EXHIBIT 5

Cornell University

Rand Hall - Fine Arts Library

Performance Based Design Report – Atrium Smoke Control

August 2017

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Appendices

1. Introduction

1.1 Purpose

The purpose of this report is to provide a professional engineering opinion relative to the smoke control arrangement using a detailed fire model analysis of the proposed Rand Hall Fine Arts Library project. This is being presented to document the engineering opinion and to help establish a specified level of life and fire safety for the atrium space, with all deemed acceptable per Code requirements by the stakeholders – especially the City of Ithaca Building and Fire Authorities Having Jurisdiction. Since this atrium arrangement has a specific book stack array, which has been previously approved as a use of the atrium by the Building and Fire Authorities Having Jurisdiction, the use of roof smoke vents/skylights has been chosen as the appropriate method of smoke venting for the atrium, rather than mechanical ventilation alone. This roof venting arrangement provides the Ithaca FD with additional easy means of venting which is directly above the book stacks and also provides for fire sprinkler activation to assist with fire control or extinguishment for these book stacks.

1.2 Background

The Rand Hall Fine Arts Library ("FAL") Project located in Ithaca, New York at Cornell University includes the continued and proposed use of the second and third floors of this existing building as a college library. Additions and modifications to the existing clearly delineated second and third floors and the roof of the existing Rand Hall building are proposed for the 2017 project. It is important to the validity of this report that it is clear that the space being analysed is only the second floor and the space above it which are all noted as the "library" or "atrium" space confined by the exterior walls of what is presently known as Rand Hall. The determinations and opinions stated throughout this report do not apply to any space that is below the second floor or outside of Rand Hall.

2. Applicable Codes & Standards

The applicable codes, standards and guidelines required by Cornell University for Performance Based Analysis include:

- *Society of Fire Protection Engineer's Engineering Guide to Performance-Based Fire protection, 2nd Edition.*
- *International Building Code, 2015 Edition,* as published by the International Code Council. This code is herein referred to as the IBC with New York State amendments (of which none are present as applied to this atrium space).
- *Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, Fifth Edition.*

3. Building Characteristics

3.1 Building Construction, Height, and Area

The building can be identified as a three or four multi-story building with the atrium connecting all mezzanines or floors above the second floor. The total footprint of the building is approximately 10,000 square feet. The construction of the Rand Hall building within the confines of the exterior walls of Rand Hall has been determined as Type IIB construction as it uses steel, concrete and other non-combustible materials for this structure.

3.2 Occupancy Classification

The space will be an assembly Group A-3 on floors/levels 2, 3 and 4 and a Group F-1 on the first floor.

3.3 Fire Suppression

The building will be provided throughout with a wet-pipe automatic sprinkler system designed per NFPA 13 including a separate fire sprinkler zone/riser covering the roof level of the atrium, a separate zone/riser protecting the book stacks including longitudinal flues and vertical structural steel members, both supplied by multiple fire mains into Rand Hall.

4. Design Approach

4.1 Establishing Project Scope

The first step in this design analysis is defining the project scope including the identification of stakeholders or people who have a vested interest in the project. These primary stakeholders are responsible for establishing and approving design fire scenarios, performance criteria for acceptance, as well as input parameters for the fire egress models. The primary stakeholders involved in the development of this performance based analysis include:

- Cornell University – Owner
- City of Ithaca Building and Fire – is designated as the Code's Authority Having Jurisdiction
- STV Architects – Prime Design Professional/Architect
- GHD Consulting Services – Sub-Consultant/Fire Protection Engineer

4.2 Identifying Project Goals & Objectives

The following steps in the design analysis process are to develop the project goals and project objectives associated with those goals. The fundamental goal of the smoke control arrangement for this atrium space is to minimize or eliminate fire-related injuries for occupants leaving this space, and allow simple use of the smoke control system by emergency responders (Ithaca Fire Department). This goal can be achieved if the analysis can show that:

- There is proper and sufficient sprinkler activation within the book stacks prior to the smoke vent operation. This is important as fire control is a higher priority than smoke control due to the back stack arrays.

Calculated egress can be achieved with regards to heat, smoke accumulation and smoke layer descent downward from the roof level to at least six feet above the top floor/mezzanine without the need for any forced ventilation.

The project objective is essentially taking these goals and further refining them into values that can be quantified in engineering terms. The project objectives associated with the aforementioned goals can be identified as follows:

- To show that the total time necessary to achieve complete egress from the “worst-case” remote occupied area does not exceed the time it takes for the smoke layer to reach an elevation that would potentially harm occupants and make the space untenable for egress purposes.

4.3 Developing Performance Criteria

The next step in the design analysis is the development of qualitative criteria that are numerical values to which the expected performance and the design fires can be compared. For this analysis, the following design performance criteria are deemed most relevant for achieving the project objective:

- Sprinkler Activation Time
- Egress time (Per floor/mezzanine level & complete library atrium space)
- Smoke layer accumulation without sprinkler activation or ventilation
- Smoke layer descent rate without sprinkler activation or ventilation

The basis of these performance criterion are discussed in detail later in this report.

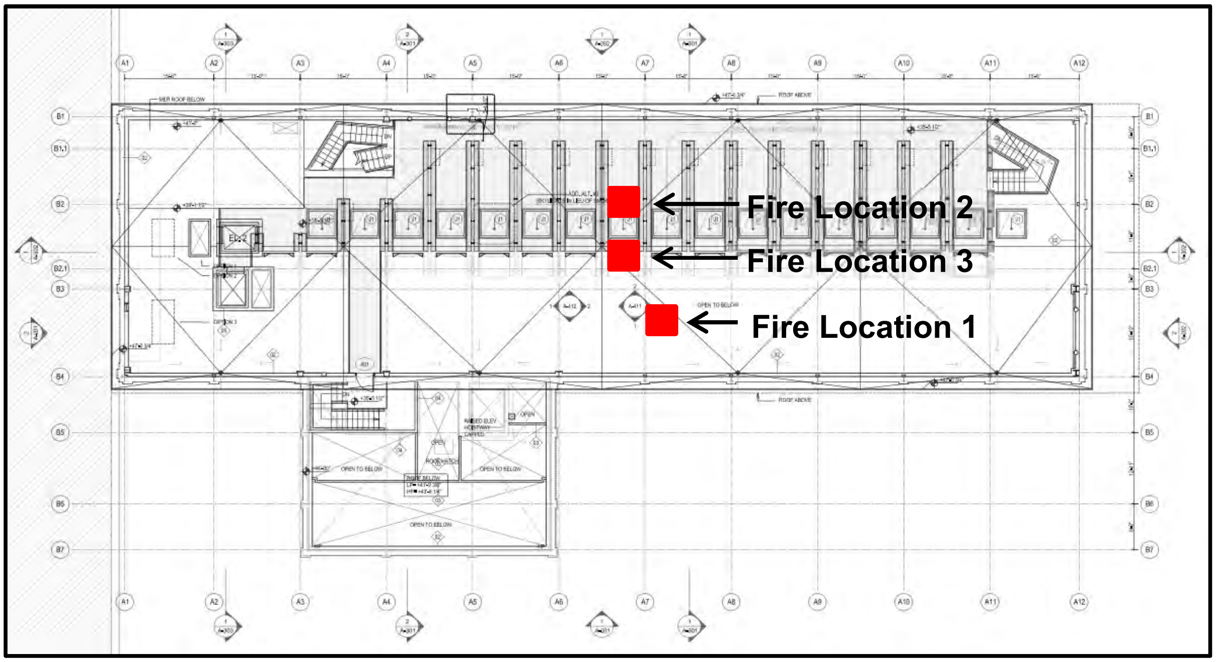
4.4 Developing Design Fire Scenarios

The next step in the design analysis is to identify and quantify the probable and most likely fire scenarios that may occur in the building. While not an applicable code for this project, NFPA 101 Chapter 5 provides eight types of fire scenarios that provide good guidance for consideration in a performance-based analysis. The following summarizes the design fire scenario that best fits this application:

- Design Fire Scenario 1: A slowly developing fire, shielded from fire protection systems, in close proximity to a high occupancy area. This fire shall address the concern regarding a relatively small ignition source causing a significant fire.
- Design Fire Scenario 2: The most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building. This fire shall address the concern regarding a rapidly developing fire and the fire protection systems effectiveness.

After review of various materials and arrangements anticipated for this library atrium space, a few fire types were used for the analysis. The specifications of the design fires are as follows:

1. Fire Location 1: The fire used in this simulation has been located closer to the south wall of the library, within the open space and not obstructed by the book stacks. The location can be seen below. This type of fire and its location utilize Design Fire Scenario 1 described above.



2. Fire Location 2: The fire used in this simulation has been located below the raised second floor, aligned in the center of the stack aisles above it. This type of fire and its location utilize the Design Fire Scenario 2 described above.
3. Fire Location 3: The fire used in this simulation has been located half below the raised second floor and half in the open space, aligned in the center of the stack aisles above. This type of fire and its location utilize the Design Fire Scenario 2 described above.
4. Fire Size: $(1\ m\quad) \times (1\ m\quad) = 1\ m^2$
5. Heat Release Rate: The peak heat release rate associated with Fire Location 1 is 1,500 kW (1.5 MW). The peak heat release rate associated with Fire Locations 2 and 3 is 1,300 kW (1.3 MW) (representing a potential small volume of a flammable liquid with ignition).

The type of fire that is being assumed at Fire Location 1 is one that originates in the center of the open space at what is being called a librarian's (reception) desk. The material that is used to build this desk is wood of combustible nature. From this the SFPE Handbook was consulted; *Figure 26.59 HRR of Display Kiosks* was determined to be the most applicable in this scenario. The figure shown in the SFPE Handbook was used solely as reference as the heat release rate above was modified to create much more conservative results and provide a "worst-case" scenario in the simulation. The type of fire that is being assumed at Fire Location 2 and 3 is a liquid fuel pool fire beneath the raised second floor with a peak heat release rate of 1.3 MW. It was determined from Isaac De Haro Martinez's *"Robert E. Kennedy Library Cal Poly, San Luis Obispo Fire Protection Analysis FPE Culminating Project (2013)"* that an approximate experimental heat release rate of 1.3 MW is a valid quantity for parallel book stacks. The quantity was also calculated using material data of ethanol and a surface area of 1 square meter as modeled. The equation below was taken from the SFPE Handbook, *Equations 65.11 and 65.12*.

$$\dot{Q} = A \, x \, \dot{m}'' \, x \, \Delta h_c$$

$$\dot{Q} = (0.9) \, x \, (1 \, m^2) \, x \, \left(0.05 \, {}^{k}/_{m^2 s}\right) \, x \, \left(28{,}865 \, {}^{k}/_{k}\right)$$

$$\dot{Q} = 1.299 \, M \quad \approx 1.3 \, M$$

In order to determine the total quantity of fuel that would create such a fire an additional calculation must be done.

$$V = (S \quad A \quad) \, x \, (S \quad D \quad h)$$

$$V = (1 \, m^2) \, x \, (0.0006 \, m)$$

$$V = 0.0006 \, m^3 = 0.6 \, L$$

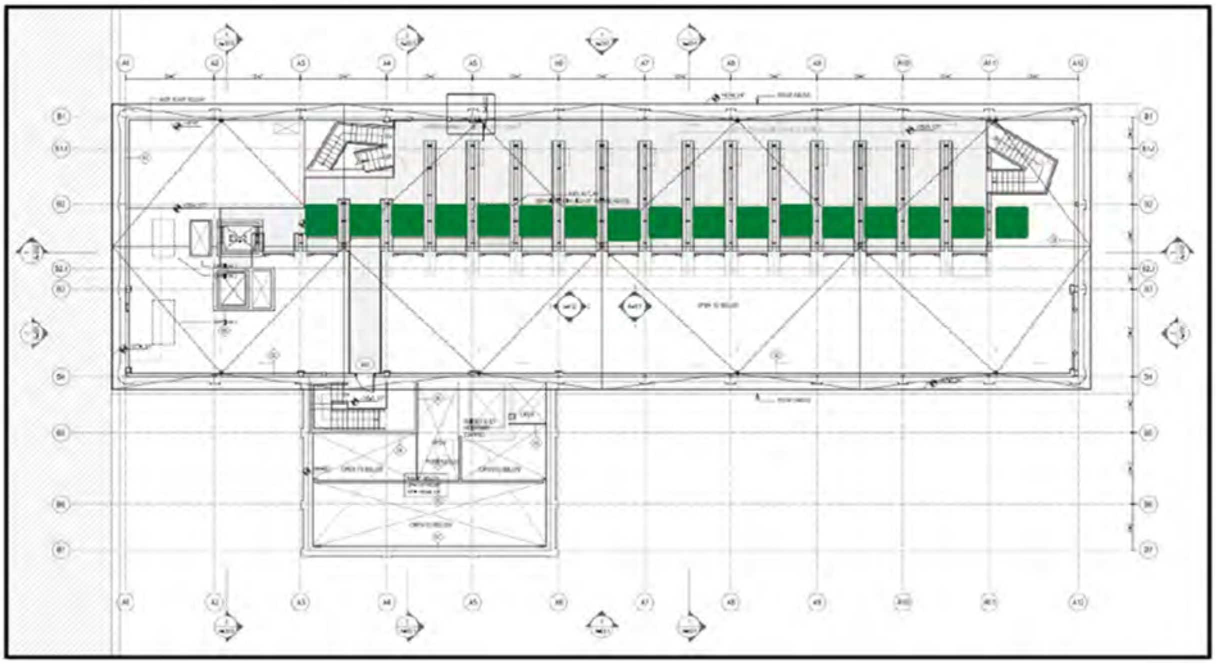
4.5 Developing Ventilation/Venting Scenarios

Part of the previous step in the design analysis is to identify the optimal combination of vents that will be used to naturally ventilate the space to assist in increasing the safety level of the building, but at the same time allow fire sprinkler activation within the book stack arrays so as not to prematurely open smoke vents which may be remotely located from the fire plume. By design intent based upon the location of open vents directly above the book stacks as being desired, the simulation has been developed as to utilize only natural ventilation throughout the building.

Two types of vents were considered during the modeling process and work together for smoke control:

- Makeup Air Windows: Supplies air from the exterior of the building inwards through the window towards the fire; this will allow fresh make up air to naturally move into the building and thus allow smoke from the design fire to rise and be vented to the outside.
- Skylights/Roof Vents: These use the natural upwards force of the fire and the smoke to vent directly to the exterior through the top of the building.

The fire model was established, multiple runs observed and finally determined that incorporating four make up windows located on the south face of the second floor of the building, as the most appropriate for the variety of fire locations in this second floor atrium. The 3D architectural rendering of the building that was provided included multiple existing skylights; it is proposed these skylights be provided for the sole purpose of being utilized in a fire situation. The approximate sizes of each of the skylights/roof vents used in the fire model were approximately 5' x 5' and located above each aisle of the book stacks. The figure below shows the proposed size and locations of the skylights/roof vents utilized in the fire model.



The above configuration has been determined by the architect in concert with numerous fire model runs to verify that the central open natural vent locations as being appropriate and successful in achieving smoke control for the atrium space. The vent configuration above will provide significant ventilation in the event of a fire on the second floor and/or the mezzanines/floors above – especially the book stacks. The activation (opening) of the smoke ventilation system will be controlled by the fire alarm system; heat/smoke detection or sprinkler water flow. Since the book stacks will rely upon proper sprinkler activation, and that smoke vents at the roof are within the book stack floor plan view area, it will be important to not have smoke vents interfere with proper sprinkler activation and at the same time allow smoke venting to allow egress from the upper level of the atrium. Thus, in review of various scenarios, the fire detection system and smoke control system must be coordinated.

There are three smoke control scenarios:

1. Fire in atrium space outside of book stacks (i.e. – the open area): Upon initial smoke detection activation of two or more sensors outside of the book stacks, or from fire sprinkler water flow of the roof level sprinkler zone, all of the 17 ceiling/roof levels smoke vents, plus the four makeup air windows will simultaneously open and begin ventilation.
2. Fire in atrium space within the book stacks: If any initial single or multiple smoke detectors within the floor plan area of the book stacks activate, or the book stacks fire sprinkler water flow zone is activated, the smoke vents shall not open, and the windows for makeup air shall not open until the electronic heat sensor at each individual smoke vent reaches 200 degrees F. Make up air windows will correspondingly open based upon groups of four (4) roof smoke vents opening – that is one make up air window for each four (4) roof vents which open based upon reaching the 200F temperature requirement.
3. Manual Fire Department activation: This will allow opening of all 17 roof smoke vents and all four (4) of the make-up air windows by use of a key switch at the main fire alarm control panel (or smoke control panel).

The results and effectiveness of the smoke ventilation system will be displayed and described in the following section.

4.6 Sprinkler Placement

The design under analysis will include a complete automatic sprinkler system designed per NFPA 13. The sprinkler system previously proposed to the stakeholders includes two sub-systems that utilize two separate risers.

The first sub-system provides a complete automatic sprinkler system at the upper ceiling level (Elev. + 55' – 2-1/4") and the lower ceiling level (Elev. + 46' – 1"). This system will also use NFPA 15 as a design reference. Standard upright or pendent quick response 155-165F sprinklers will be utilized and placed within 1" – 2" of the roof deck. The primary purpose of the ceiling level sprinklers will be to wet the main web of the roof structure I-beams. While accomplishing I-beam protection, the ceiling sprinklers will also be used to protect the floor below. To provide full and complete coverage these sprinklers will be placed within 3' of each North-South running I-beams and spaced 10' on center from the adjacent sprinklers. Upon sprinkler activation at the ceiling level, the flow switch will trip, and cause the opening of the roof smoke vents.

The second sub-system provides a complete automatic sprinkler system throughout each level of the book stacks. Standard upright or pendent quick response 155-165F sprinklers will be placed in each aisle of the book stacks 1" – 2" below the floor of the mezzanine above and spaced 7' on center from the adjacent sprinklers. For each level of book stacks, the sprinklers will be staggered in relation to the upper and/or lower levels to ensure that the space between sprinklers on one level will lead directly to a sprinkler on the level above. Each book stack contains a 6" flue space that will also have sprinkler coverage. These flue space sprinklers will also be staggered from level to level, similarly to the aisle sprinklers. To provide an extra level of protection a layer of sprinklers will be provided below the raised second floor in anticipation of combustible materials and/or liquids being spilled beneath it.

Elevation and plan view schematics of book stack sprinklers are included in Appendix A of this report.

4.7 Modeling Results

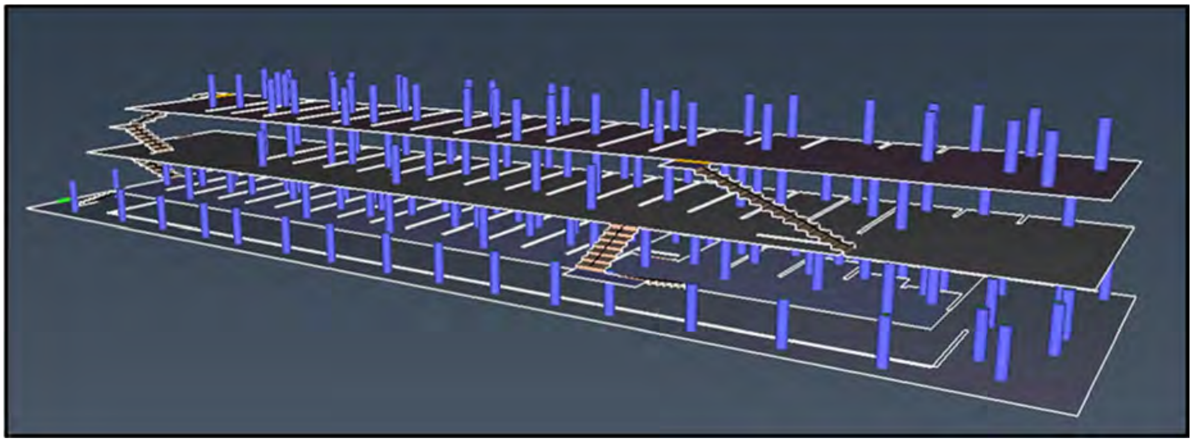
The final step in this design analysis is to review the results of the fire and evacuation models. The analysis of these results will use outputs of the modeling software to determine the following:

- If and when sprinklers would activate
- Elevation of the smoke layer across time
- How the time to evacuation compares to the smoke layer elevation

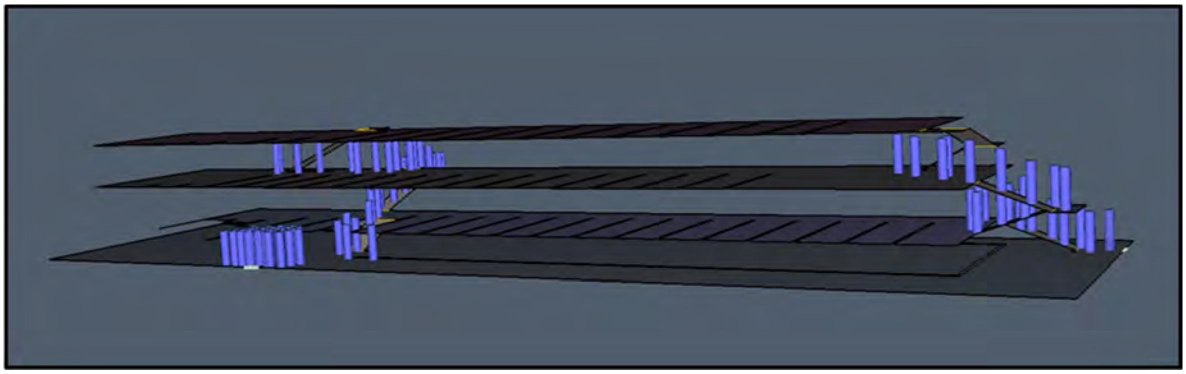
Summaries and results of the fire models can be found in Appendix B.

Egress Model

An egress model was developed to assist in determining the evacuation time of the occupants. This model includes the second floor, the raised second floor and the two mezzanines/floors above.



The paths of egress utilized by the occupants within the model are the two stairways located on each end of the raised second floor and the mezzanines/floors above. Once the simulated occupants reach the second floor they proceed to exit the building by either the exit door on the south wall into stair 1 or the exit stair door on the east wall.



The occupant load for the library space was calculated based upon the IBC. For library stack areas, Table 1004.1.2 of the 2015 IBC identifies an occupant load factor of 100 sq.ft. per occupant. Based upon the most recent floor areas of each floor and stack the occupant loads are identified in the table below.

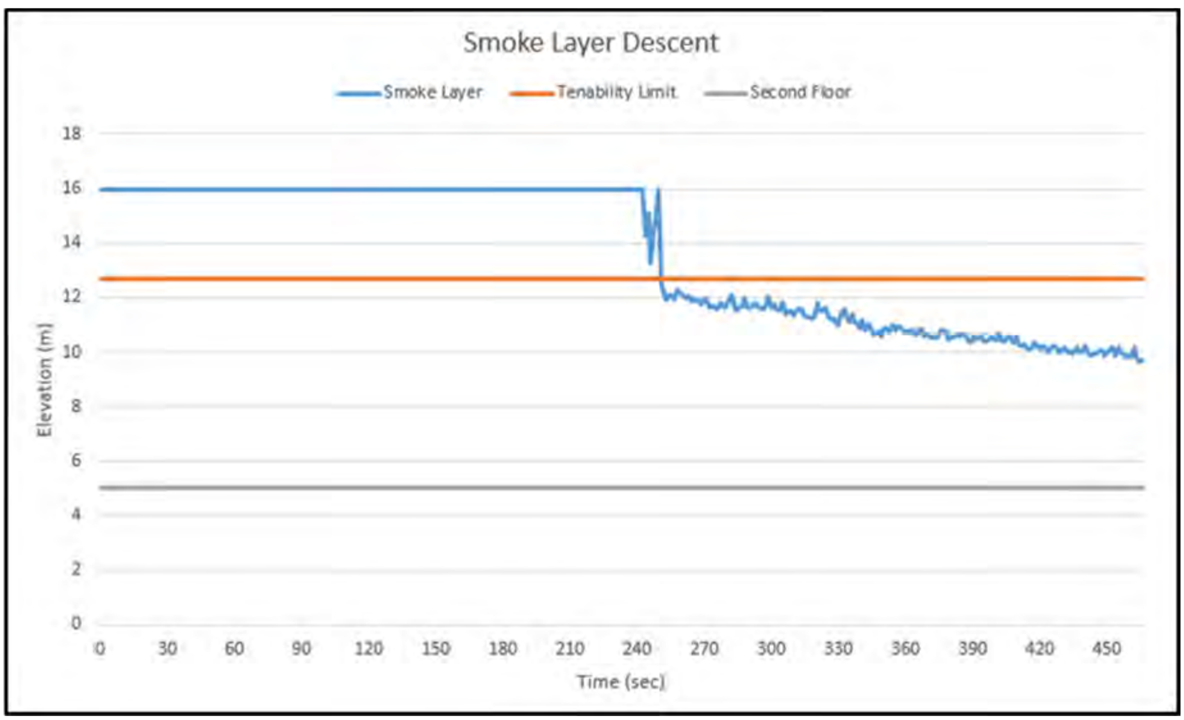
Second Floor	Raised Second Floor	Second Floor Mezzanine	Upper Mezzanine/Floor	Entire Atrium Space
60 occupants	60 occupants	40 occupants	40 occupants	200 occupants

The egress model was simulated using Pathfinder 2017, and the resulting movement and evacuation times are displayed in the table below. The movement times are directly from the modelling software, and measure only the time from when the occupants begin moving until they reach the egress destination. The evacuation time identified also includes 60 seconds for detection of the fire, 30 seconds for the occupants' perception of the fire alarm and 30 seconds for the occupants' interpretation of the fire alarm – all considered conservative based upon the ability of occupants to see/smell/hear what is happening within the open atrium space.

	Upper Mezzanine/Floor	Second Floor Mezzanine	Raised Second Floor	Second Floor
Detection Time	60 sec			
Perception	30 sec			
Interpretation	30 sec			
Movement Time	41 sec	73 sec	82 sec	102 sec
Evacuation Time	161 sec	193 sec	202 sec	222 sec

Fire Location 1 – No Venting

Fire location 1 represents the worst-case scenario in regards to smoke accumulation. This is the worst-case scenario due to all smoke vents being "closed" and not opening at all as a parameter established to see if smoke vents are necessary in this small space with small occupant load. By not utilizing the smoke vents, the true descent of the smoke layer can be determined and compared to the egress time. This is also a fire location which has the highest ceiling height, which also allows more air entrainment in the smoke/heat plume, causing additional particulate contribution to the space. Based upon the data and results of the fire model and the open space of the library, it is GHD's professional opinion that, sprinkler activation will not occur during this specific fire arrangement. This lack of sprinkler activation can be attributed to the high elevation of the sprinklers from the second floor and the large overall volume of the open space.

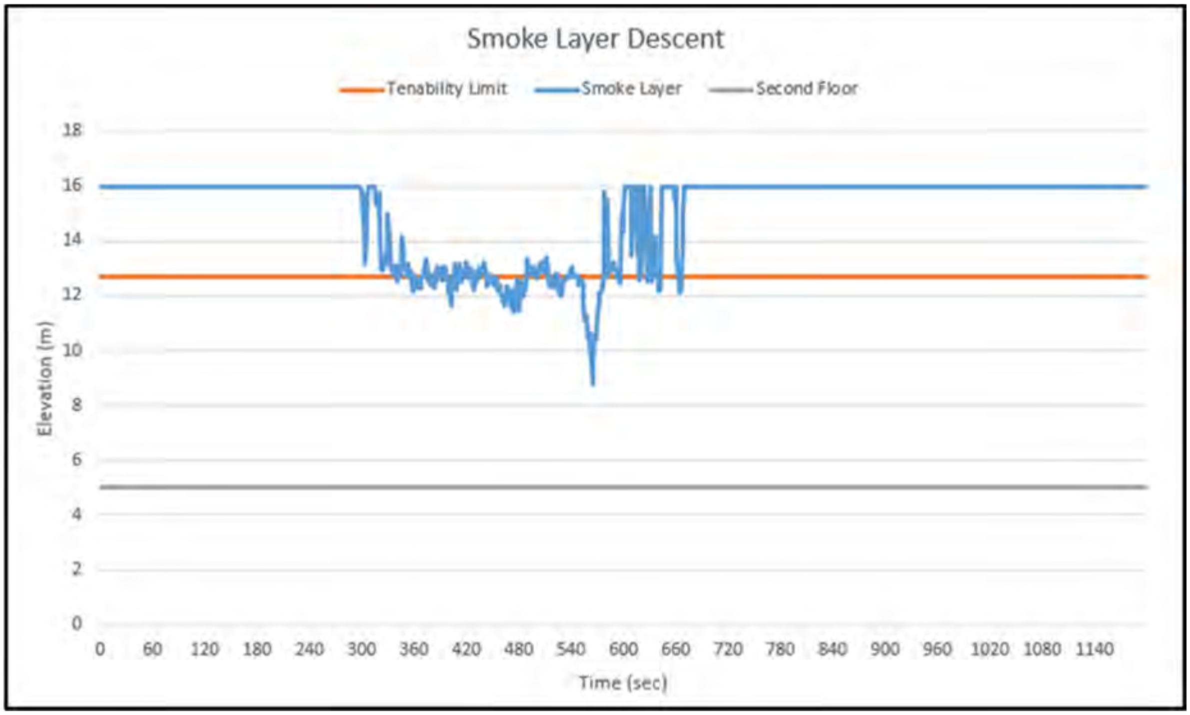


As seen from the graph above, developed from the fire model data, the smoke layer forms enough to begin descending at approximately 240 seconds. Once the smoke layer develops it descends at an average rate of 0.06 meters per second. At approximately 250 seconds it can be observed that the tenability limit for the top floor has been reached thus meaning that evacuation from the top floor must be accomplished before 250 seconds.

By comparing the egress times to the smoke layer descent, it can be determined that complete egress can be accomplished prior to the space becoming untenable to occupants.

Fire Location 1 – With Venting

Fire location 1 was used again as a worst-case scenario fire event for the library with venting. The smoke vents utilized in this fire model is the same as described previously in this report, and includes 17 smoke vents and 4 makeup air windows. The purpose of this model was to determine if the amount of smoke vents proposed is sufficient to prolong the tenability of the space to allow even more time for egress from the building and for a safer environment for first responders to fight the fire.



As seen from the graph above, developed from the fire model data, the smoke layer forms enough to begin descending at approximately 300 seconds. Once the smoke layer develops it descends at a slower average rate of 0.02 meters per second and for most of the time vents enough smoke to prevent the smoke layer from descending below the 5-6' level above the top floor/mezzanine. This is significantly better than without any venting where that smoke layer descends below the top floor and into the next level down.

Fire Location 2

This simulation was conducted to determine if and when there would be sprinkler activation within the library stacks. In order to provide the worst-case scenario within the library stacks, the sprinklers were spaced so that no same-level sprinkler was directly above the source of the fire. The first sprinkler that the plume directly hits is the sprinkler on the next level up. The spacing and staggering of the sprinklers was simulated as previously designed and follows the basic sprinkler spacing arrangement for storage array protection.

It is GHD’s professional opinion, based on the fire model results and data that a sprinkler at an elevation of 20 feet above the design fire’s location would successfully activate at sometime between three and four minutes (192 seconds) from ignition.

Fire Location 3

This simulation has the fire location partly in the book stacks and partly in the open “southerly” direction to the high ceiling area to determine if and when there would be sprinkler activation within the library stacks. In this scenario, there essentially is too much open space with fire sprinklers not located directly in the fire/heat plume to cause sprinkler activation – a remote event which could occur and can be partially alleviated by placement of sprinklers at the ends of each book stack.

It is GHD’s professional opinion, based on the fire model results and data that sprinkler activation would not occur with the fire located at this location partially in the book stacks.

4.8 Conclusions

The project goals identified earlier in this report must be referenced to determine if the building systems, as they are currently proposed, will be met.

Fire location 1, 2 and 3 provides insight into the building and its systems’ ability to achieve the atrium smoke control goal identified; complete egress can be achieved prior to the space becoming untenable. According to the fire and egress models’ results previously explained, the time for egress from each individual floor/mezzanine is less than the time the floor/mezzanine becoming untenable to the occupants by the presence of the smoke layer. It has been determined that, based upon the likely fire hazards that can lead to a fire event, GHD believes the library space is large enough that detection, occupant perception, interpretation and complete egress can be achieved before the smoke layer can reach occupied space.

It is GHD’s professional opinion that the proposed configuration of skylight/roof vents is sufficient to further ensure that the space can be maintained tenable long enough to provide occupants with sufficient time to egress the library. Thus, use of the open type vents, make up air windows, fire sprinkler and fire detection throughout the library atrium space will meet the intended objectives of the IBC for atrium spaces.

www.ghd.com