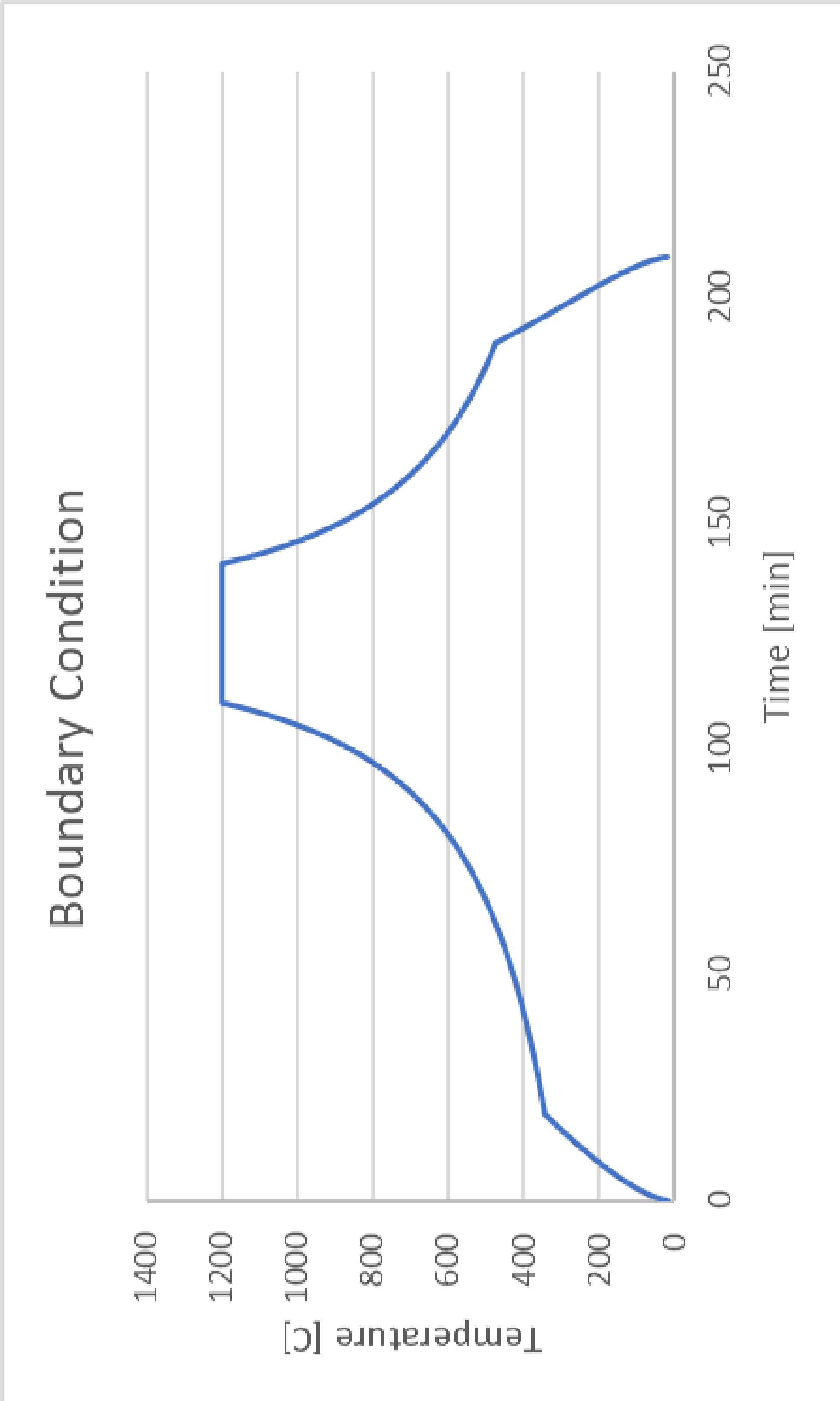


Figure # 121. Hallway Structural Member Boundary Condition, Insulated

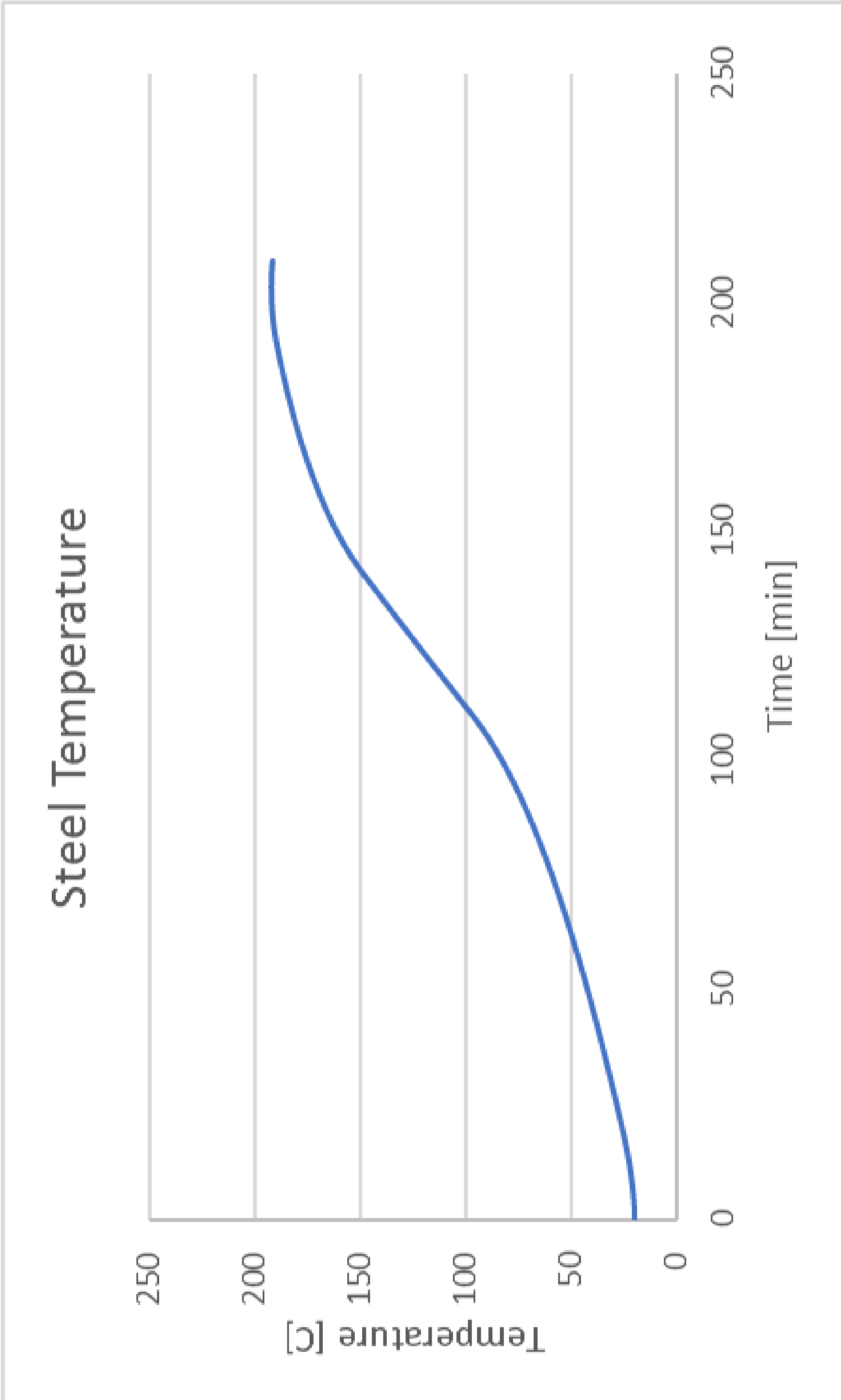


Figure # 122. Hallway Structural Member Steel Temperature, Insulated

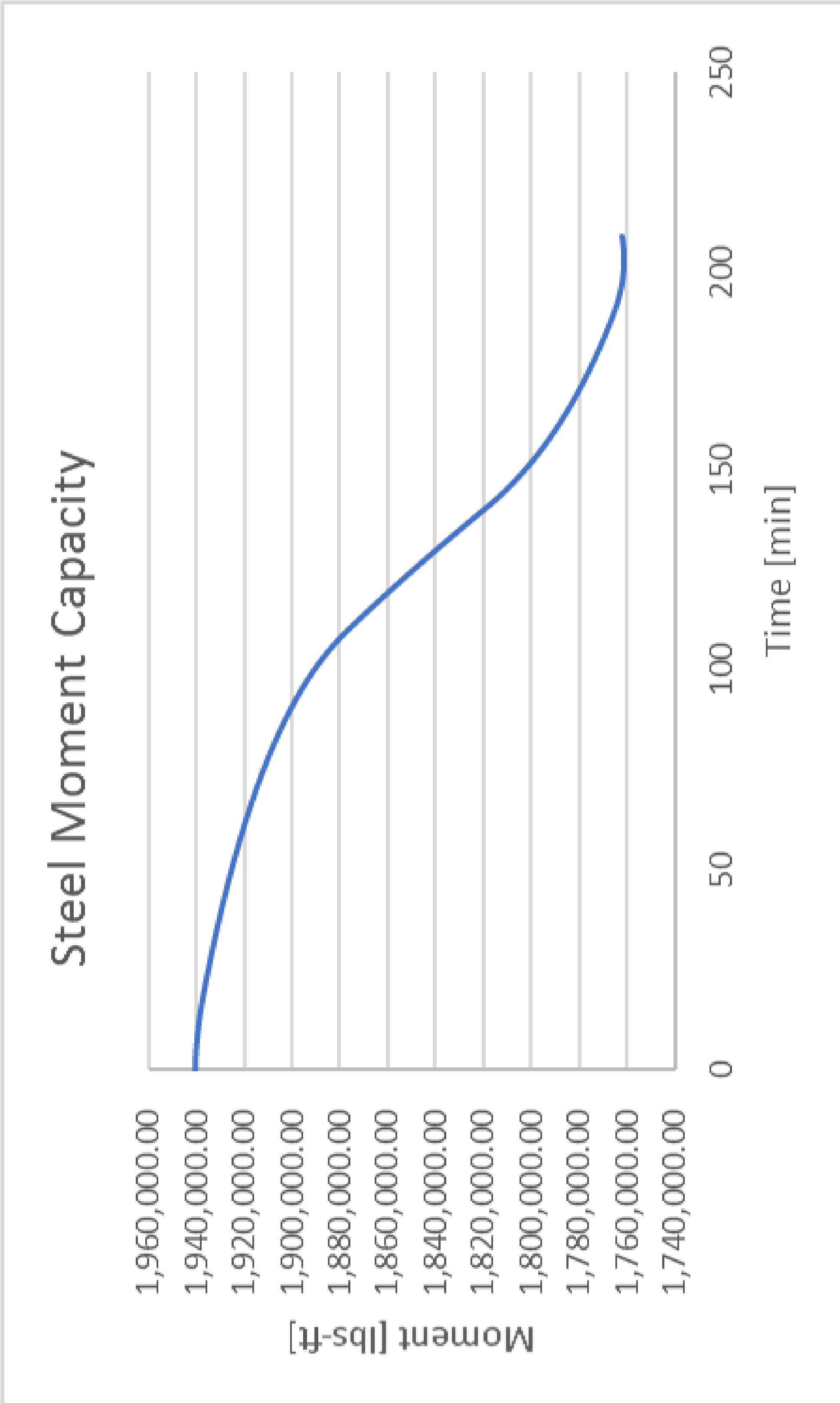


Figure # 123. Hallway Structural Member Steel Moment Capacity, Insulated

Without Insulation

Without insulation, the beam fails at approximately 396 seconds, or 6.6 minutes, in terms of moment capacity, and the beam fails at approximately 600 seconds or 10 minutes in terms of deflection adequacy. This is at a beam location of 0 meters from the start of the fire, which was iteratively determined to be the most conservative position in terms of moment capacity decrease. Graphs demonstrating the moment capacity and deflection adequacy for this fire scenario are show below in Figures 124 – 126. The result that may be drawn from these figures is that without the structural fire protection of the building, the underlying strength of the structural elements is not adequate for the traveling hallway fire scenario used in this report.

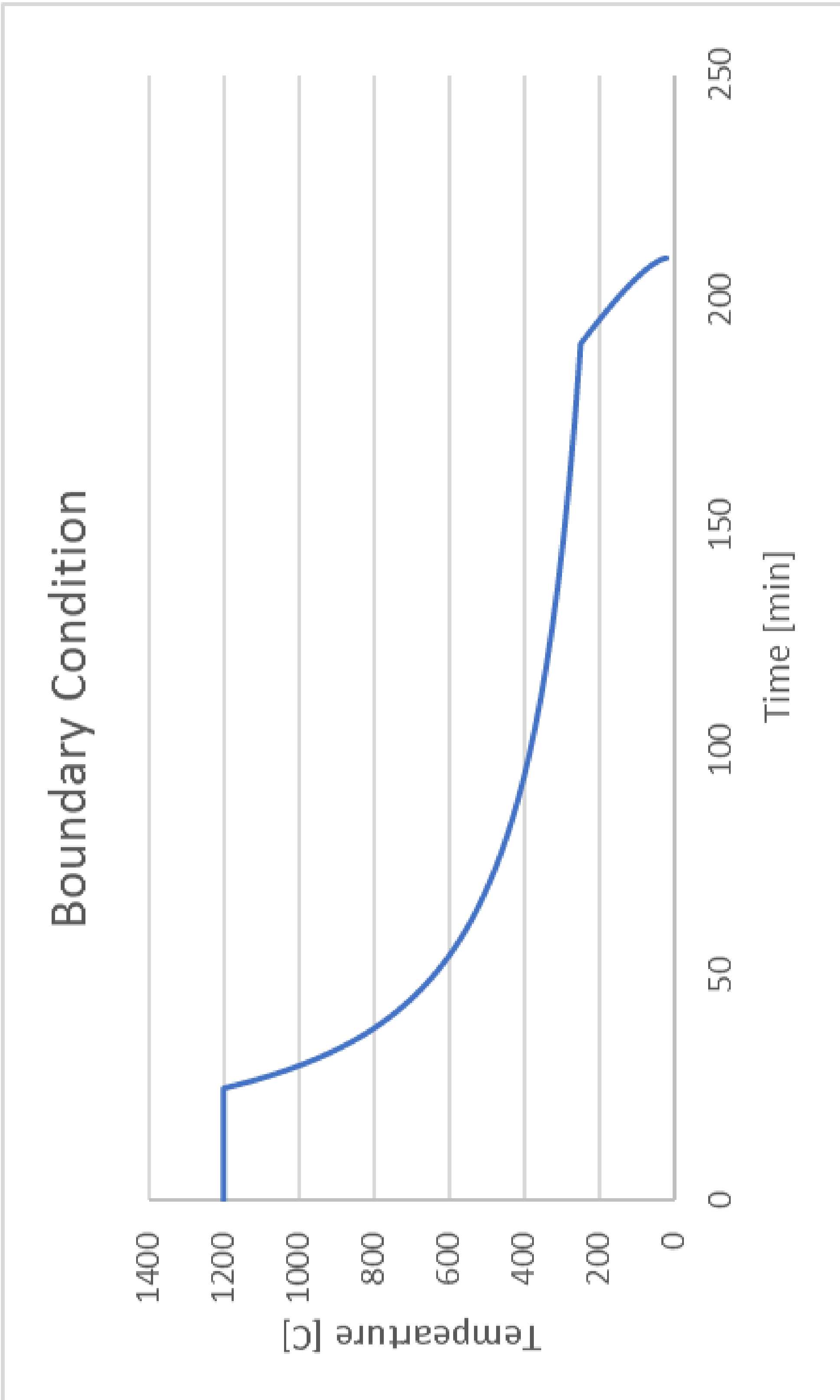


Figure # 124. Hallway Structural Member Boundary Condition, Uninsulated

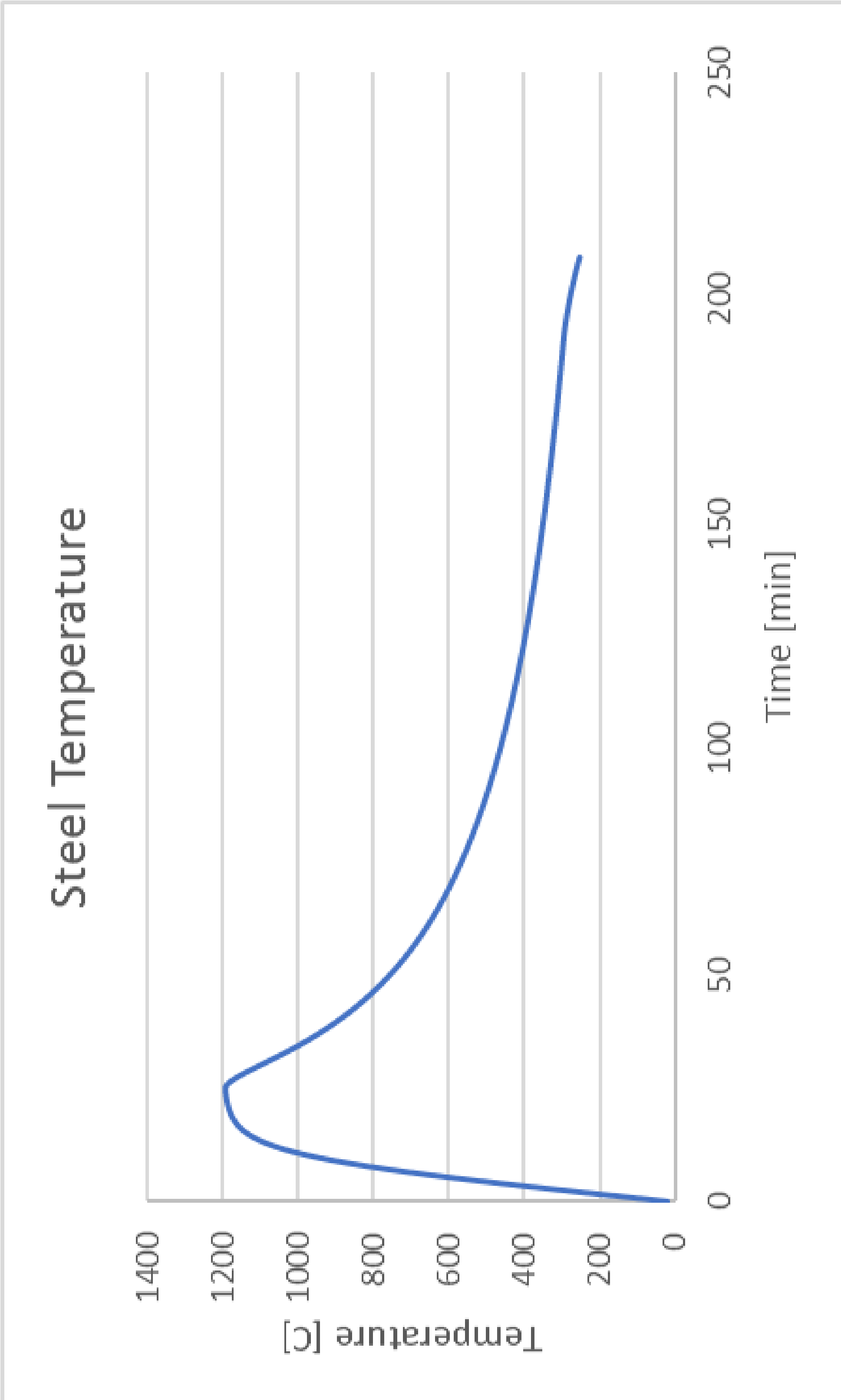


Figure # 125. Hallway Structural Member Steel Temperature, Uninsulated

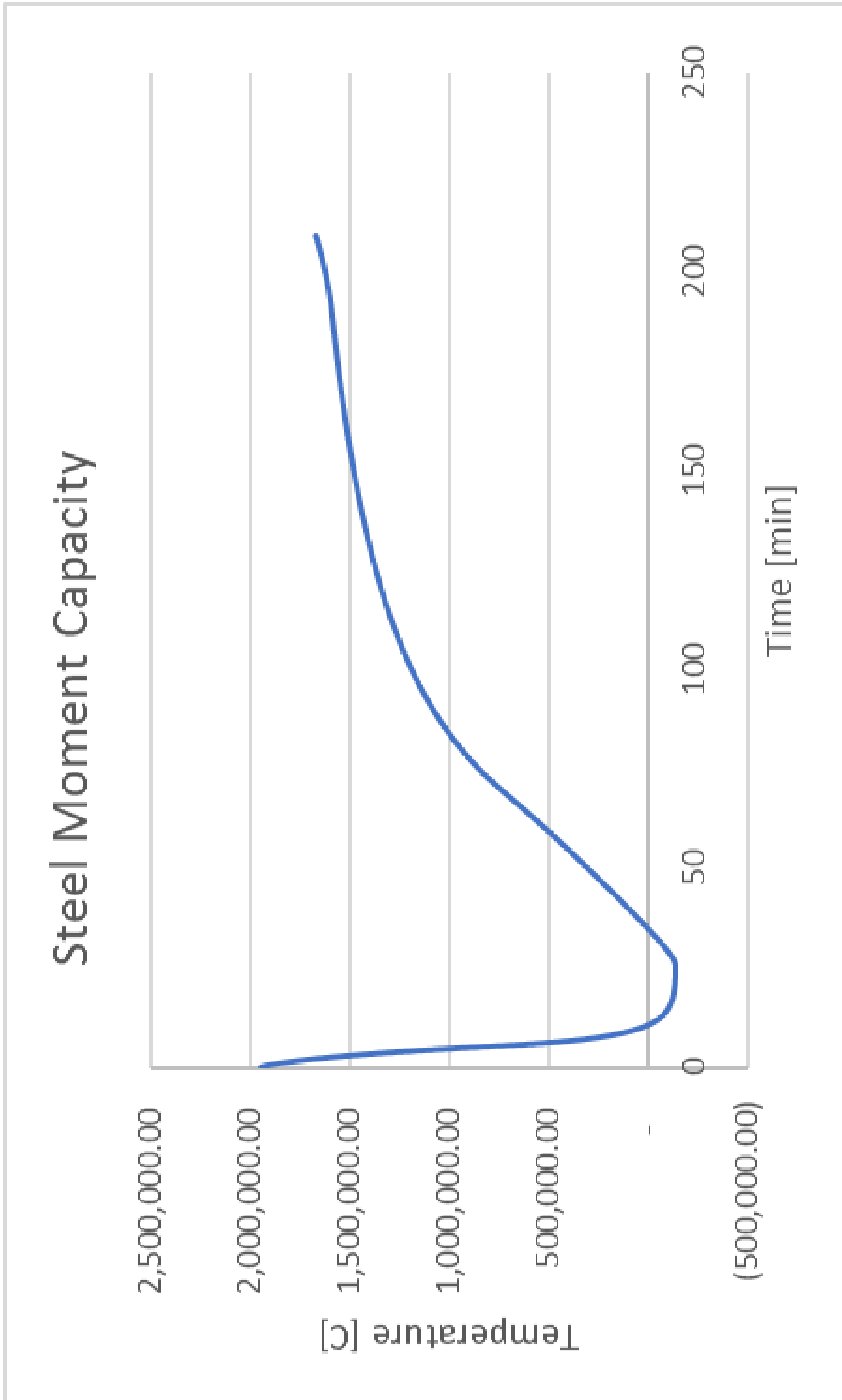


Figure # 126. Hallway Structural Member Steel Moment Capacity, Uninsulated

Office Fire

For the office fire, this report uses the Thomas Plot with the fuel load burning duration from the SFPE handbook data as a compartment fire methodology to calculate if a failure time is reached for insulated and non-insulated beams in the office.

With Insulation

With insulation, the beam does not fail either in terms of moment capacity or deflection adequacy. This is true even if the fire time is extended from 20 minutes to over 200 minutes. Graphs demonstrating the moment capacity and deflection adequacy for this fire scenario are show below in Figures 127 – 129. The result that may be drawn from these figures is that the structural fire protection of the building is adequate for the office fire scenario used in this report.

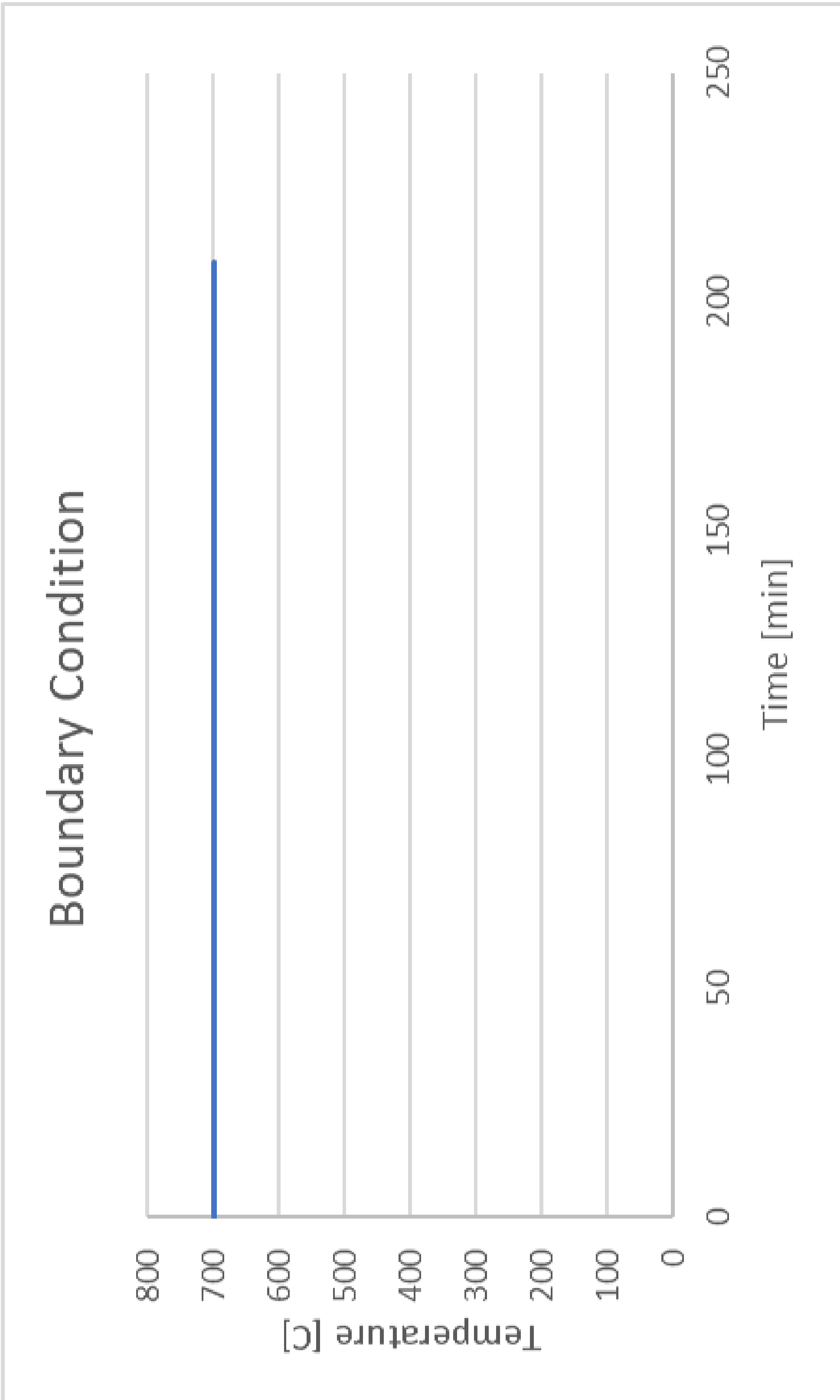


Figure # 127. Office Structural Member Boundary Condition, Insulated

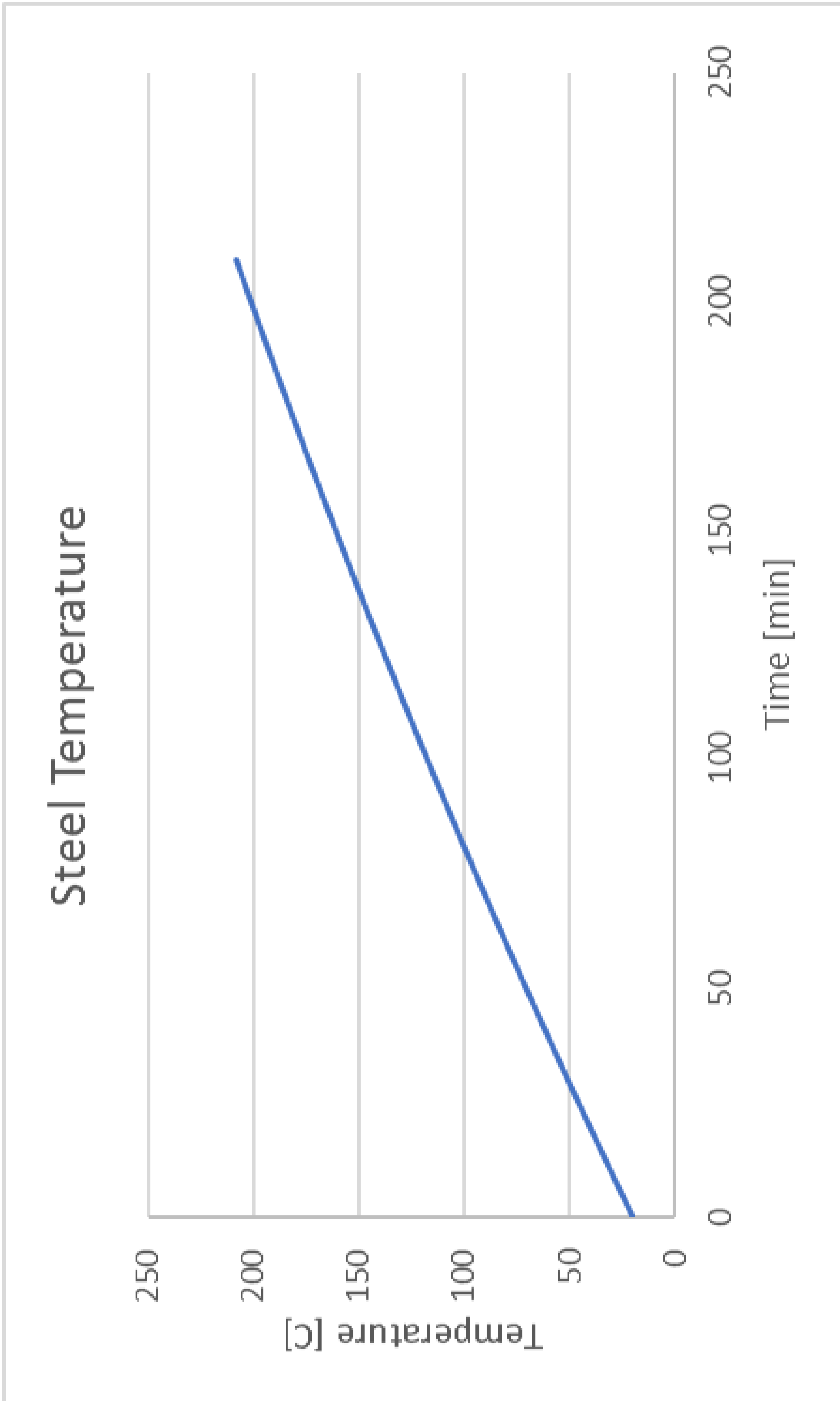


Figure # 128. Office Structural Member Steel Temperature, Insulated

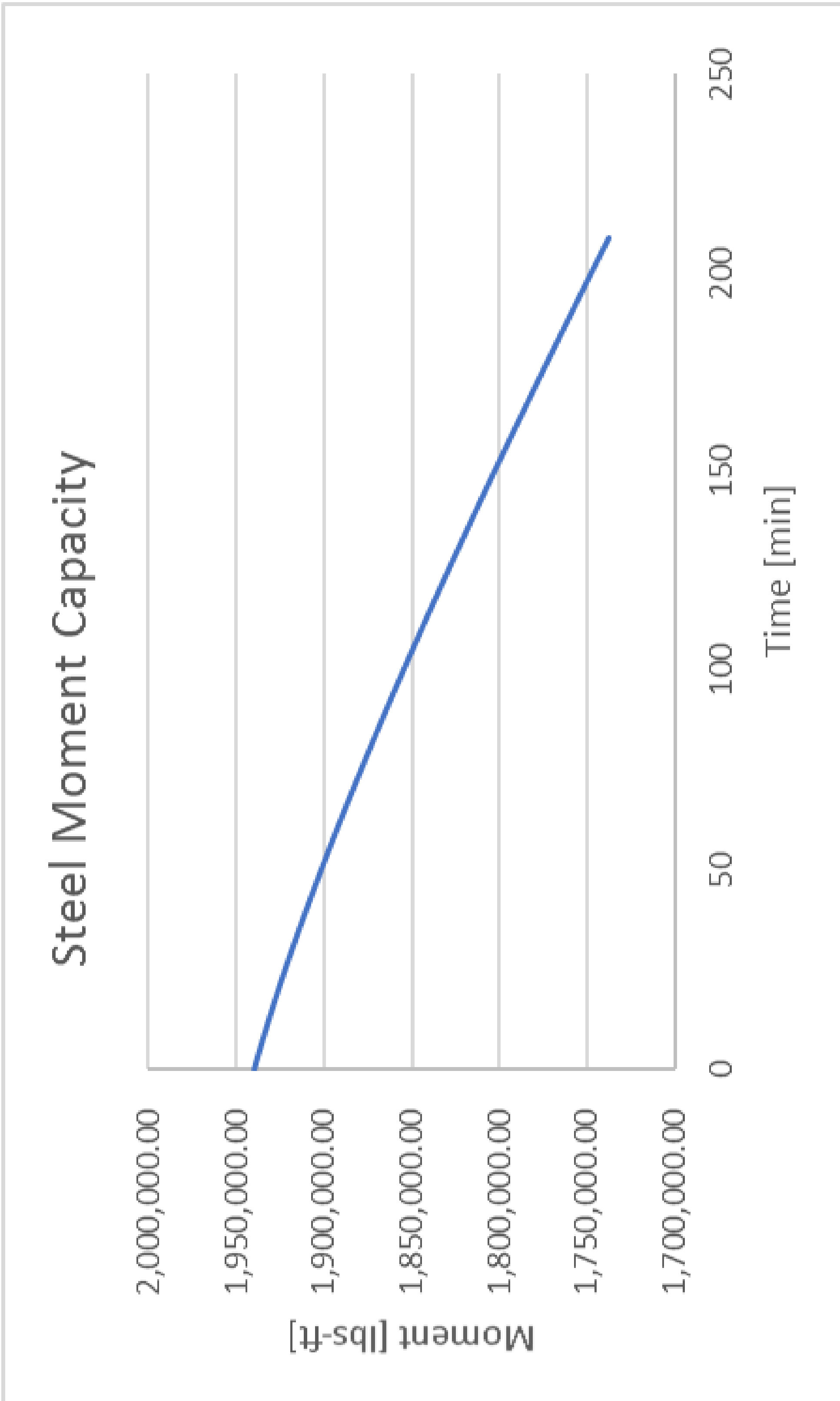


Figure # 129. Office Structural Member Steel Moment Capacity, Insulated

Without Insulation

Without insulation, the beam does not fail either in terms of moment capacity or deflection adequacy. This is true even if the fire time is extended from 20 minutes to over 200 minutes. Graphs demonstrating the moment capacity and deflection adequacy for this fire scenario are show below in Figures 130 – 132. The result that may be drawn from these figures is that even without the structural fire protection of the building, the underlying strength of the structural elements is adequate for the office fire scenario used in this report.

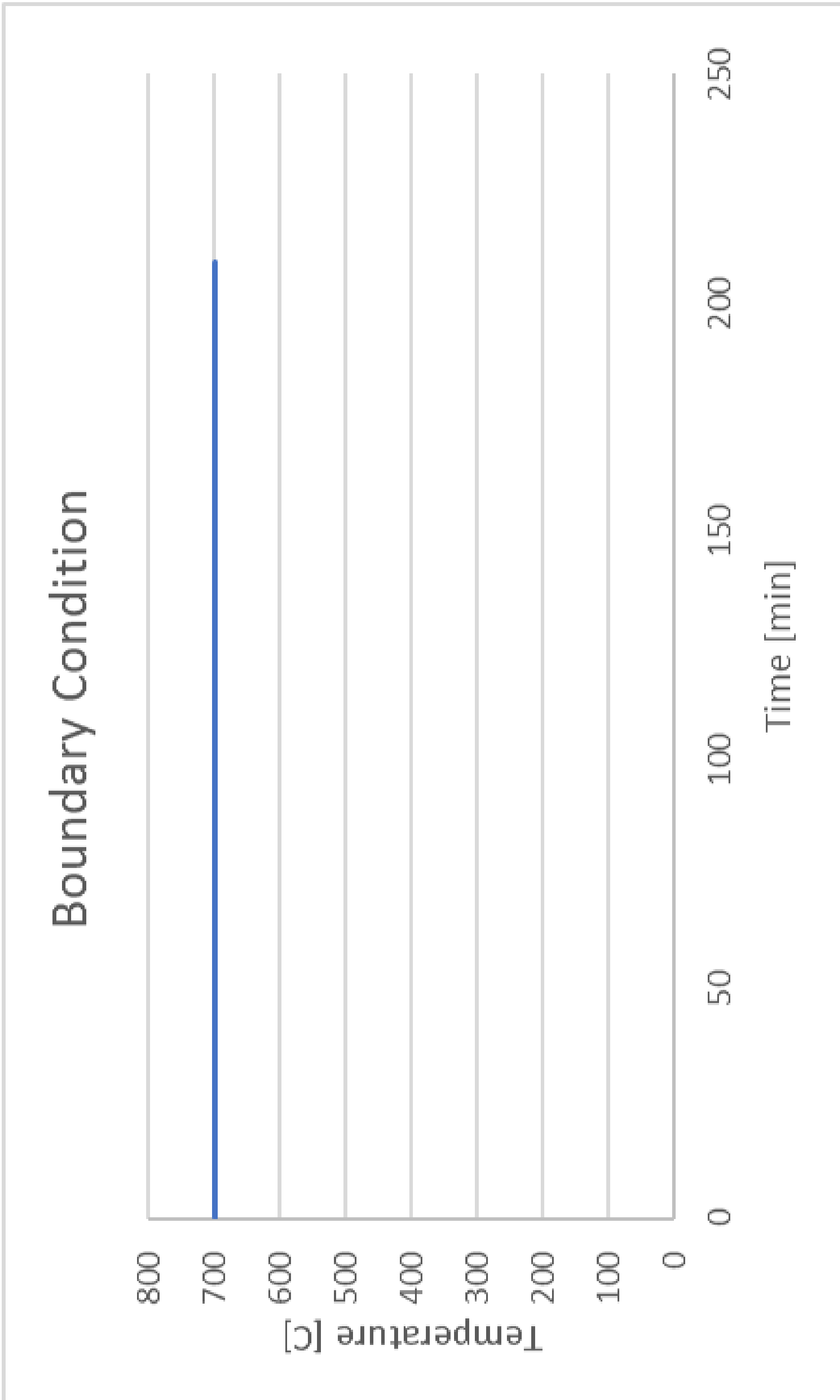


Figure # 130. Office Structural Member Boundary Condition, Uninsulated

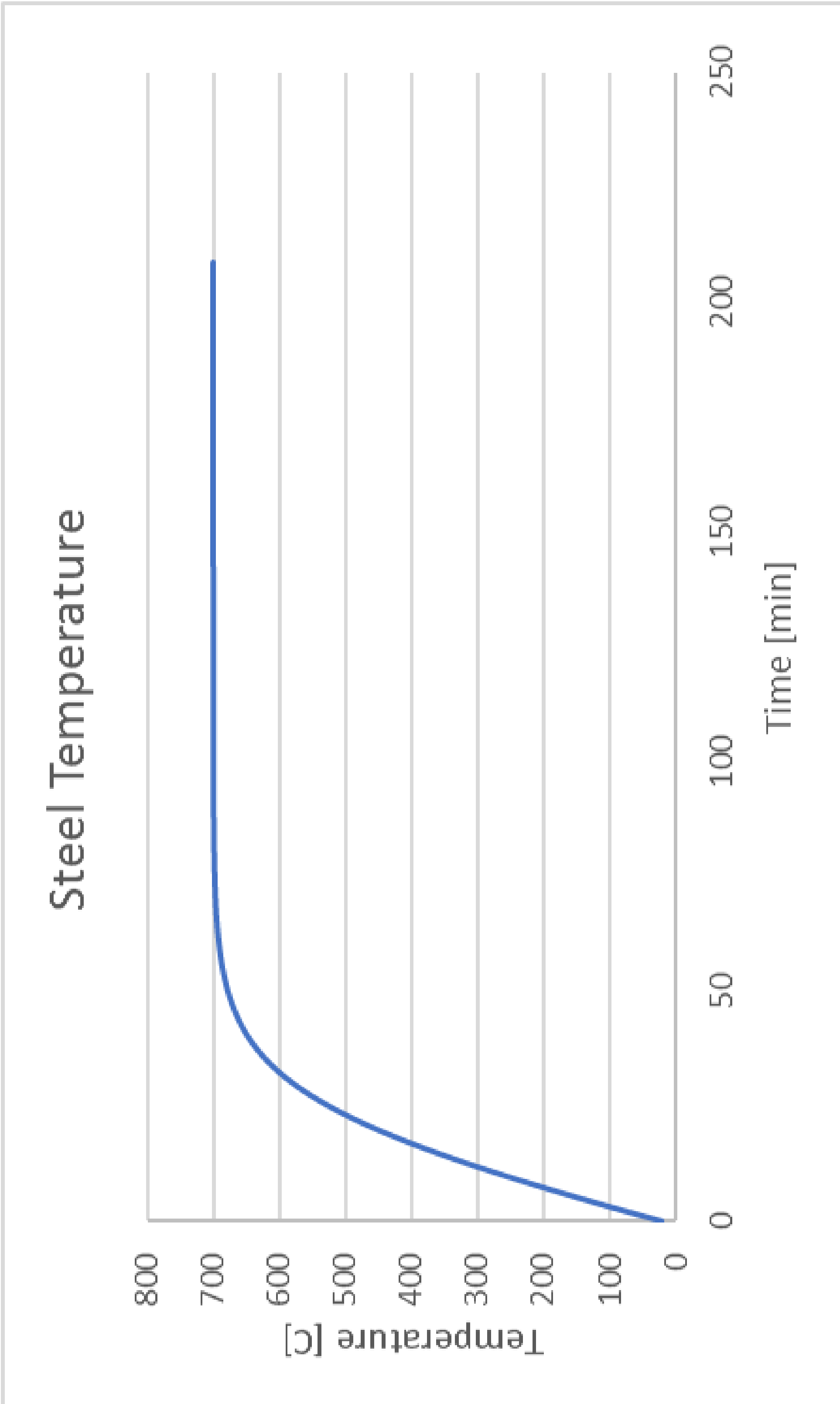


Figure # 131. Office Structural Member Steel Temperature, Uninsulated

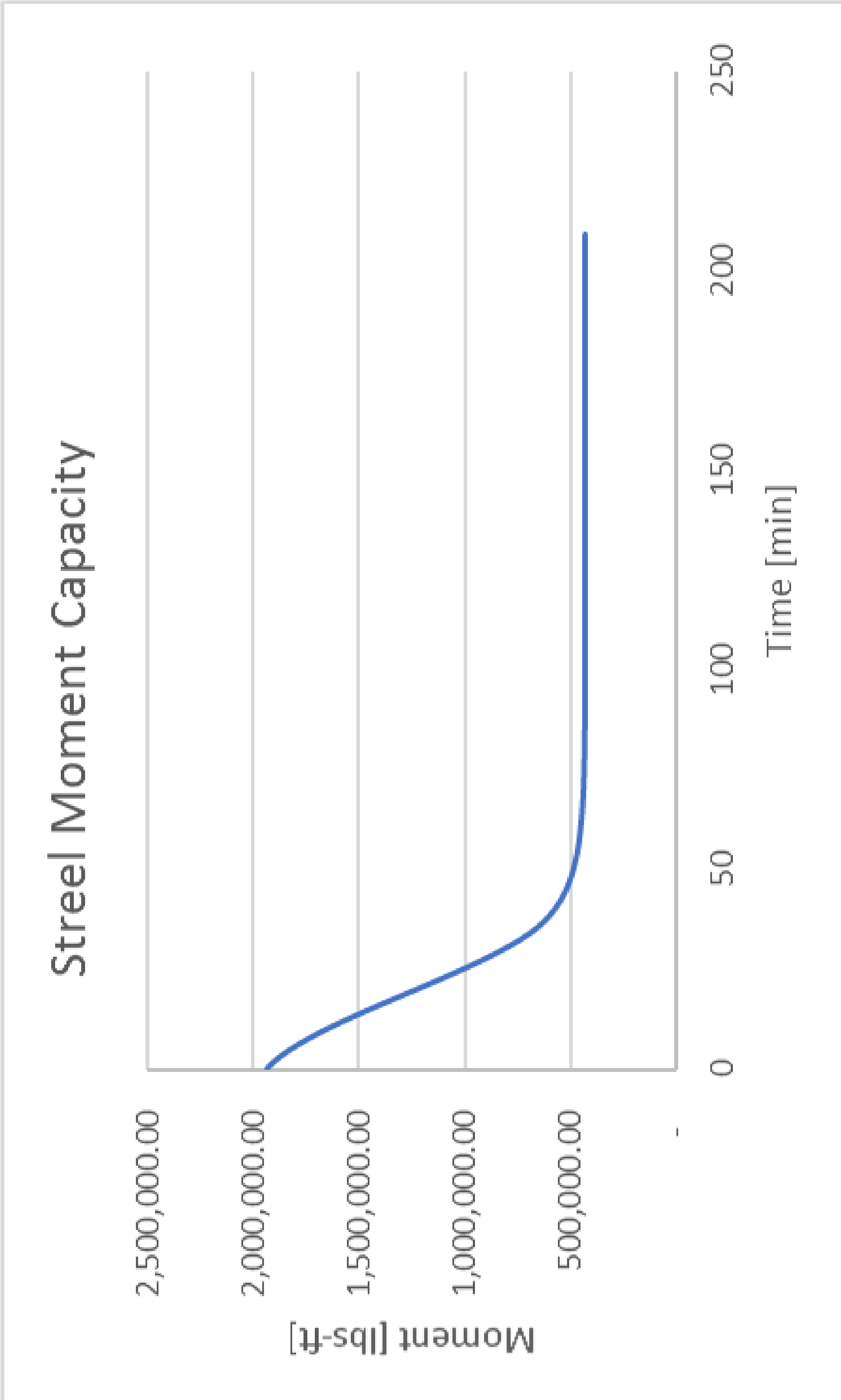


Figure # 132. Office Structural Member Steel Moment Capacity, Uninsulated

Protection Scheme for Structural Members

This report assumes that the structural members will be W-shaped steel I-beams. This report also assumes that the protection scheme will be spray-on applied insulative material, such as mineral fiber or vermiculite plaster. This report assumes that a mineral fiber insulation was used, and that its characteristics are:

Density: 300 kg/m^3

Thermal Conductivity: 0.12 W/m-K

Specific Heat: 1200 J/kg-K

Moisture Content: 1%

Note, this report assumes that moisture content can be ignored, which is a more conservative approach, because otherwise the Specific Heat would be modified around the 100°C point to account for the latent heat of vaporization of water.

This report also assumes that the thickness of the insulation was calculated according to the following equation for UL X829 mineral fiber insulation:

$R = h[C_1(W/D) + C_2]$, where

R is the fire resistance rating (hours)

h is the insulation thickness (inches)

C_1 and C_2 are material constants for SRFMs

W/D is the steel weight / heated perimeter

W/D is 1.88 lb/ft-in, which corresponds to UL X829 values for C_1 and C_2 of 1.01 and 0.66 respectively.

h is calculated to be approximately 1.8 inches, or 0.030 meters, for a 3 hour rating.

Safety Factor and Cost Savings

Surprisingly, both the insulated and uninsulated W24x162 steel I-beams passed the bedroom and office design fires. While the uninsulated W24x162 steel I-beam failed the hallway fire design fire, the insulated beam handily passed. Below is Table # 34, which summarizes the safety factors for the insulated and uninsulated beams in all three design fires. Also surprising, note that the insulated W24x162 beams in all three scenarios have very similar safety factors (note, they are shown as the same due to rounding in this table, but vary slightly).

Table # 36. Safety Factors for Insulated and Uninsulated Beams for the Three Design Fires

Design Fire	Insulated W24x162	Uninsulated W24x162
Bedroom	78% additional moment capacity, 97% additional deflection adequacy	14% additional moment capacity, 93% additional deflection adequacy
Hallway	78% additional moment capacity,	Failed

	97% additional deflection adequacy	
Office	78% additional moment capacity, 97% additional deflection adequacy	14% additional moment capacity, 93% additional deflection adequacy

In terms of cost savings, using uninsulated beams in areas where traveling fires will not be present is tempting. However, while the uninsulated beams passed the compartment fires using the Thomas Plot, it should be noted that the 14% additional moment capacity falls below the 20% safety factor "rule-of-thumb" from Cal Poly FPE 551, and it is recommended that beams should be insulated. Additional studies through the Margaret Law Time Equivalency Method, Fire Dynamic Simulator, Finite Element Analysis, etc. may help determine that the safety factor is even larger than it shown here, but at the current time this report recommends insulation should applied as prescribed by code.

An additional cost savings may be reached by discussing if future, vertical expansions are likely or not with the owner, tenant, and AHJ, such that the building construction type may be changed from Type I-A to Type I-B.

Conclusion

The FDS models show that there are potential performance-based design deficiencies for this project building. However, the scenarios and models made several conservative assumptions that should be more closely examined with all stakeholders. Most critically, this report assumes that a fire protection feature is inoperable: the doors are left open from the room with the originating fire—the office and the bedroom respectively—which allowed smoke to build up in the corridors to a level such that the tenability limits for occupants were exceeded for visibility, and this. However, it is likely that these doors would be self-closing, and are a key fire protection feature. The reason the fire models included open doors are to model a conservative, yet likely scenario. Based on other Cal Poly FPE presentations and reports, having doors closed to the rooms with the design fires leads to scenarios where ASET >> RSET. If desired by stakeholders, this scenario with closed doors can also be modeled to confirm that ASET >> REST for this model as well.

Training may reduce premovement time and allow staff to move patients with one assistant instead of two. Along that same line of logic, this model assumes all bedrooms and beds are occupied, and no additional assistants other than the original occupants are available (i.e., no other staff from other smoke compartments and floors respond. The models may be reexamined and rerun with the impact of sprinklers to the fire accounted for as well. Finally, the tenability criteria themselves may be reexamined to see if limits such as that for visibility was set is too conservatively. Overall conclusions and recommendations for the report are below.

Conclusion and Recommendations

The prescriptive analysis of the Baylor, Scott, & White College Station hospital was overall satisfactory. A prescriptive analysis of the fire protection engineering aspects of the building, including egress, fire sprinkler, fire alarm, structural, flammability assessment methods, and smoke control were conducted and found to be largely compliant with the applicable codes. However, the performance-based design review revealed potential issues that should be further examined. Specifically, there seems to be an insufficient number of vertical exits in the basement level. Additional vertical exits may in fact exist, and are simply not shown on the public floorplans used for this report. The actual number of vertical exits in the basement should be confirmed.

It is also recommended that additional time and resources be spent with stakeholders discussing all assumptions and inputs for the fire models. RSET may be decreased through staff training and preparation. Namely, if doors are left open, it is possible that the required safe egress time will exceed 150% of the available safe egress time of 199.5 seconds, or 300 seconds. This is true of the bedroom fire scenario, which had an RSET of 260 seconds, in both the noncontrolled and suppression-controlled cases. It is recommended that door closers be installed on normally occupied rooms. However, as mentioned early in this report, and as seen in other Cal Poly FPE culminating projects and reports, design fires modeled with closed doors very likely do not result in a scenario in which RSET exceeds ASET. Doors were modeled as being open as a very conservative measure, and in order to show It is also recommended that emphasis and training should be spent on ensuring that staff should understand the importance of making sure doors are not propped open. Similarly, the structural fire protection was analyzed for explicit safety, and it is not until uninsulated members in a traveling fire that moment capacity or deflection adequacy were breached. This is a convergence of events that is highly unlikely to develop in the field, but this analysis does serve to stress the importance of initial installation and continuing maintenance of insulation with the management of potentially flammable materials. Finally, it is an obvious fact that ASET may be increased by the addition of smoke compartments and horizontal exits, though the cost-benefit of such measures should be weighed against that of the other items discussed above.

To reiterate, this report is an academic exercise based on limited drawings and information. Updates and corrections to this report, secondarily for the prescriptive-based analysis but primarily for the performance-based analysis, are likely if new information becomes available about the Baylor Scott & White Medical Center in College Station, TX.

References

Fire Protection Engineering codes and standards used in this report are listed below. Material from the Cal Poly SLO FPE curriculum was also used extensively throughout this report, and includes both formal lectures and further discussions with professors during office hours.

Primary Codes and Standards

The following codes and standards were referenced throughout the report.

1. International Building Code, 2018 edition
2. International Fire Code, 2018 edition
3. NFPA 99: Health Care Facilities Code, 2018 edition
4. NFPA 101: Life Safety Code, 2018 edition

Secondary Codes and Standards

The following codes and standards were referenced in specific sections of the report. For example, the fire sprinkler standard was referenced in the water-based fire suppression section, and the fire alarm standard was referenced in the detection and notification section.

1. NFPA 13: Standard for the Installation of Sprinkler Systems, 2016 edition
2. NFPA 70: National Electrical Code, 2016 edition
3. NFPA 72: National Fire Alarm and Signaling Code, 2016 edition
4. Society of Fire Protection Engineers Handbook, 5th edition

Appendices

Appendix A

Plans and Scaling

The report project building is the Baylor Scott & White Medical Center in College Station, TX. This facility was built as the Scott & White Hospital at College Station in 2013, and is a 324,070 square feet, five-story hospital[1].

This report uses publicly available floorplans for the Baylor Scott & White Medical Center in College Station, TX[2]. These floorplans are shown below in Figures A.1 – A.6.

[1] http://www.architectmagazine.com/project-gallery/scott-white-hospital-at-college-station
[2] http://www.sw.org/resources/docs/college-station/hospital-floor-map.pdf

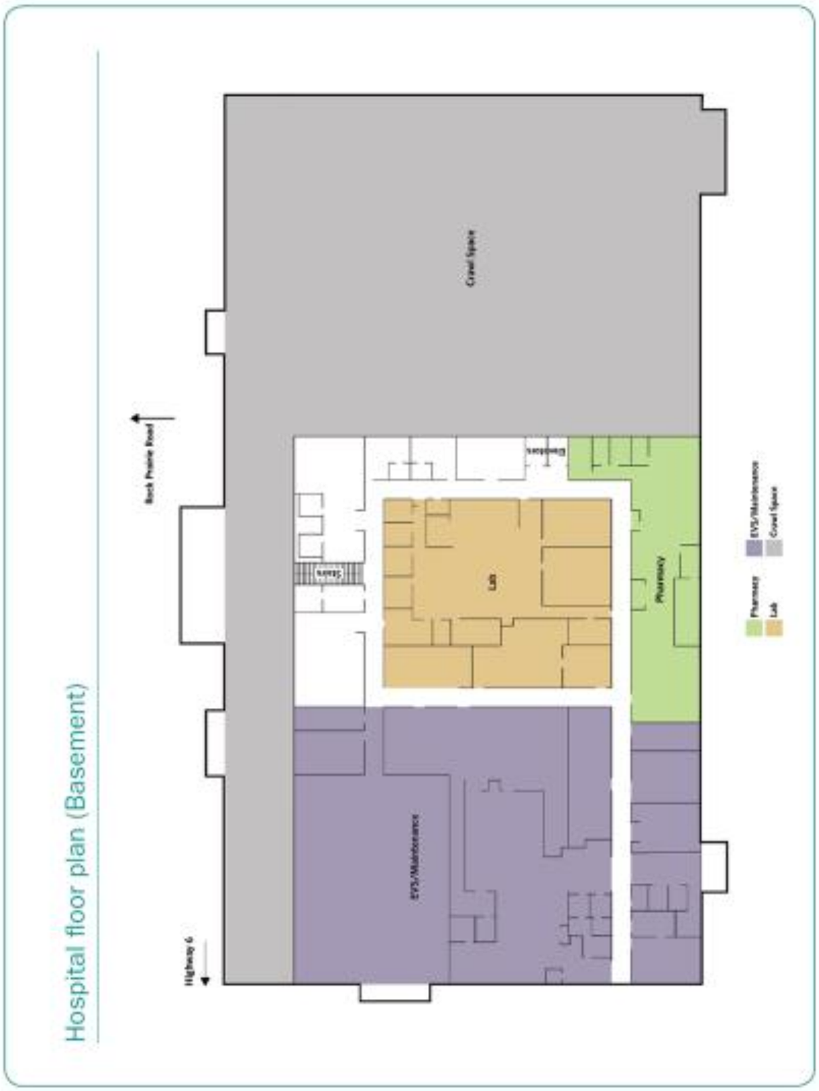


Figure # A.1. Basement Plans

Figure # A.2. Floor 1 Plans

Figure # A.3. Floor 2 Plans

Figure # A.4. Floor 3 Plans

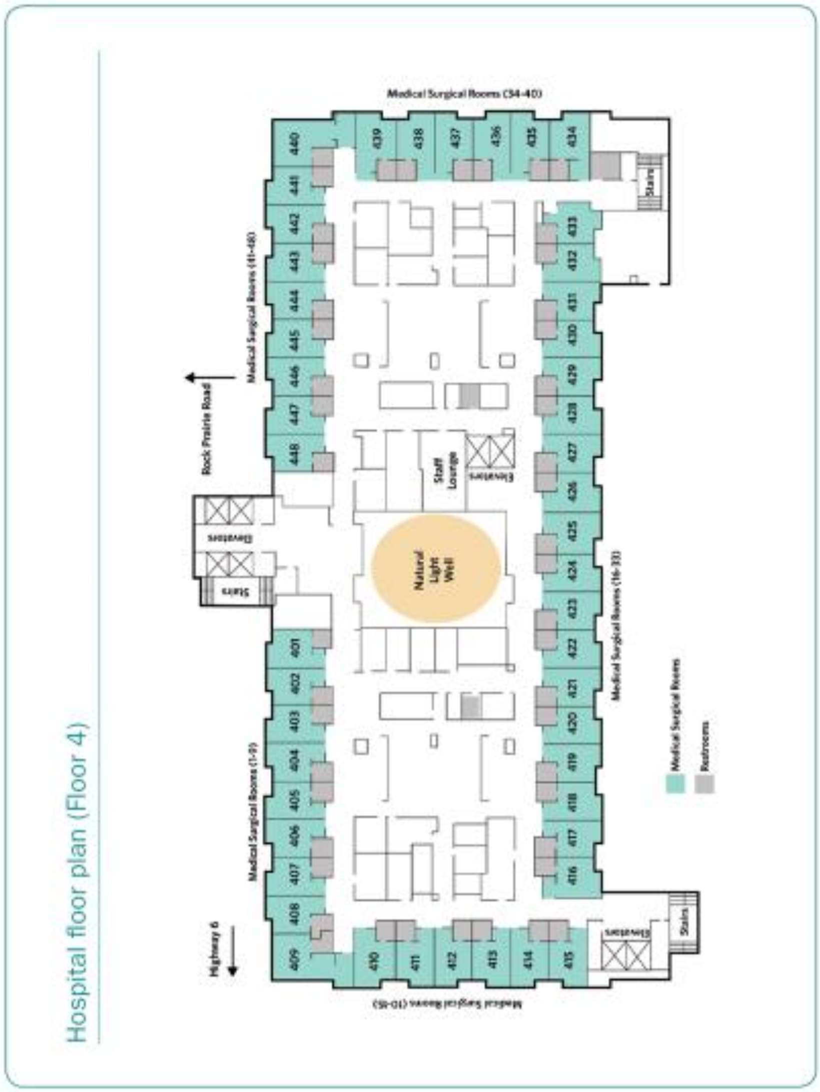


Figure # A.5. Floor 4 Plans

Figure # A.6. Floor 5 Plans

Assuming the floorplans in Figures A.1 – A.6 are to scale, the bottom three floors (including the basement) are approximately 7.5” x 4”, and the top three floors are approximately 7.5” x 3”. This gives a floor area of 30 square inches for the bottom three floors, and 22.5 square inches for the top three floors, with a total floor area of 157.5 square inches.

Equating 157.5 square inches to 324,070 square feet, 157.5 square inches = 324,070 square feet, or 1 square inch = 2,057.59 square feet. Taking the square root of each, 1 inch = 45.36 feet. Using this ratio, 3” = 136.08’, 4” = 181.44’, and 7.5” = 340.20’. Using the same ratio, 30 feet = 0.66 inches. This scale is shown in Figures A.7 – A.12.

To check if these assumptions were reasonable, this report looks at the ICU rooms on Floor 2, and the Medical Surgical Rooms on Floor 4. This report finds that these rooms are approximately 14.52’ x 14.52’ and 14.52’ x 19.05’ respectively. The doors are 4.54’ wide. This report considers hospital recommended room dimensions of 10 – 15 square meters (107.64 – 161.46 square feet) and door widths of 1.25 meters (4.10 feet) listed from a design reference standard from French Red Cross.[3] This report also considers hospital bed dimensions of 38” x 84” from vendors.[4] Taking all of this into account, this report finds that the estimated dimensions are reasonable.

[3] https://www.pseau.org/outils/ouvrages/parasismique/croix-rouge-fr-construction-et-rehabilitation/Documents/Documentation_technique/Techniques/hopital/Handbook_to_Build_an_Hospital_CRF.pdf

[4] https://www.phc-online.com/Hospital_Beds_for_Homes_s/68.htm

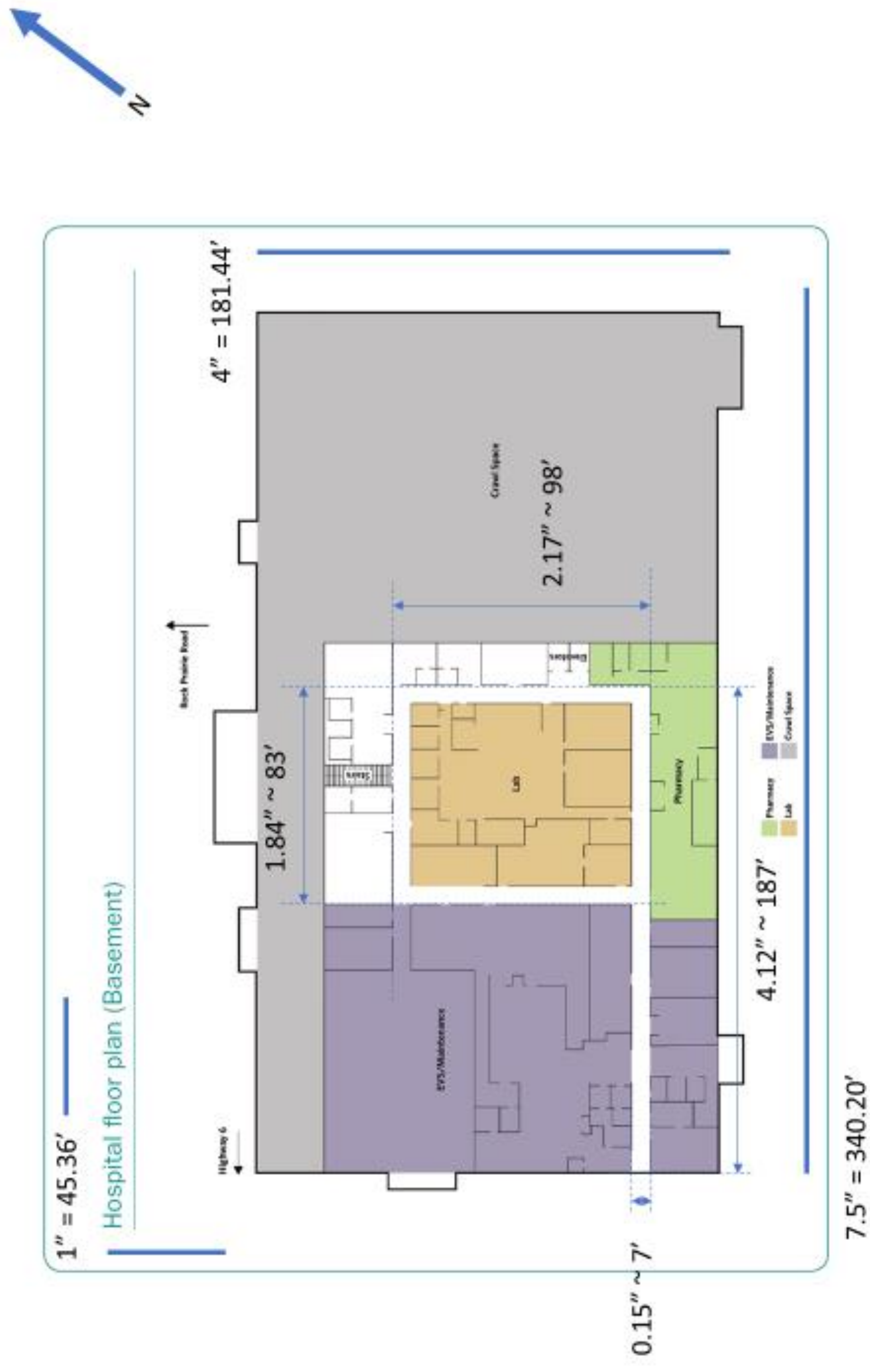


Figure # A.7. Basement Scaling

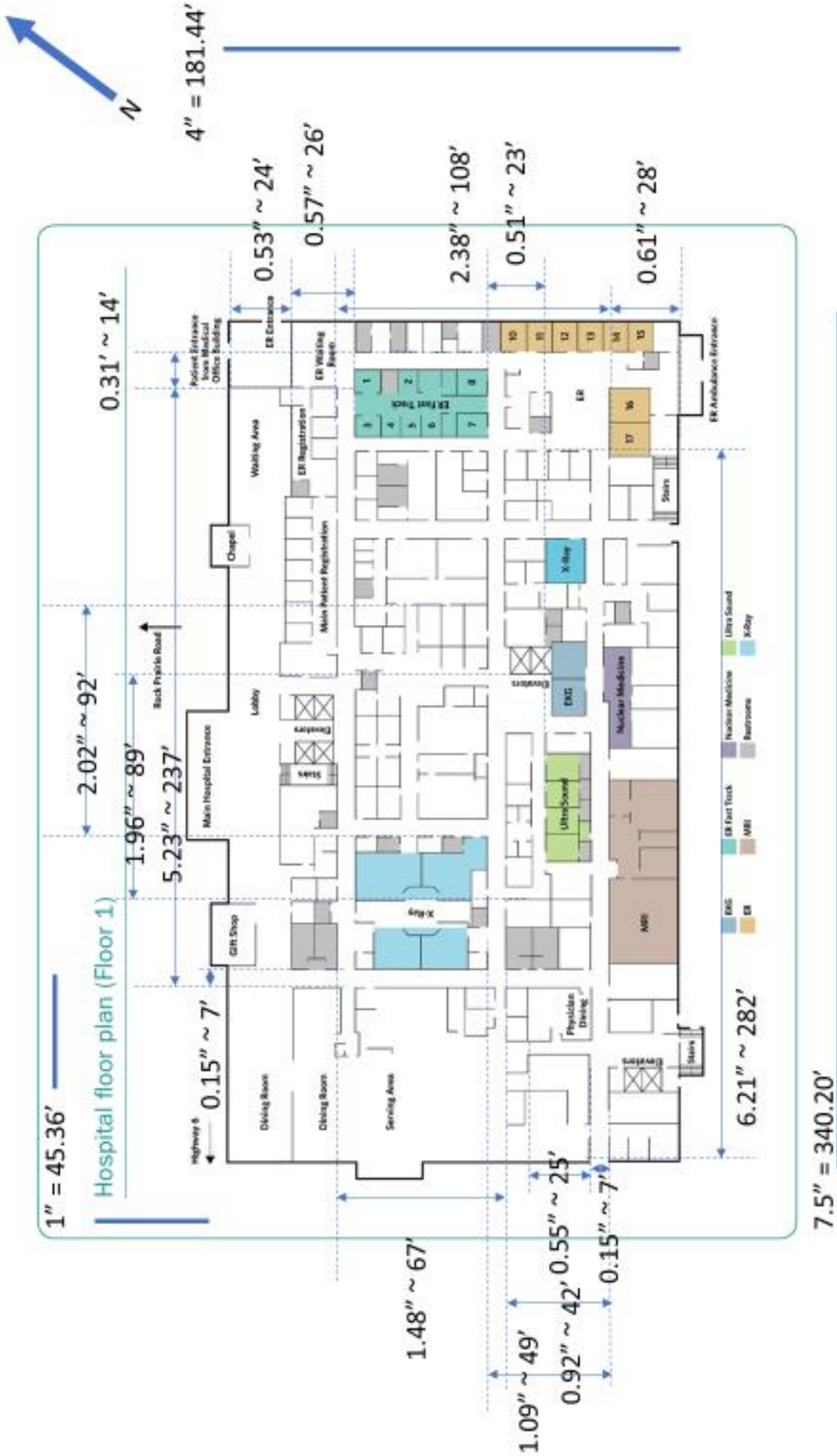


Figure # A.8. Floor 1 Scaling

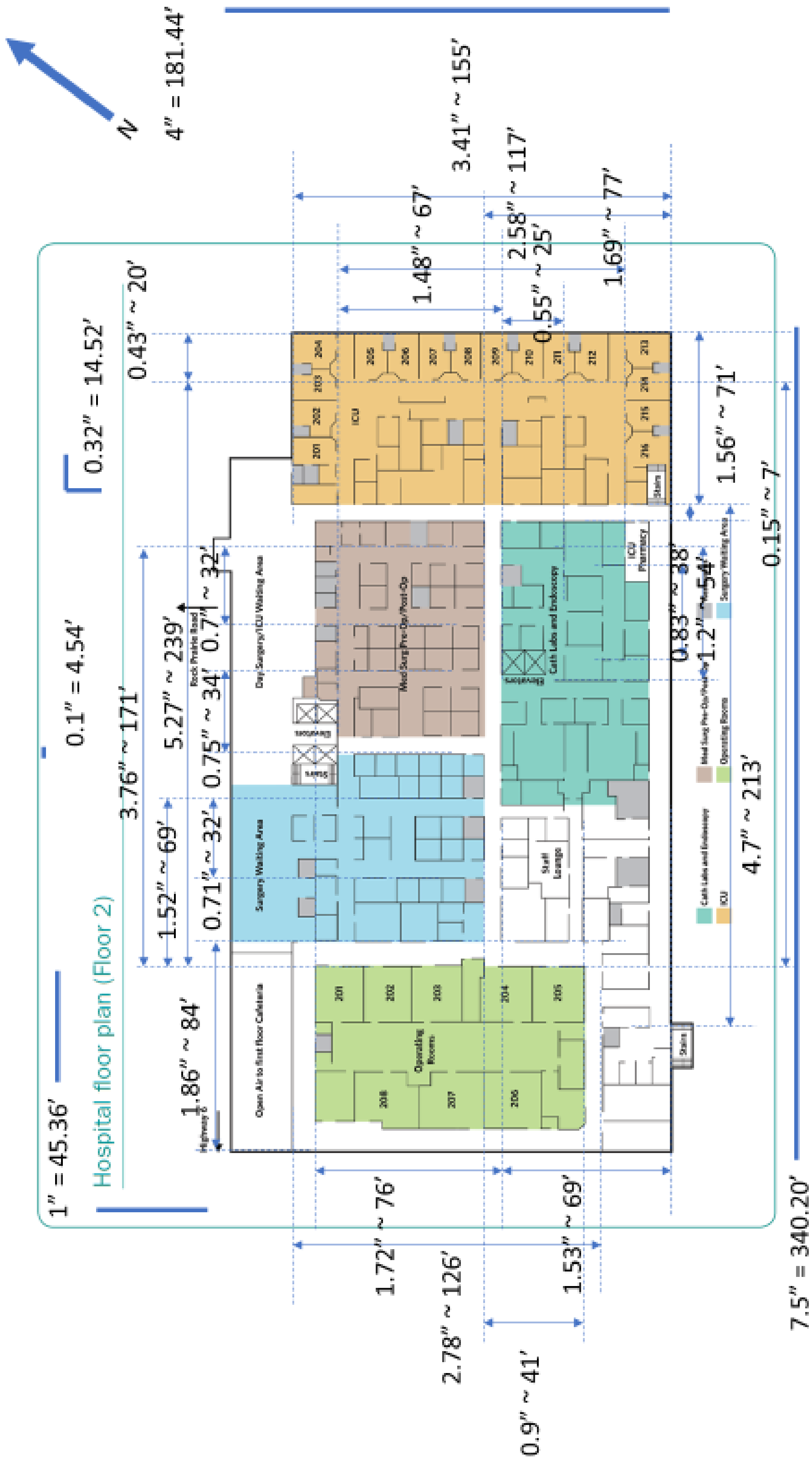


Figure # A.9. Floor 2 Scaling

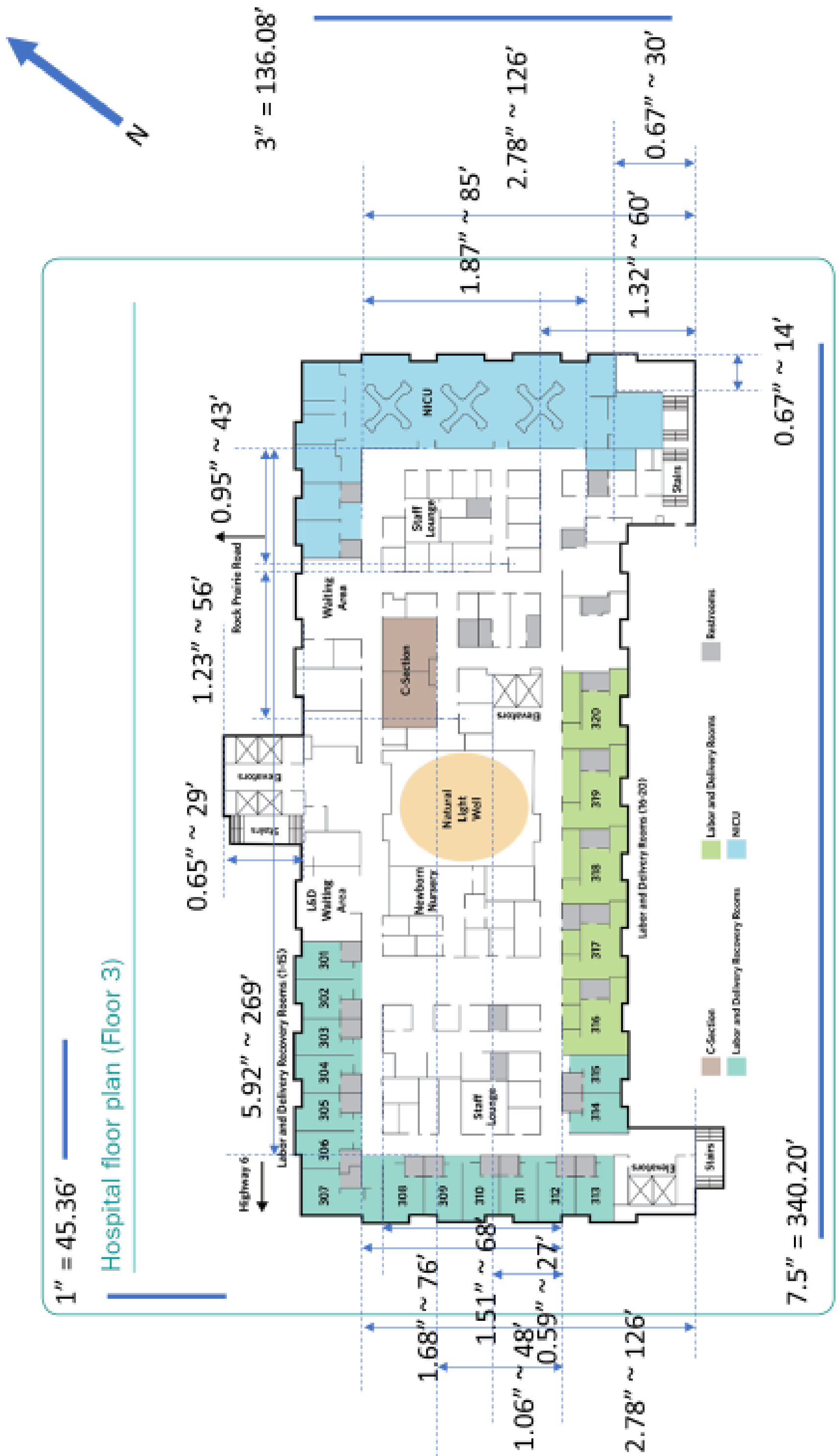


Figure # A.10. Floor 3 Scaling

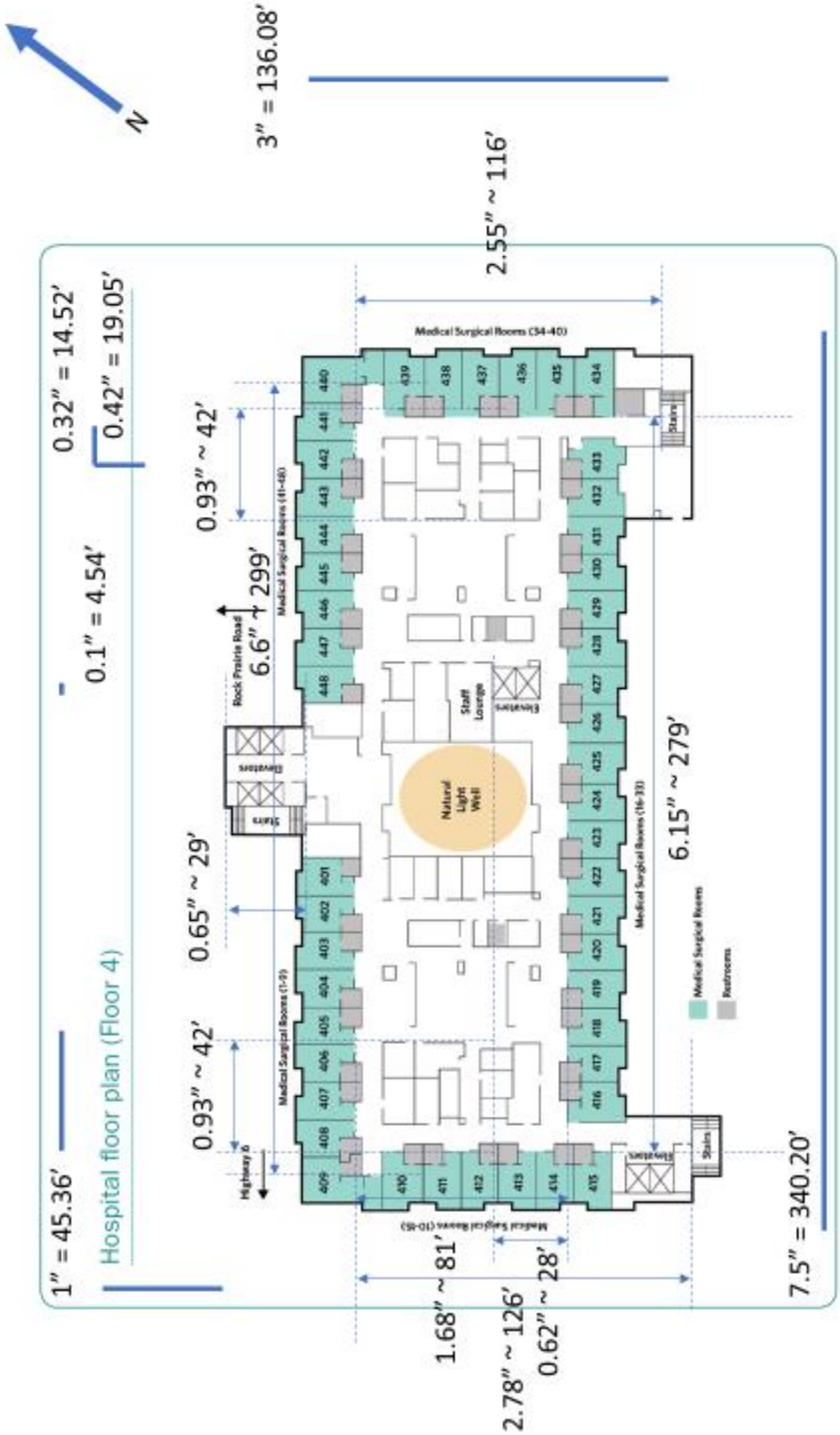


Figure # A.11. Floor 4 Scaling

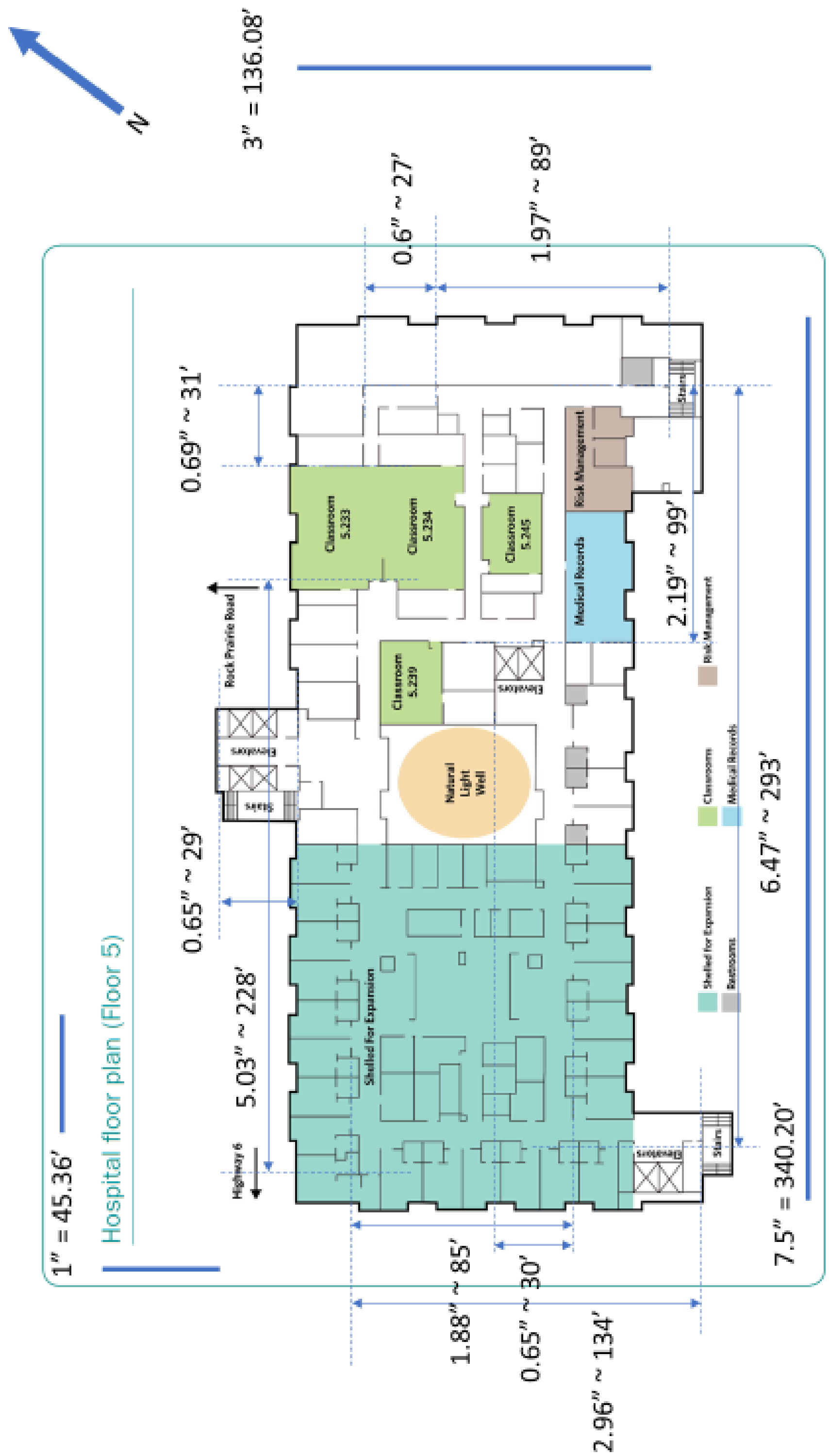


Figure # A.12. Floor 5 Scaling

Appendix B

FDS Code

Below in Figures B.1 – B.4 are views from the PyroSim model that was run as part of the performance-based design review of this building.

Office

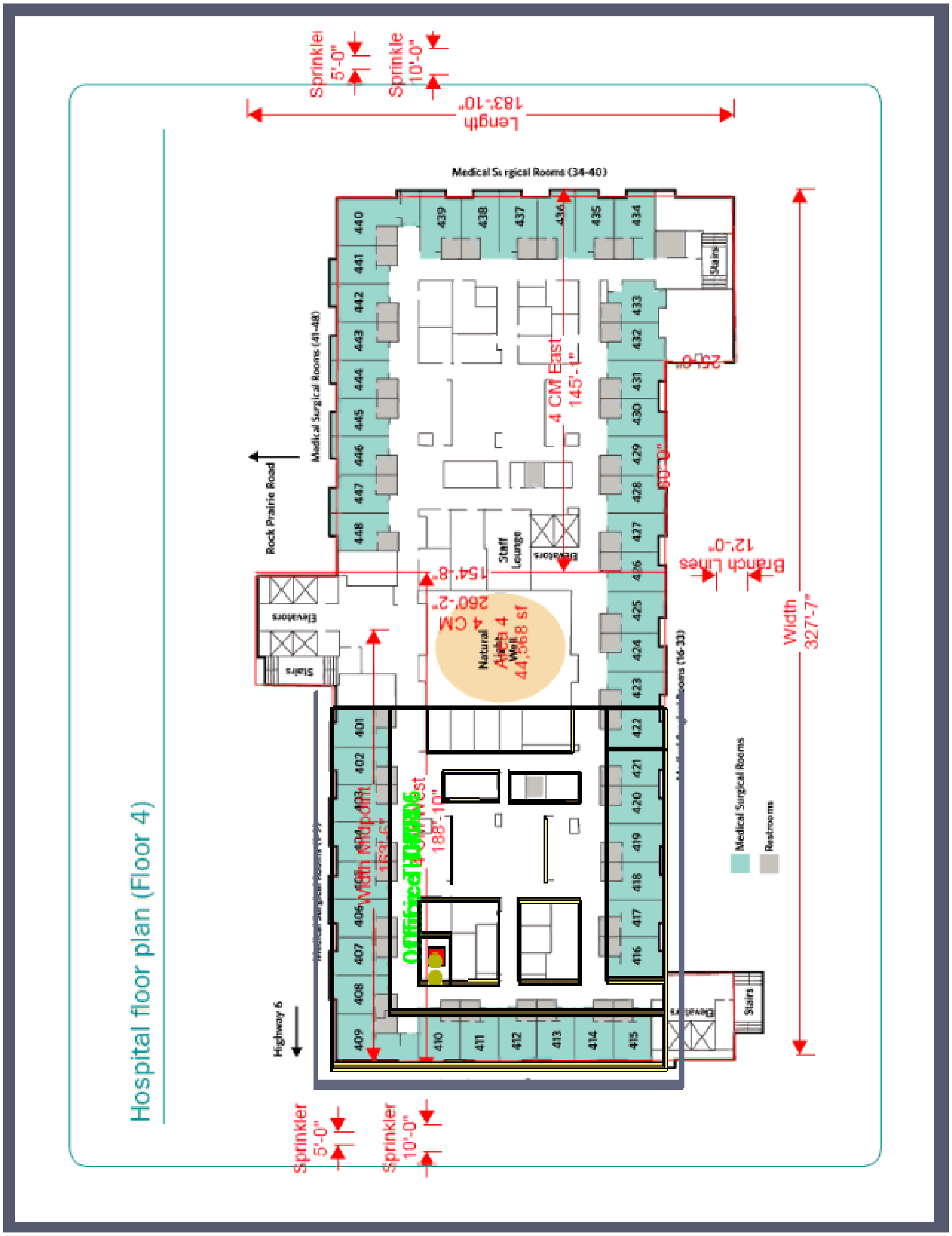


Figure # B.1. Office 3D Model

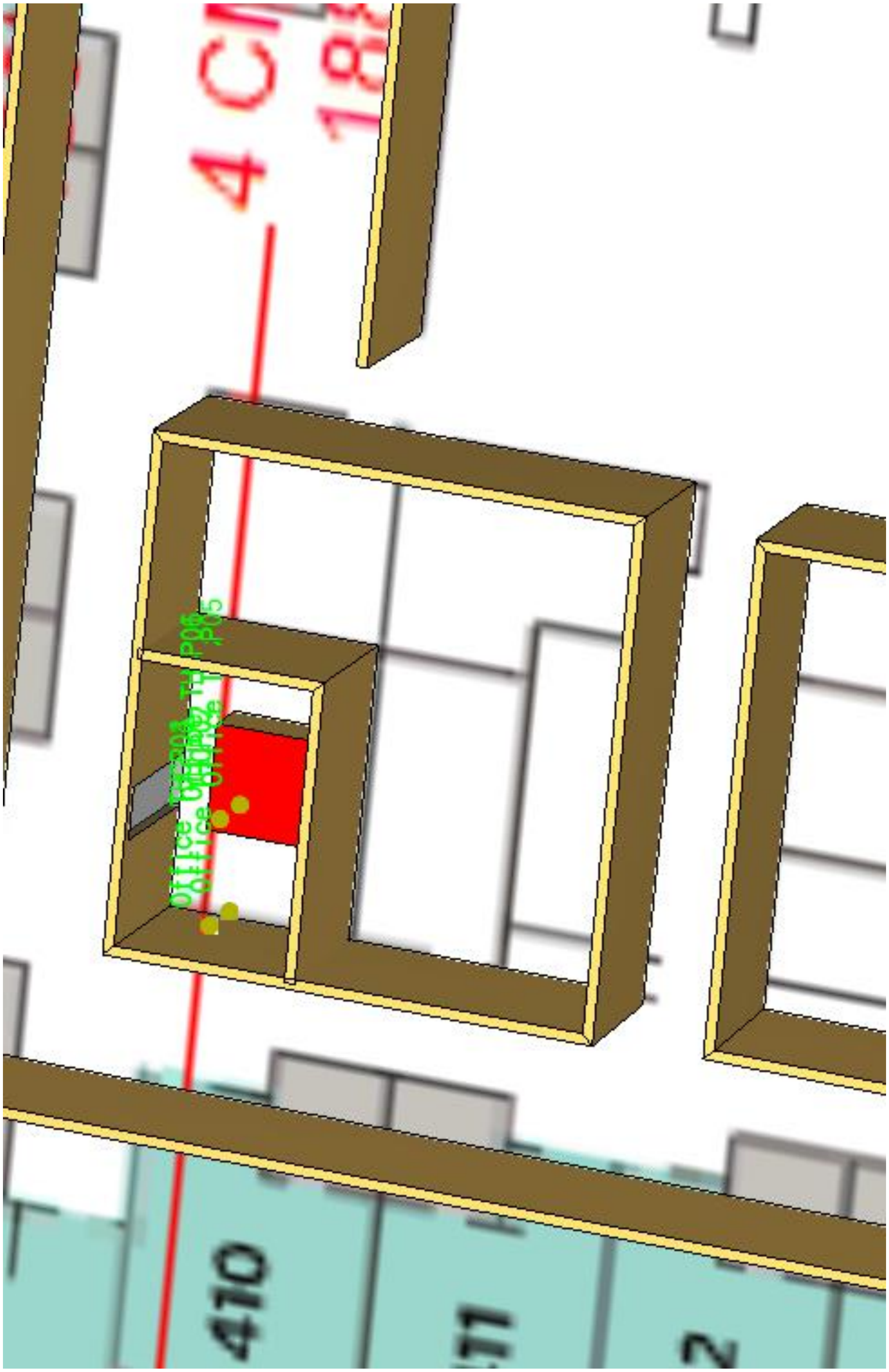


Figure # B.2. Enlarged View of Office Fire

Bedroom

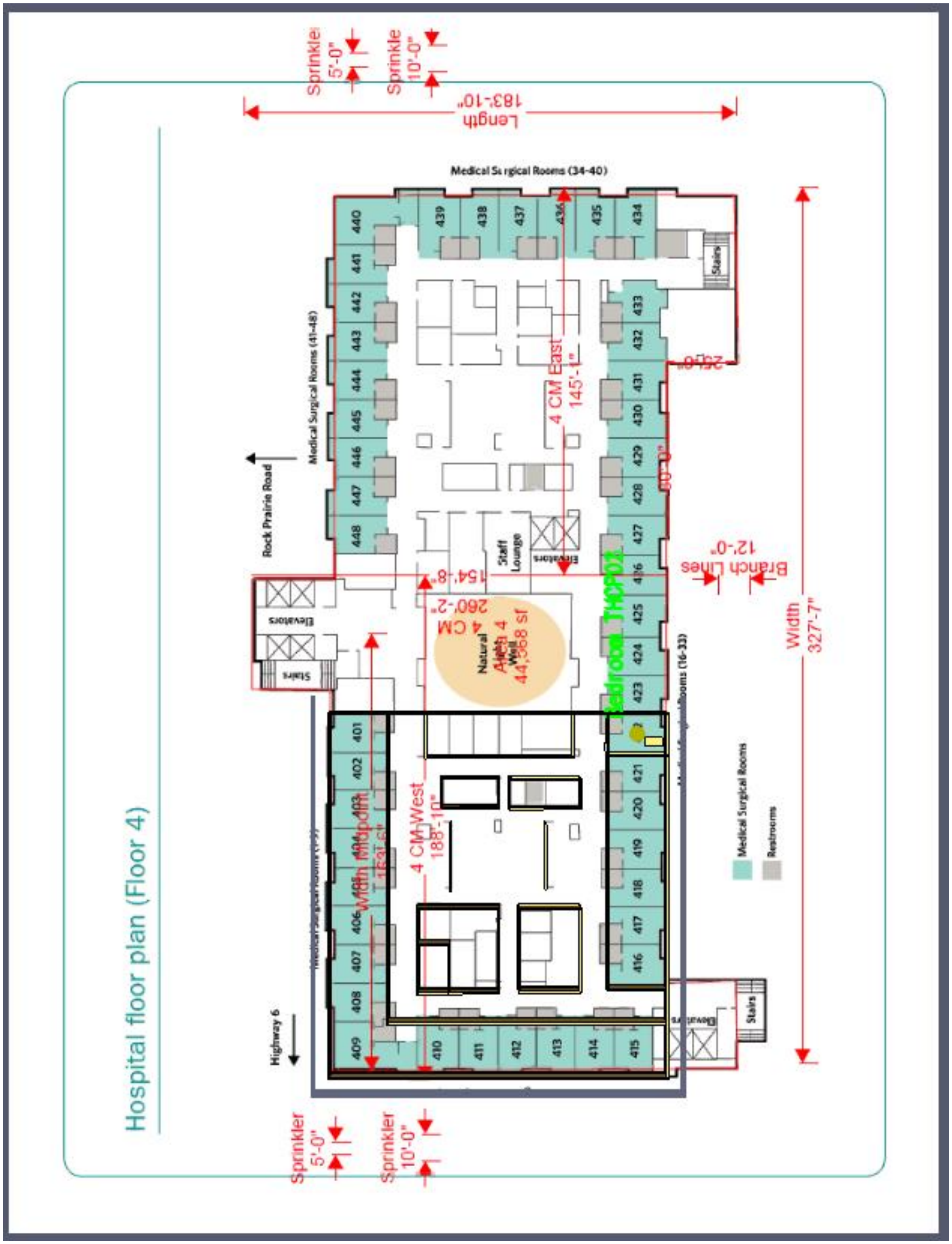


Figure # B.3. Bedroom 3D Model

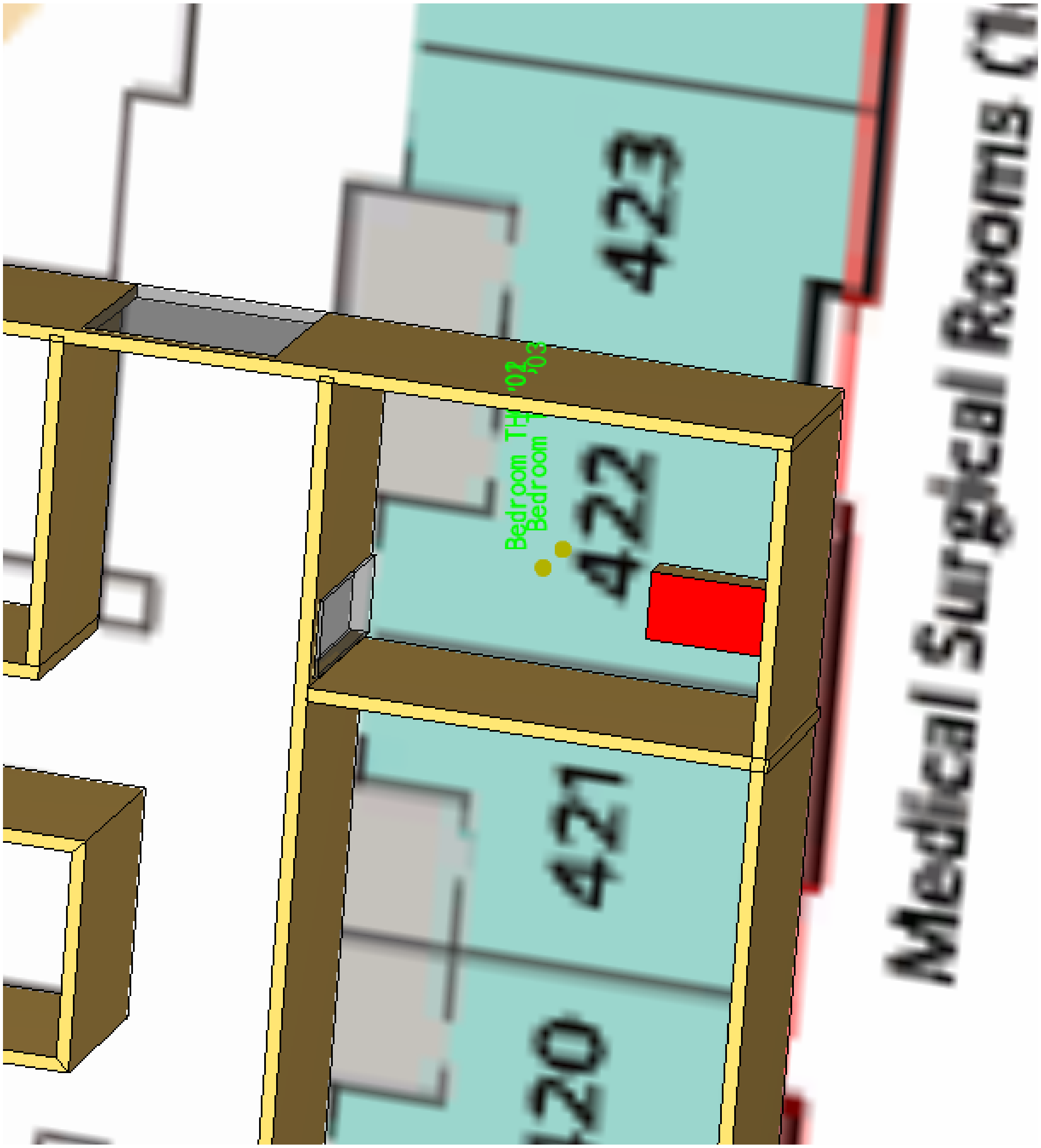


Figure # B.4. Enlarged View of Bedroom Fire

Appendix C

DETACT

The fire model in the report relied on FDS via PyroSim, and Pathfinder. DETACT had also been considered, but it was decided that PyroSim would yield a more accurate indication of detector activation. This is because PyroSim and FDS use computational fluid dynamics, versus the correlations inherent to DETACT. Additionally, the DETACT model relied on several assumptions and simplifications that were not required for the PyroSim and FDS. Nevertheless, the DETACT model is presented here for completeness.

Analysis of Fire Detector Response

Fire scenarios and expected response characteristics of fire detection devices installed in the building

In this hospital, the fire scenarios are generally one of two broad categories: rooms and corridors. This report examines these three fire scenarios and the expected response characteristics of the fire detection devices installed in the building below.

Note, other models, such as FDS and CFAST, are also useful tools to explore fire detector responses. For the purposes of this report, they are considered later.

This report uses Method 1, Optical density vs temperature (B.4.8.1) from Annex B of NFPA 72 to estimate the response characteristics of the fire detection devices installed in the building. This report uses B.4.7.5.3 and Table B.4.7.5.3, and selected the conservative value of 41.7°C temperature rise (for wood material) for detector response from Table C.1 below for a photoelectric smoke detector.

Table # C.1. Temperature Rise for Detector Response from NFPA 72-2016

Table B.4.7.5.3 Temperature Rise for Detector Response [18]

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

This report takes a worst-case scenario of a fire starting at the maximum distance from a smoke detector. In a room, this would be in the middle of a 4 x 4 grid of smoke detectors spaced 30' apart from each other. In a corridor, this would be between two smoke detectors set 42' apart. The difference between these two cases is marginal, with room fires having a radial distance of 6.5, while corridor fires have a radial distance of 6.4 (the different numbers are due to slight calculation and rounding differences). Calculations and graphs of different fires are shown below in Tables C.2 – C.6 and Figures C.1 – C.5.

Table # C.2. DETACT, Room, Fast Fire

DETACT.XLS: Estimate of the response time of ceiling mounted fire detectors

INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	3.048	m	R/H	2.121
Radial distance (R)	6.5	m	dT(cj)/dT(pl)	0.182
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.107
Actuation temperature (Td)	61.7	C	Rep. t2 coeff.	k
Response time index (RTI)	2	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.047	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp	dT/dt
0	0.0	20.0	0.00	20.00	0.0000
2	0.2	20.2	0.04	20.00	0.0162
4	0.8	20.4	0.07	20.03	0.0471
128	770.0	60.3	0.68	59.25	0.4206
130	794.3	61.1	0.68	60.09	0.4227
132	818.9	62.0	0.69	60.93	0.4249
134	843.9	62.8	0.70	61.78	0.4270
136	869.3	63.7	0.70	62.64	0.4291
138	895.1	64.5	0.71	63.49	0.4312

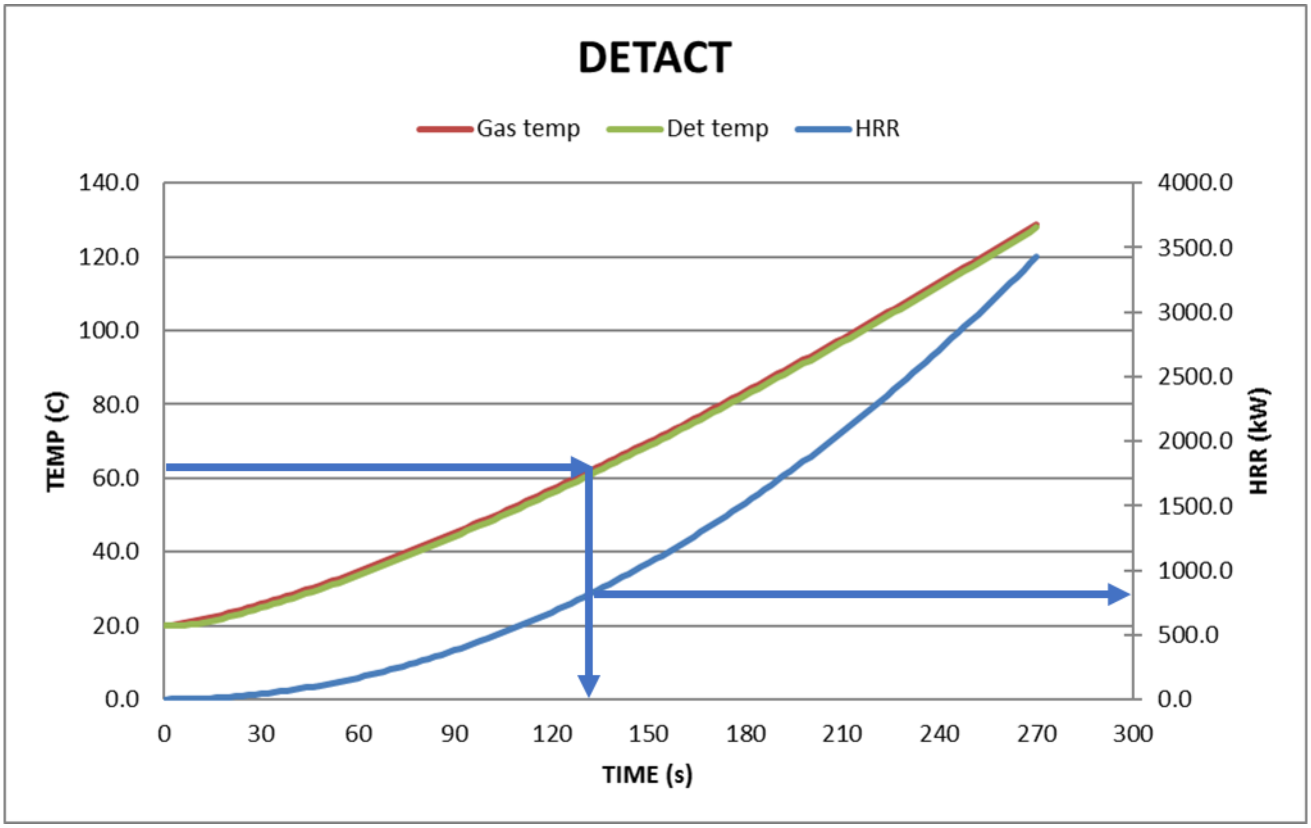


Figure # C.1. DETACT, Room, Fast Fire

Table # C.3. DETACT, Corridor, Fast Fire

DETACT.XLS: Estimate of the response time of ceiling mounted fire detectors

INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	3.048	m	R/H	2.100
Radial distance (R)	6.4	m	dT(cj)/dT(pl)	0.183
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.108
Actuation temperature (Td)	61.7	C	Rep. t2 coeff.	k
Response time index (RTI)	2	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.047	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp	dT/dt
0	0.0	20.0	0.00	20.00	0.0000
2	0.2	20.2	0.04	20.00	0.0163
4	0.8	20.4	0.07	20.03	0.0476
128	770.0	60.5	0.68	59.51	0.4234
130	794.3	61.4	0.69	60.36	0.4256
132	818.9	62.2	0.70	61.21	0.4277
134	843.9	63.1	0.70	62.06	0.4298
136	869.3	63.9	0.71	62.92	0.4319
[illegible]	[illegible]	[illegible]	0.72	[illegible]	[illegible]

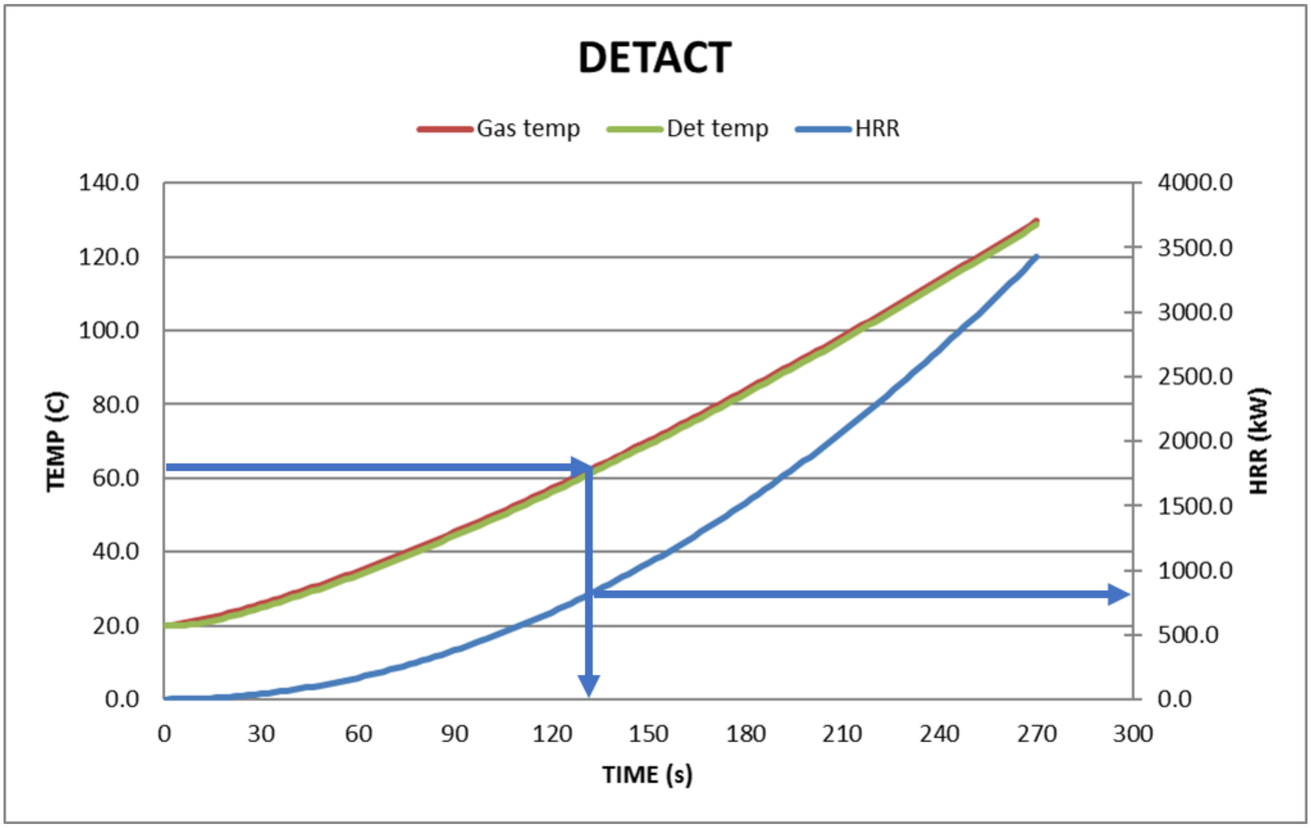


Figure # C.2. DETACT, Corridor, Fast Fire

From DETACT, this report compares the response times for a fast fire in a room and a corridor, and find that a room detector's response time is slightly slower than that of a corridor detector's (by only one or two seconds). In reality, the corridor detector's likely react even faster, as smoke is 'channeled' in one dimension within a corridor, instead of spreading out in two dimensions, along the plane of a room ceiling. With that information, to be conservative, this report applies slow, medium, fast, and ultrafast fires to find the following response times for different fires below in Tables C.4 – C.6 and Figures C.3 – C.5. Note, the scaling may change from graph to graph.

Table # C.4. DETACT, Room, Slow Fire

DETACT.XLS: Estimate of the response time of ceiling mounted fire detectors				
INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	3.048	m	R/H	2.121
Radial distance (R)	6.5	m	dT(cj)/dT(pl)	0.182
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.107
Actuation temperature (Td)	61.7	C	Rep. t2 coeff.	k
Response time index (RTI)	2	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.003	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp	dT/dt
0	0.0	20.0	0.00	20.00	0.0000
2	0.0	20.0	0.02	20.00	0.0016
4	0.0	20.1	0.03	20.00	0.0049
518	805.0	61.5	0.69	61.22	0.1068
520	811.2	61.7	0.69	61.43	0.1070
522	817.5	61.9	0.69	61.65	0.1071
524	823.7	62.1	0.69	61.86	0.1072
526	830.0	62.3	0.69	62.08	0.1074
528	836.4	62.5	0.69	62.29	0.1075

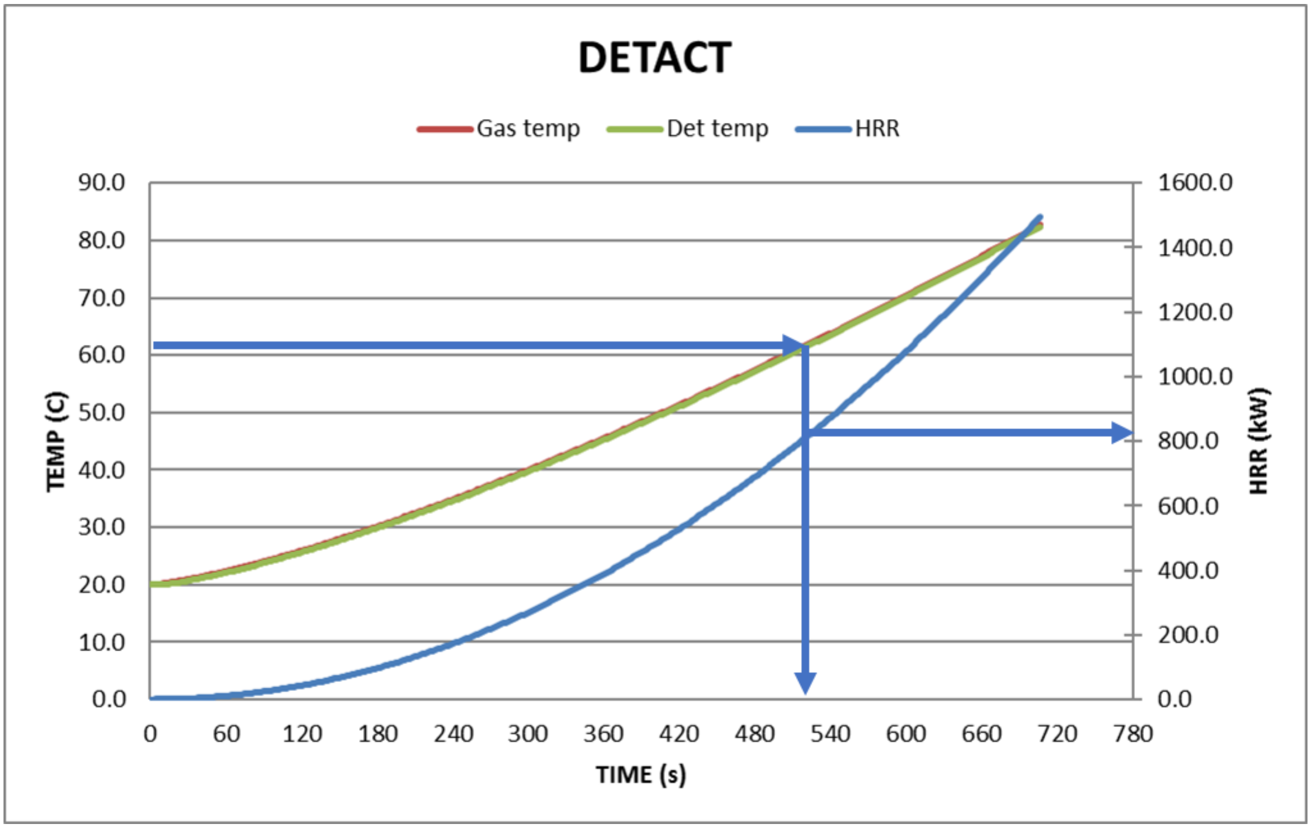


Figure # C.3. DETACT, Room, Slow Fire

Table # C.5. DETACT, Room, Medium Fire

DETACT.XLS: Estimate of the response time of ceiling mounted fire detectors				
INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	3.048	m	R/H	2.121
Radial distance (R)	6.5	m	dT(cj)/dT(pl)	0.182
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.107
Actuation temperature (Td)	61.7	C	Rep. t2 coeff.	k
Response time index (RTI)	2	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.012	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp	dT/dt
0	0.0	20.0	0.00	20.00	0.0000
2	0.0	20.1	0.03	20.00	0.0052
4	0.2	20.2	0.04	20.01	0.0154
258	798.8	61.3	0.68	60.75	0.2135
260	811.2	61.7	0.69	61.17	0.2141
262	823.7	62.1	0.69	61.60	0.2146
264	836.4	62.5	0.69	62.03	0.2152
266	849.1	63.0	0.70	62.46	0.2157
268	861.9	63.4	0.70	62.89	0.2163

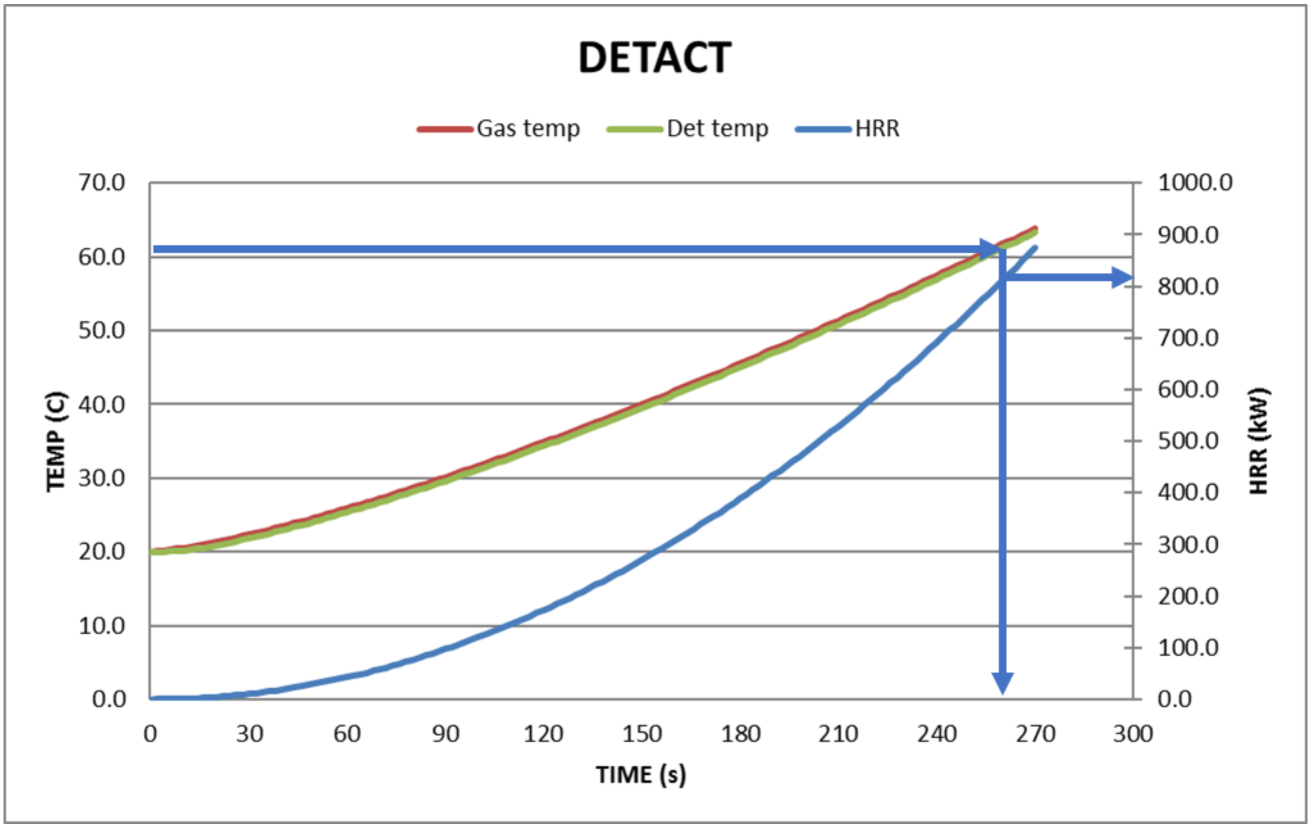


Figure # C.4. DETACT, Room, Medium Fire

Table # C.6. DETACT, Room, Ultrafast Fire

DETACT.XLS: Estimate of the response time of ceiling mounted fire detectors

INPUT PARAMETERS			CALC. PARAMETERS	
Ceiling height (H)	3.048	m	R/H	2.121
Radial distance (R)	6.5	m	dT(cj)/dT(pl)	0.182
Ambient temperature (To)	20	C	u(cj)/u(pl)	0.107
Actuation temperature (Td)	61.7	C	Rep. t2 coeff.	k
Response time index (RTI)	2	(m-s)1/2	Slow	0.003
Fire growth power (n)	2	-	Medium	0.012
Fire growth coefficient (k)	0.400	kW/s^n	Fast	0.047
Time step (dt)	2	s	Ultrafast	0.400

Calculation time (s)	HRR	Gas temp	Gas velocity	Det temp	dT/dt
0	0.0	20.0	0.00	20.00	0.0000
2	1.6	20.7	0.09	20.00	0.0963
4	6.4	21.7	0.14	20.19	0.2700
42	705.6	58.0	0.66	54.99	1.2161
44	774.4	60.4	0.68	57.42	1.2346
46	846.4	62.9	0.70	59.89	1.2526
48	921.6	65.4	0.72	62.39	1.2700
50	1000.0	67.9	0.74	64.93	1.2870
52	1081.6	70.5	0.76	67.51	1.3036

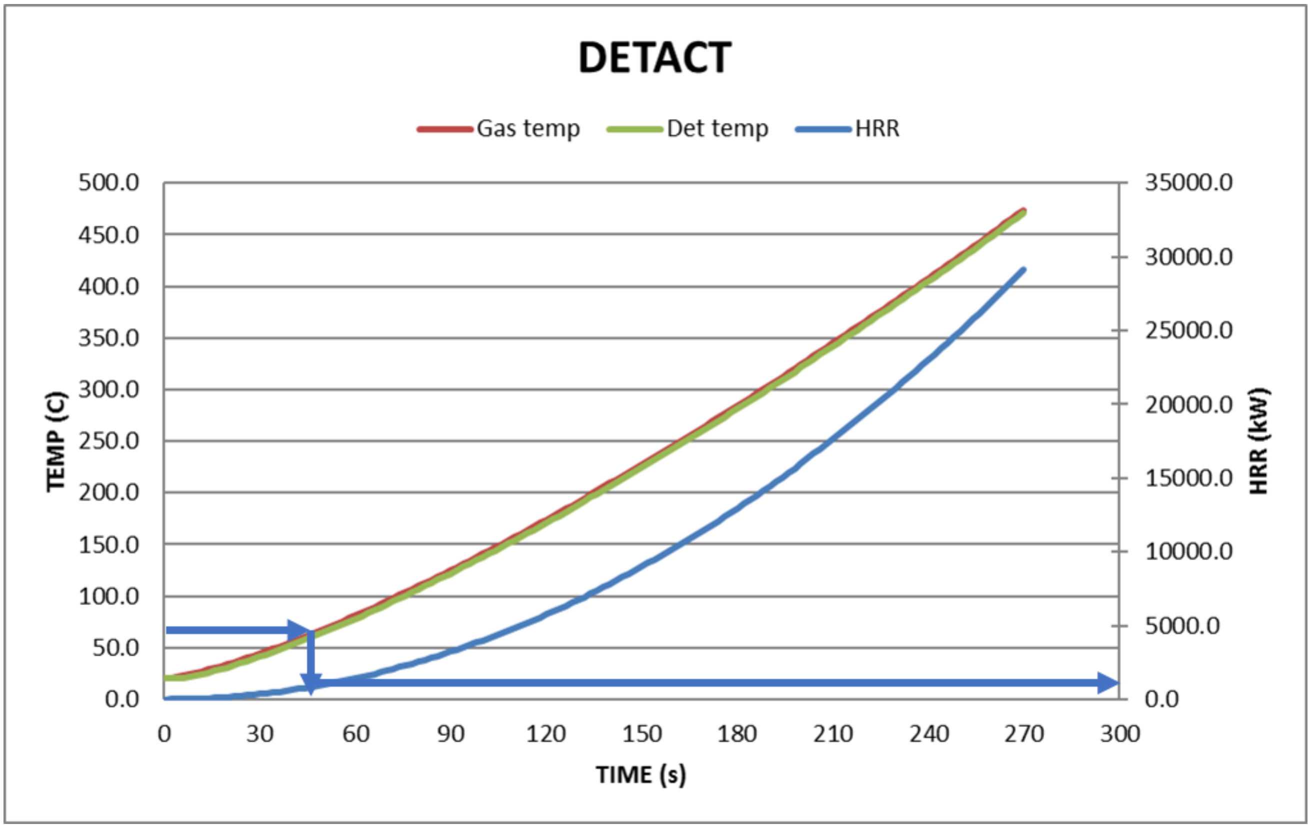


Figure # C.5. DETACT, Room, Ultrafast Fire

Summary Table

Table C.7 below summarizes the expected response time for the fire detection devices this report assumed was installed in this building.

Table # C.7. DETACT Response Times

Room Fire Type	Photoelectric smoke detector response time
Slow	524 s
Medium	264 s
Fast	134 s
Ultrafast	48 s

Fire size at the time of detector activation for selected scenarios

Using the same information and graphs as in the previous section above, the fire size at the time of detector activation for the selected scenarios may be found. The heat release rate at the time of detector activation for different types of fires is shown below in Table C.8.

Table # C.8. DETACT Fire HRR

Room Fire Type	Fire HRR at detector activation time
Slow	823.7 kW
Medium	836.4 kW
Fast	843.9 kW
Ultrafast	921.6 kW

Appendix D

Fire Alarm Sequence of Operation

Table D.1 below describes the sequence of operation for the fire alarm system. Other disciplines working on this project, including the architect, mechanical engineer-of-record, and electrical engineer-of-record should coordinate their systems with this matrix. For example, the HVAC systems automatically shut down in the event that a fire alarm detection device is activated.

Table # D.1. DETACT Response Times

Input vs Output	General Alarm	Control Panel Alarm	Control Panel Supervisory	Elevator Recall	Release Door Holders	Close Fire/Smoke Dampers	HVAC Shutdown
Manual Pull Station	X	X			X	X	X
Area Detector	X	X			X	X	X
Duct Detector	X	X			X	X	X
Elevator Lobby Detector	X	X		X	X	X	X
Sprinkler Waterflow Swtich	X	X			X	X	X
Valve Tamper Switch			X				

Additional Notification Devices

The public Baylor, Scott & White Medical Center floorplans used in this report do not include details such as the building mechanical and electrical systems. Relevant to the fire alarm system, this report does not know what type of HVAC system is used, and where the associated ductwork is routed. It is assumed that such a system exists for this hospital, and therefore, besides the area smoke detectors described in the main body of this report, duct detectors would also be installed in order to monitor the interior of the ducts for the development of fire and smoke, and to activate the general alarm, close fire and smoke dampers (FSDs), and shut down HVAC fans. This is necessary to mitigate the movement of smoke and fire through the HVAC system, especially since HVAC ducts typically cross fire and smoke barriers, and could otherwise serve as a means to spread fire and products of combustion to spaces where they would otherwise not be present, and to compromise the tenability criteria of those spaces.

HVAC System Operation

As mentioned above in this Appendix, neither detailed drawings nor information of the HVAC systems is provided for this project. This report assumes an HVAC system with fans on the roof, and a system of ductwork that extends to every floor, crossing fire and smoke barriers and connecting the various floors and smoke compartments in the building. FSDs should be installed wherever ducts cross such a boundary, to protect what would otherwise be a communicating opening that would allow fire and products of combustion to cross from one separated space to another.

This building does not require smoke control, so none of the requirements of smoke control (e.g. emergency power, non-combustible mounting, redundant fan belts, etc.) apply to the HVAC equipment, and it is not expected to operate during a fire event. This report recommends shutting down the HVAC system in the event of a fire.

Appendix E

Structural Fire Protection Calculations

Below in Figures E.1 – E.10 are examples of the calculations run on spreadsheets for the structural fire protection section of the performance-based review of this building. The calculation for the fire, and for the insulated and uninsulated structural elements (members) are shown. Note that the bedroom and office fires share the same fire information for both their respective insulated and uninsulated structural element (member) analysis, while the hallway fire, as a travel fire, was adjusted for the insulated and uninsulated cases to find the worst-case scenario for each as a deliberate choice to be conservative in the modeling of these fires.

				t (min)	t (s)	x (m) - fire location	Lt	-
Q (constant)	147000	kW		0	0	0	0	700
TA	20	C		0.05	3	0.009473684	0.000263	700
delta t	3	s		0.1	6	0.018947368	0.000526	700
Q"	5000	kW/m2		0.15	9	0.028421053	0.000789	700
H0	3.6	m		0.2	12	0.037894737	0.001053	700
X0	36	m		0.25	15	0.047368421	0.001316	700
Y0	3.6	m		0.3	18	0.056842105	0.001579	700
A	129.6	m2		0.35	21	0.066315789	0.001842	700
Percent	0.1			0.4	24	0.075789474	0.002105	700
Vs	0.003158	m/s		0.45	27	0.085263158	0.002368	700
Ab	12.96	m2		0.5	30	0.094736842	0.002632	700
tb	1140	sec		0.55	33	0.104210526	0.002895	700
qf	5700	MJ/m2		0.6	36	0.113684211	0.003158	700
				0.65	39	0.123157895	0.003421	700
t_total	12540			0.7	42	0.132631579	0.003684	700

Figure # E.1. Bedroom Structural Fire Protection Calculations, Fire

k	45.8	W/mK	time[min]	time[s]	q"net[kW/m2]	Temp S	f_y,steel	M_n	E_steel	delta_max
rho	7850	kg/m3	0	0	64.0325789193	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
cp	460	J/kgK	0.05	3	64.0312194662	20.05287	49,750.72	1,940,277.94	28,928,190.63	0.033511
delta x	0.01	meters	0.1	6	64.0298599552	20.10573	49,749.91	1,940,246.57	28,927,954.49	0.033511
delta t	3	seconds	0.15	9	64.0285003865	20.15858	49,749.11	1,940,215.17	28,927,718.19	0.033512
S.B	5.67E-08	W/m2K4	0.2	12	64.0271407599	20.21144	49,748.30	1,940,183.76	28,927,481.72	0.033512
hc	20	W/m2K	0.25	15	64.0257810755	20.26429	49,747.50	1,940,152.33	28,927,245.08	0.033512
e	1		0.3	18	64.0244213333	20.31713	49,746.69	1,940,120.88	28,927,008.28	0.033512
Fo	0.380504016	< 1/2	0.35	21	64.0230615330	20.36997	49,745.88	1,940,089.40	28,926,771.31	0.033513
			0.4	24	64.0217016749	20.42281	49,745.07	1,940,057.91	28,926,534.19	0.033513
ki	0.12	W/mK	0.45	27	64.0203417588	20.47564	49,744.27	1,940,026.41	28,926,296.89	0.033513
rho_i	300	kg/m3	0.5	30	64.0189817847	20.52847	49,743.46	1,939,994.88	28,926,059.43	0.033514
cp_i	1200	J/kgK	0.55	33	64.0176217526	20.5813	49,742.65	1,939,963.33	28,925,821.81	0.033514
			0.6	36	64.0162616624	20.63412	49,741.84	1,939,931.76	28,925,584.03	0.033514
Fs/Vs	24.05163897	m^-1	0.65	39	64.0149015141	20.68693	49,741.03	1,939,900.18	28,925,346.08	0.033514
			0.7	42	64.0135413077	20.73975	49,740.22	1,939,868.57	28,925,107.97	0.033515
d_i	0.029779584	m	0.75	45	64.0121810432	20.79256	49,739.41	1,939,836.95	28,924,869.70	0.033515
(half inch)			0.8	48	64.0108207205	20.84536	49,738.60	1,939,805.30	28,924,631.26	0.033515

Figure # E.2. Bedroom Structural Fire Protection Calculations, Insulated Member

k	45.8	W/mK	time[min]	time[s]	q"net[kW/m2]	Temp S	f_y,steel	M_n	E_steel	delta_max
rho	7850	kg/m3	0	0	64.0325789193	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
cp	460	J/kgK	0.05	3	63.9996303822	21.2795	49,731.91	1,939,544.34	28,922,664.10	0.033517
delta x	0.01	meters	0.1	6	63.9666023114	22.55834	49,711.98	1,938,767.32	28,916,799.40	0.033524
delta t	3	seconds	0.15	9	63.9334940582	23.83652	49,691.76	1,937,978.60	28,910,835.18	0.033531
S.B	5.67E-08	W/m2K4	0.2	12	63.9003049732	25.11403	49,671.24	1,937,178.50	28,904,773.83	0.033538
hc	20	W/m2K	0.25	15	63.8670344071	26.39089	49,650.44	1,936,367.32	28,898,617.56	0.033545
e	1		0.3	18	63.8336817101	27.66708	49,629.37	1,935,545.34	28,892,368.36	0.033553
Fo	0.380504016	< 1/2	0.35	21	63.8002462323	28.9426	49,608.02	1,934,712.80	28,886,028.08	0.03356
			0.4	24	63.7667273238	30.21746	49,586.41	1,933,869.93	28,879,598.42	0.033567
ki	0.12	W/mK	0.45	27	63.7331243342	31.49164	49,564.54	1,933,016.96	28,873,080.93	0.033575
rho_i	300	kg/m3	0.5	30	63.6994366133	32.76515	49,542.41	1,932,154.08	28,866,477.10	0.033583
cp_i	1200	J/kgK	0.55	33	63.6656635108	34.038	49,520.04	1,931,281.48	28,859,788.25	0.033591
			0.6	36	63.6318043762	35.31016	49,497.42	1,930,399.33	28,853,015.67	0.033598
Fs/Vs	24.05163897	m^-1	0.65	39	63.5978585591	36.58165	49,474.56	1,929,507.80	28,846,160.54	0.033606
			0.7	42	63.5638254091	37.85246	49,451.46	1,928,607.04	28,839,223.95	0.033614
d_i	0.029779584	m	0.75	45	63.5297042759	39.12259	49,428.13	1,927,697.20	28,832,206.96	0.033623
(half inch)			0.8	48	63.4954945092	40.39204	49,404.57	1,926,778.41	28,825,110.54	0.033631

Figure # E.3. Bedroom Structural Fire Protection Calculations, Uninsulated Member

				t (min)	t (s)	x (m) - fire location	Lt	22
Q (constant)	147000	kW		0	0	0	0	20
TA	20	C		0.05	3	0.009473684	0.000263	25.85403
delta t	3	s		0.1	6	0.018947368	0.000526	29.29402
Q"	5000	kW/m2		0.15	9	0.028421053	0.000789	32.18036
H0	3.6	m		0.2	12	0.037894737	0.001053	34.75758
X0	36	m		0.25	15	0.047368421	0.001316	37.12711
Y0	3.6	m		0.3	18	0.056842105	0.001579	39.34345
A	129.6	m2		0.35	21	0.066315789	0.001842	41.44014
Percent	0.1			0.4	24	0.075789474	0.002105	43.43966
Vs	0.003158	m/s		0.45	27	0.085263158	0.002368	45.35803
Ab	12.96	m2		0.5	30	0.094736842	0.002632	47.20715
tb	1140	sec		0.55	33	0.104210526	0.002895	48.99617
qf	5700	MJ/m2		0.6	36	0.113684211	0.003158	50.73233
				0.65	39	0.123157895	0.003421	52.42147
t_total	12540			0.7	42	0.132631579	0.003684	54.0684

Figure # E.4. Hallway Structural Fire Protection Calculations, Fire for Insulated Member

k	45.8	W/mK	time[min]	time[s]	q"net[kW/m2]	Temp S	f_y,steel	M_n	E_steel	delta_max
rho	7850	kg/m3	0	0	0.0000000000	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
cp	460	J/kgK	0.05	3	0.1515435955	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
delta x	0.01	meters	0.1	6	0.2415505282	20.00046	49,751.51	1,940,309.02	28,928,424.58	0.033511
delta t	3	seconds	0.15	9	0.3176299713	20.00118	49,751.50	1,940,308.60	28,928,421.35	0.033511
S.B	5.67E-08	W/m2K4	0.2	12	0.3859998768	20.00212	49,751.49	1,940,308.04	28,928,417.13	0.033511
hc	20	W/m2K	0.25	15	0.4492310867	20.00327	49,751.47	1,940,307.36	28,928,412.01	0.033511
e	1		0.3	18	0.5087004981	20.0046	49,751.45	1,940,306.57	28,928,406.07	0.033511
Fo	0.380504016	< 1/2	0.35	21	0.5652533569	20.00611	49,751.43	1,940,305.67	28,928,399.36	0.033511
			0.4	24	0.6194551686	20.00777	49,751.40	1,940,304.69	28,928,391.92	0.033511
ki	0.12	W/mK	0.45	27	0.6717075478	20.00959	49,751.37	1,940,303.61	28,928,383.79	0.033511
rho_i	300	kg/m3	0.5	30	0.7223085389	20.01157	49,751.34	1,940,302.44	28,928,375.00	0.033511
cp_i	1200	J/kgK	0.55	33	0.7714869331	20.01368	49,751.31	1,940,301.18	28,928,365.56	0.033511
			0.6	36	0.8194231392	20.01593	49,751.28	1,940,299.85	28,928,355.51	0.033511
Fs/Vs	24.05163897	m^-1	0.65	39	0.8662625566	20.01832	49,751.24	1,940,298.43	28,928,344.85	0.033511
			0.7	42	0.9121245137	20.02084	49,751.20	1,940,296.94	28,928,333.61	0.033511
d_i	0.029779584	m	0.75	45	0.9571084521	20.02349	49,751.16	1,940,295.37	28,928,321.79	0.033511
(half inch)			0.8	48	1.0012983326	20.02626	49,751.12	1,940,293.72	28,928,309.42	0.033511

Figure # E.5. Hallway Structural Fire Protection Calculations, Insulated Member

				t (min)	t (s)	x (m) - fire location	Lt	0
Q (constant)	147000	kW		0	0	0	0	1200
TA	20	C		0.05	3	0.009473684	0.000263	1200
delta t	3	s		0.1	6	0.018947368	0.000526	1200
Q"	5000	kW/m2		0.15	9	0.028421053	0.000789	1200
H0	3.6	m		0.2	12	0.037894737	0.001053	1200
X0	36	m		0.25	15	0.047368421	0.001316	1200
Y0	3.6	m		0.3	18	0.056842105	0.001579	1200
A	129.6	m2		0.35	21	0.066315789	0.001842	1200
Percent	0.1			0.4	24	0.075789474	0.002105	1200
Vs	0.003158	m/s		0.45	27	0.085263158	0.002368	1200
Ab	12.96	m2		0.5	30	0.094736842	0.002632	1200
tb	1140	sec		0.55	33	0.104210526	0.002895	1200
qf	5700	MJ/m2		0.6	36	0.113684211	0.003158	1200
				0.65	39	0.123157895	0.003421	1200
t_total	12540			0.7	42	0.132631579	0.003684	1200

Figure # E.6. Hallway Structural Fire Protection Calculations, Fire for Uninsulated Member

			time[min]	time[s]	q"net[kW/m2]	Temp S	f_y,steel	M_n	E_steel	delta_max
k	45.8	W/mK								
rho	7850	kg/m3	0	0	290.2179536548	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
cp	460	J/kgK	0.05	3	290.0678407416	25.79913	49,660.12	1,936,744.67	28,901,482.76	0.033542
delta x	0.01	meters	0.1	6	289.9157619872	31.59526	49,562.75	1,932,947.14	28,872,546.97	0.033576
delta t	3	seconds	0.15	9	289.7616416959	37.38835	49,459.93	1,928,937.12	28,841,767.07	0.033611
S.B	5.67E-08	W/m2K4	0.2	12	289.6054029882	43.17836	49,352.03	1,924,729.25	28,809,246.72	0.033649
hc	20	W/m2K	0.25	15	289.4469678181	48.96525	49,239.35	1,920,334.55	28,775,061.90	0.033689
e	1		0.3	18	289.2862569906	54.74897	49,122.09	1,915,761.61	28,739,269.97	0.033731
Fo	0.380504016	< 1/2	0.35	21	289.1231901795	60.52948	49,000.44	1,911,017.29	28,701,915.02	0.033775
			0.4	24	288.9576859460	66.30673	48,874.54	1,906,107.21	28,663,031.36	0.033821
ki	0.12	W/mK	0.45	27	288.7896617580	72.08068	48,744.51	1,901,036.01	28,622,645.76	0.033869
rho_i	300	kg/m3	0.5	30	288.6190340096	77.85127	48,610.45	1,895,807.58	28,580,779.07	0.033918
cp_i	1200	J/kgK	0.55	33	288.4457180419	83.61844	48,472.44	1,890,425.21	28,537,447.39	0.03397
			0.6	36	288.2696281638	89.38216	48,330.56	1,884,891.71	28,492,662.92	0.034023
Fs/Vs	24.05163897	m^-1	0.65	39	288.0906776737	95.14236	48,184.86	1,879,209.48	28,446,434.57	0.034079
			0.7	42	287.9087788822	100.899	48,035.40	1,873,380.58	28,398,768.50	0.034136
d_i	0.029779584	m	0.75	45	287.7238431347	106.652	47,882.23	1,867,406.81	28,349,668.47	0.034195
(half inch)			0.8	48	287.5357808359	112.4013	47,725.38	1,861,289.69	28,299,136.19	0.034256

Figure # E.7. Hallway Structural Fire Protection Calculations, Uninsulated Member

				t (min)	t (s)	x (m) - fire location	Lt	-
Q (constant)	147000	kW		0	0	0	0	700
TA	20	C		0.05	3	0.009473684	0.000263	700
delta t	3	s		0.1	6	0.018947368	0.000526	700
Q"	5000	kW/m2		0.15	9	0.028421053	0.000789	700
H0	3.6	m		0.2	12	0.037894737	0.001053	700
X0	36	m		0.25	15	0.047368421	0.001316	700
Y0	3.6	m		0.3	18	0.056842105	0.001579	700
A	129.6	m2		0.35	21	0.066315789	0.001842	700
Percent	0.1			0.4	24	0.075789474	0.002105	700
Vs	0.003158	m/s		0.45	27	0.085263158	0.002368	700
Ab	12.96	m2		0.5	30	0.094736842	0.002632	700
tb	1140	sec		0.55	33	0.104210526	0.002895	700
qf	5700	MJ/m2		0.6	36	0.113684211	0.003158	700
				0.65	39	0.123157895	0.003421	700
t_total	12540			0.7	42	0.132631579	0.003684	700

Figure # E.8. Office Structural Fire Protection Calculations, Fire

k	45.8	W/mK	time[min]	time[s]	q"net[kW/m2]	Temp S	f_y,steel	M_n	E_steel	delta_max
rho	7850	kg/m3	0	0	64.0325789193	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
cp	460	J/kgK	0.05	3	64.0312194662	20.05287	49,750.72	1,940,277.94	28,928,190.63	0.033511
delta x	0.01	meters	0.1	6	64.0298599552	20.10573	49,749.91	1,940,246.57	28,927,954.49	0.033511
delta t	3	seconds	0.15	9	64.0285003865	20.15858	49,749.11	1,940,215.17	28,927,718.19	0.033512
S.B	5.67E-08	W/m2K4	0.2	12	64.0271407599	20.21144	49,748.30	1,940,183.76	28,927,481.72	0.033512
hc	20	W/m2K	0.25	15	64.0257810755	20.26429	49,747.50	1,940,152.33	28,927,245.08	0.033512
e	1		0.3	18	64.0244213333	20.31713	49,746.69	1,940,120.88	28,927,008.28	0.033512
Fo	0.380504016	< 1/2	0.35	21	64.0230615330	20.36997	49,745.88	1,940,089.40	28,926,771.31	0.033513
			0.4	24	64.0217016749	20.42281	49,745.07	1,940,057.91	28,926,534.19	0.033513
ki	0.12	W/mK	0.45	27	64.0203417588	20.47564	49,744.27	1,940,026.41	28,926,296.89	0.033513
rho_i	300	kg/m3	0.5	30	64.0189817847	20.52847	49,743.46	1,939,994.88	28,926,059.43	0.033514
cp_i	1200	J/kgK	0.55	33	64.0176217526	20.5813	49,742.65	1,939,963.33	28,925,821.81	0.033514
			0.6	36	64.0162616624	20.63412	49,741.84	1,939,931.76	28,925,584.03	0.033514
Fs/Vs	24.05163897	m^-1	0.65	39	64.0149015141	20.68693	49,741.03	1,939,900.18	28,925,346.08	0.033514
			0.7	42	64.0135413077	20.73975	49,740.22	1,939,868.57	28,925,107.97	0.033515
d_i	0.029779584	m	0.75	45	64.0121810432	20.79256	49,739.41	1,939,836.95	28,924,869.70	0.033515
(half inch)			0.8	48	64.0108207205	20.84536	49,738.60	1,939,805.30	28,924,631.26	0.033515

Figure # E.9. Office Structural Fire Protection Calculations, Insulated Member

k	45.8	W/mK	time[min]	time[s]	q"net[kW/m2]	Temp S	f_y,steel	M_n	E_steel	delta_max
rho	7850	kg/m3	0	0	64.0325789193	20	49,751.52	1,940,309.29	28,928,426.61	0.033511
cp	460	J/kgK	0.05	3	63.9996303822	21.2795	49,731.91	1,939,544.34	28,922,664.10	0.033517
delta x	0.01	meters	0.1	6	63.9666023114	22.55834	49,711.98	1,938,767.32	28,916,799.40	0.033524
delta t	3	seconds	0.15	9	63.9334940582	23.83652	49,691.76	1,937,978.60	28,910,835.18	0.033531
S.B	5.67E-08	W/m2K4	0.2	12	63.9003049732	25.11403	49,671.24	1,937,178.50	28,904,773.83	0.033538
hc	20	W/m2K	0.25	15	63.8670344071	26.39089	49,650.44	1,936,367.32	28,898,617.56	0.033545
e	1		0.3	18	63.8336817101	27.66708	49,629.37	1,935,545.34	28,892,368.36	0.033553
Fo	0.380504016	< 1/2	0.35	21	63.8002462323	28.9426	49,608.02	1,934,712.80	28,886,028.08	0.03356
			0.4	24	63.7667273238	30.21746	49,586.41	1,933,869.93	28,879,598.42	0.033567
ki	0.12	W/mK	0.45	27	63.7331243342	31.49164	49,564.54	1,933,016.96	28,873,080.93	0.033575
rho_i	300	kg/m3	0.5	30	63.6994366133	32.76515	49,542.41	1,932,154.08	28,866,477.10	0.033583
cp_i	1200	J/kgK	0.55	33	63.6656635108	34.038	49,520.04	1,931,281.48	28,859,788.25	0.033591
			0.6	36	63.6318043762	35.31016	49,497.42	1,930,399.33	28,853,015.67	0.033598
Fs/Vs	24.05163897	m^-1	0.65	39	63.5978585591	36.58165	49,474.56	1,929,507.80	28,846,160.54	0.033606
			0.7	42	63.5638254091	37.85246	49,451.46	1,928,607.04	28,839,223.95	0.033614
d_i	0.029779584	m	0.75	45	63.5297042759	39.12259	49,428.13	1,927,697.20	28,832,206.96	0.033623
(half inch)			0.8	48	63.4954945092	40.39204	49,404.57	1,926,778.41	28,825,110.54	0.033631

Figure # E.10. Office Structural Fire Protection Calculations, Uninsulated Member